8TH ASIAN REGIONAL CONFERENCE

May 2-4, 2018, Kathmandu, Nepal

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PROCEEDINGS

ICID-CIID

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Title : Proceedings of 8TH Asian Regional Conference on "Irrigation in Support of Evergreen Revolution"

Edited by : Utsav Bhattarai, Vishnu Prasad Pandey

Publication Coordination : Water Modening Solutions Pvt. Ltd. (WMS)

Published by : Nepal National Committee of ICID (NENCID)

Department of Water Resources and Irrigation Building, Jawalakhel, Lalitpur, Nepal

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Computer Layout & Design : RL Design & Printing, Chabahil, Kathmandu

Cover Concept : Suman Maharjan

Cover Photo : Department of Irrigation

Printed by : Apollo Offset Press Pvt. Ltd.
Chabahil, Kathmandu-7

ISBN : 978-9937-0-3792-1

Citation : NENCID (2018). Proceedings of 8TH Asian Regional Conference on "Irrigation in Support of Evergreen Revolution". Publisher: Nepal National Committee of ICID (NENCID). May 2-4, Kathmandu, Nepal.

Publication of this proceedings is made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this proceedings are the sole responsibility of authors and do not necessarily reflect the views of USAID or the United States Government.

ORGANIZERS

Nepal National Committee on Irrigation and Drainage (NENCID): Nepal is one of the earliest members joining International Commission on Irrigation and Drainage (ICID) in 1973 and is active both nationally and internationally in the fields of irrigation and drainage. However, NENCID registered formally as a Non-Governmental Organization in 2016. Any individual or institution working in the field of irrigation and drainage can obtain the membership of the committee. The Annual General Meeting held in April 2017, elected a new Executive Committee, which is chaired by the Director General, Department of Water Resources and Irrigation (formerly, Department of Irrigation) and other officials and members are from government, non-government organizations, academic institutions, etc. The National Committee has been conducting various activities to promote policies and programs to enhance sustainable development of irrigated agriculture and water management related activities in the country. This international conference is being organized by NENCID National Committee for the first time in Nepal.

Department of Water Resources and Irrigation, Government of Nepal: The Department of Water Resources and Irrigation (DoWRI), formed by merging Department of Irrigation and Department of Water Induced Disaster Management, is a government agency currently under the Ministry of Energy, Water Resources, and Irrigation. It evolved through different stages working under different ministries, finally ending up as DoI in 1987 and DoWRI in 2018. The department has a mandate to plan, develop, maintain, operate, manage and monitor different modes of environmentally sustainable and socially acceptable irrigation and drainage systems – from small to larger scale surface systems and from individual to community groundwater schemes. In addition, DoWRI is also responsible for planning and development of irrigation-led multipurpose water resources projects. Its ultimate aim is to provide year-round irrigation facilities and increase the irrigable area of the country to highest potential. Apart from this, DoWRI has to carry out river training activities to protect the floodways, floodplains, river corridor lands in the form of river bank protection caused by flooding, and landslide protection works to minimize the loss of lives and properties with structural as well as non-structural countermeasures.

CO-ORGANIZER

USAID Paani Program (Paani): Paani is a sister project to the USAID-funded Nepal Hydropower Development Project (NHDP) and complementary projects implemented by the U.S. Forest Service and the International Water Management Institute (IWMI). The program is part of USAID's on-going investment in strengthening natural resource management in the country. Paani is playing a pivotal role in shaping Nepal's management of critical water resources between now and 2020. A Paani goal is to enhance Nepal's ability to manage water resources for multiple uses and users through climate change adaptation and the conservation of freshwater biodiversity. Through activities at the watershed, basin and national scales, Paani aims to reduce threats to freshwater biodiversity and strengthen the resilience of targeted communities in the Karnali, Mahakali and Rapti river basins to adapt to the adverse impacts of climate

change through improved water resource management. Paani works to raise the profile of freshwater issues through policy engagement, academic research, curriculum development, and sponsorship of international forums. The project emphasizes user-centered design to analyze how various stakeholders, including fishermen, government officials, and hydropower developers, use water resources to better incentivize their engagement in water conservation and management activities. Please refer following site for further details: https://www.usaid.gov/nepal.

ASSOCIATES

ADB ASIAN DEVELOPMENT BANK

Asian Development Bank (ADB): The ADB is a multilateral development finance institution which aims for an Asia and Pacific free from poverty. The Asian Development Bank mission is to help developing member countries reduce poverty and improve the quality of life of their people. It's headquarter is located at Manila in Philippines and regional offices across Asia and Pacific region. ADB assists its members, and partners, by providing loans, technical assistance, grants, and equity investments to promote social and economic development. ADB in partnership with member governments, independent specialists and other financial institutions is focused on delivering projects in developing member countries that create economic and development impact. ADB has been working as a key development partner with the Government of Nepal since it joined as a founding member in 1966. The Nepal Resident Mission was opened in 1989 and provides the primary operational link for activities between ADB and the government, the private sector, civil society stakeholders, and development partners. The resident mission engages in policy dialogue, country partnership strategy development and programming, and portfolio management, while also acting as a knowledge base on development issues in Nepal. The Nepal government agency handling ADB affairs is the Ministry of Finance. Please refer following site for further details: https://www.adb.org/

ICE WaRM
International Centre of Excellence in Water Resources Management

International Centre of Excellence in Water Resources Management (ICEWaRM): ICEWaRM is recognized globally for leadership and innovation in collaborative approaches to capacity development for water management and sustainable economic development. It was founded as an Australian Government initiative and incorporates a charitable trust. ICEWaRM mission is to develop capacity, capability and confidence for the sustainable management and use of water resources, and access to safe drinking water and sanitation. ICEWaRM is successfully providing a gateway to Australian water expertise to support capacity building in the international water sector. As a collaborator and trusted partner, ICEWaRM links policy and practice experts with governments and institutions, supports the formulation of robust water policies that combine community engagement, integrated water resources management, sustainable development and strong transparent governance and regulation ICEWaRM is delivering services through advocacy, capacity development (institutions), accredited training, short courses and webinars domestically and internationally. ICEWarm works in partnership with development agencies, governments and the private sector for the progressive realization of the Sustainable Development Goals. Please refer following site for further details: https://www.icewarm.com.au/

International Centre for Integrated Mountain Development (ICIMOD): ICIMOD is a regional intergovernmental learning and knowledge sharing centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. ICIMOD mission is to enable sustainable and resilient mountain development for improved and equitable livelihoods through knowledge and regional cooperation. ICIMOD is committed to bringing about transformative change in the region by improving the environmental conditions and livelihoods of mountain and downstream communities. ICIMOD serve as a regional knowledge hub, strengthens networking among regional and global centers of excellence, supports regional trans boundary programmes through partnership with regional partner institutions, and facilitates the exchange of experience. ICIMOD is working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream now, and for the future. ICIMOD Working together with regional and international partners, with a wide variety of institutions, including strategic and policy partners, operational and research partners, development partners, and knowledge, science and network partners. Please refer following site for further details: http://www.icimod.org/

International Water Management Institute (IWMI): IWMI is a non-profit, scientific research organization focusing on the sustainable use of water and land resources in developing countries. It is a CGIAR Research Center and leads the CGIAR Research Program on Water, Land and Ecosystems(WLE). It's headquarter is located at Colombo in Sri Lanka and regional offices across Asia and Africa. IWMI's Mission is to provide evidence-based solutions to sustainably manage water and land resources for food security, people's livelihoods and the environment. IWMI's Vision, as reflected in the Strategy 2014-2018, is 'a water-secure world'. IWMI works in partnership with governments, civil society and the private sector to develop scalable agricultural water management solutions that have a real impact on poverty reduction, food security and ecosystem health. IWMI targets water and land management challenges faced by poor communities in the developing countries, and through this contributes towards the achievement of the Sustainable Development Goals (SDGs) of reducing poverty and hunger, and maintaining a sustainable environment. IWMI works through collaborative research with many partners in the North and South, and targets policymakers, development agencies, individual farmers and private sector organizations. Please refer following site for further details: http://www.iwmi.cgiar.org

World Bank: The World Bank is one of the world's largest sources of development assistance. World Bank Group (WBG) is headquartered in Washington, D.C. and 120 regional offices worldwide. World Bank mission is to fight poverty with passion and professionalism for lasting results. The World Bank is a vital source of financial and technical assistance to developing countries around the world, a unique partnership to reduce poverty and support development. The World Bank is working closely with Nepal to fight poverty for lasting results and over the years, the Bank's support has evolved in focus and form to meet the changing needs of Nepal. The World Bank Group has been a development partner in Nepal for

almost five decades, providing financing, technical assistance and advice to raise the living standards of the Nepali people and reduction of poverty. The WBG is also intensifying its support for institutional governance, particularly for fiscal devolution and establishing a new federal government structure, for economic sustainability and job creation and for earthquake reconstruction and disaster preparedness. Please refer following site for further details: https://www.worldbank.org/

Farmer Managed Irrigation System Promotional Trust (FMIST): FMIST representing members of different disciplines was formally established on 7 June 1998 and is recognized as a non-governmental entity under the provisions of the Association Registration Act 1977. FMIST mission is to develop human resources and knowledge base on FMIST through applied research and training, seminar, workshop and contribution in academic papers. FMIST plays a role of advocacy and promotional activities of farmer managed irrigation systems of Nepal. It is registered in the District Administration Office, Kathmandu of the Home Ministry of Government of Nepal. The Trust is affiliated with the Social Welfare Coordination Council. The organization and operations of the Trust are guided by the Constitution of the Trust. According to the provisions of the Constitution of the Trust, the Trust financial status is audited annually as required by the provision of the Act. Trust is required to renew its registration each fiscal year. The organization of FMIST is composed of Executive Committee and the Friends of FMIST. The Friends of FMIS is composed of individuals recognized by the executive committee decision on the written or verbal expression of interest to be member in the Friends of FMIST group. Hence, a person or an organization engaged for development, promotion and research of FMIS can be member of the Trust. It acts as General Assembly and holds meeting once a year to discuss on organizational, programs and financial matters. Please refer following site for further details: https://fmistnepal.wordpress.com/

CONFERENCE COMMITTEES

Steering Committee

- Honourable Minister, Ministry of Energy, Water Resources and Irrigation – Chairperson
- Secretary (Energy), Energy, Water Resources and Irrigation – Member
- Secretary (Irrigation), Energy, Water Resources and Irrigation – Member
- Secretary, Ministry of Home Affairs – Member
- Secretary, Ministry of Finance – Member
- Secretary, Ministry of Foreign Affairs – Member
- Secretary (Agriculture), Ministry of Agriculture, Land Management and Cooperatives – Member
- Secretary, Ministry of Culture, Tourism and Civil Aviation – Member
- Secretary, Water and Energy Commission Secretariat (WECS) – Member
- Vice-Chairperson of ICID, Mr. Madhav Belbase – Member
- Director General, Department of Irrigation – Member Secretary
- Director General, Department of Water Induced Disaster Management - Member

Technical Advisory Committee (TAC)

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- Mr. Bashu Dev Lohanee – Member
- Mr. Damodar Bhattarai - Member
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- Dr. Upendra Gautam – Member
- Dr. Vishnu Prasad Pandey – Member

THE 8TH ASIAN REGIONAL CONFERENCE (8ARC)

The global population is expected to grow from current 7.4 billion to 9.1 billion by 2050. The proportion of population living in rural areas, in contrast, is expected to decline globally from current 3.4 billion people (or 45% of the population) to 3.1 billion (or 34% of the population) by the mid-century. In contrast to the global scenario, developing countries have about 75% of population living in rural areas, which are dependent on and continue to depend on agriculture for their livelihood. Furthermore, growing trend in urbanization may bring up the need for urban irrigation in near to mid future. This perspective, therefore, should also be reflected in irrigation planning in developing countries.

It is estimated that overall food production would require to be raised by some 70% between 2005/07 and 2050. In case of developing nations, the food production needs to be doubled to feed the growing population. Depletion and degradation of land and water resources is posing serious challenges to producing enough food and other agricultural products to sustain livelihoods and meet the needs of both rural and urban populations. Since increased food production will have to come from the same limited land and water resources, the focus will have to be on increasing agricultural and water productivity with efficient and optimal use of available resources. This will require adoption of improved agriculture practices, bringing more area under irrigation along with modernisation of existing irrigation systems, institutional reforms and strengthening of irrigated agriculture. In this connection, the role of more enabled water users' institutions (WUIs) in meeting increasing demands in the face of more competitive and volatile markets and increasing (frequencies and intensities) extreme events induced by climate change will be crucial.

In Asia, since the majority of the population still lives in rural areas, it is likely that rural transformation and development will be a powerful engine of sustainable development and improving the resilience of rural households to cope with emerging challenges. For this purpose, four key issues need to be taken into account: i) leveraging the rural-urban nexus for development; ii) promoting an empowerment agenda for rural livelihoods; iii) investing in middle and large-scale farming, as well as in small scale irrigation for smallholder family agriculture; and iv) promoting the resilience of poor rural households. Access to irrigation and drainage will play a significant role to enable more resilient household income for farmers, especially the smallholder farmers, since reliable access to water for crops can reduce vulnerability to drought, increase the farm yields, and provide a mechanism for the utilization of improved inputs leading to evergreen sustainable development.

The International Commission on Irrigation and Drainage (ICID),established in 1950, is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO) that is playing a crucial role to address the aforementioned issues. Through its network of professionals spread across more than a hundred countries, ICID has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework. It also organizes regional conferences at four regions of the world – Asian Region, European Region, African Region, and Pan-American Region. The Asian Regional Conference (ARC) was started with the first one held during 16-21 September, 2001 in Seoul South Korea. The second to seventh ARCs were held in 2004 (Echuca, Australia), 2006 (Kuala Lumpur, Malaysia), 2007 (Iran), 2009 (New Delhi, India), 2010 (Yogyakarta, Indonesia) and 2012 (Adelaide, Australia).

This 8TH ARC is hosted by Nepal National Committee of ICID (NENCID) during 2-4 May 2018 in Kathmandu, Nepal. The 8TH ARC will focus on the theme of *"Irrigation in Support of an Evergreen Revolution"* considering the need to address the aforementioned challenges to increase agriculture productivity for ensuring food security for the present and future population in the Asian region. Following five sub-themes are envisioned under the theme;

I. **Enabling small holders' capacity to obviate farmers' distress:** enhancing access to appropriate technology and non-conventional banking services; promoting asset management of small holders'; innovative and workable financing mechanisms; addressing to low productivity and market uncertainty; legal and institutional arrangements for collective farming of small holders' organization; etc.

II. **Coping with recurring droughts and floods in the context of climate change:** characterizing climate variability/change and climatic extremes; climate change impacts on water availability and demand; issues/challenges of land and water management; developing resilience to climatic variability and extreme events; crop insurance; etc.

III. **Modernising irrigation systems for better services:** multi-perspective evaluation of irrigation systems; approaches of irrigation system modernization for achieving Sustainable Development Goals (SDGs); innovation and technical advances for water- energy-food security; system automation for efficient/effective management options; institutional reforms of large scale irrigation systems; cases of modernization as an intervention and lessons learnt; mainstreaming modernization process through various reforms; etc.

IV. **Enabling Water Users Institutions (WUIs) for sustainability of irrigation systems:** performance assessment, enterprising, and sustainability of WUIs; institutional and policy landscape of irrigation/drainage sectors; process and procedure of participatory irrigation development/operation/maintenance in various countries; role of irrigation/farmers/water users' organization in improved irrigation system performance; etc.

V. **Irrigation, ecosystem services, and aquatic biodiversity:** assessment of trade-offs between and optimization of consumptive uses of water and environmental flows; water-related natural infrastructure and ecosystem services in the water-energy-food nexus; impact of irrigation on water-related ecosystem services; contributions of traditional knowledge and citizen science to understanding and managing irrigation ecosystems; using information from valuation and other assessments in decision-making for long-term ecological sustainability.

ACKNOWLEDGEMENTS

The Organizing Committee, on behalf of the Organizers, Co-organizers, and Associates, extends its gratitude to the Right Honorable President of the Federal Democratic Republic of Nepal for graciously inaugurating the conference as the Chief Guest and delivering the inaugural keynote speech. Similarly, the Organizing Committee would like to thank Honorable Minister for Energy, Water Resources and Irrigation Mr. Barsha Man Pun for his presence as Special Guest and delivering the remarks in the Inaugural Session and also for accepting the invitation to be the Chief Guest of the Closing Session.

Our sincere appreciation is due to Dr. Sanjay Sharma for chairing the Inaugural and Closing Sessions. We would like to extend our deep appreciation to all the Session Chairs who conducted the sessions in a professional manner within the time schedule. The keynote speakers, panelists, facilitators and coordinators of the symposiums deserve our sincere thanks for their contribution to the Conference. We are indebted to the national and international participants for their lively and active participation throughout the Conference. We wish to extend our gratitude to the Sub-committee chairs and coordinators of the sessions. The Organizing Committee would like to acknowledge the tireless efforts from Ms Rashmi Shrestha, Conference Coordinator, Ms Manisha Ghimire, Conference Secretary, Ms. Richa Karki, Procurement Manager, Mr. Suresh Ranjit, Procurement officer and all the Paani staff members in making this Conference happen.

The event manager Emazing (P) Ltd. deserves our sincere appreciation for their excellent feat as the event management partner using effective combination of technical fineness and expertise. There are many visible and invisible hands who have contributed significantly to organize the conference and the Committee appreciates their contribution.

And lastly, the Organizing Committee would like to thank Water Modeling Solutions Pvt. Ltd. (WMS) for their excellent work in providing technical editing as well as printing services for the publication of this document.

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FOREWORD

Dear Honourable Participants,

On behalf of the Steering Committee of 8TH Asian Regional Conference of International Commission on Irrigation and Drainage (ICID) jointly organized by ICID and NENCID, I am honoured and delighted to welcome you to this International Conference. The "Irrigation in Support of an Ever Green Revolution" which is rightly selected as Conference theme, is quite pertinent at this time where we have to meet challenges of increasing population of the world as well as the climate change affecting on the food production chains.

I believe we have a venue that guarantees a successful conference amid the unique culture and scenery of Kathmandu and Nepal mountains. Those of you who participate in the irrigation study tour will have opportunity to visit our farmer managed irrigation systems and beautiful scenery and snow clad mountains.

As a Steering Committee Chair, I know that the success of the conference depends ultimately on many people who have worked with us in planning and organizing both the technical program and supporting social arrangements. In particular, we thank the Organizing Committee Chair and Technical Advisory Committee (TAC) Chair for their advice and suggestions on organizing the technical program. I would like to thank the Technical Advisory Committee for their thorough and timely reviewing of the papers. We recognize the contribution of sponsors who have generously made resources available for this important conference.

Finally, I would like to thank to the Local Organizing Committee members who have all worked extremely hard for the details of important aspects of the conference programs and social activities.

Have pleasant stay and fruitful deliberations in the conference

Barsha Man Pun "Ananta"
Minister, Energy, Water Resources and Irrigation, Nepal
Chairperson, Steering Committee, 8TH Asian Regional Conference

FOREWORD

Asia, the largest continent has 60% of the population of the world. About 70% of the world's irrigated area is in Asia and more than 80 percent of water withdrawals are used for irrigation. Eight countries (India, China, Pakistan, Iran, Indonesia, Thailand, Turkey and Bangladesh) account for 82% of the total irrigated land in Asia. ICID had the pleasure of supporting the first Green Revolution that has made Asian countries not only self-sufficient in food but they are also exporting food and fibre. To feed the ever increasing population, we need to find ways to increase the productivity of irrigation to produce the food, fibre and fuel needed for tomorrow's population. We need an 'Evergreen Revolution'.

Nepal is one of the earliest members, joining ICID in 1973 and is very active both nationally and internationally in the fields of irrigation and drainage. Members of NENCID play a prominent role in the management and leadership of ICID, serving as Office-Bearers and work body members. I am extremely pleased that the Nepalese National Committee of ICID (NENCID) will be hosting the 8TH Asian Regional Conference in the Himalayan destination of Kathmandu. The destination also provides for unique tourism opportunities in form of the highest mountains of the world and heritage sites across the country.

The 8TH Asian Regional Conference of ICID will be held from 2-4 May 2018 at Kathmandu, Nepal. The theme of the Regional Conference is "Irrigation in support of an evergreen revolution". The topics covered would address the challenges to increase agriculture productivity in order to ensure food security for the present and future population in the Asian region. Experts from the region and beyond would have an opportunity to discuss and contribute to an upcoming evergreen revolution that is the need of the hour to ensure food security in Asia.

During the Conference, papers will be presented and discuss various aspects of the themes. The Conference proceedings would include a printed volume containing 'Abstracts' and a USB containing all full length papers. These proceedings are a fine collection of technical papers which hopefully will be very useful to all delegates during the Conference and many others who may refer to it in future.

Yours Truly,

Felix B Reinders
President
International Commission on Irrigation and Drainage (ICID)

FOREWORD

The 8TH Asian Regional Conference of the International Commission on Irrigation and Drainage (ICID) is being held in Kathmandu on 2-4 May 2018, hosted by its Nepal chapter NENCID. The theme of the conference is Irrigation in Support of an Evergreen Revolution.

It is worth a few moments of reflection on why this theme was chosen and what it implies. In Nepal, we are living through some interesting revolutionary times: the country is undergoing deep-seated restructuring of our governance system focused around decentralization and devolution which will have far-reaching consequences for how our resources are managed and mobilized, including in the water sector. A major lesson, however, has been imbibed that stems from the last half-century of scientific and activist concerns about the nature of development to be pursued as revolutionary changes get underway: it is that environment and its sustainability matter because without it, economic growth howsoever rapid will neither endure in the long run, nor will it benefit the whole society, including its weakest members. Hence the choice was made of Evergreen Revolution as the conference theme's focus, also by keeping in mind that other countries too are grappling with similar (maybe less intense) stress of change and that this aspect would be of interest to them as well.

The choice of the phrase Irrigation in Support must also be understood in the spirit it was intended: irrigation is not an end in itself but an important means to an end, which is increased food production. And that does not happen without a wide range of interlinked nexus of critical issues coming into play as well. The foremost is to understand that as rice growing civilization, Nepal and much of Asia have been home to some of oldest irrigation practices known to humankind. This ancient history has defined our land and water management institutions that robustly survive to this day as (some still informal) farmer-managed irrigation systems. They need to be modernized, but in a manner not by circumventing them but by building on their pre-existing strengths.

It is with these concerns in mind that five sub-themes were selected. The first sub-theme tackles the problem of small farmers, the silent majority that faces nexused problems of access to credit, market assurance and reduction of weather-related risks. Second sub-theme realizes that we live not just in a semi-arid zone with four months of floods and eight months of drought but that this nature's reality is made more uncertain by climate change. How should we cope with it? Third sub-theme deals with the challenge of modernization and our global obligation to address concerns of the Sustainable Development Goals (SDGs). The fourth sub-theme is about Nepal's very rich institutional asset, traditional and modernizing farmer-managed water users' institutions. It is about ancient practices coming to terms with modern management in a manner that enriches them both. The fifth sub-theme has come from the realization that when we extract water for human needs from a water body, not only does it affect aquatic life that also depends upon that very water but also some of the most marginalized poor who depend on that aquatic life for their livelihood and sustenance.

The response we received to our call for abstracts was impressive: some 105 abstracts were submitted from 22 countries, many of them promising interesting new insights. The theme and sub-themes are about serious challenges being faced by irrigation managers in developing countries

while they seek to balance tradition with change, human needs with that of the environment, and traditional certainty of the past with climatic uncertainty of the future. It is the hope of the Technical Advisory Committee that the participants of the 8TH Asian Regional Conference will enjoy the conference intellectually as well as through Nepali hospitality in Kathmandu.

Dipak Gyawali

Pragya (Academician), Nepal Academy of Science and Technology

Former Minister of Water Resources and

Chair, Technical Advisory Committee, 8TH Asian Regional Conference

FOREWORD

Human civilization took its first major leap forward by the advent of agriculture practices and furthered it by the development of irrigated agriculture. Irrigation and drainage interventions lead to multiple advantages and opportunities by providing not only adequate agricultural water, but also adequate nutrition, employment generation and poverty reduction at the rural level especially in the Global South. The steady increase in world population, climate change, and frequent spells of droughts are some of the factors that need to be addressed in order to achieve food security and thus guarantee the very existence of human kind. The steady increase in population requires a sustainable growth in agriculture output in which the role of irrigation is of paramount importance and we need to work hard towards making it more accessible and reliable for the end users. Irrigation and drainage policies therefore need to be based upon scientific rationale, wider experience sharing and learning from the successful implementations around the world.

The 8TH Asian Regional Conference (8ARC) is scheduled to convene during 2-4 May 2018 in Kathmandu with the theme of "Irrigation in Support of an Evergreen Revolution". This is a great opportunity for the Nepal National Committee of ICID (NENCID) for hosting the event in collaboration with Department of Irrigation, the Government of Nepal and other partners.

I have full confidence that this conference will provide an excellent forum for sharing experiences from different parts of the world in various fronts such as policy, successful practices, technology, scientific researches and awareness. It is expected that the deliberations will revolve around the concerns, issues, and challenges pertinent to food security in Asia and beyond. The papers cover a wide range of topics namely enabling farmers and water users' institutions, coping with climate change, modernization of irrigation systems, ecosystem services and aquatic biodiversity. It is a matter of profound satisfaction that a large number of participants from many countries have expressed commitment to participate in the conference and more than a hundred abstracts have been received.

I would like to compliment the efforts of all involved in organizing this conference and convey my best wishes that the papers and the presentations made during the conference will address the dire issues as stipulated in our subthemes as well as our main theme. Moreover, I believe that the conference will draw the attention of our policymakers towards the importance of irrigation in order to achieve food security and an Evergreen Revolution as the main theme suggests. Thank you and once again, my best wishes to all.

Saroj Pandit

Director General, Department of Irrigation; Ministery of Energy, Water Resources and Irrigation, Government of Nepal
President, Nepal National Committee of ICID (NENCID)
Chairperson, Organizing Committee, 8TH Asian Regional Conference

FOREWORD

Depletion and degradation of land and water resources is posing serious challenges to producing enough food and other agricultural products to sustain livelihoods and meet the needs of both rural and urban populations. Since increased food production will have to come from the same limited land and water resources, the focus will have to be on increasing agricultural and water productivity with efficient and optimal use of available resources.

In Asia, since the majority of the population still lives in rural areas, it is likely that rural transformation and development will be a powerful engine of sustainable development and improving the resilience of rural households to cope with emerging challenges. Access to irrigation and drainage will play a significant role to enable more resilient household income for farmers, especially the smallholder farmers in Asia. Since access to reliable water for crops can reduce vulnerability to drought, increase the farm yields, and provide a mechanism for the utilization of improved inputs, it would thus lead to evergreen sustainable development.

In order to address the above challenges and to increase agriculture productivity for ensuring food security for the present and future population in the Asian region, the Nepal National Committee (NENCID) is organizing the 8TH Asian Regional Conference (ARC) on the theme "Irrigation in Support of an Evergreen Revolution" from 2-4 May 2018 at Kathmandu, Nepal.

A large number of participants from across the globe especially from Asia are expected to make it to the conference, which will help in enriching our knowledge and expertise in the relevant areas through various technical sessions of the conference.

Ashwin B Pandya
Secretary General
International Commission on Irrigation and Drainage (ICID)

PLENARY

Summary of Plenary Sessions

SUMMARY OF PLENARY SESSIONS

The 8TH ARC was organized jointly by the Government of Nepal through Department of Water Resources and Irrigation, DoWRI (formerly, Department Irrigation and Department of Water Induced Disaster Management) and NENCID and co-organized by USAID. Other partners (in alphabetical order) who joined hands in organizing the conference were the Asian Development Bank (ADB), ICEWaRM, International Center for Integrated Mountain Development (ICIMOD), International Water Management Institute (IWMI), and the World Bank. The conference was held during May 2-4, 2018 at Hotel Yak and Yeti in Kathmandu, Nepal. There were more than 520 participants from 22 countries in Asia and beyond from a wide range of disciplines including academicians, practitioners, policy makers and research scholars. One hundred and five (105) abstracts were accepted for oral presentation in 15 technical sessions (TSs) and/or plenary symposiums. There were two TSs in sub-theme 1, four in sub-theme 2, five in sub-theme 3, three in sub-theme 4, and one in sub-theme 5. The conference provided a valuable networking opportunity and set the stage for further cooperation among the participants.

Eight plenary sessions, including opening and closing, were convened during the three days. The proceedings of the plenary sessions are summarized below.

Plenary 1: Inaugural and Opening

The conference was graciously inaugurated by Rt. Hon'ble Bidya Devi Bhandari, President, Federal Democratic Republic of Nepal. Hon'ble Barsha Man Pun, Minister, Energy, Water Resources and Irrigation was also present in the inaugural session. Opening remarks were delivered by the President and Vice President of International Commission on Irrigation and Drainage (ICID), Joint secretary for Energy, Water Resources and Irrigation of Nepal and representative of Department of Irrigation (currently, Department of Water Resources and Irrigation, DoWRI), Government of Nepal (GoN).

The opening plenary was moderated by Mr. Dipak Gyawali, Chair of the Technical Advisory Committee (TAC) of the 8^{TH} ARC. It was divided into two parts. In the first part, Mr. Gyawali provided context of the conference as well as technical highlights. Six dignitaries delivered their keynote speeches in the session. The speakers include, Mr. Arnaud Cauchaous (Senior Water Resources Specialist, ADB), Ms. Carol Jenkins (Head of SEED Office, USAID), Mr. Saroj Pandit (Director General, DoWRI, GoN), Mr. A. B. Pandya (General Secretary, ICID), and Dr. Ahmed Shawky (Senior Water Resources Specialist, the World Bank).

Mr. Gyawali discussed the cultural theory of social solidarities and their technological choices and highlighted the importance of understanding their key aspects such as – *What type of technology is appropriate? To whom it is appropriate? What are the risks associated to the choices and who bears them?* Mr. Cauchaous discussed current global/regional mega challenges and shared how the ADB is responding to address such water challenges. Ms. Jenkins shared learnings from recent field visit in western Nepal and mentioned that lack of irrigation water is the key constraint for agricultural productivity in Nepal. She also highlighted how USAID-funded projects such as KISAN, PAHAL, SABAL, among others are contributing to improve access of water to farmers through various approaches including multiple use of water system (MUS). She then emphasized the need for integrated watershed management approach, water use productivity/efficiency, and workable collaborative platform for all partners to provide better solutions to increase irrigation access. Mr. Pandit provided an overview of irrigation development in Nepal and evolution of policies, institutions, and technology. He also highlighted how development partners are continuously supporting the irrigation development of Nepal. Mr. Pandya shared ICID vision 2030, which consists of six goals and corresponding action plans. Mr. Shawky from the World Bank shared thoughts on the topic of "Water in Agriculture" with focus on water accounting, management efforts required for different levels of irrigation, and how vulnerable agriculture is to climate change.

The second part of the opening session included release of the Technical Report of ASRWG-WT titled "Contribution of Agriculture Water to the Rural Development of Asia" jointly by the President and Vice-President of ICID.

Plenary 2: Modernization of Irrigation Systems

The symposium on "Modernization of Irrigation Systems" was organized jointly by the then DoI (currently, MoWRI) and the World Bank. It was moderated/facilitated by Dr. Guna Nidhi Paudyal and Mr. Sanjeeb Baral. The three-hour session was addressed by three keynote speakers - Dr. Bart Schulz (Professor, UNESCO-IHE), Dr. Ian Makin (Asia Director, IWMI), and Mr. Kyu Sung Choi (Chairperson of Korean Rural Community Corporation, KRC). Five experts, namely, Mr. Arnaud Cauchaous (Senior Water Resources Specialist, ADB), Mr Ahmad Shawky (Senior Water Resources Specialist, the World Bank), Dr. Puspa Khanal (Senior Water Resources and Irrigation Expert, FAO), Dr. Purna Bahadur Chhetri (Senior Agricultural Specialist, the World Bank), and Mr. Bakhodir Mirzaev (Senior Water Resources Specialist, Islamic Development Bank Group), provided their views on the main theme of the symposium. During the keynote session, Mr. Choi shared the experiences in modernization of agriculture in Korea through KRC. Water shortage due to climate change and lack of manpower due to decreasing rural population was the key driver to move towards modernization of agriculture in Korea. Key aspects of irrigation modernization in Korea highlighted by Mr. Choi are rehabilitation of irrigation facilities, Information and Communication Technology (ICT)-based smart water management, flood control to cope with climate change, and integrated systems through river basin inter-link for complementary irrigation. Prof. Schultz provided an overview of irrigation and drainage facilities in three types of countries (i.e., high income, middle income, and low income) and emphasized that there is a lot to be done in low-income countries as they have only 6% of irrigation and 1% of drainage facilities. He concluded that the farm size and farming systems need to be increased/upgraded if a higher yield per hectare is expected in the future. Mr. Makin presented the evolution of irrigation modernization process and highlighted that technical, managerial, and institutional elements are equally important and reforms of these elements in a balanced way are required to achieve irrigation modernization. He emphasized for realigning yesterday's system with the need of today and tomorrow.

During the panel discussion session, Dr. Puspa Khanal stressed the need of focusing on dual objectives of land productivity and water productivity in irrigation modernization. He further mentioned that a comprehensive framework is to be developed for that by building national capacities and bringing about changes in the teaching approach in academic institutions. Mr. Mirzaev discussed about measurements, water accountability, and adequate capacity for sustainable modernization of irrigation systems. Dr. Purna Chhetri, on the other hand, emphasized on sustaining land use, strengthening Water Users' Association, crop system planning, and incentive to agricultural people as key elements for modernization. Dr. Shawky linked his discussion with modernization of Rani-Jamara-Kuleriya Irrigation System in Nepal and emphasized that the need of modernization is to retain people from migration to Arab/Gulf countries. He talked about positive incentives for increasing irrigation water use efficiency and also discussed various options on the Public-Private-Partnership (PPP) model. Mr. Cauchaous discussed characteristics of earlier irrigation systems and mentioned that future systems should be different and be market/ commercially oriented, flexible, reliable, cheaper and efficient. He also stressed the need for managerial, institutional, and technical aspects in modernizing irrigation systems. The session was very lively with active participation during the question and answers time.

Plenary 3: Irrigation, Ecosystem Services and Aquatic Biodiversity

This plenary was organized by the USAID Paani Program (Paani). Dr. Jeff Opperman (Global Lead Scientist for Fresh Water, WWF) gave the keynote speech, and Dr. Ram Devi Tachamo Shah (Postdoc Researcher, Aquatic Ecology Center, Kathmandu University), Mr. Dibesh Karmacharya (Director, Center for Molecular Dynamics), Mr. Sanjeeb Baral (Project Director, Water Resources Project Preparatory Facility, DOI, GoN), and Dr. Maheshwor Shrestha (Sr. Divisional Engineer, Water and Energy Commission Secretariat, WECS, GoN) each gave one technical presentation. The presentation was followed by a panel discussion, in which five panellists (Dr. Jeff Opperman, Prof. Mark Weinhold, Prof. Ashutosh Shukla (Senior Research Faculty, ISET-Nepal), Mr. Ashok Tharu (Community Leader, Falkapur, Dang), and Ms. Madhu Ghimire (Section Chief, Environment Section, Ministry of Forest and Environment, Government of Nepal) shared their views.

The symposium commenced with a keynote presentation by Dr. Opperman. In his presentation, Dr. Opperman discussed the power of rivers, focusing on the need to develop water infrastructure while maintaining healthy rivers. He highlighted several potential threats to ecosystems due to water infrastructure development and shared some thoughts on minimizing their effects on the health of the rivers. He also highlighted systems-scale approaches to feasible infrastructure planning and management, revealing their economic value to countries and their financial value to developers/investors, showcasing examples of Myitnge River (Myanmar), Tana River (Kenya) and Magdalena River (Colombia).

Dr. Shah presented the importance of ecological assessment of a watershed that includes evaluations of multiple aspects of watershed health such as water quality, habitat condition, and biological community composition. She focused on the various benthic macroinvertebrate composition collected from the tributaries of the Mahakali, Karnali and Mohana basins during post-monsoon, base-flow and pre-monsoon seasons; flow alterations and Epemetoptera, Plceoptera and Trichoptera (EPT) metrics. The outcomes of the study are expected to contribute to a better understanding of aquatic responses to flow modification that allow to design sustainable flow for the preservation and conservation of aquatic ecosystems, ensuring goods and services to human beings.

Dr. Karmacharya presented novel work on creating Nepal's first fish genetic reference database using DNA barcoding and environmental DNA metabarcoding techniques. He highlighted the importance of such a database as part of an environmental assessment for planned hydroelectricity in the Karnali River.

Mr. Sanjeeb Baral / Dr. Binod Shakya introduced the usefulness of the newly developed MIP 2016 method for estimating reliable monthly flow and e-flows in ungauged rivers in a cost effective manner for the design of the small water resources projects such as medium irrigation projects and micro- and mini-hydropower projects. Their presentation also highlighted different policies related to e-flows in Nepal. They concluded that the development of water resources infrastructure should have the provision of maintaining the e-flows to sustain aquatic ecosystems in addition to satisfying human needs.

Dr. Shrestha highlighted ongoing national level activities such as WECS's involvement in drafting the National Water Resources Policy for integrated water resource planning following the concept of efficiency, equity and environmental sustainability and completion of river basin plans and hydropower development master plan within the next three years. Based on the Kamala basin study, he demonstrated the successful application of the participatory planning process that involves identifying the priorities and aspirations of different sectors and stakeholders, defining options and scenarios for future development, and negotiating how to maximize synergies among development objectives while minimizing undesired consequences.

The presentation was followed by a panel discussion carried out in two rounds. In the first round, the panelists shared their views focusing on a key question, "*What does a river scape and ecosystem approach to understanding and management mean?*" The panelists' views ranged from the linkage between upper and lower riparian ecosystems to integrated approaches for water resources management, respecting and

following socio-economic and cultural values, and regulatory measures for protection and conservation of biodiversity and the ecosystem.

Discussion in the second round focused on, "*What have we learned and how can we put these lessons to good use in Nepal?*" The panelists pointed out the lack of systematic and updated information, access to that information, and flow within and outside the government system. In addition, they discussed how there is an immense opportunity for water infrastructure development in Nepal but that political will is necessary to utilize resources in an effective manner.

Mr. Allen Turner (Chief of Party) and Ms. Nilu Basnyat (Deputy Chief of Party), with coordination from Dr. Anjana Shakya, facilitated the panel discussion with gracious support from Ms. Sarah Gray (Communications Specialist), Mr. Deepak Gyawali, Mr. Madhav Belbase, Mr. Basu Dev Timilsina, Mr. Mitra Baral, Mr. Navin Mangal Joshi, Dr. Vishnu Prasad Pandey, Mr. Rajesh Sada, Ms. Deepika Sharma, Ms. Rashmi Shrestha and Ms. Manisha Ghimire.

Plenary 4: Sustainable Irrigation

From supporting famed hydraulic civilizations in the ancient past to spearheading the 'green revolution' in the 1960s and 1970s, irrigation has always played a pivotal role in the agrarian economy of Asia. Indeed, it is equally true that many ancient civilizations like that of Angkor in Southeast Asia collapsed owing to failure of irrigation management. It therefore comes as no surprise that Asia accounts for the bulk of irrigated land in the world (70% of all irrigated land) and is home to some of the largest, as well as oldest, surface irrigation schemes. Largest and oldest as they may be, Asia's surface irrigation sector is also beset by a number of intractable problems. Important among these is the consistent under-performance of irrigation schemes; more often than not, these deliver much more water than required for head end farmers and irrigate much less land than they were originally designed to do, thereby affecting the tail end farmers. This results in low land and water productivity, low returns on investments and deferred operation and maintenance (O&M) and the disinterest and apathy of the end users (farmers) of these systems and their eventual exit, if they have such an option, from these formal irrigation systems. Male outmigration and feminization of agriculture are also affecting irrigation systems. Furthermore, technical design and management problems also make the systems often unproductive. All these problems are now exacerbated by impacts of climate change. Either there is too much, or too little water and occurrence of extreme weather events has increased manifold. These puts tremendous pressures on already old and dilapidated surface irrigation systems. Here the challenge is: *how do irrigation systems manage risks emanating from climate and other social-demographic changes?* While the problems are well known and much dwelt upon, the solutions are not as well known.

In this context, the plenary was organized jointly by International Water Management Institute (IWMI) and International Center for Integrated Mountain Development (ICIMOD) and facilitated by Dr. Luna Bharati (IWMI) and Dr. Aditi Mukherjee (ICIMOD). The session covered topics on the emerging solutions in the arena of technological and institutional innovations and the various ways of managing future uncertainty and risks so that we move towards a more sustainable irrigation sector in the future. The plenary was divided into two parts. The first part consisted of five presentations one each by Dr. Santosh Nepal (Water and Climate Specialist, ICIMOD), Dr. Alok Sikka, (Principal Researcher, IWMI), Dr. Xueliang Cai (Professor, UNESCO-IHE), Prof. Mathias Becker (Professor, University of Bonn) and Dr. Alan Nicol (Strategic Program Leaer, IWMI). It was then followed by a high level panel consisting of Hon. Karlene Mayward (Former Minister, Australia), Dr. David Molden (Director General, ICIMOD, Nepal), Dr. Vadim Sokolov (Head of the International Fund for Saving the Aral Sea (IFAS), Central Asia), Mr. Felix Reinders (President, ICID), and Mr. Ian Makin (Asia Director, IWMI). The panel discussion focused on technological and institutional innovations aimed at improving efficiency, equity and sustainability of irrigation systems in Asia.

Dr. Nepal presented climate change scenarios and its implication on water resources and agriculture in Nepal. He emphasized future projection results with wetter and hotter future climate, decreasing glaciers, floods and extreme events, which would adversely affect irrigation systems and agriculture production. In his presentation on managing climatic risks for sustainable irrigation, Dr. Sikka presented various solutions to build climate resilience. The solutions included, optimizing reservoir operations, internalizing climate scenarios in the design of water infrastructures, water supply and demand management, risk transfer schemes such as insurance, modernizing irrigation, water and energy smart solutions including solar irrigation, capacity strengthening and regional cooperation. Dr. Cai, mentioned that his studies with remote sensing tools show that small farmers are leading the bigger irrigation development and productivity gains in agriculture. Therefore, there is a need to further support new farmer led initiatives. The presentation by Prof. Becker on the benefits and trade-offs on water-saving rice production stressed that water-saving production methods may entail production risks and possible trade-offs that have not been sufficiently considered when advocating these innovative cropping strategies. Finally, Dr. Nicol, presented the social and institutional aspects of managing future risk and uncertainty. His presentation

highlighted that although farmers see migration as a coping strategy against future risks, it is both a 'safety valve', and 'debt trap'. He further emphasized the need to tackle future risks as part of a wider socio-economic development strategy.

The high-level panel discussion on "Technological and Institutional Innovations for Sustainable Irrigation" emphasized that the context of irrigation is changing very fast due to rapid socio-economic changes and climate change. The panellists concluded that for irrigation to be sustainable, it has to cater to the changing context through appropriate policies, strategies and technologies. The discussion further stressed the need for farmers to be at the center stage of sustainable irrigation development.

Plenary 5: Nexus Challenges in Irrigation Institutions

Irrigation is a combination of socio- technical and institutional components. It operates within a socio-ecological system consisting of hydrology, hydraulics, civil engineering, soil science, agronomy, institutions and human organizations and marketing. Hence, in order to be effective, irrigation institutions have to break the conventional silo approach.

In this context, this plenary was organized by Farmer Managed Irrigation System Promotion Trust (FMIST) and facilitated by Dr. Prachanda Pradhan. It had a keynote session followed by panel discussion. During the key note session, Prof. Asit Biswas (Visiting Professor, Lee Kuan Yew School of Public Policy, National University of Singapore), Dr. Douglas Merrey (Irrigation Institution Expert, Former Deputy Director General, IWMI), and Mr. Devesh Belbase (Research Assistant, ICIMOD) shared their thoughts on nexus challenges in irrigation institutions.

The video keynote speech by Dr. Biswas emphasized that new approach is to be taken and to go beyond the boundary of traditional concept in meeting the food requirement of the growing population. Examples of India and China suggest that despite the limited land and water, food production can be increased by adopting new technologies and approaches including expansion of connectivity by bringing food from surplus to deficit areas. The presentation further suggests looking for new institutional arrangements. Dr. Merrey, in his keynote speech, stated that the 21st century Water Users' Associations need to do better than in the 20th century. He emphasized that the new approach is needed to support farmer-led collective management of irrigation. Following these keynote speeches, Mr. Belbase presented a case study on irrigation and hydropower trade-off which suggests that, due to rapid development of water infrastructures for irrigation and hydropower, there is now an immense need of catchment management and basin planning for rational water allocation and management to attain a win-win situation for irrigation and hydropower.

A panel discussion followed the three presentations. Five distinguished panel members namely Dr. Hafied Gany (Vice President Honorary, ICID, Indonesia), Mr. Susheel Acharya (Project Manager, Rani Jamara Kuleria Irrigation Project, Nepal), Dr. Masayoshi Satoh (Professor, University of Tsukuba, Japan), Dr. Ding Kunlin (Vice President Honorary, ICID, China) and Mr. A. B. Pandya (Secretary General, ICID, India) deliberated on the issues identified and provided insights from their vast experiences in the field of irrigation institutions. The panel discussion focused on the following key issues;

- *What policy instrument would help break the silo approach in performance improvement of irrigation institutions?*
- *How should irrigation institutions be promoted with features of self-governing, self-regulating and self-supporting?*
- *How can irrigation and agriculture institutions work together to ensure food security?*
- *How can external and internal factors of irrigation institutions be integrated to meet the growing impact of climate change?*

Plenary 6: Climate Change and Adaptation/Mitigation to Floods/Droughts

This plenary was organized by ICEWaRM and facilitated by Hon'ble Karlene Maywald (Former Minister, the Government of Australia). The session had a keynote presentation from Dr. David Molden and five panellists (Dr. David Molden, Dr. Kaluvai Yella Reddy, Mr. Dipak Gyawali, Mr. Daniel Casement, and Dr. Luna Bharati). The key discussions of the session are summarized hereunder:

- Most glaciers are losing ice volume but in some regions like Karakoram region, thickening of glaciers is observed. Irrigated agriculture in high altitude and communities depending on glacier/ snow melt are hardest hit. To stop glacier melting, reduction of Green House Gas emission is needed. Activities like real-time monitoring of floods, identification of recharge areas, irrigation water management, drainage area management and rainfall management are needed.
- Climate change impacts not only the bio-physical activities but also socio-economical activities; so better analysis of climate change is needed. Data collection at the local level and decision making at the higher level by utilizing citizen science make management at the local level more effective.
- Valuing of water and incentivising the water use efficiency for the benefit of farmers can be done.

Water saving crop production techniques and micro-irrigation techniques can be adopted for more production with less water. Training for the future and gender mainstreaming are necessary.

- Carbon footprint has practically doubled for no reason. Impacts of climate change can be beyond our expectations which may require critical decisions on water management.

Plenary 7: Inter-Basin Water Transfer in Bheri-Babai Irrigation Project – Experience Sharing

This plenary was conducted by Bheri Babai Diversion Multipurpose Project (BBDMP) under the Department of Irrigation (DoI), the Government of Nepal (GoN). Considering the need for assured year-round irrigation, development of several Inter-Basin Water Transfer (IBWT) projects are identified by the government of Nepal with the aim of diverting water from "water surplus" to "water deficit" rivers to supplement irrigation water requirement during deficit periods. Among several IBWT projects in pipeline BBDMP is the first one undertaken for implementation. Considering its significance, the GoN has classified the project as a "**Project of National Pride**" in July 2013 and has allocated assured funds from government's own exchequer.

The main objective of BBDMP is to provide round-the-year irrigation water to 51000 ha agricultural land in Bardiya and Banke districts by augmenting 40 m^3/s water in Babai river. In addition, the secondary objective of this project is to produce about 48 MW hydroelectricity by utilizing the difference in elevation of 152 m between the donating Bheri River and receiving Babai River. Total annual benefit is estimated to be about NRs 7.5 Billion (at 2017 price).

BBDMP comprises of three main components, namely, diversion headwork across Bheri River, head race tunnel through the mountain between the two rivers and powerhouse and accessories at Babai River. Because of the risks owing to the geology and topography of the alignment the head race tunnel is being implemented first which will be followed by construction of headworks and powerhouse in the second phase.

Geologically, the tunnel alignment lies in the region occupied by rocks of the Siwalik group. Interbedded

mudstone, sandstone and conglomerate type of rocks with variable soil cover lies along the alignment which also intersects two local faults. For the given geology and topographical mountain situation of the tunnel alignment, mechanized tunnelling using Tunnel Boring Machine (TBM) and lined with precast concrete segments has been adopted to be the preferred method of tunnelling over the traditional Drill and Blast Method (DBM). It is for the first time that a tunnel is being constructed in Nepal using a TBM.

Highest overburden in the alignment is the Harre peak which is 820 m above the alignment and lowest is the overburden in valley formed by Toli khola which is about 220 m. Risks associated owing to highest overburden, the faults - especially the Bheri fault, and water ingress along the alignment mixed with mudstone are the key factors in the design and selection of TBM. A hard rock double shield TBM with excavation diameter of 5.1 m manufactured by Robbins company has been adopted to construct the tunnel. The TBM has facility for installation of segments at the rear end of the shield. Also, facility for injection of pea gravel in the annular space and grouting, facility for advance probing and/or grouting of more than 30m are the key features of the TBM.

Hexagonal honeycomb type segment 0.3 m thick and 1.4 m long with design strength of 50 MPa is used for lining of the tunnel. Actual strength of the segments produced using state of the art segment production moulds is more than 60 MPa. Four number of segments are erected to form a ring with a finished diameter of 4.2 m (water flowing section).

Muck generated is transferred from the head to the train of muck carrying cart using conveyor belt and thereafter the muck cart discharges to the muck discharging platform which is then carried to various disposal sited using dump trucks.

All works associated with construction of the HRT including access road, TBM platform, TBM entry portal, site camp etc. has been grouped into one single contract at a contract value of NRs NRs10,569,832,141.52. Contractor is China Overseas Engineering Group Co Ltd. (COVEC), China. The starting date is June 04, 2015 and is scheduled to be completed by is April 2020.

TBM was designed at the Robbins office at Seattle, USA and manufactured at Shanghai China after which it was dismantled and transported suing 56 containers to site via Kolkata to Rupaidiha. It took about 14 months for the entire operation including assembly at site which was concluded in October, 2017. Actual excavation and tunneling using TBM was started on November 06, 2017.

In the meantime, all peripheral works such as TBM platform, TBM entry portal, employer's camp, contractor's camp etc has been completed. Likewise segment production plant is completed in all respects and about 80 segments are being produced each day.

As of April 25, 2018, 3.7 Km of the total 12 Km tunnel (31 %) has been successfully constructed including excavation, precast concrete segment lining and grouting of annular space (except for final grouting). Highest overburden at Harre peak which lies at 2.3 Km has been crossed smoothly. Average progress so far has been 22 m per day with a maximum of 52.8 m. Similarly, weekly maximum is 287 m with monthly maximum of 1001 m in April beating the Robbins TBM record of 879 m in India. Average monthly progress is of 660 m which is more than the estimated 400 to 500 m per month

Main geology encountered has been the alternate interbedded mudstone (sometime siltstone), sandstone (fine grained as well as coarse grained) and conglomerate (at few locations). Water ingress which seems to have been released from the water lying in the joints in sandstone is observed at various locations along the alignment, it is managed by allowing gravity flow in the channel provided in the bottom segment. In a few cases, the discharge is reduced after sometime whereas in others, continuous discharge is observed.

Thus, based on experience so far, it can be concluded that TBM can be successfully used to construct tunnel in the Siwalik geology to expedite the implementation of IBWTP where tunnel is in critical path of the overall schedule. It makes large projects techno economically viable providing the facilities to the users in a relatively short period.

Plenary 8: Closing

The conference was concluded successfully on 4th May, 2018 with closing remarks by the Minister for Energy, Water Resources and Irrigation, GoN. the President and Vice-President of ICID, Joint Secretary of the Ministry for Energy, Water Resources and Irrigation, GoN, and Director General of the Department of Irrigation, GoN appreciated the efforts of the symposium. It was followed by certificate distribution to the participants of young professional training program and a farewell dinner to celebrate the success of the event. The event concluded with a very positive response from all the participants and stakeholders.

Following five key conclusions were presented by the Chair of the Technical Committee of the 8TH ARC as take home message of the conference,

- Consolidating collective farming, not just physical, but in terms of their social capacity to demand services; and risk transfer approach (e.g., insurance mechanism) may help to obviate farmers' distress
- Focus on multiple storage approaches, including artificial groundwater recharge, could be workable coping strategies/mechanisms in semi-arid Asia
- Solar pumping is a key emerging factor in modernization, but it can be both a blessing and a curse. Focus on multi-purpose projects (e.g. hydropower + irrigation + others) will be a key impetus to sustainable modernization.
- Farmlands are not only the food producing units, but they also have multi-functional role, such as education, recreation, etc. Water use institutions will be better empowered when they are linked intrinsically with other important social functions of farms.
- Biodiversity conservation and irrigation have hitherto worked at cross-purposes creating sub-optimal conditions for both sectors. Two communities (irrigation & biodiversity conservation) should interact closely from the very conceptualization stage to assure healthy development of both these sectors.

THEME – I

Enabling Small Holders' Capacity to Obviate Farmers' Distress

Irrigation water for an evergreen revolution in Pakistan

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Abstract

Pakistan has arid to sub-arid climate with an average rainfall of 240 mm, mostly in monsoon months (July-September). Population of Pakistan is 200 million and growth rate is high, expected to grow to 227 million by 2025. Total area of Pakistan is 79.6 million-hectares (Mha) out of which 29.4 Mha is cultivable. Irrigated (by canals and tubewells) and rain-fed areas are 15.4 Mha and 5.2 Mha, respectively. Annual surface flows in rivers vary from 90 to 180 million acre feet (MAF). Due to short canal supplies, more pressure is on groundwater. If water is available, 8.8 Mha additional, virgin lands can be brought under plough. Agriculture is the main stake of economy in Pakistan and contributes about one-fourth of Gross Domestic Product (GDP) and source of livelihood of over 70% of the population.

Consequent to Indus Water Treaty, Pakistan built Mangla and Tarbela dams and link canals to transfer inter-rivers (Indus Jhelum and Chenab) waters for irrigated agriculture in the commands of Ravi, Beas and Sutlej rivers whose waters were allocated to India. This opportunity of assured supplies through building additional storages and network of irrigation canals brought green revolution in the 1970's. Further productivity was enhanced by adopting better varieties of crops like Maxi Pak wheat, Irri.8 rice and Baharia Maize along with genetic techniques and cultural practices. With high population growth and reduction in storage capacity due to sedimentation of the reservoirs, Pakistan which was affluent in water in seventies, became water scarce by the end of 2000. No mega storage dam was built after completion of Tarbela in 1976. Although Kala Bagh dam design was ready by 1987 but it could not be built due to non-consensus between stakeholders. Pakistan faces recurrent floods and droughts. During the last two decades three flood diversion canals phase-1 i.e. Greater Thal, Rainee and Kachhi Canals were completed to irrigate 0.21 Mha. A few small dams such as Mirani, Sabakzai, Gomal Zam and Satpara were built, which irrigated 0.11 Mha of area. Diamer Basha dam with live storage of 6.4 MAF is being started, which would not only meet water shortages in the Indus Basin but would also supply water to some additional land for an evergreen revolution in Pakistan.

Pakistan until now is using mostly flood irrigation system. Water is diverted from rivers, by constructing dams/barrages, into canals, distributaries and water courses leading to the

farm. Indus Basin Irrigation System, one of the world's oldest and the largest contiguous irrigation system, comprises of 19 barrages and 54 main canals having length over 60,000 kms and water courses length 1.6 million kms. Most of the canals built are unlined and about 40% of the diverted water at canal head is lost during conveyance to the farm gate. There has been significant improvement due to on-farm water management; lining of canals distributaries and watercourses, laser land leveling, low delta crops, salt tolerant varieties, furrow and bed, high efficiency drip and sprinkler irrigation techniques. Campaign on efficient use of water in domestic, industrial and agricultural sector has been launched to disseminate knowledge and information to the water users, especially farmers. Rain water harvesting and use of treated water are also being adopted. Water is a key factor for agro-socio-economic upliftment through green revolution in the country. The additional water availability for irrigation and other relevant developments of efficient water use coupled with crop management as anticipated above, would not only be able to sustain food security in the country but also would enable exporting more agricultural products.

Keywords: *additional irrigation; crop varieties; efficient use of water; green revolution.*

1. Preamble

The management of water for an evergreen revolution towards food security emerged as a concept in the mid-1970s, after rapid increase of prices causing global food crises. The commonly accepted definition of food security is "when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for active and healthy life". However, water plays a key role in upliftment of agro-socio-economic standards with evaluation of green revolution of progressive economies like Pakistan. Today the world has more than enough food to feed everyone, yet 850 million people are food insecure. Achieving food security requires adequate food availability, access and use. The world has witnessed the seven billion population mark in July 2011 and it is projected to rise to 10 billion by 2050. The global challenge of increasing food production, while using less water is exemplified in the case of Pakistan. The population there has increased by over 25% in just the last 10 years and continues to expand faster than global averages. Over 90 million people are now barely getting enough to eat with more than 30 million people living in abject poverty.

With critical population growth and patterns of human activity (increasing demand for more food, more vehicles, more fuel and more buildings), science and technology may not be able to prevent the irreversible degradation of the environment. Mankind today stands at cross-roads. The road to further population growth leads inevitably to starvation, poverty and social disparity. The other road leads to population stabilization at a sustainable level. It leads to a world population in balance with its environment and resources thus creating a condition that will allow the human race to live in peace and prosperity.

Agriculture plays a key role in providing (i) food availability (ii) an important source of income to purchase food; and (iii) foods with high nutritional status. Food security in Pakistan is dependent on agriculture, which again depends on availability of land and water. There has neither been any substantial horizontal expansion (new lands coming under cultivation) nor any significant vertical (per hectare yield) growth despite having massive potential on each of the two areas. At the same time, land and water resources are becoming scarcer every day. The vertical growth has been more difficult and arduous part. Over the last six decades, our institutions and relevant agencies have not been able to educate farmers on crop

management issues. The farming practices are still archaic and about 30% of horticulture crops are lost at post-harvest level. Yields of all major cash and food crops are well below the world average. Pakistan at present does not seem apparently a food-insecure country. However, due to lack of resource base, per capita water availability is falling and the country is heading fast towards water deficiency and resultantly a food-insecure nation.

Along with other developing countries, Pakistan is facing the key issues of high demographic pressure, growing rural exodus, and change in food consumption practices, rapid deterioration of natural resources, low agricultural productivity and water scarcity. The issues are becoming drastic in scale and impact. To meet the future food demand and water for competing sectors as well, improvement and modification of agricultural production system and water resources management are determining factors. To ensure food security, we have to address not only the issue of water supply but also agriculture in an integrated manner. To achieve food security, we need technology transfer and improved water use efficiency. It is essential to create an enabling environment, which is built upon the principles of sustainable development, poverty reduction, knowledge-based institutions and a favorable investment program.

1.1 Water resources

Pakistan's water resources comprise of surface water and groundwater. Their status is briefly described as follows:

1.1.1 Surface water

The Indus River System is the major source of surface water which derives mostly from snow and glacial melting. Schematic diagrams of rivers and irrigation system and land use in Pakistan are shown in Figs. 1 and 2, respectively. Pakistan receives snowfall on the mountains during winter. Majority of rainfall is received during monsoon season (July – September). The rainfall varies in magnitude, time of occurrence, and aerial distribution. The mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain to over 750 mm near the foothills in the Upper Indus Plain.

Pakistan is dependent on the four western rivers including Kabul, Indus, Jhelum and Chenab. Post-Tarbela (1976-2017) flows in Indus at Kalabagh, Jhelum at Mangla and Chenab at Marala and with eastern rivers small contribution on an average are 140 MAF. The three eastern tributaries of the Indus – Ravi, Sutlej and Beas – were allocated to India for its exclusive use. The Kabul River contributes 17 MAF on an average to the surface supplies of the country.

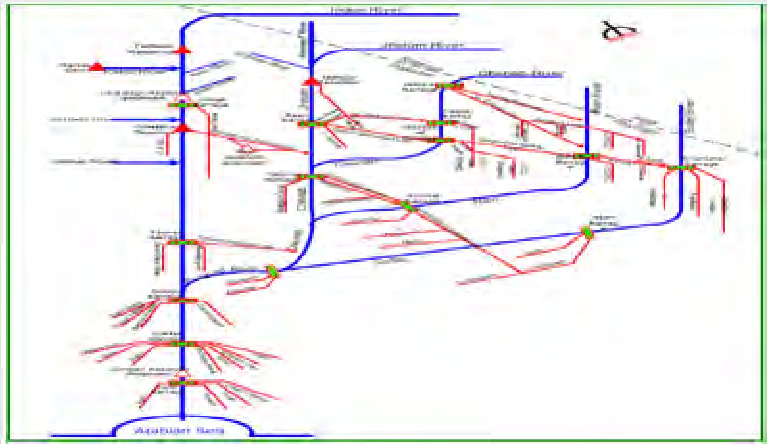

Figure 1: *Schematic diagram of rivers and irrigation systems in Pakistan*

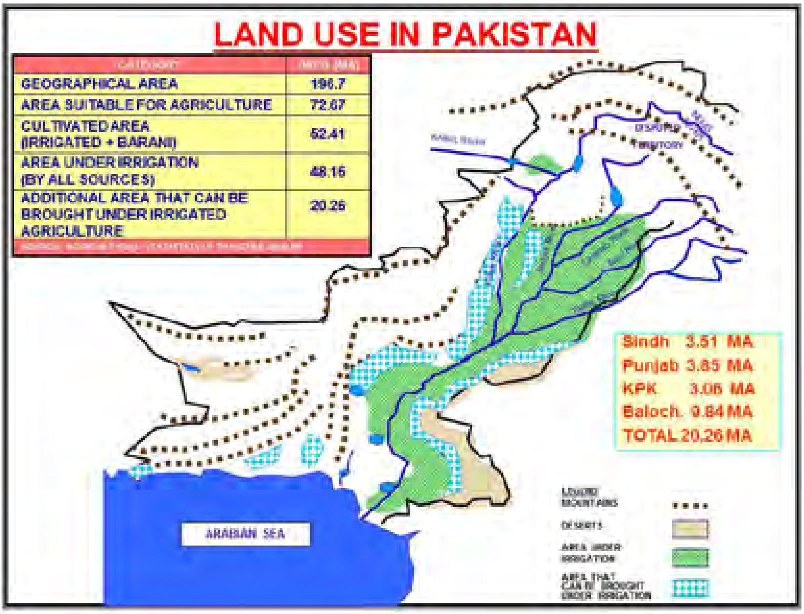

Figure 2: *Land use map of Pakistan*

Consequent to Indus Water Treaty, Pakistan built Mangla and Tarbela dams and link canals for inter-basin transfer of waters (Indus, Jhelum and Chenab) for irrigated agriculture in the commands of Ravi, Beas and Sutlej rivers, whose waters were allocated to India. This opportunity of assured supplies through building additional storages and network of irrigation canals brought green revolution in the 1970s. Further, productivity was enhanced by adopting better varieties of crops like Maxi Pak wheat, Irri.8 rice and Baharia maize along with genetic techniques and cultural practices. With high population growth and reduction in storage capacity due to sedimentation of the reservoirs, Pakistan which was affluent in water in the seventies, became water scarce by the end of 2000. No mega storage dam was built after completion of Tarbela in 1976. Although Kalabagh dam design was ready by 1987, it could not be built due to non-consensus between stakeholders. Pakistan faces recurrent floods and droughts. During the last two decades three flood diversion canals phase-1, i.e. Greater Thal, Rainee and Kachhi canals were completed to irrigate 0.21 Mha. A few small dams were built; i.e. Mirani, Sabakzai, Gomal Zam and Satpara, which irrigate 0.11 Mha area. Diamer Basha dam with live storage of 6.4 MAF is being started which would not only meet water shortages in the Indus Basin but would also supply water to some additional land.

Until now Pakistan is mostly using flood irrigation system. Water is diverted from rivers, by constructing dams/barrages, into canals, distributaries and water courses leading to the farm. Indus Basin Irrigation System, one of the world's oldest and the largest contiguous irrigation system, comprises of 19 barrages, and 54 main canals having length over 60,000 kms and water courses length 1.6 million kms. Most of the canals built are unlined and about 40% of the diverted water at canal head is lost during conveyance to the farm gate. There has been significant improvement due to on-farm water management (OFWM); lining of canals distributaries and watercourses, laser land leveling, low delta crops, salt tolerant varieties, furrow and bed, high efficiency drip and sprinkler irrigation techniques.

1.1.2 Groundwater

Pakistan is extracting about 50 MAF from the aquifers. In fresh areas it has crossed the sustainable limit of safe yield. This over-mining and pollution of aquifers has resulted in secondary salinity and the presence of fluorides and arsenic in water, which in turn is degrading the quality of agricultural lands and creating health issues. The northern part of the Indus Basin has freshwater and most of the southern part has saline.

The Indus Waters Treaty led to the construction of multiple hydraulic structures. These enabled Pakistan to enhance water availability at canal headworks to about 104 MAF. However, this has now decreased to 100 MAF because of the lack of further surface water development since construction of Tarbela dam and the significant loss of on-line storage capacity due to sedimentation. Out of the 100 MAF of annual canal diversion, only 58.3 MAF reaches the farm-gate and remaining 41.7 MAF is lost due to seepage and evaporation.

Pakistan is faced with increasing water scarcity and depending on assumptions of various future demand scenarios, annual water requirements at canal head could be in the range of 135-170 MAF in the coming years. Existing irrigation system is working on 40-45 % efficiency. The National Water Strategy envisages raising irrigation efficiency to 50% from the current level of 40%. In order to improve the existing system, initiatives such as OFWM projects have been started in all provinces, including Gilgit-Baltistan, Azad Jamu and Kashmir and Islamabad Capital Territory areas. The projects undertaken are: - National Programme for Improvement of Watercourses in Pakistan, Chaghai Water Management and Agriculture Development Project (IDB Assisted), National Project to stimulate the Adaptation of Permanent Raised Beds in Maize-Wheat and Cotton-Wheat Farming System in Pakistan. Efficient irrigation system is a pre-requisite for higher agricultural production as it helps in increasing the crop intensity. Despite the existence of a good irrigation canal network in Pakistan, it suffers from wastage of a large amount of water in the irrigation process. During the Rabi season 2010-11 (October-March), the canal head withdrawals show a significant change, as it remained at 37.29 MAF compared to 28.59 MAF during the same period last year.

Water is the key input for agriculture, industry & urban development, as well as achieving Millennium Development Goals (MDGs) and targets and reducing poverty. The water sector gained major focus throughout the last decade in the development programs. Since water availability is persistently decreasing, the challenge is to formulate an effective and comprehensively efficient system of water resource management. The focus areas of investments in water sector are:

- Augmentation of surface water resources by construction of small/medium and large dams.
- Conservation measures (lining of irrigation channels, modernization/ rehabilitation of irrigation system, lining of watercourses and efficiency enhancement etc.).
- Protection of infrastructure from onslaught of floods, water logging and salinity.
- Adoption of resources conservation technologies.

The major water sector projects under implementation are given in **Table-1**. Although being a technically viable project, the proposed Kalabagh dam's design was ready since 1987, it could not be constructed due to lack of consensus between provinces.

Table 1: *WAPDA major water sector on-going and recently completed projects*

Projects	Location	Live Storage (MAF)	Area Under Irrigation (Acres)
Gomal Zam Dam	KPK	1.14	163,086
Greater Thal Canal (phase-I)	Punjab	-	355,000
Rainee Canal (phase-I)	Sindh	-	412,000
Kachhi Canal (phase-I)	Balochistan	-	102,000
Raising of Mangla Dam	AJ & K	2.88	In all provinces of Pakistan
Satpara Dam	Skardu	0.05	15,536
Diamir Basha Dam	GB/KPK	6.4	In all provinces of Pakistan

In addition to the storage and irrigated projects, to upgrade irrigation for 291,000 Acres, a program has been started under "National Program for Water Conservation through High Efficiency Irrigation System (drip & sprinkler)" in Pakistan.

1.2 Water sector issues

There are many water sector issues faced by the country and major ones are as follows:

1.2.1 Water shortage

Pakistan is one of the world's arid countries, with an average rainfall of under 240 mm a year. According to the benchmark water scarcity indicator (the Faulken Mark Indicators), Pakistan's estimated per capita water availability of around 900 m^3 in 2017 places the country in the "high water stress" category (**Table-2**).

Table 2: *Water scarcity (Falkenmark Indicators, FAO – 1992)*

Threshold (m^3/capita/year)	Scarcity level
>1,700	Rare water scarcity
<1,700	Country faces seasonal or regular water-stressed conditions
<1,000	Water shortages hamper the health and wellbeing of the human beings - economic activities are affected
<500	Shortages are severe constraints to human life

The water shortage scenario in Pakistan is further aggravated with high variability of rainfall. The climate change and global warming is likely to severely affect the availability of water. After the loss of 3 major

rivers, Ravi, Sutlej and Beas, to India under the Indus Waters Treaty 1960, India's construction of water storage infrastructure at Baghlihar and Kishanganga, is threatening the uninterrupted flow of water downstream into Pakistan. The per capita water availability v/s population is shown in Fig. 3.

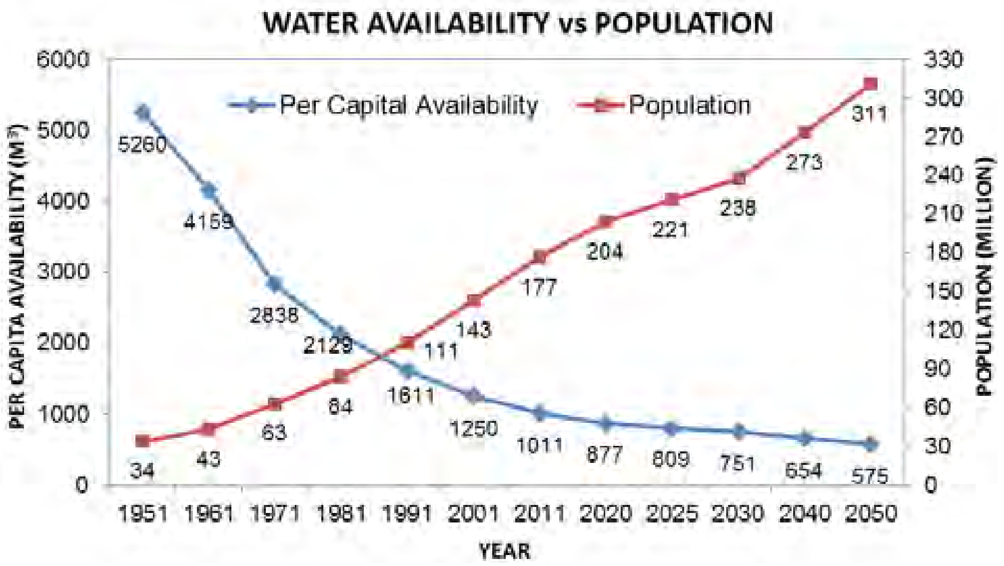

Figure 3: *Water availability and canal water diversions v/s population*

1.2.2 Low water productivity

Whatever water is available is utilized in an inefficient manner. A comparison of wheat yields in California (USA), the Indian Punjab and the Pakistan Punjab shows that productivity of Pakistan in relative proportion to India and California is about 3:6:10 per unit of land and about 5:8:10 per unit of water.

1.2.3 Ageing and outdated infrastructure

Pakistan is blessed with one of the largest contiguous irrigation infrastructures. However, it was designed for water requirements of the 20th century and not for the 21st century. The design of system was for 60% cropping intensity and now the cropping intensity has crossed over 120%. Further the cropping pattern on which water demands and withdrawals were worked out was not supposed to cater for crops like sugarcane and rice which are water intensive.

1.2.4 Low water charges

The water charges are very low and covers only 19% of O&M cost of irrigation network. The system maintenance requires a lot more attention due to deferred maintenance over the past 100 years. Adequate water pricing could offset O&M cost and could generate finances for new water sector projects.

1.2.5 Innovative knowledge-based management

Challenges of the 21st century require the frontiers of knowledge and innovative approaches rather than historic practices. The institutions need redefining of their roles and to develop their capacities according to new responsibilities.

1.2.6 Ownership, reforms and joint management

The irrigation infrastructure operation and on-farm practices need ownership of the stakeholders such as farmers, professionals and revenue collectors. A joint management mode needs to be devised as Area Water Boards and Farmer's Organizations.

Equity: Water provides prosperity and jobs, and acts as a "force multiplier" in the national economy. However, serious concerns exist with respect to spending common pool money to the benefit of selected groups in the absence of policy on equity. The disadvantaged groups are:

- Users at tail-end of canal commands
- Farmers outside Indus Basin

1.2.7 Reservoir sedimentation

Pakistan has three major reservoirs, which has built storage capacity of 18.64 MAF. The storage capacity of Tarbela, Mangla and Chashma reservoirs has depleted by 4.99 MAF (or 27%) by the year 2017 due to sedimentation. It is estimated that the gross storage capacity would be reduced by 6.00 MAF (or 32%) by the year 2025 as shown in Table-3. Due to loss of storage, agriculture of Pakistan is facing water shortage during low flow season.

Table 3: *Storage loss due to sedimentation*

Reservoir (Commissioning Year)	Storage capacity			Storage loss	
	Original	Year 2017	Year 2025	Year 2017	Year 2025
	MAF	MAF (%)	MAF (%)	MAF (%)	MAF (%)
Tarbela (1976)	9.68	6.06 (63%)	5.37 (56%)	3.62 (37%)	4.3 (44%)
Mangla (1967)	5.34	4.35 (82%)	4.19 (79%)	0.99 (18%)	1.15 (21%)
Chashma (1971)	0.72	0.38 (53%)	0.27 (38%)	0.34 (47%)	0.45 (62%)
Sub-Total	**15.74**	**10.79 (69%)**	**9.83 (63%)**	**4.95 (31%)**	**5.91 (37%)**
Addition of Raising Mangla (2012)	2.90	2.86 (99%)	2.81 (97%)	0.04 (1%)	0.09 (3%)
Total	**18.64**	**13.65 (73%)**	**12.64 (68%)**	**4.99 (27%)**	**6.00 (32%)**

(Source: WRM Directorate, WAPDA)

1.2.8 Un-captured water

Despite acute water shortage in the system, data shows that a substantial amount of water escapes below Kotri to the Arabian Sea. During the post-construction of Tarbela (1976-2010), average annual escapes below Kotri are 31.48 MAF, with a maximum of 91.83 MAF in 1994-95 and minimum of 0.79 MAF in 2000-01 (Fig. 4). Most of the flow to the sea occurs during Kharif season and very little during Rabi season. For better water management, storage capacity should be equivalent to at least 40% of total water availability but Pakistan's live storage capacity is about 7% of its overall river flows.

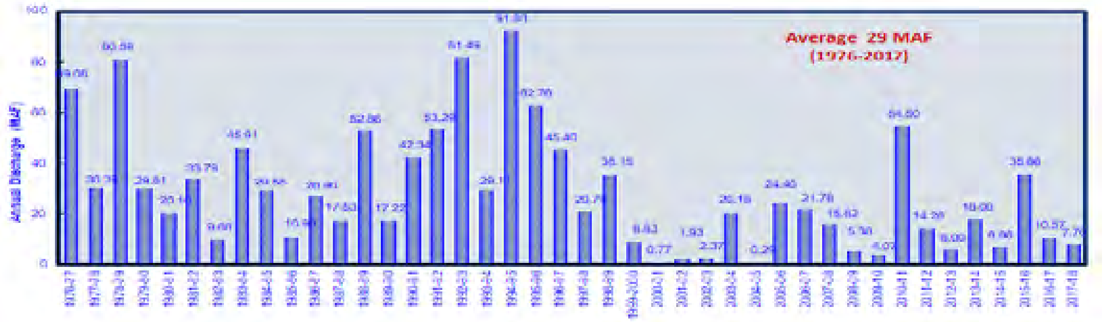

Figure 4: *Water escapes below Kotri (MAF)*

(*Source: WRMD WAPDA based on data supplied by Govt. of Sindh*)

1.2.9 Groundwater issues

Groundwater under the Indus Irrigation System has developed over centuries and due to infiltration of surface water as well as local rainfall. However, depending upon the quality, the useable groundwater is confined to an area of 10 Mha. Development of this resource is through private tubewells and accounts for a gross abstraction of about 50 MAF per annum. The surface water and groundwater in all canal commands are being used conjunctively. In many canal commands, pumping is greater than recharge, thus causing subsidence. There is no regular and proper monitoring of private tubewells' capacity, their pumping hours and utilization. The number of private tubewells has increased over one million; exploiting groundwater indiscriminately and over mining is occurring in certain areas. Due to this situation saline water intrusion is causing pollution of fresh water aquifers. Thus, groundwater regulation is necessary to overcome such problems.

1.3 Present population and food security

Pakistan is the world's sixth most populous country, with an estimated population of over 200 million in 2017, and with an annual growth rate of 1.8%, it is expected that Pakistan will become the fourth largest nation in population terms by 2050. The proportion of population residing in urban centers has risen to 36% since 1950. Future population growth at various index years upto 2030 is given in Table-4. Future population of about 242 million will have to be fed in the year 2030.

Table 4: *Future population growth*

Year	Population (Million)
2010	173.51
2015	191.71
2020	210.35
2025	227.35
2030	242.05

(Source: *Pakistan Economic Survey 2010 – 11)*

According to a report titled "Food Insecurity in Pakistan, 2009", it is observed that state of food security in Pakistan has deteriorated since 2003. The conditions for food security are inadequate in 61% districts (80 out of 131 districts) of Pakistan. There is a sharp increase from 2003, when conditions for food security were inadequate in 45% districts (54 out of 120 districts) of Pakistan before 2003. Almost half of the current population of Pakistan (48.6%) does not have access to sufficient food for active and healthy life at all times. FATA has highest percentage of food insecure population (67.7%) followed by Balochistan (61.2%) and Khyber Pakhtunkhwa (56.2%). The lowest percentage of food insecure population (23.6%) is in Islamabad.

Balochistan has the maximum number of districts with worst conditions in terms of food security. The 20 districts of Pakistan with worst conditions for food security include 10 districts from Balochistan, 5 from FATA, 3 from KPK and 1 from Gilgit Baltistan and Sindh each. Dera Bugti, Musa Khel, Upper Dir, North Waziristan, Kohistan, Mohmand, Dalbaudin, South Waziristan, Orakzai and Panjgur are the 10 districts with worst conditions of food security in Pakistan.

The consumption of wheat in Pakistan declined by 10% in 2009-10 due to lack of purchasing power as result of price hike assuming safely that ensuring food security is much beyond increased wheat production. Only 7.6% districts fall in the category of having reasonable conditions for access to food. The third pillar of food security is food absorption measured through state of sanitation, drinking water, female literacy etc. Only 7.6% district met pre-requisites for reasonable food absorption in 2009 which was 9% during 2003. It is revealed that individual food security in Pakistan has deteriorated from 2003 to 2009. The four levels of food security; individual, national, regional and global are inter-connected and ignoring any one of them may threaten rest of the three levels of security.

This growing population will need more food, water, fibre and energy to meet the necessary requirements. Fifty years ago, the world had fewer than half as many people as it has today. They consumed calories, ate less meat and thus require less water to produce their food. Today the competition for scarce water resources in many places is intense, which will become acute in coming years. The feeding habits will have to change. As population grows, it will demand more food and water. The future food requirement projections will be determined by the driving factors such as, population growth and dietary changes. With rising incomes and urbanization food habits change towards more nutritious and more varied diets; a shift from cereals to livestock and fish products and high value crops. Keeping the case simple, income elasticity factor has not been taken into account and food grain projections have been worked out taking

annual rate of consumption (kg/capita) for various commodities (food grains & edible oils) as given in WSIPS Report 1990 and National Water Policy 2003 Report. The detail is given in Table 5.

Table 5: *Projected food production requirements, 2010 to 2030*

Commodity	Consumption rate* (kg/capita/year	Production requirement (Million Tons)**				
		2010	2015	2020	2025	2030
Wheat	128	24.43	26.99	29.59	32.01	34.08
Rice	15	2.76	3.05	3.34	3.61	3.85
Maize	9.8	1.87	2.07	2.27	2.45	2.61
Pulses	6.3	1.35	1.50	1.64	1.77	1.88
Other grains	3.8	0.73	0.80	0.88	0.95	1.01
Edible oils	11.4	1.98	2.19	2.40	2.59	2.76

* *Source: Water Sector Investment Planning Study Main Report Dec. 1990 & National Water Policy 2003.*

** *Assuming wastage & seed requirement for wheat, maize and other grains @ 10%, for rice @ 6% and for pulses @ 24%.*

2. Shortages in Water Availability and Food Grains

The scarcity of water and shortages of food grains are described as under:

2.1 Water requirements v/s availability

Pakistan's population of 200 million in the year 2017 will reach 242 million by the year 2030. Population rise, rapid urbanization and better socio-economic conditions will bring about increasing pressure on water resources. Future water requirements for all sectors are given in Table 6 and discussed in the proceeding paragraphs:

Table 6: *Future water needs at farm gate (MAF)*

Sector	Year					
	2000*	2010**	2017**	2020**	2025*	2030**
Agriculture	99.0	104.0	109.0	114.0	119.0	124.0
Water Supply & Sanitation	4.5	6.0	7.5	9.0	10.5	12.0
Industry	3.5	3.8	4.1	4.5	4.8	5.1

Environmental Protection	1.3	1.4	1.5	1.6	1.7	1.8
Total	**108.3**	**115.2**	**122.1**	**129.1**	**1.36.0**	**142.9**

*Source: *National Water Policy Vol.-II, January 2003-(2000 & 2025)*
*** Computed (2010, 2017, 2020 & 2030)*

2.1.1 Agriculture

The total area of the country is 79.61 Mha of which 29.4 Mha is designated as cultivated area. About 15.4 Mha cultivated land is irrigated, while the remaining 5.2 Mha is rainfed and the remaining 8.8 Mha area is barren, needing additional water for irrigation. Almost 90 percent of water resources are being used to meet cropwater demand. Increase in agricultural production to meet the needs of a rising population, will require additional water. Based on population growth projections, by 2030 an estimated additional 15 MAF in the year 2017 will be needed for agriculture at the farm gate (assuming a 50% increase in crop yields from non-water inputs).

2.1.2 Municipal use

The current total water uses for domestic and municipal purposes in both urban and rural areas are estimated at 7.5 MAF. By 2030 requirements for water supply, rural potable water and sanitation are estimated to be 12.0 MAF with an increase of 4.5 MAF as compared to 2017.

2.1.3 Industry

There are over half a million large and small industrial units in the country, of which nearly 120,000 are engaged in textile, chemical, fertilizer, tanneries and other manufacturing and processing activities. The water use by all industries and mines in 2017 is estimated to be 4.1 MAF. This is expected to rise to 5.1 MAF by 2030, i.e. an additional requirement of 1.0 MAF.

2.1.4 Environment

In order to ensure adequate water throughout Pakistan for wetlands, environmental protection and increased irrigated forestry, about 1.8 MAF water will be required by the year 2030. The equivalent water requirement for 2017 is about 1.5 MAF.

Water availability in Pakistan is 900 m^3/capita/year in 2017; this is already well below the 1,700 m^3/capita/year threshold for water stressed conditions. Thus, Pakistan is already fast moving into a condition of 'water scarcity'. This situation is likely to deteriorate in future as the gap between supply and demand widens. However, the gross additional water demand (at the farm gate) for all sectors over year 2010 will be about 21.0 MAF (15 MAF for agriculture and 6.0 MAF for municipal water supply, rural potable and sanitation, industry and the environment). The corresponding requirement at the canal head (including provision for system losses where applicable) would be nearly 30 MAF. Water available for future development is about 38 billion-cubic-meters (BCM) (i.e., 31 MAF) including 21.5 MAF of river flow, 6.4 MAF from groundwater and 3 MAF from rainwater harvesting.

This shortfall of about 30 MAF of water by the year 2030 is to be met through creating storage facilities and diverting 21.5 MAF to canals which at present is flowing to sea after allowing 8.6 MAF for environmental flows. This additional diversion of 21.5 MAF at canal head would add about 15.6 MAF at farm gate. Exploiting, a potential of 6.4 MAF from groundwater and 3 MAF from rainwater harvesting will add to this, making additional water availability at farm gate, about 25 MAF. The program of water course improvement by 2030 will cover all the water courses of the country enhancing water course efficiency significantly and will save wastage of about 10 MAF in the irrigation system and thus the total water availability at farm gate would be about 143 MAF. The water requirements of 143 MAF by 2030 for all water using sectors would be safely met. The evergreen revolution with enhanced water availability would remain intact to grow more food.

Campaign on efficient use of water in domestic, industrial and agricultural sectors has been launched to disseminate knowledge and information to the water users, especially farmers. Rainwater harvesting and use of treated water are also being adopted. Water is a key factor for agro-socio-economic upliftment through green revolution in the country. The additional water availability for irrigation and other relevant developments of efficient water use coupled with crop management as anticipated above would not only be able to sustain food security in the country but also would enable exporting more agricultural products.

2.2 Food grains requirement v/s availability

Food grains are to be supplied through reliance on our agriculture. The agriculture sector continues to play a central role in Pakistan's economy. It is the second largest sector, accounting for over 21% of GDP, and remains by far the largest employer, absorbing 45% of the country's total labour force. Nearly 62% of the country's population resides in rural areas and is directly or indirectly linked with agriculture for their livelihood. The agriculture sector's strong linkages with the rest of the economy are not fully captured in the statistics. While on the one hand, the sector is a primary supplier of raw materials to downstream industry, contributing substantially to Pakistan's exports, on the other, it is a large market for industrial products such as fertilizer, pesticides, tractors and agricultural implements. Despite its critical importance to growth, exports, incomes, and food security, the agriculture sector has been suffering from cyclic decline (Table 7).

Table 7: *Historical agricultural growth performance*

Years	Percentage Increase
1960's	5.1
1970's	2.4
1980's	5.4
1990's	4.4
2000's	3.2

(Source: Pakistan Economic Survey 2010-11)

Growth in the sector, particularly in the crop sub-sector, has been falling in the past three decades. Productivity remains low, with yield gaps rising i.e. 36% in case of rice, paddy and 52% in case of wheat and cotton seed (Fig. 5) Critical investments in new seeds, farming technology and techniques, and the water infrastructure are not being made. Without major new investments in agriculture, it is unclear how Pakistan would tackle emerging challenges such as declining water availability, climate change and food insecurity.

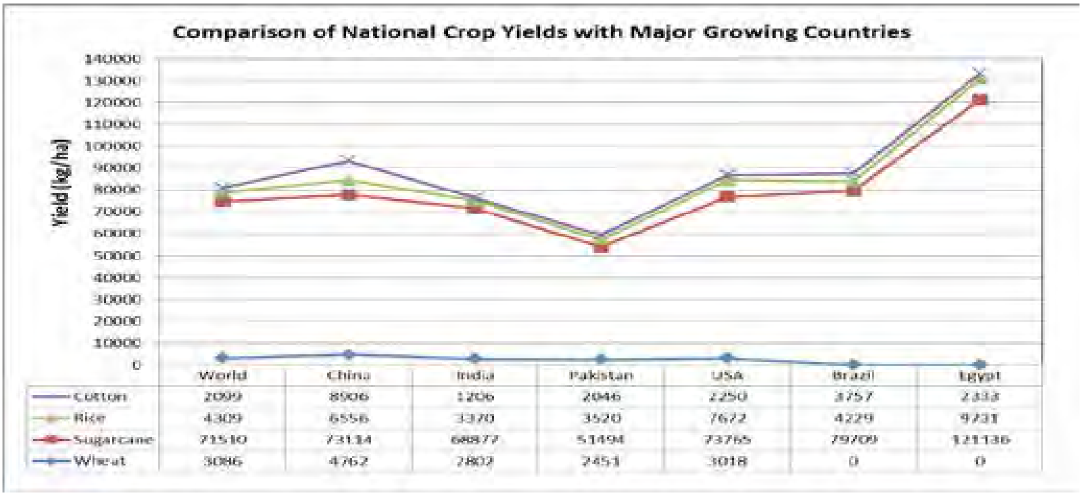

Figure 5: *Comparison of national crop yields with major growing countries (kg/ha)*
(Source: Ministry of Food and Agriculture, 2008)

2.2.1 Role of water in bridging the production gap

The additional supplies of irrigation water are necessary to irrigate the increased cropped area given in Table 8. Table 9 gives the additional water requirements at Farm Gate considering the projected food requirements of the rapidly growing population and export targets. The food production targets are to be achieved on the basis of increased cropped area and yield. The potential for future expansion in cropped area and yield increase as compared to major growing countries present yield were considered. About 2.5 Mha additional cropped area would be required during 2030 for meeting the food requirements (Table 8). Based on this additional cropped area, 20 MAF water would be required at farm gate as given in Table 9.

Table 8: *Additional crop area requirements to meet production targets (Mha)*

Crop	Base year 2009-10 cropped area	2015	2020	2025	2030
Wheat	9.13	0.16	0.33	0.49	0.66
Rice	2.88	0.22	0.45	0.70	0.96
Maize	0.94	0.04	0.08	0.12	0.17

Pulses	1.39	0.08	0.15	0.23	0.31
Other Grains	0.81	0.04	0.08	0.13	0.18
Edible oil seeds	0.62	0.04	0.10	0.16	0.22
Total	**15.77**	**0.58**	**1.19**	**1.83**	**2.50**

Table 9: *Additional water requirements at farm gate to meet crop production targets based on area and yields (MAF)*

Crop	Water requirement (AF/acre) at		2015	2020	2025	2030
	Root zone*	Farm gate @ 80% efficiency				
Wheat	1.08	1.33	0.53	1.08	1.61	2.17
Rice	5.00	6.17	3.35	6.86	10.67	14.50
Maize	2.08	2.57	0.25	0.51	0.76	1.08
Pulses	0.83	1.02	0.20	0.38	0.58	0.78
Other Grain	1.08	1.33	0.13	0.26	0.43	0.58
Edible oil seeds	1.33	1.64	0.16	0.41	0.65	0.89
		Total:	**4.52**	**9.50**	**14.70**	**20.00**

(Source: Water Sector Investment Planning Study Report, 1990)*

3. Future Strategic Areas for Water Management to Ensure Food Security

The core areas requiring immediate attention while formulating contingency action plan and management/ policy plans to keep the country evergreen are described in the proceeding paragraphs.

3.1 Water demand management

Water availability is diminishing with a growing population and increasing urbanization. The need for better water demand management is well established. The following strategy represents some areas of immediate attention:

- Promoting efficient use
- Rationalizing water price
- Optimizing cropping pattern
- Integrated use and recycling of water
- Groundwater regulation

3.2 Climate change impact on water and agriculture

Global weather changes and water resources are deeply inter-related. The largest source of freshwater is rain. Global climatic changes will have major effects on precipitation and runoff. In the relatively arid and semi-arid regions, modest changes in precipitation can have proportionately large impacts on water supplies. In mountainous watersheds, higher temperatures will increase the ratio of rain to snow, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid, earlier, and greater spring runoff. Because the temperature projections of climate models are less speculative than the projections of precipitation, temperature-induced shifts in the relative amounts of rain and snow and in the timing of snowmelt in mountainous areas are considered likely. Climate-induced changes in hydrology will affect the magnitude, frequency, and costs of extreme events, which produce the greatest economic and social costs to humans. Flooding could become more frequent and extreme. Recent reports of the Intergovernmental Panel on Climate Change (IPCC) suggest that greenhouse warming is likely to increase the number of intense precipitation days as well as flood-frequencies in northern latitudes and snowmelt-driven basins. These reports also suggest that the frequency and severity of droughts could increase in some areas, as a result of a decrease in total rainfall and more frequent dry spells.

A macro-scale hydrological model for river-flow suggests that the runoff of the Indus will decrease significantly by the year 2050 (IPCC, A4-WG-II). This implies that the availability of freshwater in Pakistan is highly vulnerable to climate change. A reduction in average flow of snow-fed rivers, coupled with an increase in peak flows and sediment-yield would have major impacts on hydropower generation and agriculture. Availability of water from snow-fed rivers may increase in the short term but decrease in the long-run. Runoff from rainfed rivers may also change in the future. A reduction in snowmelt water will put the dry-season flow of these rivers under more stress than is the case now, especially in Pakistan where one major snow fed river, the Indus, accounts for as much as 80% of the normal water flow. Increased population and increasing demand for the agricultural, industrial and hydropower sectors will put additional stress on water resources.

Pakistan has been cited amongst the most vulnerable country due to extreme weather, change in temperature and rainfall. To mitigate impacts of climatic change, the following actions will be required:

- Need for carry over dams
- Efficient irrigation (water conservation & demand management)
- Controlling population growth rate
- Changed cropping pattern
- Crop zoning
- Reduce delta of water

3.3 Saline water potential

Pakistan's groundwater aquifer consists of adjoining layers of fresh and saline waters and the existential proportion of these layers varies from place to place. Today's groundwater pumping is around 50 MAF which can be increased by harnessing additional pumping of groundwater and utilization of saline drainage surplus, 6.4 MAF. The bio-saline technology is to be promoted. The investment will be required in future for adoption of bio-saline agricultural technology.

3.4 Increasing productivity of land and water

The hope lies in closing the gap in agricultural productivity. Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. Adoption of best agriculture practices and resource conservation technologies can help to gain more yield per limit area.

4. Conclusion and Recommendations

Based on the preceding discussions, the following conclusions and recommendations are framed.

4.1 Conclusions

- Water has played a key role in agro-socio-economic upliftment in evergreen Pakistan. However, the per capita water availability has reduced (from 5,260 m^3 in 1951) to 900 m^3 in 2017) and storage capacity of reservoirs has also reduced (by 27%).
- Food security situation at present is satisfactory and in future by 2030, an additional population of about 68.5 million will require additional food grains of about 12.3 million tons and edible oil of about 0.8 million tons. The additional area of about 2.5 Mha and additional 20 MAF water at farm gate will be required to meet the food requirements.
- Land and water productivity are low as compared to world standards, which needs to be increased using suitable interventions such as increasing cost of water for irrigation, including others.

4.2 Recommendations

- Construction of major reservoirs as well as enhancing groundwater recharge are required for evergreen Pakistan.
- Enhancing water and land productivity, especially in agricultural sector, is required to enhance water use efficiency
- Need to invest on resource conservation technologies to save water
- Climate change impacts on water and agriculture are serious and need careful attention.
- The groundwater is being mined due to surface water shortage. Groundwater extraction regulation is necessary.
- Rationalize the canal water charges to offset operation and maintenance charges of irrigation system.

References

IWMI (2003). IWMI Annual Report 2002-2003. Colombo, Sri Lanka: International Water Management Institute (IWMI). 44p. doi: http://dx.doi.org/10.5337/2011.0022

Munir Ch., M., ul Hassan, Z., Sufi, A. B. (2013). Addressing Water and Power Needs of Pakistan through Construction of Major Storage Dams. Presented in 72ND Annual Session of Pakistan Engineering Congress. December 20-23, 2013, Lahore, Pakistan.

National Water Policy (2003). Federal Flood Commission/ Chief Engineering Advisor MOWP, Islamabad

PBS (2011). Agricultural Statistics of Pakistan 2009-10. Islamabad, Pakistan: Pakistan Bureau of Statistics (PBS), Statistical Division, Government of Pakistan, Islamabad.

MINFA (2011). Project Impact Evaluation Study (PIES) for the project National Program for Improvement of Water

Courses in Pakistan (NPIWC) final report April, 2011, MINFA, GOP, Islamabad.

IWMI (2010). Water Figures Turning Research into Development. Newsletter of the International Water Management Institute (IWMI) special issue 2010.

IWMI (2007). Water for Food, Water for life, a Comprehensive Assessment of Water Management in Agriculture. Summary, IWMI, 2007.

ICID (2008). Water Saving in Agriculture. Publication No. 95. International Commission on Irrigation and Drainage (ICID).

Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plain

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Abstract

The Eastern Gangetic Plains is one of the most densely populated, poverty stricken belts in South Asia. Poor access to irrigation water in the dry season, limited irrigation capacity and low agricultural innovation combines with entrenched social structures of class and caste which impact many marginal farming communities.

A project funded by the Australian Centre for International Agricultural Research (ACIAR) is targeting marginal farmers as the primary beneficiaries, to address these challenges, through collective farming approaches and improved irrigated agriculture. The project is in its third year of a 5-year program.

This paper summarises progress following the establishment of eighteen pilot sites across six villages in Saptari (Nepal), Madhubani and Cooch Behar (India). Farming collectives have been established practicing dry season cropping systems and improved irrigation practices. There have been significant changes in community knowledge, attitude and skills in response to extensive capacity development.

Traditional rice-wheat cropping systems have been supplemented through diversification into high value vegetable crops. Conjunctive use of pond and groundwater as well as improved irrigation practices are limiting over-extraction from groundwater and solar pumping has been introduced in response to expensive diesel and unreliable electricity supply.

A key achievement has been the initiation of collective farms, increasing farmers' confidence to work together for mutual benefit, especially women farmers who represent 60% of the farmers. The importance of local institutions and engagement to realise the potential of new irrigation technologies is highlighted.

The project is a multidisciplinary partnership involving communities, researchers, government and non- government organizations.

Keywords: *collective farming; dry season agriculture; Gangetic plains; irrigation*

1. Introduction

The Eastern Gangetic Plains (EGP), which include the Nepal Tarai, Bihar and West Bengal regions, is one of the most densely populated, poverty-stricken belts in South Asia. Behind this persisting poverty are deeply entrenched social structures of class and caste, with a high incidence of inequitable landlord-tenant relations. This is combined with poor access to irrigation water in the dry season, limited irrigation capacity and low agricultural innovation. There are clear linkages between poverty and access to water. At present technical, social and economic constraints have limited the effective use of groundwater and ponds for irrigation, and large areas of land remain fallow during the dry months. Access to year-round water for irrigation would significantly promote the productivity of agriculture, improving incomes and food security. Marginal and tenant farmers, youth and women are the target set of farmers who could benefit from a new approach to irrigation provision.

This project funded by the Australian Centre for International Agricultural Research (ACIAR) is targeting marginal farmers as the primary beneficiaries, to address these challenges, through collective farming approaches and improved irrigated agriculture. This research is crucial to the long-term sustainability of small scale agriculture in the EGP. The region must alleviate poverty and achieve food security in part through a program of improved water management and irrigation using efficient systems, which are less reliant on expensive or unreliable electricity and diesel, and are appropriate to the needs of the marginal (owning <0.5ha) and tenant farmer majority. The key research objective is to evaluate approaches to access water for irrigation using efficient irrigation technologies and assess alternate approaches to land tenure and collective farming, and their impact on livelihoods and resilience.

2. Study Area and Methodology

The location of the six villages in southern Nepal's Saptari district, and India's Bihar and West Bengal states is given in Fig. 1. In Nepal, the villages are Koiladi and Kanakpatti in Saptari district in the Eastern Terai. In India, two villages are Bhagwatipur and Mahuyahi in Madhubani district, Bihar, and Dholaguri in Cooch Behar, West Bengal and Uttar Chakoakheti, which falls in the neighboring district of Alipurduar. A comparative research is being undertaken in North-West Bangladesh but is not a focus of this paper.

Figure 1: *Location of study area and villages*

The selection of villages was informed by extensive past research by the project team on critical constraints facing marginal and tenant farmers as well as census data and local knowledge of project partners (Sugden, 2014).

The research approach includes:

- An assessment of available groundwater and surface water resources, potential demand for irrigation water, and water available for irrigation in selected districts.
- Qualitative and quantitative research to identify livelihoods, land tenure, water management institutions, gender relations and different farmer groupings and their impact on water management in Nepal, India and Bangladesh.
- Evaluation of social and technological interventions for improving agriculture through participatory action research approaches
- Capacity building and scaled up engagement to broader villages and communities to deliver training and demonstration of successes.

The project is a multidisciplinary partnership involving communities, researchers across twelve government and non- government organizations.

3. Results and Discussion

3.1 Farmer typology and collective farming approaches

Fig. 2 illustrates the farmer typology for the villages in which the dominance of landless, tenant and marginal or small owner cultivators is clearly seen (Sugden et al, 2017). Assessing opportunities for collective farming is a key part of the study.

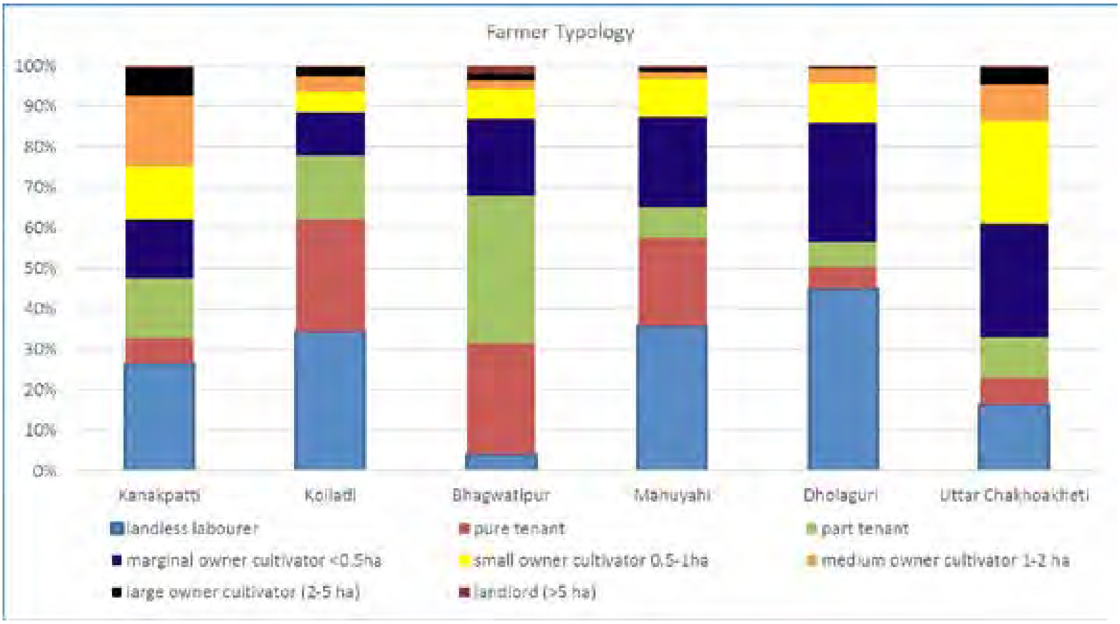

Figure 2: *Farmer typology in the study villages*

Models for collective farming are varied in terms of level of cooperation, land arrangement (leasing, consolidation, maintaining individual plots with cooperation in inputs and irrigation), and labour allocation (pooled vs individual labour inputs).

Formation of and dynamic engagement with the groups has been a key focus of the project. Key benefits of farmer collective has been shown to include:

- Labor management, especially relevant for women in the context of male outmigration and labor intensive tasks which traditionally require some hired-in labor.
- Operation of contiguous plots of land which allows better sharing and use of technology such as mechanization and irrigation.
- Increased bargaining power with external stakeholders such as landlords and government agencies for entitlements.

Observed challenges include:

- Time keeping and equitable labor sharing, especially important in labor intensive crops.
- Challenges in financial management and allocation and collection of funds.
- Gendered division of labor and inequities where based on traditional gender roles and responsibilities.

3.2 Cropping intensity and access to irrigation

Cropping intensity in the study villages has in the past been low, typically between 115% and 175%, with predominantly winter wheat following monsoon rice crop. As indicated in Fig. 3 dry season summer cropping has been limited. This is linked mainly to lack of access to irrigation equipment by marginal farmers. Landlords and large owner cultivators control water supplies making it hard for marginal farmers to participate in high value vegetable crops.

The project has helped farmers get access to irrigation infrastructure by supporting negotiation with landlords, facilitating consolidation of small blocks of land and collective farming arrangements and supporting installation of water infrastructure (tubewells and pumps). The cropping intensity has now increased to between 200% and 250% in project sites with introduction of a range of new crops and cropping systems. As an example Table 1 summarises some of the cropping system changes before and after project commencement for the two villages in West Bengal.

These new crop calendars have been supported by a range of changed agricultural practices including

- Zero tillage in wheat
- Improved irrigation of potato using short furrow
- Liming in Jute
- Ridge-furrow systems for irrigation of maize
- Introduction of short duration rice varieties
- Protected cultivation for off season vegetables
- Introduction of vegetables in open field condition

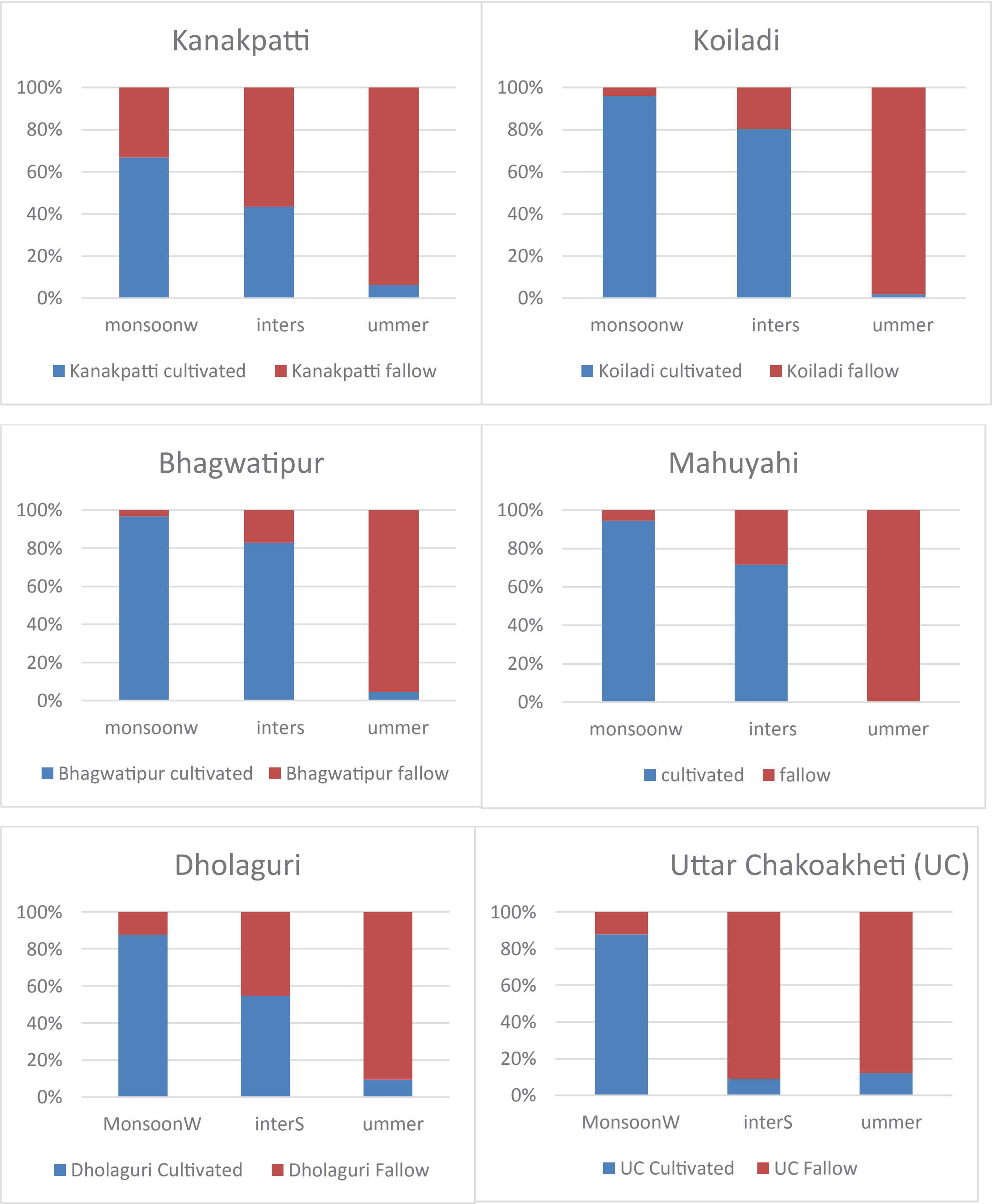

Figure 3: *Cropping intensity before the project.*

Table 1: *Cropping systems before and after project commencement in West Bengal*

Before Project Intervention	After Project Intervention
Uttar Chakoakheti Village	
Paddy-Fallow-Fallow	Paddy-Rapeseed/mustard-Jute
Paddy-Fallow-Jute	Paddy-Wheat-Jute
Paddy-Potato-Fallow(2-3%)	Paddy-Maize
Paddy-Maize(2-3%)	Paddy-Vegetables-Jute
	Paddy-Potato-Jute/Vegetables
Dholaguri Village	
Paddy-Fallow-Fallow	Paddy-Rapeseed/mustard-Jute
Paddy-Fallow-Jute	Paddy-Wheat-Jute
Paddy-Potato-Jute	Paddy-Maize
Paddy-Vegetables-Jute	Paddy-Vegetables-Jute
Paddy-Maize	Paddy-Potato-Jute/Vegetables

3.3 Sustainable utilisation of water resources for irrigation

Bio-physical data is being collected from intervention villages, including weekly monitoring of water level from ponds, tubewells and dugwells, daily rainfall and weekly water evaporation data. Seasonal irrigation data and economic and bio-physical crop information has also been collected from all sites and is used for seasonal reporting.

Novel methods for monitoring water resources have been developed, using digital systems such as smart phone Apps for recording pond and groundwater levels and rainfall data which is synced back to the project central servers and made available to project participants. This allows an assessment of seasonal trends in both groundwater and surface water availability and sharing with local communities.

As an example, Fig. 4 provides an overview map of the four intervention sites at Bhagwatipur, Madhubani indicating the demonstration field sites, water resources and monitoring points. The map includes a chart of water levels as recorded by local partners. The limited scale of irrigation means there is little impact on groundwater reserves. The process implemented with local farmers and NGO's will allow ongoing local monitoring and evaluation of water resources.

An important aspect of the project has been assessment of the efficiency of irrigation systems. These have included:

- Seepage and evaporation losses from storages.
- Conveyance losses from irrigation channels and piped systems.
- Solar pump assessments.
- Diesel pump assessments to determine the cost to pump a unit volume of water and also the effect that different size and length delivery pipe has on the discharge delivered to the field.
- Drip and sprinkler assessments to assess the distribution uniformity before and after cleaning emitters, to demonstrate the improvement that results from regular maintenance.

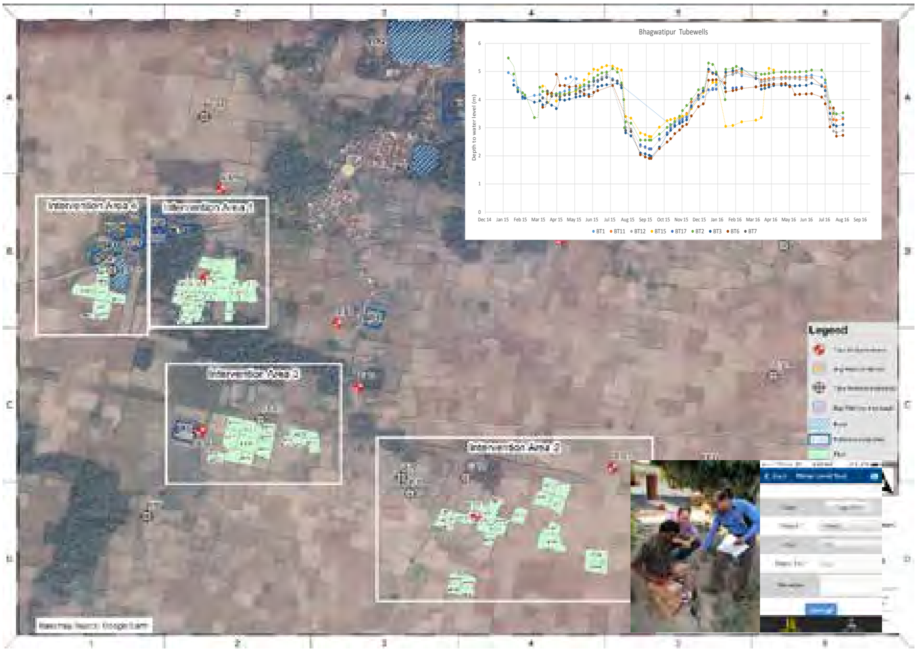

Figure 4: *Map of demonstration field sites and water infrastructure. Water resources are monitored by local farmers and representatives using Apps (see insert).*

Selected examples of these evaluations are given below.

- Seepage and evaporation losses from ponds in Dholaguri village were shown to be 9.7mm/day of which 81% is attributed to seepage. The need to improve compaction and sealing of the pond basin has been highlighted.
- Conveyance losses from pump to field of 47% over 100m of open irrigation ditch at Bhagwatipur village has been reduced to 11% with introduction of polypipe distribution systems.
- Drip irrigation distribution uniformity of between 85 and 95% was measured at Kanakpatti village and the impact of maintenance and filtration on blockages has been demonstrated.
- Improved irrigation efficiency of 47% was demonstrated when changing from basin irrigation to short furrow irrigation of potatoes in Dholaguri village.

A key aspect has been the training of local project officers and farmers in technical irrigation evaluations for sustainable irrigation management.

3.4 Water management institutions

Water management institutions are also being evaluated through focus groups and informal qualitative interviews. Results suggest that while policy and institutional frameworks for water management exist at national, state and district levels, they do not trickle down to the local level in an effective way. There is also generally inadequate institutional development at local level. High energy cost, land tenancy and poor water infrastructure are major constraints of water management, mainly resulting due to a poor

institutional environment at local level. Local institutions are crucial in effective water management. The project is facilitating better engagement with district and state agencies to improve access to support services and schemes.

3.5 Gender perspective

An assessment of gender issues has been a key focus area of the study. The findings highlight the changing responsibilities women face in the context of male out-migration. Alongside their traditional tasks in the reproductive space, they increasingly have to access irrigation facilities, markets, deal with money, obtain agricultural inputs, and bargain with male counterparts. As they enter male's space, women become critically aware of how gendered norms constrain their ability to access water. Additionally, women become aware of their own limitations that is their limited skills and knowledge to bargain with men. This leads to the question of how women can become empowered and engage effectively in decision-making to influence their own well-being outcomes (Leder, 2015a). A key product of the project has been development of a manual for critical discussions on gender norms, roles and relations (Leder, 2015b).

3.6 Community engagement

The success of participatory research projects is heavily impacted by the processes of community engagement. The project strives for an ethical engagement process (Mishra, 2016) that would require:

- Farmers are involved as partners in the project with a full understanding of the project,
- The farmers undergo a collective and reflective exercise to see benefits of coming together,
- Inclusive local institutions evolve and are strengthened to direct and channel collective efforts into sustainable outcomes,
- The technological experts appreciate the traditional wisdom and capacity of the farmers and prepare themselves to foster partnerships in knowledge transactions. Participatory technology development may be one possible answer,
- Farmers join together to monitor programs both for the technological and bio-physical developments, as well as any social and institutional findings
- Collaborative analysis, where the community and the researchers reflect on the processes, impacts and outcomes,
- Create forward-thinking strategies and programs for up-scaling and policy integration. At this point, the stage is set for the dissemination of the knowledge, building of theory and eventual publication.

There are many issues and challenges in maintaining an ethical engagement process which takes place in a dynamic socio-cultural and political environment which has different impacts in time and space (Mishra, 2016). What is clear is that technologies for improved water management by marginal farmers are best delivered under a collective institutional framework developed under through ethical engagement processes. Collectivisation is essential for strong institutional development which together offer opportunities for innovation and empowering small and marginal farmers.

3.7 Community vulnerability

The communities have low per capita income, limited assets and little access to credit. They therefore have the greatest vulnerability to climate variability and limited adaptation strategies. Adaptation strategies

include crop diversification, improved crop management, area expansion and supplementary irrigation. Access to these strategies is limited for marginal farmers but can be addressed in part through collective farming arrangements, when risk can also be shared. Enhanced awareness, skill development and training is an important part of this. Better access to government programs and insurance is important. Marginal communities are also more vulnerable to the impacts of climate variability and change and the project is providing more resilience through improved access to water, diversified farming systems and better collective capacity and risk mitigation.

3.8 Technological and management interventions

The technical feasibility and value for money of different irrigation systems is being evaluated with communities. This has included support in irrigation infrastructure deployment and management. Table 1 gave an example for West Bengal where new dry season crop production has been supported by installation of additional tubewells. Protected polyhouses have also been introduced to cultivate offseason vegetables, which have shown to be very profitable given premium price obtained from crops such as cucumber, capsicum, coriander, palak (spinach) and cauliflower. Payback of less than 3 years has been demonstrated and farmers are now expanding these protected structures at their own initiative.

In three villages (Bhagwatipur, Dholaguri and Uttar Chakoakethi), solar pumps have been introduced. For example, in Bhagwatipur two 3hp submersible solar pumps have been introduced which deliver 4.5 to 5.5 l/sec and have a command area of around 1.5ha. Compared with local cost of purchasing water from diesel pump operators at Rs120/hr the payback with full-time usage has been shown to be 2.5yrs. When comparing solar and diesel pumping based on diesel usage cost (0.4l/hr at Rs70/litre diesel), the payback is longer, 8-9 years.

Affordability and ability to payback capital cost of solar systems is driven by the net margin from crops produced. In Bihar there is a 90% subsidy, which makes beneficiary payments more affordable. The payback period is reduced with full irrigation during sunshine hours, maximising crop area, high value crops and water efficient irrigation systems.

3.9 Capacity building

Capacity building in all communities is a key focus of non-governmental organization (NGO) partners and covers a range of disciplines such as collective formation, crop planning and management, irrigation technology, record keeping, gender training, market chain development and government linkages. Annual cropping calendars are planned with farmers with scientific support from project partners. Initial informal market chain linkages have also been established and supply chains mapped.

3.10 Monitoring and evaluation

An important part of monitoring and evaluation has been the use of case studies. These include cases looking at how the project has benefited individual households, how technical interventions are being used and opportunities and challenges and case studies evaluating how the engagement process has strengthened institutions, encouraged participatory approaches, consolidated the leadership base and stakeholder's network. The project web page http://dsi4mtf.usq.edu.au/dsi4mtf/ provides a range of blog posts illustrating these outcomes and impacts.

3.11 Development of interactive tools

Eleven web Apps have been developed with different target audiences including project engineers, support staff and farmers. The tools have proved very effective in collecting data from site and integrating into the project database (see Fig. 4). Some of the tools have been designed for the one way transfer of data (e.g., rainfall, and water level records) and are aimed at field staff. Other tools are quick calculators to assess pump and irrigation system performance and allow immediate feedback to the user. Fig. 5 shows a field officer collecting information on produce price from the market. Information on market price allows information to be shared with farmers to help secure best price and negotiate with buyers. Graphs can also be viewed to assess seasonal price trends.

***Figure 5**: An App is being used by project participants to track price of products across markets and share with farmers to achieve best price points.*

4. Conclusions

The project has established eighteen demonstration sites, and is working directly with approximately three hundred farmers, typically hosting over 100 farmer meetings and 50training events annually. In response to this, communities are demonstrating changes in knowledge, attitude and skills with regard to improved irrigation management and collective farming arrangements. There is improved confidence in water management approaches, and practice change is evident within the demonstration sites, with participating marginal farmers adopting new dry season cropping systems. There is demonstrated empowerment by farmers through group cooperation and collective establishment. Engagement with higher level government and private sector agencies is accelerating and stakeholder forums have been held to increase awareness and link with other government programs. The project is having significant impact on a range of fronts.

4.1 Scientific impacts

The project is fairly unique in marrying the scientific skill sets of researchers in social sciences, irrigation and water management, with community engagement. A key scientific impact of the project has been its successful implementation of interdisciplinary and cross-institutional scientific enquiry.

4.2 Capacity impacts

There has been significant capacity development, driven through farmer group meetings and training events and continuous onsite technical support and social mobilisation. Farmers have also carried out a number of field visits oriented to technical and institutional capacity building. This includes farmer exchange visits, which has resulted in substantial change in confidence, knowledge and skills of participants.

In most of the sites, farmers now have a greater capacity to work collectively at a range of levels, from the stage of input procurement up to marketing. Farmers have adopted a range of collective farming models, and the project team has been working with them to identify problems and refine the way they work together, encouraging continuous learning and critical reflection.

Farmers are exposed to new agricultural, water and technological management practices in comparison to their conventional farming methods. The project has, through this engagement, achieved success in moving participants from predominantly rice-based cropping systems to multi crop systems (including vegetables) with increased cropping in winter and summer seasons and improved irrigation practices.

Farmers also now have experience of new irrigation management practices, both through the introduction of new technologies such as solar or sprinkler / drip systems and through improved water management practices, such as introduction of ridge and furrow irrigation rather than flatbed basin irrigation, and lay flat piping for better water distribution, improved soil conditions and controlled water application. Farmers also have expanded their knowledge of agronomic practices such as seed treatment and fertiliser placement, use of weedicide, composting, mulching, raised bed cultivation and pro tray nursery cultivation.

Farmers are participating in irrigation system assessment tests and getting a better understanding on the need for regular maintenance and monitoring. Though traditionally, irrigation is considered as man's responsibility, women have started operating irrigation systems at intervention sites. For example, women are using solar pumps and drip kits at Saptari and are also applying fertigation to crop through drip irrigation system.

4.3 Economic impacts

Within the project groups and pilot sites, there has been demonstrated increase in income from new cropping systems and irrigation practices, and increased food security. This is a considerable contrast with the pre-project situation, when farmers were engaged in subsistence oriented paddy cultivation with limited winter wheat farming.

Economic impacts will increase as farmers become familiar with new agronomic and irrigation practices. Nevertheless, farmers have an additional source of cash, and this is particularly valuable for women who are most active in the groups.

4.4 Environmental impacts

In a number of sites, farming has commenced on land which had been fallow and neglected for a decade. Land fertility is being improved and better fertiliser and agronomic practices are being introduced, which will improve soil nutrition and weed control. These improved management practices are starting to be adopted by farmers adjacent to pilot sites. Farmers are learning that land will be more productive over a longer period with correct application of especially organic fertilizers and judicious use of water. There is greater understanding of the role of pulses in increasing soil nutrition. Environment friendly technology has also been used to control pest and insects.

Better irrigation practices and more efficient systems have been introduced, limiting water waste and unnecessary extractions from groundwater. In many sites, where the cropping system has been dominated by monsoon rice production, sustainable rice intensification has been demonstrated in which alternate drying and wetting has resulted in a saving of water, and repeated tillage operations needed for puddling have been avoided. Less water demanding pulses and oil seeds have also been introduced.

The major environment impact has been crop diversification. In many parts, the traditional rice-wheat cropping system has been replaced with new crops like moong bean, okra, lentil, cabbage, cauliflower, cucumber and eggplant (brinjal). This assists in building of soil health and management of some pests and diseases which were prevalent in the rice-wheat cropping systems.

Acknowledgements: The project is a multidisciplinary partnership involving communities, researchers, government and non- government organizations. The participation of the project partner organisations is acknowledged, namely: University of Southern Queensland (USQ), International Water Management Institute (IWMI), and CSIRO Australia. In Nepal, iDE, Department of Irrigation (DoI) and Groundwater Resources Development Board (GWRDB). In West Bengal, Uttar Banga Krishi Vishwavidyalaya (UBKV), and the NGO CDHI. In Bihar, the Indian Council of Agricultural Research (ICAR) and NGO Sakhi Bihar. In Bangladesh, Bangladesh Rice Research Institute (BRRI).

References

Leder, S. (2015a). Gendered access to water resources within the feminisation of agriculture. Unpublished ACIAR project report.

Leder, S. (2015b). Participatory gender training for community groups. A manual for critical discussions on gender, norms, roles and relations. CGIAR Research report. http://dsi4mtf.usq.edu.au/dsi4mtf/wp-content/uploads/2016/11/Participatory-Gender-Training-for-Community-Groups.pdf

Mishra, R. (2016). Community engagement. Perspectives, processes and practices. Research report. Jalpaiguri. http://dsi4mtf.usq.edu.au/dsi4mtf/wp-content/uploads/2016/11/Participatory-Gender-Training-for-Community-Groups.pdf

Sugden, F. (2014). Landlordism, tenants, and the groundwater sector: Lessons from the Terai – Madhesh, Nepal. Colombo, Sri Lanka. International Water Management Institute, IWMI. Research Report No 162.

Sugden, F., Leder, S., Saikia, P., Raut, M., and Agarwal, B. (2017). Farmer collectives to overcome agrarian stress and inequalities: learnings and opportunities from the Eastern Gangetic Plains. Report for the ACIAR-funded LWR project LWR/2012/79: "Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains"

Empowering small growers by gravity micro irrigation technology

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Abstract

In third world countries, smallholdings are usually farms supporting a single family with rural lifestyle consisting of a mixture of cash crops and animal husbandry achieving self-sufficiency for their family's needs. They may be able to supplement their income by selling surplus produce at a market. As a country becomes more affluent and farming practices become more efficient, smallholdings may persist as a legacy of historical land ownership practices. There are 500 million smallholder farms in the world, mainly concentrated in Asian (India, Nepal, China, Bangladesh, etc.), African (Kenya, Rwanda, etc.) and Latin American countries supporting almost 2 billion people and contributing economy and direct–indirect employment in the country. Because of it, some companies are encouraging smallholders to be part of their value chain and providing agri-inputs like seeds, feeds, fertilizers, irrigation, machineries to receive stable supply of quality yield. While focusing sustainability, it has been observed that smallholders are facing shortage of electrical power, water (irrigation), and advanced technologies. However, sourcing electrical power and water (irrigation) is too expensive and not easily accessible to small growers. To overwhelm the issue, Jain Irrigation Systems Ltd has innovated affordable advanced technology of gravity micro irrigation for small growers with unlimited benefits. Assortment trials and experiments were conducted at various parts of the world and established persuading results. Gravity Micro Irrigation has been successfully implemented in Africa and Asia. This article describes a proven Advanced Gravity Micro Irrigation (GMI) technology with design aspects, algebraic expression, schematic, photos and representative success story of a small grower in Africa. Main objective of the article is to highlight how the problems of power and water can be overcome by adapting GMI technology for empowerment of small growers by enhancing agricultural productivity without aid from government.

Keywords: *adaptation; climate change; micro irrigation; smallholdings, small growers.*

1. Introduction

Irrigation is one of the key functions in crop production. Appropriate premeditated and designed micro (drip) irrigation system results in achieving benefits like increase in yield, water savings, power stash, fertilizer stash, etc. In the modern scenario, power economy is becoming very important in the irrigation sector because of colossal investment and chronic cost and short fall.

Micro irrigation is an advanced method of applying water to the crops via network of macro & micro tubing and regulated emitters /drippers. It is true that the micro irrigation systems in the world are working at higher pressure and require higher energy / power (electrical or diesel). Cumulative indirect side effects of such systems are trouncing of power, addition pollution to environment and wastage of natural resources and finally deterrence of small growers.

Hydraulic principle: Fundamentally hydraulic principle is that potential energy of the earth is being used to counter balance the cumulative frictional head losses occurring in the hydraulically balanced network by limiting the velocity at minimal at chock-full discharge. The Bernoulli's Energy Equation is further integrated to balance the head losses as under;

$$\text{(Integration) } Z_e = V_e + Hf$$

Where

Z_e = Potential Energy

V_e = Velocity Energy

hf - Hydraulic frictional head losses.

Following objectives are to be kept in mind while designing a Gravity Micro Irrigation System (GMIS):

- To maintain the irrigation efficiency by means of higher emission uniformity at lower discharge rate.
- To maintain the zero energy level during operating of irrigation system.
- To maintain optimum moisture level in soil for optimization of crop yield.
- To keep both initial investment and annual cost at a minimum level.
- To design a suitable type of system that will last and perform well.
- To design a manageable system that can be easily operated and maintained.
- To fulfill the water and fertilizer application requirement of crops.

Design Inputs: Following inputs are required for designing of zero-energy micro irrigation system:

- Engineering Survey: Topographical map, detailed contour survey.
- Agricultural data: Crops, spacing, variety, water requirements, agronomical practices.
- Meteorological data: Temperature, relative humidity, rainfall, wind velocity / direction, sunshine hours, evaporation, etc.
- Water Resource / Hydrology data: Main source, location, seasonal water availability and water balance.
- Soil Characteristics: Soil texture & type, water holding capacity, hydraulic conductivity, fertility, pH & EC, salinity.
- Soil and water sample collection and analysis in lab.

Design Output: Considering the above parameters an appropriate GMI system has to be designed in various stages:

- Design of system capacity and water assessment.
- Crop water requirement, water balancing and irrigation scheduling.
- Hydraulic network designing and balancing of drip irrigation system.

System design starts with selection of the suitable emitter depending on type of crop, water requirement, operating time, soil type, and water quality. The length and size of lateral lines are determined based on the lateral line flow rate, field size, etc. Similarly, the size and length of the sub-main pipe is determined. Each sub-main is an individual unit with its own control valve. The whole area is then divided into different sub-main units and the number of sub-main units that can operate at any given time is based on system capacity and ground elevation. Operational sections should be designed in such a way that the discharge is in equilibrium for all operational sections at minimal velocity. The size of the main pipe can be determined by limiting velocity and discharge so that frictional head losses should be within specified limits given by the manufacturer. Total energy requirement has to be worked out by addition of parameter like frictional head losses in filtration unit, fittings plus permissible operating pressure of the system. Hydraulic calculations can be done by algebraic expression and limiting the potential head without external energy, velocity and designed discharge to determine the networking model.

2. Components in Gravity Micro-Irrigation System

GMIS is very simple, does not require any advanced equipment, and consists of mainly following components (Fig. 1).

- Water tank (scrap – plastic or metal): for water storage.
- Screen filter: for filtration of water to avoid clogging of drippers/driplines.
- Main pipes: for transportation of water from water tank to field / sub-main.
- Sub-main pipes: for distribution of water among driplines.
- Dripline: for emission of water near to root zone of plant.

3. Advantages of Gravity Micro Irrigation System

Following are the advantages of the GMIS technology;

- No power (electrical /diesel) is required to operate the system.
- Simple to install, operate and maintain. No skilled person required for installation.
- Maintenance cost is negligible.
- Requires less water for production of crops.
- Higher yield than conventional irrigation system.
- Labor cost is less because of no weeds.
- Fertilizer can be applied easily and uniformly.
- Irrigation, water use efficiency & fertilizer use efficiency more than 90%.
- Suitable for flat and undulating terrain.
- Suitable for multi cropping pattern and helps to become self-sustainabile.

- Opportunity for youth employment directly and in an indirect way.
- Pollution & environment problems can be addressed.

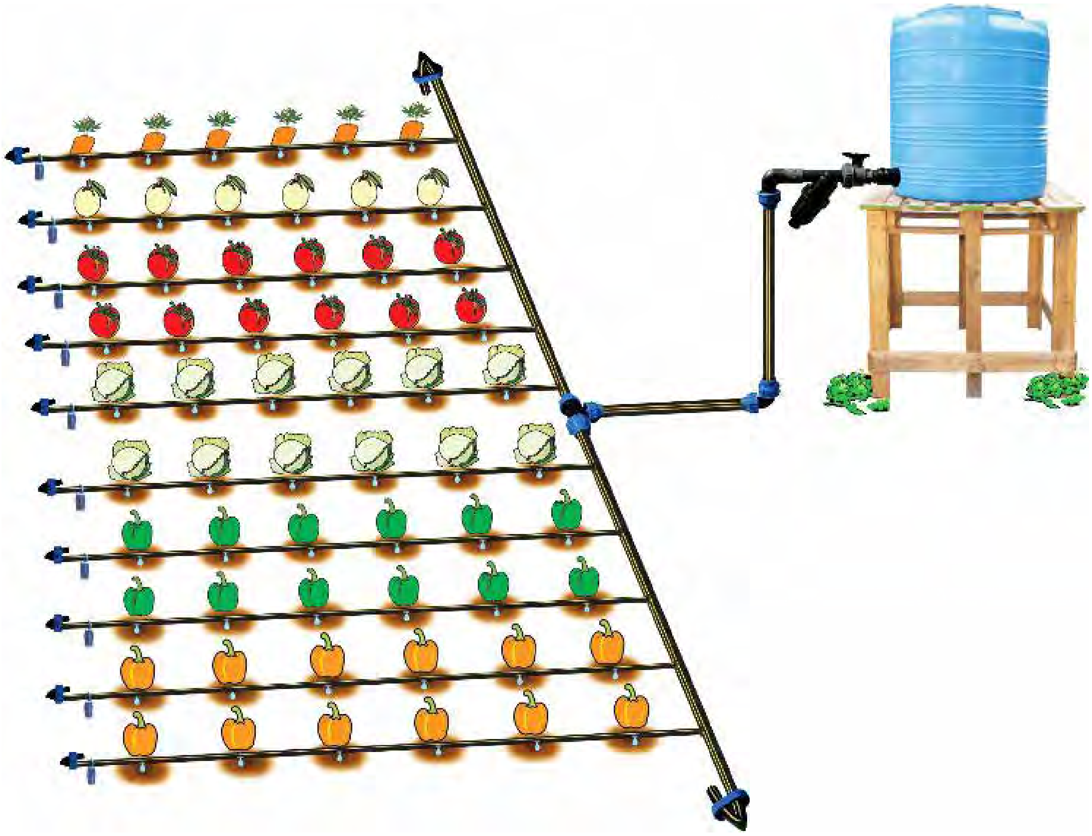

Figure 1: *Schematic layout of Gravity Micro Irrigation System*

4. Representative Success Story of Small Grower

i. Project: Empowering community of small Growers by GMIS in Kenya - 800 acres and 800 small growers.

ii. Review: Kibwezi, a drone-prone district in Kenya located 250 km away from Nairobi, surviving on seasonal agriculture. Since many generations, growers have not seen a drop of water at their door.

iii. Challenges

- No electrical power is available around the area.
- Limited water available in Kibwezi River and not sufficient to irrigate even 500 acres.
- Agriculture knowledge of farmers is very limited.

iv. Methodology: Following methodology followed in sequence.
   - Survey, collection & assessment of farm details, crop details, climatic data, water resources data, agri-inputs, marketing and allied data.
   - Water assessment round the year.
   - Year round crop planning based on climate, market demand, water available.
   - Crop water requirement and balancing for year round crops.
   - Design of GMIS.
   - Execution of GMIS.
   - Monitoring of GMIS.
   - Agricultural services and training to growers
   - Capacity building
   - Timely assistance to small growers

v. Results: The results after introducing GMIS is reported in Table 1.

Table 1: *Comparison between (rainfed) furrow irrigation and gravity micro irrigation*

Sr.	Description	(#) Rainfed furrow Irrigation	(*) Gravity Micro Irrigation
1.	Small Growers	Mrs Aane Mbuvi, Village: Masimbini, Kibwezi District, Kenya	
2.	Land holding	1 acre	1 acre
3.	Crop / Intercrop	Pigeon Peas (no intercrop)	Pigeon Peas/Pumpkin/Egg plant
4.	Variety	Local	Local
5.	Spacing	6 m x 3 m	6 m x 3 m
6.	Period of plantation	During rainy season only	Any time
7.	Irrigation frequency	(Rainfed) furrow (once in month)	On daily basis-Micro Irrigation
8.	Harvesting period	Limited to once in a year.	Continues harvest 6-7months.
9.	Crop physiology	Overall health of crop is weak. Thin& pale main stem & branches, leaves are fainted and yellowish number of branches less, canopy cover less, number of flowers are less & fruit density is less; Overall yield is less.	Overall health of crop is good. Thick & green stem & branches. Leaves are dark green, number of branches more, spread of canopy large, more number of flowers & fruits; Overall yield is more.

10.	Agro Inputs cost	(Ksh- Kenyan Shillings)	(Exchange rate: 1USD = 80 ksh)
a.	Land Preparation	2,000.00 ksh (25 $)	4,000.00ksh (25 $)
b.	Seed Cost	1,000.00 ksh (12.5 $)	2,000.00 ksh (12.5$)
c.	Fertilizers cost	500.00 ksh (6.25 $)	2,000.00 ksh (12.5 $)
d.	Pesticides	200.00 ksh (2.5 $)	400.00ksh (2.5 $)
e.	Labour cost for plantation, harvesting and farm operation	1,000.00ksh (12.5 $)	12,000.00 ksh (75 $)
f.	Total cost	4,700.00ksh (58.75 $)	20,400.00ksh (127.5 $)
11.	Yield at one time	270.00 kg of Pigeon peas	1,350.00 kg of Pigeon peas
12.	Rate per kg	20.00ksh (0.25 $)	20.00ksh (0.25 $)
13.	Income	5,400.00ksh (67.5 $)	27,000.00ksh (337.5 $)
14.	Harvest in year	Once in year	Two times in year
15.	Total Income in year	5,400.00ksh (67.5 $)	54,000.00ksh (675 $)
16.	Net Income in year	700.00ksh (8.75 $)	33,600.00ksh (547.5 $)
17.	Benefit Cost ratio	1.14	2.64
18.	IRR	14.89 %	165 %
19.	Other benefits		
a.	Employment	Seasonal for 1-2 months	Year round employment
b.	Income	Seasonal for 1-2 months	Every month income in average
c.	Power cost	600 $ pa (if powered irrigation)	No
d.	Cropping pattern	Only one crop can possible	Inter / other crops possible
e.	Quality of produce	Poor – freshness dull.	Good – fresh
f.	Market availability	No market	Assured market by Super market

g.	Marketing port	On street or local bazar	Directly lifting from farm.
h.	Transportation cost	Involved.	No transportation cost. Because supermarket's vehicle comes at farm.
i.	Standard of living	Remain poor	Improved.

NB.

1. Because of unavoidable circumstances commercial investment figures could not be displayed.
2. Yield data is taken for main crop – Pigeon peas. No data of intercrop taken
3. (#) Before implementation of GMIS, estimated based on information provided by growers.
4. (*) After implementation of GMIS, actually recorded data by our agronomist at growers' farms.
5. Values are converted from local currency to USD for ease of understanding.
6. Representative success story has been chosen for average potential small grower out of 800 small growers. Other growers have also achieved better result and substantial income. On demand results can be shown separately.
7. Said project has been implemented successful by Jain Irrigation Systems Ltd right from scratch to yield during year 2012-13. In this
8. project around 20 types of crops have been planted in such way that small growers can get income every month like a salary.

5. Conclusions

Many countries suffering with shortage of power, water and economy, are not ready to invest money in large irrigation projects because of social, political and environmental issues besides financial viability. It is true that government has limitation to focus on small growers. With proven unlimited benefits of GMIS, the government can encourage small growers to adapt to become self-reliance and to overcome the shortage of power and indirect benefits to nations in terms of environment fortification, pollution control and carbon credits.

Ms Aane Mbuvi,Small Grower, Harvested pumpkin

Ms Meri,Small Grower, Harvesting Pigeon peas

Drip Irrigation System (Ms Aane Mbuvi's farm)

Gravity Micro Irrigation (Ms Meri's Farm)

Strategic role of drip irrigation in efficient management of water resources and enhancing livelihoods: select case study –India

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Abstract

Drip irrigation(DI) system has been emerging as one of the strategic options to provide irrigation efficiently in the context of fast depleting water resources. Studies reveal that DI increases yield up to 230%, saves water up to 70% compared to flood irrigation. This paper presents a case of how public, private, people partnership (PPPP) in drip irrigation is helping remote upland villagers in Adhra Pradesh of India to improve their livelihood. A project envisaged with project outlay of INR. 50.027 Million under PPPP model was successful in all sense. Financial indicators like net present value (NPV), internal rate of return (IRR), and benefit-cost (B/C) ratio indicated that the project is financially feasible. Participation of multiple stakeholders including pertinent government agencies, corporate sector, and beneficiaries added high value in the success of the project. The projected yielded multi-pronged impacts, which includes but not limited to, improved socio-economic conditions and livelihood of people in the project area and contribution of sugarcane production in the global food supply.

Keywords: *drip irrigation, dry lands, stakeholders, water resource, food supply*

1. Introduction

Water and prosperity goes hand in hand. Places with abundant water, in general, are in the state of prosperity, peace, softness, and better developed. Water is life, water is prosperity, and water is a promising strategy to alleviate long persisting problems like poverty. In fact, significant contributor of India's economy is agriculture and lifeline of the agriculture sector is water/irrigation. Every Rupee invested in irrigation renders multiple benefits to the society. According to Fan et al. (1999), every crore invested in irrigation lifts 97 persons out of poverty. Water is one of the strategic measures for poverty reduction and economic development. Those nations and states who have water and those who utilize the available water efficiently are considered to be developed states and nations. Water is not only a precious resource gifted by nature but also a vivid source for holistic development of the society. Yet water cannot be manufactured, hence efficient and effective utilization of water is indispensable for development. On the contrary, water resources are dwindling swiftly, that will gradually pave for number of impediments for

the economic growth and development of the society. Hence, continuous quest for water resources management techniques is the current need. As a result, drip irrigation (DI) system has been emerging as one of the strategic options for ensuring economic growth and development. DI has become a need, because water, the nature's free gift to humans, is not abundant and perpetual. Measures like DI are not only vivid strategies to manage water efficiently but also results in enhancing livelihoods of the poor people and increased food supply to the world. Studies reveal that DI increases yield up to 230%, saves water up to 70% compared to flood irrigation, crop grows consistently, healthier and matures fast, fertilizer use efficiency increases.

Agriculture is a major constituent of the Indian economy that account not only for the major source of employment to the rural population but also has decisive say in all economic policies of India. About 90% of rural Indian people are dependent on agricultural for their survival and growth. Indian industry is also largely relying on agriculture for both inputs and end user applications. A major proportion of the rural Indian agriculture sector is constituted by small and marginal farmers participating in the resource-based agriculture programmes. One of the basic inputs to agriculture is irrigation without which it is not possible to initiate even small agriculture activities. This paper presents a case of how public, private, people partnership (PPPP) in DI project is helping remote upland villagers in Adhra Pradesh of India to improve their livelihood.

2. Methodology

This study entailed conduction of a field survey to elicit necessary data from stakeholders through schedules and checklists. Individual interviews, focused group discussions, and participatory rural appraisal (PRA) methods have been held to collect the data. To choose respondents purposive sampling technique was used. The financial viability was studied by employing financial analysis tools including net present value (NPV), internal rate of return (IRR), pay-back period, and cost–benefit ratio. It was assumed that total project life is 10 years, and NPV discount rate is 12%.

3. A Review of Drip Irrigation System

Drip irrigation (DI) is defined as the precise, slow and frequent application of water through point or line source emitters on or below the soil surface at a small operating pressure (20-200 kPa) and at a low discharge rate (0.6 to 20 liters per hour, LPH), resulting in partial wetting of the soil surface. Each dripper/emitter, orifice supplies a measured, precisely controlled uniform application of water, nutrients, and other required growth substances directly into the root zone of the plant. Water and nutrients enter the soil from the emitters, moving into the root zone of the plants through the combined forces of gravity and capillary. In this way, the plant's withdrawal of moisture and nutrients are replenished almost immediately, ensuring that the plant never suffers from water stress, thus enhancing quality, its ability to achieve optimum growth and high yield. Both surface and sub-surface DI systems (Fig. 1) are in practice. Whether or not drip will be successful depends on a host of agronomic, engineering and economic factors.

Drip irrigation, commercialized by Israeli engineers in the1950s, delivers water directly to crops' roots through porous or perforated tubing installed on or below the soil surface. Compared with conventional flood or furrow irrigation, drip methods can reduce the volume of water applied to fields by up to 70%, while increasing crop yields by 20-90%.

Over the last twenty years, the area under drip and other "micro" irrigation methods have risen at least6.4-fold, from1.6 Million hectares (Mha) to more than10.3 Mha. The most dramatic gains have occurred in China and India, the world's top two irrigators, where the area under micro-irrigation expanded88-fold and 111-fold, respectively, over the last two decades. India now leads the world, with nearly 2 Mha under micro-irrigation methods.

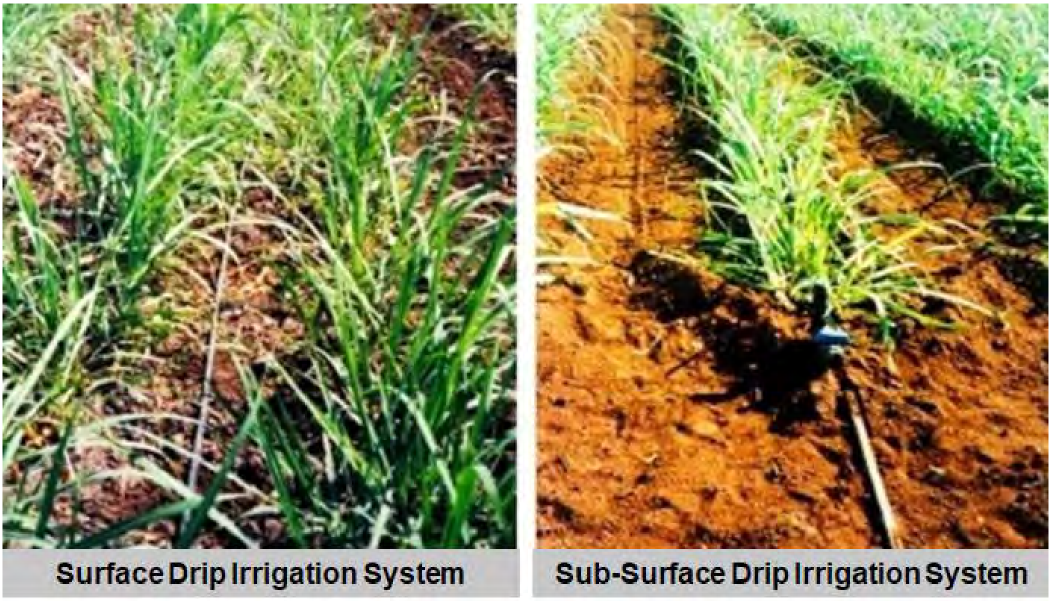

Figure 1: *Surface and sub-surface drip irrigation systems*

Today, as throughout modern history, irrigation is crucial to the global food supply: 18% of the world's farmland that is irrigated yields 40% of the world's food. Yet less than4%of the world's irrigated land is equipped with micro-irrigation systems. Clearly, the irrigation revolution has a long way to go.

To date, farmers have adopted micro-irrigation mainly for fruits, vegetables and other high-value crops that can provide a good return on the investment. California is the king of DI in the United States, mainly because it is the nation's fruit and vegetable bowl. It accounts for 62% of the nation's area under micro-irrigation; Florida and Texas come in a distant second and third.

Netafim, the global market leader in DI, has expanded drip's use on cotton in Australia, Egypt, Israel, the United States and elsewhere. In the Philippines the installation of a subsurface drip system on a sugar cane farm resulted in a90%increase in yield compared with a conventional (center-pivot) sprinkler, and a70%reduction in water use– resulting in a dramatic increase in water productivity. Netafim reports that the cane's sucrose content increased by5%, an added bonus.

Jain Irrigation – the second biggest global micro-irrigation company – expects the DI market in India to expand by 1 Mha/yr. But what really caught my attention was to expand DI to rice, a notoriously thirsty crop and the food staple for nearly half of humanity. India alone has some43 Mha of rice under cultivation, so saving even 10% of the water now used to grow the crop could free up a great deal of water for other purposes and help slow the depletion of India's aquifers.

DI system is today's need because water, nature's gift to mankind, is not unlimited and free forever. The DI systems help enhance water use efficiency, and therefore irrigate more areas from less amount of water. It will ultimately help deal with the global issue of water resources depletion and subsequence scarcity.

Key benefits of DI systems are listed hereunder;

- Has recorded increase in yield up to 230%.
- Saves water up to 70% compared to flood irrigation. More land can be irrigated with the water thus saved
- Crop grows consistently, healthier and matures fast
- Early maturity results in higher and faster returns on investment
- Fertilizer use efficiency increases by 30%
- Cost of fertilizers, inter–culturing and labor use gets reduced
- Fertilizer and chemical treatment can be given through micro-irrigation system itself
- Undulating terrains, saline, water logged, sandy and hilly lands can also be brought under productive cultivation.

4. Case Study of Valu Thimmapuram Drip Irrigation Project

This case details a success of a public, private, people partnership (PPPP) for DI projects in five remote upland villages in Andhra Pradesh, India. Valu Thimmapuram, Kondapalli, Anuru, Ramesampeta and Surampalem are the five remote upland villages in Peddapuram and Gandepalli mandals of East Godavari district, Andhra Pradesh, India. These villages have sizeable number of schedule cast (SC) population living below poverty line (BPL). Their struggle for existence and the agony for years to bring their assigned land into cultivation finally found a solution for them in the form of Comprehensive Land Development Project (CLDP). Their livelihood problem that existed for nearly two decades ended in a happy note not only in the form of finding a solution, but also getting the marketing facility for their produce with good financial returns.

The District Water Management Agency (DWMA) in the East Godavari district took the challenge and made a comprehensive study to develop the land of 730.35 acres. Taking 540 number of beneficiaries into confidence, a comprehensive programme for land development was taken up with the financial assistance of National Bank for Agriculture and Rural Development (NABARD) under RIDF-X. The project with the total cost of IRs.50.027 Million was finally initiated under the PPPP model. Details of cost breakdown of entire project is provided in Table 1 and block-wise details in Table 2.

The project was envisaged with project outlay of INRs.50.027 Million;37.2 Million out of which was allocated for DI. The payback period of the project without DI was estimated as 3 years and 8 months and with DI as 2 years. NPV without and with DI are was estimated as INR. 26.3 million and 68.7 million, respectively. IRR without and with DI was estimated as 23.8% and 49.4%, respectively. Benefit-cost ratio without DI is estimated as 1.69, whereas with DI as 2.54. Multi-stakeholders including pertinent government agencies, NABARD, DCCB, corporate sector and beneficiaries were participated in the project.

Table 1: *Breakdown of total project cost of CLDP project*

SN	Description	Amount (IRs.), lakhs	Remarks
01	Cost of Land Development	88.52	DWMA
02	Cost of Drilling of 71 Tube wells @ Rs.1.6 lakhs per well	113.6	Schedule Caste S.C. Cooperative Society Limited
03	Cost of Energisation of 71 Tube wells.	78.52	DWMA 39.26 Lakhs; S.C. Society -39.26 Lakhs
04	Providing 71 Switched mode power supply SMPS of 10HP each @ Rs.0.60 lakhs each	42.6	Margin Money MM of S.C. Cooperative Society - 8.52; S.C.A subsidy of S.C. Cooperative Society Limited-12.78; Bank loan -21.30
05	Providing of Micro Irrigation	137.45	DWMA-27.49; S.C. Cooperative Society Limited27.49;Andhra Pradesh Micro Irritation Project APMIP -82.47
06	Crop Loan from Commercial Banks for 27 RMGs	16.44	RMG finance by bankers through DWMA
07	Off-farm Livelihoods	13.59	Indira Kranthi Patham – Indira Development Plan IKP- District Rural Development Agency DRDA
08	Laying of Roads & construction of small godowns	8.00	Marketing department funds released by District Collector
09	Laying of Roads	1.00	Navabharat Ventures Private limited (Deccan Sugars),Samalkota
10	Construction of small godowns	0.25	Premier Irrigation equipment limited
11	Construction of small godowns	0.20	Jain Irrigation System Limited
12	Construction of small godowns	0.10	Kumar Drip Irrigation Pvt. Limited
	TOTAL	500.27	

Table 2: Block-wise details of Valu Thimmapuram model CLDP block

SN	Mandal	Block	No.of Beneficiaries (S.Cs)	No.of Borewells	Area (in Acres)	Plantation	Amount Sanctioned (IRs., Lakhs)	Amount Released (IRs, lakhs)
1	Gandepalli	Surampalem-I	81	12	110.70	Cashew	14.34	13.91
2		Surampalem-II	50	2	67.50	Cashew	7.80	7.57
3		Rameswarampeta-I	31	10	41.9	Cashew	11.81	11.46
4	Peddapuram	V.Thimmapuram-I	85	8	114.75	Cashew & Sugarcane	20.14	19.53
5		V.Thimmapuram-II	62	8	83.70	Cashew & Sugarcane	17.83	17.29
6		Kondapalli-I	38	3	51.30	Cashew & Sugarcane	10.89	10.56
7		Kondapalli-II	33	5	44.6	Cashew & Sugarcane	9.83	9.53
8		Kondapalli-III	47	7	63.5	Cashew & Sugarcane	13.26	12.86
9		Anuru-I	79	15	107	Cashew	18.35	17.80
10		Anuru-II	34	1	45.90	Cashew	3.53	3.07
TOTAL			540	71	730		127.78	123.58

A glimpse of the land before taking up the project and sugarcane plantation after completion of the project is shown in Fig. 2 and the project's impacts are discussed in the following sub-sections.

Sugarcane plantation after completion of project

Figure 2: *The case study area before and after the project*

4.1 Economic condition of farmers

The financial status of the farmers has improved. The migration of labour to nearby urban areas has reduced to a great extent. There has been favorable shift in the mindset of the people. The farmers have shown interest on modern technologies in farming. Further, with the availability of augmented irrigation facilities the farmers are keen for training and exposure visits to progressive farms/demonstration centers to replicate good farming practices in their areas.

4.2 People's participation

A total number of 27 Rythu Mithra Groups(RMGs) have been formed under the project to ensure people's participation. The RMGs have been playing a proactive role in ensuring the successful implementation of the project, i.e. in eliciting the support of people's representatives/District Administration in solving the problems of their own and in disseminating the information to the farmers on the judicious use of water for irrigation with introduction of micro-irrigation.

4.3 Selective crop for the benefit of the farmers

Every care was taken in selecting the crop keeping in view of good financial returns. In the three blocks of Surampalem of Gandepalli mandal covering an area of 219 acres, cashew was taken up benefiting 162 farmers. In the remaining 7 blocks of Peddapuram mandal, cashew and sugarcane were planted in 511 acres of land benefiting 378 farmers.

4.4 Salient feature of the project

The programme under CLDP has its own significance. In the first instance, the cultivation of sugarcane was taken up with less water usage under drip irrigation. In addition to this the farmers of upland areas were shown the way in cultivating the sugarcane with less water use in the lands developed under CLDP. The other salient feature includes provision of inputs for marketing. The DWMA authorities were able to get the market support for the sugarcane by succeeding in getting an arrangement with M/s Deccan Sugars of Samalkot in East Godavari district.

5. Conclusions

The case study discussed in this paper leads to the following conclusions.

- DI has improved the socio-economic conditions and livelihood of the people
- Multi-stakeholders' participation, including pertinent government agencies, NABARD, DCCB, corporate sector and beneficiaries, was a key reason for the success
- Choice of crop considering financial returns is a wise decision for the success of the project. This project without and with DI is adding 35,040 Metric Tonnes (MT) and 57,670 MT/year of sugarcane, respectively, to the global food supply.

Acknowledgement: This paper is prepared largely based on the success story of comprehensive land development project in East Godavari District of Andhra Pradesh (Indira Prabha): Valu Thimmapuram model CLDP Block. The author acknowledges due gratitude to all concerned of the project.

References

Fan, S., Hazell, P., Thorat, S. (1999). Linkages between Government Spending, Growth, and Poverty in Rural India, Research Report 110, International Food Policy Research Institute, Washington, D.C. As reproduced by Partha Mukhopadhyay (2004), in India Infrastructure Report 2004, Ensuring Value for Money, Oxford University press, New Delhi, 2004, pp 68.

http://rd.ap.gov.in/crds_stories/CLDP/East%20Godavari%20-CLDP%20Success%20Story1.htm

http://www.jaindrip.com/

http://www.sugarcanecrops.com/drip_irrigation/

http://drip.mashovgroup.net/en/%D7%93%D7%A3/Drip%20Irrigation%20Expanding%20Worldwide/

Feasibility study of rice water management under micro irrigation in Tarai condition of Uttarakhand, India

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Abstract

Rice is the major contributor of stable food in the world. It is also the biggest water user. Irrigated systems alone use over 70% of freshwater depletion in Asian countries, half of which are used in irrigated rice production systems. The water requirement to produce unit kg of paddy is as high as 4000-5000 liters under conventional methods of water application (transplanted rice under standing water). During the crop growth period, the amount of water usually applied to field is often much more than the actual field requirement. One of the demand management strategies is micro-irrigation, which supplies water at the right time and in desired quantity at the location where water is demanded using a pipe network and emitters which results in low conveyance, distribution and field application losses, thus leading to higher water use efficiency. Keeping this in view, a field study was undertaken during 2014 - 2016 at G. B. Pant University of Agriculture and Technology, Pantnagar (India), to investigate feasibility of micro irrigation system for the effective water management of rice crop. The study resulted that the water requirement of drip irrigated direct seeded rice (DSR) ranged between 1200 to 1700 liters per kg as compared to over 4000 liters/ kg of transplanted rice (TPR) grown under surface basin irrigation.

Keywords: *direct select rice; micro irrigation; rice water productivity; TPR*

1. Introduction

Rice is the most important food crop with more than 90% produced in Asia, providing on an average, 32% of the total world's calorie uptake. About 75% of the global rice volume is produced in the irrigated lowlands. Rice is typically grown in bunded fields that are continuously flooded up to 7-10 days before harvest. Continuous flooding ensures sufficient water needed for crop and also control weeds. Irrigated rice has very low water use efficiency as it consumes as high as 6667 liters of water to produce one kg (0.15 kg of milled rice / m^3) of rice (FAO, 2002). The traditional rice production system not only leads to wastage but also causes environmental degradation and reduces fertilizer use efficiency. Along with high water requirement, the traditional system of transplanted rice production in puddled soil on long run leads to destruction of soil aggregates and subsequently reduces the yields of post rice crops. Added to

this, irrigated rice fields will cut off the oxygen supply from the atmosphere resulting in the anaerobic fermentation of soil organic matter. Methane, a major end product of anaerobic fermentation is released from the submerged soil to the atmosphere through roots and stems of rice plants. Its concentration in the atmosphere has increased by more than double during the last 200 years. Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice (Guerra et al., 1998). Conventional water management in lowland rice aims at keeping the fields continuously submerged. Water inputs can be reduced and water productivity increased by introducing periods of no submerged conditions of several days throughout the growing season until cracks are formed through the plough sole (Bouman and Tuong, 2001). It is worth mentioning utilization, especially, usage of nitrogen fertilizer is a very significant factor in the growth of rice. When nitrogen fertilizer is used at tillering stage, paddy yield increases (Bacon, 1989) with significantly higher water productivity.

There is a great need to increase the productivity of water in rice irrigation systems in a sustainable way. Any water management technique that can achieve this objective must be viewed as an important contribution to sustainable development. Micro irrigation technique has potential to increase water productivity by eliminating the losses occurred during irrigation. Keeping this in view an effort has been made to investigate the feasibility of rice cultivation under micro irrigation during main season of rice cultivation in tarai condition of Uttarakhand, India. The challenges for rice water management, water productivity and main outcomes of study conducted on rice cultivation under micro irrigation at Pantnagar, India are discussed and areas for further research and prospects for implementation are identified in this paper.

2. Challenges for Water Management of Rice under Limited Irrigation Water Availability

The past years have seen a growing scarcity of water worldwide. The pressure to reduce water use in irrigated agriculture is mounting, especially in rice growing countries like India. Rice is an obvious target for water conservation. It is grown on more than 30% of irrigated land and accounts for 50% of irrigation water (Barker et al., 1999). Reducing water input in rice production can have a high societal and environmental impact if the water saved can be diverted to areas where competition is high. A reduction of 10% in water used in irrigated rice would free 150,000 million m3, corresponding to about 25% of the total freshwater used globally for non-agricultural purposes (Klemm, 1999). However, rice is very sensitive to water stress. Attempts to reduce water in rice production may result in yield reduction and may threaten food security in rice-based agriculture economy, including India. Reducing water input for rice will change the soil from submergence to greater aeration. These shifts may have profound and largely unknown effects on the sustainability of the lowland rice ecosystem. Our challenge is to develop socially acceptable, economically viable and environmentally sustainable novel rice-based systems that allow rice production to be maintained or increased in the face of declining water availability.

3. Water Productivity of Rice

Water productivity is the amount of grain yield obtained per unit water used. Depending on the type of water flows considered, water productivity can be defined as grain yield per unit water evapotranspired (WPET) or grain yield per unit total water input through irrigation plus rainfall (WPIP). At the field level, WPET values under typical lowland conditions range from 0.4 to 1.6 g/kg and WPIP values from 0.20 to 1.1 g/kg (Bouman and Tuong, 2001). The wide range of WPET reflects the large variation in rice yield

as well as in evapotranspiration caused by differences in environmental conditions under which rice is grown. Lowland rice is mostly transplanted or direct (wet) seeded into puddled, lowland paddy-fields. Land preparation for paddy consists of soaking, ploughing and puddling. Puddling is mainly done for weed control but it also increases water retention, reduces soil permeability and eases field leveling and transplanting. Soaking is a one-time operation and requires water to bring the topsoil to saturation and to create a ponded water layer. There are often 'idle periods' in between tillage operations and transplanting, prolonging the land preparation period up to 1–2 months in large-scale irrigation systems. The crop growth period runs from transplanting to harvest. During this period, fields are flooded with typically 6–10 cm of water until the final drainage some 10 days before the harvest. Under flooded conditions, water is required to match outflows (seepage and deep percolation) to the surroundings and depletions to the atmosphere (evaporation and transpiration). The flow rates of seepage and percolation (SP) are governed by the water-head (depth of ponded water) on the field and the resistance to water movement in the soil and they are difficult to separate in the field. The SP can be as high as 25 mm/ day during land preparation, because soil cracks do not close completely during land soaking (Tuong et al., 1996). Typical SP rates for paddy-fields during the crop growth period vary from 1–5 mm/day in heavy clay soils to 25–30 mm/day in sandy and sandy loam soils (Wickham and Singh, 1978; Jha et al., 1981). Only evaporation (from ponded water or moist soil) takes place during land preparation, whereas both evaporation (from soil and water surface between crops) and transpiration occur during the crop growth period. Since it is difficult to separate evaporation and transpiration during crop growth, they are often expressed in one term, evapo-transpiration (ET). Typical ET rates of rice range from 4 to 7 mm/ day (De Datta, 1981). The water input in paddy-fields depends on the rates of the outflow processes and on the duration of land preparation and crop growth. Most of the water input to a rice field, however, is to compensate for evaporation during land preparation and seepage and percolation during land preparation and the crop growth period. These flows are unproductive as they do not contribute to crop growth and yield formation.

4. Results of Micro Irrigation Application in Uttarkhand (India)

Increasing water productivity at the field level can be accomplished by: (i) increasing the yield per unit cumulative ET; (ii) reducing the unproductive water outflows and depletions (SP, E); or (iii) making more effective use of rainfall. The second strategy is important from the system of irrigation point of view. Instead of keeping the rice-field continuously flooded with 5-10 cm of water, the flood water depth can be decreased, the soil can be kept around saturation. Soil saturation is mostly achieved by irrigating to about 1 cm of water depth a day or so after disappearance of standing water. There are reports that reduction in yield if soil moisture in the rice field is maintained at saturation level as compared to 5-10 cm continuous folding. However, relative reduction in water input are larger than relative losses in yield, and therefore water productivities in respect of total water input increase.

Micro irrigation system has ability to maintain soil moisture in the rice field at saturation level continuously with minimum or no losses of field water through seepage and deep percolation besides elimination of conveyance losses. Therefore, all the irrigation efficiencies reducing parameters are eliminated or minimized which increases the water use efficiency / water productivity. Cultivation of rice under drip irrigation at G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand resulted high water use efficiency (0.09 – 0.11 and 0.0544 -0.0621 t/ha-cm) under drip irrigated treatments (surface & sub-surface) as compared to conventional continuous flooding treatment (0.021 and 0.0181 t/ha-cm) as shown in Table 1 and 2 (Gunjan, 2015 and Sharma, 2016). However, grain yield was significantly higher

under conventional continuous flooding treatment (7.7 and 7.9 t/ha)) as compared to drip irrigated treatments (5.0-6.4 and 5.4 – 6.9 t/ha). The results also reveal that the amount of water applied to produce one kg of rice were significantly lower under drip irrigated (surface & subsurface) treatments (938 -1110 and 1607-1733 liters) as compared to high water demand under conventional continuous flooding treatment (4658-5508 liters).

Table 1: *Water applied, grain yield and water productivity of rice under surface drip irrigation and conventional methods of water application*

Treatment	Total irrigation water applied (mm)	Effective rainfall (mm)	Total amount of water applied (mm)	Grain yield (t/ha)	Water use efficiency (t/ha-cm)	amount of water to produce unit yield (l/kg)
T_1-V at 20 × 20 cm spacing under drip irrigation	311	366	677	6.4	0.095	1052
T_2-0.8V at 20 × 20cm spacing under drip irrigation	249	366	615	6.2	0.1	989
T_3-0.6V at 20 × 20 cm spacing under drip irrigation	187	366	553	5.9	0.11	938
T_4-V at 15 × 20 cm spacing under drip irrigation	233	366	599	5.4	0.09	1110
T_5-0.8V at 15 × 20cm spacing under drip irrigation	183	366	549	5.4	0.098	1017
T_6-0.6V at 15 × 20 cm spacing under drip irrigation	151	366	517	5.0	0.096	1034
T_7-DSR with saturated level of soil moisture at 20×20 cm spacing under surface irrigation	1125	366	1491	5.9	0.04	2528
T_8-TPR with submerged irrigation at 20×10 cm spacing under surface irrigation	3220	366	3586	7.7	0.021	4658

Table 2: *Water applied, grain yield and water productivity of rice under surface and subsurface drip irrigation and conventional methods of water application*

Treatment	Total irrigation water applied (mm)	Effective rainfall (mm)	Total amount of water applied (mm)	Grain yield (t/ha)	Water use efficiency (t/ha-cm)	Amount of water to produce unit yield (l/kg)
T_1: V - Volume of water application under surface drip irrigation in DSR planted at 20 cm row spacing	261.2	796	1057.2	6.1	0.0576	1733
T_2: 1.2V - Volume of water application under surface drip irrigation in DSR planted at 20 cm row spacing	313.4	796	1109.4	6.5	0.0585	1706
T_3: 1.2V - Volume of water application under subsurface drip irrigation in DSR planted at 20 cm row spacing	313.4	796	1109.4	6.9	0.0621	1607
T_4: V - Volume of water application under surface drip irrigation in DSR planted at 15 cm row spacing	195.8	796	991.8	5.4	0.0544	1836
T_5: 1.2V - Volume of water application under surface drip irrigation in DSR planted at 15 cm row spacing	235.1	796	1031.1	6.0	0.0581	1718

T_6: 1.2V - Volume of water application under subsurface drip irrigation in DSR planted at 15 cm row spacing	235.1	796	1031.1	6.4	0.0620	1611
T_7: Surface irrigation (soil moisture maintained at saturation) in DSR planted at 20 cm row spacing	2222	796	3018	7.1	0.0235	4250
T_8 : Conventional flood irrigation (Standing Water) in TPR planted at 20 cm row spacing	3555.5	796	4351.5	7.9	0.0181	5508

5. Aerobic and Micro Irrigation

An important approach for reducing water requirement in rice is to grow the crop like an irrigated upland crop, such as wheat. Instead of trying to reduce water input in lowland paddy-fields, the concept of having the field flooded or saturated is abandoned altogether. Upland crops are grown in non-puddled, aerobic soil without standing water. Irrigation is applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold. The amount of irrigation water should match soil evaporation and crop transpiration plus water lost by any application inefficiency. The potential water savings when rice can be grown as an upland crop are large, especially on soils with high seepage and percolation rates (Bouman, 2001). Besides cutting down seepage and percolation losses, soil evaporation is also reduced, since there is no standing water layer. De Datta et al. (1973) experimented with the cultivation of a high yielding lowland rice variety (IR20) like an upland crop under furrow irrigation. Total water savings were 56% and irrigation water savings were 78% compared with growing the crop under flooded conditions. However, the yield was reduced from7.9 t/ha to 3.4 t/ha. Gunjan (2015) experimented with low land paddy cultivar under drip irrigation at different irrigation levels and zinc deficiency symptoms were observed under the treatments in which soil moisture was maintained at field capacity or lower levels during the vegetative growth stage. Sharma (2016) observed significant reduction in the zinc deficiency symptoms when irrigation applied under drip irrigation at 20% higher than field capacity level to maintain the saturation during the vegetative growth stage of paddy crop. Studies on non-flooded irrigated rice using sprinkler irrigation were conducted in Louisiana and Texas, USA (Westcott and Vines, 1986). The experiments used commercial lowland rice cultivars. Irrigation water requirements were 20–50% less than in flooded conditions, depending on soil type, rainfall and water management. The highest yielding cultivars (producing 7–8 t under flooded conditions), however, had yield reductions of 20–30% compared with flooded conditions. The most drought-resistant cultivars produced the same under both conditions, but yield levels were much lower (5–6 t/ha). New varieties must be developed if the concept of growing rice like an irrigated upland crop is to be successful. Upland rice varieties exist, but have been developed to give stable though low yields in adverse environments

where rainfall is low, irrigation is absent, soils are poor or toxic, weed pressure is high and farmers are too poor to supply high inputs. IRRI coined the term 'aerobic rice' to refer to high-yielding rice grown in non-puddled, aerobic soil (Bouman, 2001). Aerobic rice has to combine characteristics of both the upland and the high-yielding lowland varieties. Evidence for its feasibility comes from Brazil and northern China. In Brazil, aerobic rice cultivars have come out of a 20-year breeding programme to improve upland rice with yields of 5–7 t/ha under sprinkler irrigation in farmers' fields. These varieties are grown commercially on significant area in the state of Mato Grosso. In north China, aerobic rice cultivars called Han Dao have been developed that yield up to 6–7.5 t/ha under flash irrigation in bunded fields (Wang Huaqi et al., 2003). Development of high yielding aerobic rice cultivar sown under DSR (direct seeded rice) combined with sprinkler / micro irrigation have great potential to produce rice with significant reduction in water requirement without much reduction in grain yield for the areas where irrigation water supply is limited.

6. Conclusions

Growing rice in continuously flooded fields has been taken for granted for centuries, but the 'looming water crisis' may change the way rice is produced in the future. Water saving micro irrigation technologies such as surface and sub-surface drip irrigation started receiving attention by researchers. The basic ingredients of implementing these technologies seem to be in place in many crops. However, integration of micro irrigation with aerobic rice cultivars has tremendous scope for the future of rice cultivation under limited irrigation water supplies. This way, it is possible to reduce the water requirement for rice cultivation by 40-60% without loss in grain yield.

References

Bacon, P. (1989). Response of Inga rice to application of nitrogen fertilizer at varying growth stages. Australian journal of experimental agriculture and animal husbandry (Australia).

Barker, R., Dawe, D., Tuong, T.P., Bhuiyan, S.I., Guerra, L.C. (1999) The outlook for water resources in the year 2020: challenges for research on water management in rice production. In: Proceedings of 19th Session of the International Rice Commission "Assessment and Orientation Towards the 21st Century", Cairo, Egypt, 7–9 September 1998. FAO, Rome, pp. 96–109.

Bouman, B.A.M. (2001) Water-efficient Management Strategies in Rice Production. Notes 16.2, International Rice Research Institute (IRRI), IRRI, Los Baños, Philippines, pp. 17–22.

Bouman, B.A.M., Tuong, T.P. (2001) Field water management to save water and increase its productivity in irrigated rice. Agricultural Water Management, 49(1), 11–30.

Bouman, B.A.M., Wang, H. Q., Yang, X. G., Zhao, J. F., Wang, C. G. (2002). Aerobic rice (Han Dao): a new way of growing rice in water-short areas. In: Proceedings of the 12th International Soil Conservation Organization Conference, 26–31 May 2002, Beijing, China. Tsinghua University Press, Beijing, China, pp. 175–181.

De Datta, S.K. (1981). Principles and Practices of Rice Production. IRRI, Los Baños, Philippines, 618 pp.

De Datta, S.K., Krupp, H.K., Alvarez, E.I., Modgal, S.C. (1973) Water management in flooded rice. In: Water Management in Philippine Irrigation Systems: Research and Operations. IRRI, Los Baños, Philippines, pp. 1–18.

FAO (2002). Issues and challenges in rice technological development for sustainable food security. Keynote address at "The International Rice Commission(IRC) 02/05, 20th Session", Bangkok, Thailand, 23-26 July 2002.

Gunjan, P. (2015). Performance evaluation of AquaCrop model for rice-wheat cropping system grown under drip irrigation. M.Tech. Thesis, G.B.P.U.A.7T., Pantnagar, Uttarakhand.

Guerra, L.C., Bhuiyan, S.I., Tuong, T.P., Barker, R. (1998). Producing More Rice with Less Water from Irrigated Systems. SWIM Paper 5, IWMI/IRRI, Colombo, Sri Lanka, 24 pp.

Jha, K.P., Chandra, D., Challaiah (1981). Irrigation requirement of high-yielding rice varieties grown on soils having

shallow water-table. Indian Journal of Agricultural Science 51, 732–737.

Jongdee, B., Fukai, S., Cooper, M. (2002). Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice. Field Crop Research, 76,153-163.

Klemm, W. (1999). Water saving in rice cultivation. In: Assessment and Orientation Towards the 21st Century. Proceedings of 19th Session of the International Rice Commission, Cairo, Egypt, 7–9 September 1998. FAO, Rome, pp. 110–117.

Sharma, V. (2016). Rice-Wheat Cropping System: Studies on Effective Water Management under Drip Irrigation. M.Tech. theses, G.B.P.U.A.7T., Pantnagar, Uttarakhand.

Tuong, T.P., Cabangon, R., Wopereis, M.C.S. (1996). Quantifying flow processes during land soaking of cracked rice soils. Society of Soil Science America Journal, 60(3), 872–879.

Tuong, T.P., Pablico, P.P., Yamauchi, M., Confesor, R., Moody, K. (2000). Increasing water productivityand weed suppression of wet seeded rice: effect of water management and rice genotypes. Journal of Experimental Agriculture, 36, 1–19.

Wang, H., Bouman, B.A.M., Zhao, D., Wang, C., Moya, P.F. (2003). Aerobic rice in northernChina – opportunities and challenges. In: Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bidraban, P.S., Tuong, T.P., Lafitte, R. and Ladha, J.K. (Eds) Water-wise Rice Production. IRRI, Los Baños, Philippines, pp. 143–154.

Westcott, M.P., Vines, K.W. (1986). A comparison of sprinkler and flooded irrigation for rice. Agronomy, 78, 637–640.

Wickham, T.H., Singh, V.P. (1978). Water movement through wet soils. In: Soils and Rice. IRRI, LosBaños, Philippines, pp. 337–358.

Decentralized approach for wastewater treatment and long-term effect of treated and untreated wastewater irrigation on crop and soil quality

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Abstract

Due to easy availability, disposal problems and scarcity of freshwater, many farmers in peri-urban areas use wastewater contaminated water for irrigating crops. Such waters are contaminated with excessive quantities of nutrients, pathogens and toxic chemical substances. Continuous irrigation of agricultural land with such wastewater may cause heavy metal accumulation in the soil and vegetables, and then introduced into the food chain. Due to the non-biodegradable and persistent nature, heavy metals are accumulated in vital organs of the human body such as the kidneys, bones and liver and are associated with numerous serious health disorders.

A field experiment was conducted from 2015 - 2017 to investigate the effects of drip irrigation with wastewater, and treated wastewater on crop quality at the 12-C Research farm of Indian Agriculture Research Institute, Delhi. A bioreactor was installed at 12-C field for the purpose of cleaning the wastewater for the irrigation. After wastewater irrigation, the level of metals in the wastewater irrigated field got increased with time in the soil. While in treated water irrigated soil, concentration of metals was very less. In case of crops, the level of heavy metals was found more in wastewater irrigated crops than the treated water irrigated crops. From the study, it can be concluded that unlike treated wastewater, untreated wastewater cannot be used in agricultural land for a long time. Further, use of treated wastewater for irrigation does not have a negative impact on the consumers' health as well.

Keywords: *bioreactor; drip irrigation; heavy metal; treatment; wastewater*

1. Introduction

Due to rapid industrialization, urbanization, and subsequent change in lifestyles, amount of wastewater generation is gradually increasing. In many cases, they are disposed either in the river or on open ground without adequate treatment. Therefore, use of contaminated water to sustain farmers' livelihoods has been a common practice in urban and peri-urban areas (Saravanan et al., 2011). Such waters are typically

polluted by excessive quantities of nutrients as well as contaminated with pathogens and toxic chemical substances that affect both the ecosystem and the public's health (Okereke et al., 2016). In many urban and peri-urban areas, these discharges are used by local farmers for irrigating crops, thus introducing these pollutants to the crops and then to the food chain. It's because, they are relatively easily available, have issues for proper disposal, and freshwater for irrigation are not abundantly available (Khan et al., 2008a, Sharma et al., 2008). Continuous irrigation of agricultural land with such wastewater may cause heavy metal accumulation in the soil and vegetables. Intake of heavy metals through the food chain by human populations has been widely reported throughout the world (Muchuweti et al., 2006). Due to the non-biodegradable and persistent nature, heavy metals are accumulated in vital organs of the human body such as kidneys, bones and liver and are associated with numerous serious health disorders (Duruibe et al., 2007). With the health hazards, wastewater irrigation is expected to cause changes in the soil and agricultural produce quality. While some of the changes in soil properties such as increase in micronutrients and organic carbon are beneficial, the risk of metal accumulation and microbial contamination needs to be carefully considered. Metal contamination from wastewater leads to damage of soil quality and these accumulated metals are further taken up by the crops grown with wastewater.

This study aims to evaluate effectiveness of treated wastewater and drip irrigation method for sustainability of agriculture as well as in minimizing health risks by means of carrying out field experiments. The experiment was carried out at the 12-C Research farm of Indian Agricultural Research Institute (IARI), Delhi.

2. Material and Methods

2.1 Site selection and design/installation of water conveyance system

12C Field is situated at IARI, New Delhi at 28°38'30" N, 77°08'59" E. The site is chosen due to easy availability of wastewater, i.e. Lohamandi Drain throughout the year which ultimately flows into Yamuna river. Polyvinyl chloride (PVC) pipe system has been designed and installed for the supply of water. A power supply and control panel with two 3-hp motors and a 2-hp motor with pump is also installed and connected with 3-inch pipe inlet and 2-inch pipe outlet. The headworks and pump house were also constructed at the 12C field. Three different pipe systems, namely, untreated wastewater, treated waste water (bio-remediated), and groundwater for the treatment were also constructed.

2.2 Bioreactor

A bioreactor has been installed for the treatment of wastewater with support from IIT Delhi and University of Delhi. Design of the wastewater treatment reactor consists of a motor system to uplift the wastewater into a storage tank (2000 litres). this collected wastewater was connected to the small 1-hp motor to transfer the wastewater to the pilot plant (1000 litres). In this pilot plant, the consortium was processed so that treatment of water with indigenous microorganisms was performed. Initially, the wastewater was treated for seven days, and afterwards, it became a continuous bioreactor. It was connected to the settler through the pipes so that the solid waste mass which was coming with the treated water is settled and remaining clean water is stored in a tank (750 litres) (Fig. 1). Then this water was used for irrigation.

Figure 1: *Bioreactor (Settler and Pilot Plant)*

2.3 Layout

The layout of the study site is shown in Fig. 2 and associated details in Table 1.

Figure 2: *Location of 12C field at IARI, New Delhi premise.*

Table 1: *Layout of the treatments*

Treatment type	Irrigation type	Crop
Wastewater	Drip	Okra
Treated wastewater	Drip	Okra
Wastewater	Flood	Okra
Treated wastewater	Flood	Okra

2.4 Treatments

The 12C field has been divided into two main plots of untreated wastewater irrigation and treated wastewater irrigation with drip irrigated and flood irrigated sub-plots. All the treatments are in triplicates with split plot design. Each plot is of 24 m^2 of size. The selection of crop and its varieties has been done by choosing the crops locally grown in the Delhi-NCR regions. Details of crops and their varieties are listed in Table 2, geometry of the crop in Table 3, and crop growing stages in Table 4.

Table 2: *Details of crop*

S.No.	Crop	Varieties	Season
1	Okra	*PUSA A-4*	Summer

Table 3: *Geometry of crops*

Crop	Crop spacing		Dripper to dripper spacing	Lateral to lateral spacing	Dripper discharge rate (lph)
	Row to row(cm)	Plant to plant(cm)			
Okra	60	30	30	120	1.07

Table 4: *Crops growth stages*

Crop	Initial (Days)	Developmental (Days)	Middle (Days)	Late (Days)	Total
Okra	20	20	30	20	90

2.5 Water samples digestion and analysis for heavy metals

Water samples (100 ml) were digested after adding 15ml of Di acid mixture (HNO_3 and $HClO_4$ in ratio 9:4) at 80°C until a transparent solution was obtained (standard protocols of waste water analysis by APHA (American Public Health Association), AWW & WEA (Arkansas Water Works and Water Environment Association). After cooling, the digested sample was filtered using Whatman no. 42 filter paper and the filtrate was finally maintained to 100 ml with double distilled water.

2.6 Soil samples digestion and analysis for heavy metals

Soil samples were collected in triplicate at different depths (0-15cm, 15-30cm and 30-45cm) and at varying distance (5m, 100m and 300m) from the river bank. Soil samples were air dried, crushed and passed through 2 mm mesh size sieve and stored at ambient temperature before analysis. (Singh et al., 2010)

Soil (1 g) was digested after adding 15 ml of tri-acid mixture (HNO3, H2SO4, and HClO4 in 5:1:1 ratio) at 80° C until a transparent solution was obtained. After cooling, the digested sample was filtered using

Whatman No. 42 filter paper and the filtrate was finally maintained to 25 ml with distilled water.

The analysis for heavy metals was conducted using AAS4141 ECIL Atomic absorption spectrophotometer. The instrument was fitted with specific lamp of particular metal. The instrument was calibrated using manually prepared standard solution of respective heavy metals as well as drift blanks. Standard stock solutions for all the metals were obtained from Sisco research laboratories Pvt. Ltd. India. These solutions were diluted for the desired concentrations to calibrate the instrument. Acetylene gas was used as the fuel and air as the support. An oxidising lamp was used in all cases. (Pal et al., 2015)

2.7 Crop samples digestion and analysis for heavy metals

Plant samples (1g) were digested after adding 15ml of tri acid mixture (HNO_3, H_2SO_4 and $HClO_4$ in the ratio 5:1:1) at 80°C until a transparent solution was obtained. After cooling, the digested sample was filtered using Whatman no. 42 filter paper and the filtrate was finally maintained to 25 ml with double distil water. Triplicate digestion of each sample was carried out together. The analysis was conducted using AAS4141 ECIL Atomic absorption spectrophotometer.

2.8 Quality control analysis

Blank and drift standards (Sisco research laboratories Pvt. Ltd., India.) were run after five determinations to calibrate the instrument. The coefficients of variation of replicate analysis were calculated for different determinations for the precision of analysis and variations below 10% were considered correct.

2.9 Microbial community analysis

Soil samples from untreated wastewater irrigated soil and treated wastewater irrigated soil were collected from 0-15cm depth at the field and analysed for the microbial community. After collection, samples were stored at - 20°C until further analysis.

2.9.1 Sampling for DNA extraction

For DNA extraction, the soil sample was collected in sterilized polythene bags. DNA was isolated from 1gram of the soil sample using manufacture's protocol via FastDNA SPIN kit (for soil) (MP Biomedical, Cambridge, United Kingdom). The concentration of DNA after extraction was quantified with Eonc Take 3 microliter plate (Biotek).

2.9.2 Amplification of 16s rRNA gene

Primer set of F1 (5'-ATTACCGCGGCTGCTGG-3') and R2 (5'-ATTACCGCGGCTGCTGG-3') targeting conserved V3 domain of 16s rRNA was employed for the partial amplification of 16s rRNA gene (Muyzer and Waal, 1993). A 40-nucleotide GC-rich sequence (GC-clamp) was added to the 5'-end of the forward primer (F1) (Muyzer and Waal, 1993). The PCR reaction mixture of total volume 50µL was prepared [PCR supermix™- 25 µL (Gene Direx), Forward primer (F1)-4 µL, R2-4 µL, DNA template- 6 µL, MQ water- 11 µL] for amplification. The PCR cycling conditions used was: Initial denaturation: at 94°C for 1 min; 35 cycles of denaturation at 94°C for 1 min; Annealing at 55°C for 1 min; Extension at 72°C for 1 min. It was followed by final elongation at 72 °C for 7 min.

2.9.3 DGGE (Denaturing gradient gel electrophoresis)

DGGE was performed for PCR amplicons obtained with a DCode system (Bio-rad, CA). PCR products were loaded onto a 10% (w/v) acrylamide gel having a 30-60% denaturing gradient. Chemicals used in preparation of DGGE gel is listed in Table 5. Electrophoresis was performed at 60 volts for 16 h in 1x TAE buffer. Composition of 1x TAE buffer was: 40mM tris acetate, 1 mM Sodium ethylenediaminetetraacetic acid, pH: 8). The DGGE gel was stained with 1x TAE buffer containing EtBr (Ethidium Bromide: 10mg mL^{-1}) for 45 min using gel rocker (REMI). Image of gel was captured by Gel Doc imaging system (Bio-rad, CA). Visible bands on gel were excised using a sterile blade and stored in TE buffer. To elute out the DNA bands from excised gel to TE buffer, bands were incubated at 95°C for 5 min. The eluted DNA bands were amplified using the same primer set and PCR conditions as described above. PCR reaction obtained were purified with QIAquick™ purification kit (Qiagen, Germany) as per the protocol provided by the manufacturer. After purification, sequencing of the amplicons were performed using dye termination reaction (MicroSEQTM500 16S rDNA Identification, applied bio-system) and products were loaded into the genetic analyser (Applied BiosystemsTM 3500 Series Genetic Analyzers — Use MicroSEQTM ID Analysis Software Version 3.0) to determine the sequence of the PCR products (Green et.al. 2010).

Table 5: *Chemical constituent of denaturing gradient gel electrophoresis (DGGE) gel*

Chemicals	30% denaturing gel	60% denaturing gel
40% Bis acrylamide	5 mL	5 mL
50 x TAE buffer	0.4 mL	0.4 mL
Formamide	2.4 mL	4.8 mL
Urea	2.52 gm	5.04 gm
Final Volume	20 mL	20 mL
APS (10%) solution	120 µL	120 µL
TEMED	12 µL	12 µL

2.9.4 Phylogenetic analysis

Sequence similarity search for the obtained sequence was performed using BLAST programme whereas alignment was performed by CLUSTALW. The evolutionary history was inferred using the UPGMA method (Unweighted Pair Group Method with Arithmetic Mean). The evolutionary distances were computed using the Maximum Composite Likelihood method and are in the units of the number of base substitutions per site. Codon positions included were 1st+2nd. All positions containing gaps and missing data were eliminated. Evolutionary analyses were conducted in MEGA5.

3. Results

3.1 Monthly variation of heavy metals in raw and treated wastewater

Studying the monthly variation from 2015 - 2017 of Lohamandi drain water and treated Lohamandi drain water, the following (Table 6) average variation in heavy metal concentration has been observed

in a particular year, which are above the permissible limits of FAO (permissible limits of heavy metals in irrigation water: Zn:2ppm, Cu:0.2ppm, Ni:0.2ppm, Pb:5ppm and Cr: 0.1ppm). The metals like chromium and nickel are above the permissible limits in most of the months, while other metals were not above limits but high in concentrations in wastewater. On the other hand, in treated wastewater (2016-2017) the concentration of all the studied metals was very low and chromium was below the detectable range in the treated water. Hence, the treated wastewater is safe to use over untreated wastewater.

Table 6: *Average monthly variation (year-wise) of heavy metals in wastewater*

Years	Zn (ppm)		Cu (ppm)		Cr (ppm)		Ni (ppm)		Pb (ppm)		Cd (ppm)	
	WW	TW	WW	TW	WW	TW	WW	TW	WW	TW	WW	TW
2015	0.838	-	0.158	-	0.155	-	0.143	-	0.633	-	Nd	-
2016	1.083	0.170	0.138	0.025	0.088	Nd	0.155	0.033	1.727	0.068	Nd	Nd
2017	1.185	0.267	0.149	0.017	0.128	Nd	0.20 4	0.033	2.006	0.071	Nd	Nd
Permissible Limit (ppm) FAO	2	2	0.2	0.2	0.1	0.1	0.2	0.2	5	5	0.01	0.01

Notes: WW is Wastewater; TW: Treated wastewater

3.2 Impacts of drip and flood wastewater irrigation on soil and crop

Impacts of drip irrigation and flood wastewater irrigation on soil and crop were assessed. The studied soil was sandy loam and the crop was okra. The physical properties of the soil are shown in Table 7. In terms of chemical properties, nitrogen, phosphorus and potassium in soil of wastewater and treated wastewater in drip and flood irrigated soil is increasing with time. This study also identified that the amount of nitrogen and phosphorus was increasing with the depth of soil. The concentration of nutrients was increasing by wastewater irrigation and also the amount of nutrients in drip irrigated plots was more the than flood irrigated ones. The percentage increase of nutrient was 50%-66% in the final year. Heavy metals present in wastewater irrigated soil increase with time and get accumulated in the soil. The value of copper, chromium, nickel, zinc and lead in okra is under permissible limit in soil of 1st year. But the range has been increased in the last year of study. The amount of lead is 129 mg/kg and nickel 74.59 mg/kg in flood irrigated soil. It proves that the accumulation of metal crosses the permissible limits provided by European Union (i.e. Cu-100 mg/kg, Cr-100 mg/kg, Ni- 50 mg/kg, Pb-100 mg/kg and Zn- 300 mg/kg)

Table 7: Physical properties of soil

Depth (cm)	Particle size distribution			Textural class	Hydraulic conductivity (cm h^{-1})	Bulk density (gm cm^{-3})	FC (%)	PWP (%)
	Clay (%)	Silt (%)	Sand (%)					
0-15	12	16	72	Sandy loam	1.32	1.56	29	9.6
15-30	14	16	70	Sandy loam	1.29	1.55	28.9	9.7
30-45	15	21	64	Sandy loam	1.22	1.58	30.5	10.2
45-60	15	25	60	Sandy loam	1.21	1.58	30.4	10.5
60-75	17	25	58	Sandy loam	1.12	1.59	30.8	10.9
75-90	18	24	58	Sandy loam	0.99	1.61	30.5	10.8

In crop, the initial year of study has shown that heavy metals i.e. chromium, nickel and lead was above the permissible limits of FAO while copper was below the permissible limits in okra. The concentration of metal accumulation in crops was higher in flood than drip irrigated ones. The results of heavy metal concentration in okra is presented hereunder.

- The concentrations in the beginning,
    - o In flood irrigation: Nickel (7.06 mg/kg), Lead (7.69 mg/kg) and Zinc (52.89 mg/kg),
    - o In drip irrigation: Nickel (2.40 mg/kg) and Lead (8.96 mg/kg), which are above the permissible limits of FAO/Codex. (i.e., Cu: 30 mg/kg, Cr: 2.3 mg/kg, Ni: 1.5 mg/kg, Pb: 2.5 mg/kg, Zn: 50 mg/kg)
- Concentrations in the final year,
    - o In flood irrigation: Nickel (9.07 mg/kg), Lead (11.52 mg/kg) and Zinc (76.77 mg/kg).
    - o In drip irrigation: Nickel (2.22 mg/kg) and Lead (9.03 mg/kg), which are above the permissible limits of FAO.

Here, the accumulation has been increased by 20 to 33% in flood irrigated crops and 1.25 to 24% in drip irrigated crops. Also, the metal accumulation causes fast degradation of crops then the normal grown.

3.3 Impacts of drip and flood irrigation of treated wastewater on soil and crop

In treated water irrigated soil, the concentration of heavy metals was found to be very low. The amount of nitrogen, phosphorus and potassium is in medium range. The concentration of nutrients was also decreasing with depth in the soil. In treated water irrigated okra, all the five metals are below the permissible limits of FAO. Also, the degradation rate was less than that of wastewater irrigated okra. These metals in okra have been estimated as;

- In flood irrigation: Copper (2.8 mg/kg), Chromium (1.4 mg/kg), Nickel (2.06 mg/kg), Lead (2.01 mg/kg) and Zinc (40.08 mg/kg).

- Drip: Copper (1.3 mg/kg), Chromium (1.3 mg/kg), Nickel (1.9 mg/kg), Lead (1.9 mg/kg) and Zinc (16.6 mg/kg).

3.4 Impacts of drip and flood irrigation of wastewater and treated wastewater on crop yield

The yield of okra, was more in drip irrigated wastewater and treated water than the flood irrigated. In treated water, yield was less than wastewater but the contamination was very less than waste water irrigated crops.

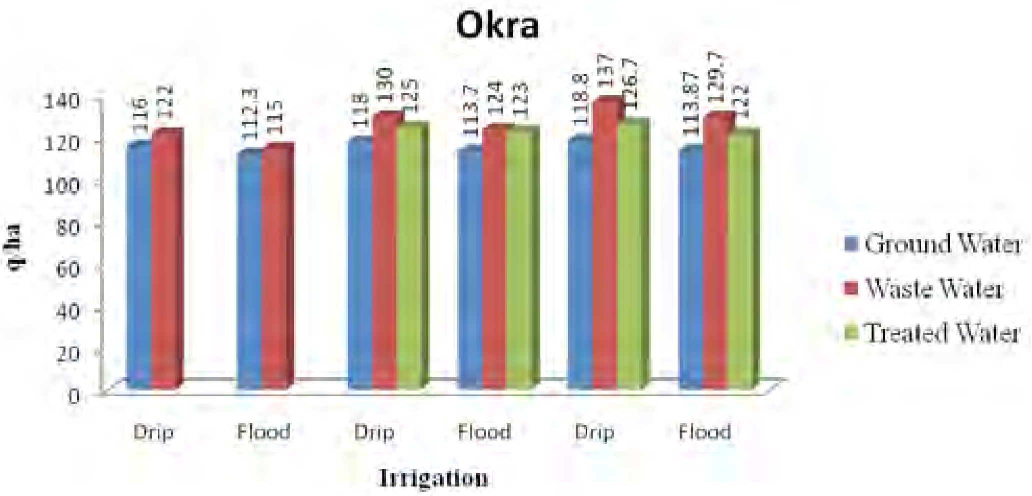

Figure 3: *Year-wise yield of Okra*

3.5 Impacts of wastewater and treated water on soil microbiological biodiversity

After studying the DGGE (Denaturing gel gradient electrophoresis), of wastewater and treated water soil, following community has been observed:

3.5.1 Microbial communities in wastewater irrigated soil

Telluria mixta strain 58-Y97, Shewanella sp. FS8-2, Shewanella putrefaciens strain DHS01, proteobacterium clone Upland_40_6285, Burkholderia vietnamiensis strain KNL-16, Halochromatium sp. isolate DGGE gel band 17BAC, Burkholderia vietnamiensis strain KNL-16, alpha proteobacterium IICTSVMME1, bacterium isolate DGGE gel band B23, Alcaligenes pakistanensis strain DBT26, Alcaligenes sp. ST3-13, Alcaligenes faecalis strain 3d, Candidimonas sp. UCM-F49, Pusillimonas sp. N12, Alcaligenes faecalis strain DBT18, Alcaligenes faecalis strain ABE1a, Burkholderia cepacia gene, Alcaligenes faecalis strain C_9, Alcaligenes sp. clone K2DN258, Pseudomonas sp. DGGE band 5, Micrococcus sp. strain YM47, Bacterium MS-AsIII-61, Uncultured bacterium clone OTU33, Acidobacteria bacterium clone PBM3_H10, Bacterium T-2-48-9A, Gemmatimonadetes bacterium partial 16S rRNA gene clone UMAB-cl-124, Hymenobacter sp. RP-2016a strain CCM 8649, Sphingomonas sp. strain A835, bacterium clone 3c08, bacterium clone RM157, bacterium gene.

3.5.2 Microbial community in treated water irrigated soil

Shewanella sp. FS8-2, Shewanella putrefaciens strain DHS01, Burkholderia vietnamiensis strain KNL-16, alpha proteobacterium IICTSVMME1, bacterium isolate DGGE gel band B23, Alcaligenes pakistanensis strain DBT26, Candidimonas sp. UCM-F49, Pusillimonas sp. N12, Burkholderia cepacia gene, Alcaligenes sp. clone K2DN258, Micrococcus sp. strain YM47, Pseudomonas sp. DGGE band 5, Bacterium MS-AsIII-61, Uncultured bacterium clone OTU33, Acidobacteria bacterium clone PBM3_H10, 1 Bacterium T-2-48-9A.

In Lohamandi drain irrigated soil has more pathogenic microorganisms then the treated water irrigated soil. Some uncultured microorganisms were also present in soil which could behave both pathogenic and non pathogenic.

4. Discussion

In 12C IARI field, water of Lohamandi drain are polluted with chromium and nickel, while other heavy metals are at the borderline of permissible limits in wastewater, which got accumulated in the soil and then to crops. In most of the months, chromium and nickel was above the permissible limits in Lohamandi drain. In soil, the concentration of metal was increasing with time and in the final year of study the concentration of nickel and lead was above the permissible limits in soil irrigated with wastewater. While in treated water all the metal limits are below. In case of crop, the wastewater irrigated crops had higher concentration of chromium, nickel, lead and zinc.

The flood irrigated crops had increase of total metal percentage by 28% in okra. While in drip irrigation, the concentration of metal has been increased by 24% in okra. This study also reveals that in the 3rd year, drip accumulates 27.1%, less total metals than flood in edible part of okra. Nearly the same trend follows in the 1st year and 2nd year of crops also. Yield is also better in drip irrigated crops with wastewater, treated water and groundwater then the flood irrigated. Drip irrigation accumulates less metal with better crop yield then flood irrigated one. In treated water and wastewater, the metal accumulation got reduced with treated water with very less reduction in yield of crops. Also, the microbiological diversity study reveals that, pathogenic microorganisms were more in the wastewater irrigated soil. This study recommends that the drip irrigation with treated water is cost effective, less hazardous and prominent for sustainable agriculture. Farmers will be highly benefited and this eco-friendly approach of treatment of waste water will be helpful in reduction of environmental and health risk.

Acknowledgements: This research is funded by National Agricultural Science fund, ICAR, New Delhi and research and technical support from IIT Delhi and University of Delhi.

References

Duruibe, J.O., Ogwuegbu, M.O.C., Egwurugwu, J.N. (2007). Heavy metal pollution and human biotoxic effects. International Journal of Physical Sciences, 2(5), 112-118

Green, S. J., Leigh, M. B., Neufeld, J. D. (2010). Denaturing gradient gel electrophoresis (DGGE) for microbial community analysis. In: Handbook of hydrocarbon and lipid microbiology (pp. 4137-4158). Springer Berlin Heidelberg.

Khan, S., Aijun, L., Zhang, S., Hu, Q., Zhu, Y. G. (2008a). Accumulation of polycyclic aromatic hydrocarbons and heavy metals in lettuce grown in the soils contaminated with long-term wastewater irrigation. Journal of Hazardous Materials, 152(2), 506–515.

Muchuweti, M., Birkett, J., Chinyanga, E., Zvauya, R., Scrimshaw, M., Lister, J. (2006). Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: implication for human health. Agri. Ecosys. Environ., 112, 41–48.

Okereke, J. N., Ogidi, O. I., Obasi, K. O. (2016). Environmental and health impact of industrial wastewater effluents in Nigeria-A Review. Int. J. Adv. Res. Biol. Sci, 3(6), 55-67.

Pal S., Patel, N., Malik, A., Singh, D. K. (2015). Heavy metal health risk assessment and microbial menaces via dietary intake of vegetables collected from Delhi and national capital regions peri urban area, India, Journal of Food, Agriculture & Environment, 13 (2), 82-88.

Saravanan, V. S., Mollinga, P. P., Bogardi, J. J. (2011). Global change, wastewater and health in fast growing economies. Current Opinion in Environmental Sustainability, 3(6), 461-466.

Sharma, R. K., Agrawal, M., Marshall, F. M. (2008). Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: A case study in Varanasi. Environmental Pollution, 154 (2), 254–263.

Singh, A., Sharma, R. K., Agrawal, M., Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food and Chemical Toxicology, 48(2), 611-619.

Gender differences in water security and capabilities in Far-West Nepal

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Abstract

As in other parts of the world, approaches to water resource development in Nepal are popular as technical endeavours, focusing on engineering solutions at the expense of ignoring issues of gender and social well-being. Water specific work in Nepal revolves around the nature of participation of women in water resource user groups, however lack attention to the changing rural dynamics in the villages that govern gender relations and shape women's capabilities around water use, access and management. Understanding what factors impact women's capabilities is important in informing plans and policies on gender equality and sustainable use of water resources. This research investigates the norms and practices that govern local water resource management and the role it plays in enhancing or limiting capabilities of women in rural villages in far-west Nepal.

Two villages in the hills (Doti) and one in the plains (Kailali) have been studied using qualitative research tools such as focus group discussion, village mapping, historical timelines, key informant interviews, household interviews and participant observation. To validate qualitative data, we also draw on quantitative data from the basin-wide survey in far-west Nepal. We frame our analysis around the conceptual framework of capabilities developed by Sen (1990) and literatures on social capital.

The findings suggest that among other factors, social capital (social networks, trust and institutions) is influential in shaping capabilities in relation to water resource management. Social capital is influenced by gender and other social identities such as caste, class, age and disability. We argue that the existing configuration of local water governance is informed by traditional gendered norms and practices which reinforce gender inequality and deprive women from equal access to and benefit from water resources. This study further identifies that for effective and just management of water resources, women's social capital and capabilities must increase, a process which also builds individual capacity and enables collective action in the community.

Keywords: *capabilities; gender; social capital; water security, Nepal*

1. Introduction

Access to water is a key to human survival and well-being. Water access defines good health, food security, livelihoods and the fulfilment of spiritual and cultural needs. Nonetheless, not everyone has equal access to water and suffer distress and poverty.Various factors have been documented to facilitate and curtail equal access to water resources, which includes both biophysical and social factors. Among them gender differences in water access and management is prominent. The gender difference in access to water enlarges with other intersectional identities of social beings such as caste, class, age, disability, location and so on (Das and Hatzfeldt 2017). Basically, the poor and marginalized with limited access to assets, networks and livelihood options face greater vulnerability in times of change and uncertainty (Ibid).

The advocacy for equal inclusion of both men and women to plan and manage gradually depleting and scarce water resources is immense (Naiga, Penker and Hogl 2017). Moreover, water supply scarcity has been widely attributed to poor non-inclusive water governance (Partnership 2002). The argument is since women, more than men, deal with water given by their gender role both in domestic and productive water use, women equally should be encouraged to be water managers (Cleaver 1998). This is important especially from two perspectives. First, the issue is not limited to unequal access to water for domestic and productive use but the concern is also about the increasing water risks and conflicts in terms of water scarcity and water-induced disasters. Water scarcity and disaster impact human well-being negatively and compound poverty and inequalities in communities. Second, due to changing family structures, changing lifestyle, fragmented land holdings and increasing food insecurity, men are increasingly out-migrating from the villages in search of better livelihood options. The declining interest of men, especially youths, in agriculture as a livelihood option is documented widely. In such a scenario, women are responsible for the household, including agricultural and other livelihood activities (Jaquet et al. 2016). However, due to unequal gender power relations, women, especially from vulnerable households, do not have influence on water decision-making (Upadhyay 2003). Research indicates that even the provision of women quota has been very elusive with regard to meaningful representation of women in water user associations (Pradhan 2015, Prokopy 2004 , Wambu and Kindiki 2015.).

Despite a large body of literature exploring women's role and participation in water management, few studies have examined how women's capabilities shape and are shaped by access to water resources and related benefits. Existing literature investigating women's capabilities with regard to access and management of water resources indicates both institutional and individual attributes constraining women's effective participation in water management (Naiga et al. 2017, Ahmed 2009). A capability approach goes beyond a utilitarian approach to water access to position water security as a hydro-social process (Jepson et al. 2017). A notable work in this regard is that of Mehta (2014) who focuses away from volumetric issues of supply, demand and considerations of utility and efficiency and relates water access to freedom, capabilities and human well-being. Likewise, the recent work by Jepson et al. (2017) proposes 'hydro-social analytical framework to assess the ability of individuals to engage with and benefit from a sustained hydro-social process that supports water flows, water quality and water services in support of human capabilities and well-being ' (p. 2).

This research recognises the unequal human capabilities of men and women and also among women due to unequal social and political circumstances (Nassubaum 2000) and builds on a capability approach. We investigated access to water along varying intersectionality and discuss the inequities in capabilities and well-being of women in the rural villages of Doti in the hills and Kailali in the plains.

2. Methodology

We draw on data collected in two hamlets of Doti and one hamlet in Kailali district in far-western Nepal. These hamlets were prior selected by Digo Jal Bikas (DJB) research project (www.djb.iwmi.org) based on its biophysical and social characteristics. Respondents were selected using purposive sampling. The data was collected in April and May 2017. A range of different qualitative tools such as village mapping, historical timeline, key informant interview, in-depth interviews, transect walk and participant observation was used. The raw data was coded using QDAminorlite following conceptual framework on capabilities developed by Sen (1990) and tried to connect it with the social capital approach.

3. Study Area

Each of the three studied hamlets (Fig. 1) consists of more than 5 villages. While in Doti, the villages are in majority inhabited by Chettri and Dalit households, villages in Kailali were distinctly marked by various ethnic groups such as Tharu, Rajhi, Madehsi and Pahadis (Brahmin/Chettri). To study a big area and diverse ethnic composition within stipulated time and resources posed a serious limitation to the study.

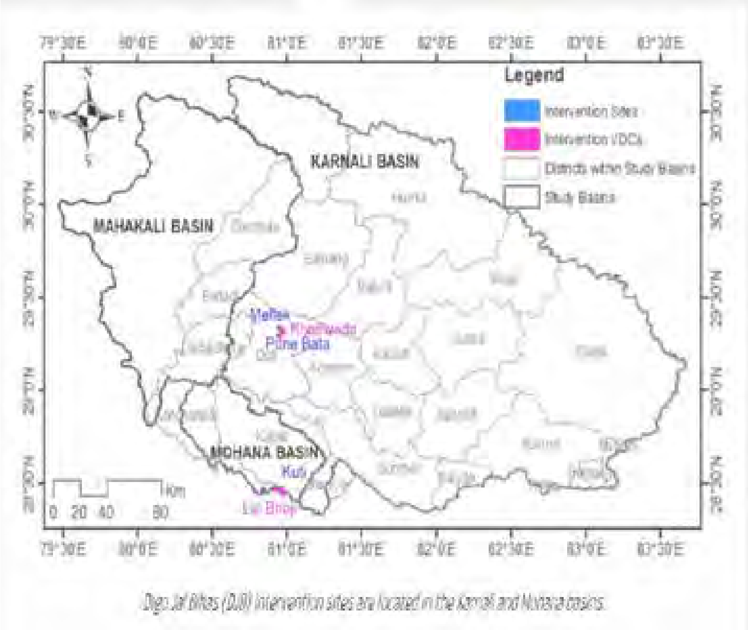

Figure 1: *Location map of three study hamlets Doti and Kailali (Source: IWMI, Nepal)*

4. Conceptual Framework

4.1 Sen's idea of capabilities

In Sen's perspective, justice is defined in terms of choice and freedom of the people involved, that is their capabilities to achieve the functioning (i.e., the 'beings' and 'doings') that they value (Sen 1999). Sen suggests 'the question of gender inequality can be understood much better by comparing those things that intrinsically matter (such as functioning and capabilities), rather than just the means [to achieve

them] like resources. According to him, the issue of gender inequality is ultimately one of the disparate freedoms' (Sen 1992).

The capability approach contrasts with philosophical approaches that concentrate on people's happiness or on the means to achieve well-being such as access to resources. Sen argues that policies and development programs should focus on what people are able to do and be, on the quality of their life, and on removing obstacles in their lives so that they have more freedom to live the kind of life that, upon reflection, they have reason to value. The capabilities approach brings out the relationship between the public and private spheres of society and the implications of private inequalities, especially gender inequalities, in the establishment of social justice (Sen 2004). The capability approach has notably been adopted by Nussbaum (2003) to analyse gender justice – Nussbaum, however, offers a different stance on the capability approach by providing a list of ten central human capabilities, that are related to the body, mind and environment. Her approach contrasts to Sen's argument in that the definition of capabilities should be context-specific and based on open discussion and deliberation.

4.2 Social capital

Formal and informal relationships are central to the concept of social capital. It is defined as the personal relationships which are accumulated when people interact with each other in families, workplaces, neighbourhoods, local associations and a range of informal and formal meeting places. It is through such relationships that people reassert and renegotiate the rules governing the access to resources in society and influence the distribution, control and transformation of assets (Bebbington 1999, 2035). Individuals with a strong social network and associations will have stronger capabilities to confront with shocks, vulnerability and poverty and receives new opportunities to maximize their assets (Moser 1996). Possession of social capital builds new capabilities and individuals improve their welfare. New capabilities allow individuals to create new connections and access new networks (Migheli 2011).

The importance of social capital in establishing individual well-being has been increasingly under discussion. Especially in the context of Nepal where kinship and networks historically have determined the distribution and ownership of resources, it becomes imperative to study the role it can play in sustainable resource use and development. It is important to know about the role of social capital in producing new and possible hidden forms of gendered and social exclusion and its impact on the material and social well-being of men and women. Existing studies on social capital are suggestive of enhanced collective behaviour in the community. Research indicates that better social capital helps the communities respond to crisis effectively (Helliwell, Huang and Wang 2013).

4.3 Capabilities and social capital

Limited attempts have been made in the past to explore interlinkages between capabilities and social capital. Most of the existing literature investigates the importance of social capital in enhancing organisational, entrepreneurial and intellectual capabilities. Micro-level studies on capabilities and social capital are rare. Some scholars posit social capital as an important determinant of human capital which later they argue form the basis for inclusive growth (Dinda 2014). What is common in all these studies is the focus on the quality of a relationship between members which as Giraud et al. (2012) put forward facilitates human and social development. They draw on Sen and Nussbaum's capability approach and devise a Relational Capability Index (RCI). RCI focuses on three dimensions related to relational capabilities– 1. To be integrated into networks; 2. To have specific attachments to others, including friendship and love;

3. To commit to a project within a group: which aims at serving a common good or a social interest, to take part in decision-making in a political society. Ostrom and Ahn (2007) describe social capital as a synthesizing approach which impacts the cultural, social and institutional capacity of the community members to deal with collective action problems. Similarly, Ireland and Thomalla (2011) see social capital as an important component of collective action for building the adaptive capacity of the community to adversities. Migheli (2011) on the other hand argue for a dynamic connection between social capital, capabilities and functioning. According to his theory, the ability to attain new capabilities is enhanced by the possession of social capital; hence investing in its accumulation allows individuals to improve their welfare. Furthermore, new capabilities allow the individual to create new connections and access new networks, accruing his or her stock of social capital and opening the door to the possibility of attaining new capabilities.

4.4 Social capital and gender

Research analysing social capital from a gendered perspective is rare. Gender dimensions of social capital have been paid less attention in the literature on social capital (Fox and Gershman 2000, Molinas 1998). Scholars argue that the investigation of social capital is incomplete without investigating gendered hierarchies within which social networks are forged (Silvey and Elmhirst 2003). The authors also theorized social capital that exists within a broader context of gender inequality can exacerbate women's disadvantages, as women remain excluded from the more powerful networks of trust and reciprocity that exist among men (Ibid). Westermann, Ashby and Pretty (2005) find significant differences in the gender aspects of social capital impacts, the activities and outcomes for natural resource management groups.

4.4. Justice, well-being and capabilities in water resource development

Water is a key component of human well-being. Whereas access to water for hygiene and sanitation is a key pre-requisite for bodily health and dignity. It is also a critical input for farming and rural livelihoods. Water also has a deep cultural, spiritual and symbolic value in South Asia, as in many other parts of the world and at the same time, supports healthy ecosystems and environment. The mainstream approach to water resources development and management, e.g. drawing from integrated water resource management (IWRM), has been criticised for delinking water issues from socio-political processes and issues related to social and gender equity around use, distribution and management of water resources (Mehta 2006). Generally, water policies worldwide have been largely guided by markets and efficiency models, whereas they have rarely considered the needs and the interests of the marginalised (Syme et al. 2008). One of the reasons lies in the way water resources development has been framed. The latter is represented as a technical endeavour, where the objective is to control and distribute biophysical resources and that is supported by engineering solutions (Allan 2005, Mehta 2006). Its impacts have been largely evaluated in terms of economic efficiency, whereas there has been less attention on how water resource development affects social and environmental justice and well-being.

Conventionally, water's contribution to well-being is measured in terms of quantity, quality, regular supply and proximity to water sources. Mehta (2006) proposes to adopt broader values – freedom to choose, decision-making, social relations, autonomy and control, culture and identity and security. These broader values evaluate social exclusion, social displacement, and inequities in water supply and use, which have tangible/intangible implications for livelihood options, health, socio-cultural identity, daily routine and social relations (Mehta, 2006).

The capability approach helps to qualitatively evaluate the well-being of the disadvantaged and marginalised communities based on their capabilities and freedom rather than evaluating the aggregate benefits from the water resources. Therefore, the capability approach can help evaluate the varied impacts of socio-political process on diverse groups of people, recognize the diverse needs and competing values of the Water user associations (WUAs).

5. Findings and Discussion

5.1. How gender intersect with social and bio-physical factors and shape capabilities to access water resources?

Water security is a broad term. It defines adequacy, quality and reliability (Jepson et al. 2017). Adequate, clean and reliable access to water is important for human survival and well-being. Water access however, is not only determined by biophysical factors such as the topography, geology and distance from the water sources but also by social-economic attributes of individuals, households and the community.

Social hierarchies in all the studied areas were evident not only through widely practised caste system but also from different land size holdings and the varied capabilities of the households to diversify livelihood strategies. In hamlets, especially heterogeneous in terms of traditional caste structure, caste has an important bearing on the capabilities of men and women with regard to access to water. These villages practice separate springs for Dalit and non-Dalit. Ironically, similar water arrangement practices are also prevalent in hamlets most intervened by development organisations. In a hamlet called Saudnara for instance, Nepal Water for Health project (NEWAH) has built 9 taps. As informed, water flow in these taps interrupts very frequently due to blockage at the source. In such circumstances, people rely on nearby located water springs which are separate for Dalit and non-Dalit. The conversation below exemplifies how water access is still marked by caste differentiation in the hamlets.

Box 1 A Dalit girl asks researchers' caste.
The water in the tap was interrupted for the last three days. Men had gone to the source to remove the obstructions. A young girl was fetching water from one of the two spring taps near-by.
R – Can I drink water from this tap? (Pointing the tap the girl was using)
The girl – Where do you belong? (Dalit/Non-Dalit)
R – I belong same as you.
The girl – Stares!

With given gender roles, women and young girls bear the burden of water collection mostly. The water stress increases if these women are economically poor and have a migrant husband. In Saudnara, most Dalit women who were interviewed had a migrant husband. With given time constraint, it was difficult for the research team to understand the complete water arrangement impacted by caste dynamics in Saudnara, especially when there were plenty of water interventions by different organisations to ease the access to water. In the group discussion, women stated that there are two different sources of water for these 9 taps. Further research investigating the source location, and the reliable flow of water is important. It is because the water flow interrupts almost every week and available men who are only high caste go and mend the source, and if the source is different for different groups, women with migrant husbands face more constraint to reliable water access than women with husbands in the village or who have strong kinship ties with men relatives.

We observed similar water arrangements in another hamlet called Rokainaragaon, the farthest located hamlet from the market area, with fewer interventions with regard to water infrastructure. Interestingly, unlike Saudnara the spring sources were located not at a similar height. The water source used by Dalit was at a lower elevation than that of Chettris. These sources, as informed, are the traditional water sources used by the people for generations. Evidently, the caste system demarcated the clean water to Chettris and water which gets polluted due to laundry/bath at higher elevation water source was given to Dalit. Furthermore, the water source used by Chettri has better flow than that is used by Dalit.. The system is still intact. Similar water arrangement based on caste was also heard from other hamlets in Mellekh.

Traditionally, women are responsible to fulfil domestic water needs. It is basically children, young woman and daughter-in-law who are responsible for fetching water for cooking, vegetable farm, livestock, bathing, and sanitation.. In this sense, women, not men needs strength, time and face water conflicts (if any) with regard to water collection. A young pregnant woman from Saudnara added –

> "I also carry water 4-5 times a day even if it is hard, I do it". (Source: Female, Focus Group Discussion in Doti, 2017)

Women in Katalgaon and Alaitwada reported collecting water a maximum of 14-20 times a day. It was stated that since all women collect water after finishing household and farm activities, the queue is usually long and each wait for their turn. In Alaitwada, we observed that the tap is constructed near a temple, which as informed by the women later, is why women do not clean themselves at the tap but carry water to the house and bath there. Access to water for women also differs while they menstruate. It was shared most of the women go to the river stream to clean themselves. The continuous and rapid flow of water makes it easy for them to wash stained clothes without any embarrassment Traditional mensuration taboo considers female impure and prohibits them from touching water sources. Even to mention mensuration or visibility of blood becomes a source of embarrassment and considered unclean. This shows how historically culture have played major role in maintaining and reinforcing gender inequalities with regard to equal access to water resources.

> "We collect drinking water only. We don't do laundry here. We don't bathe. We carry water and do washing in the house. There is a temple, so we don't do it here. For washing clothes, we go to the khola. We also take livestock there". (Source: Female, Focus Group Discussion in Doti, 2017)

When we compare the access of women to water based on caste, Dalit women retain the disadvantaged position. It is because they do not have access to clean water and also they have to devote long hours due to less flow in the spring. The problem becomes intense during the dry season, when the flow is reduced extremely. In terms of hamlets, as stated before, Saudnara appears to have maximum water infrastructure. We observed young educated men in the villages who are involved with government and non-governmental job. They are also well connected to their kin settled in the market areas. We assume that this could be one reason for greater access to institutions for funding for water infrastructures. Furthermore, the household with higher resources have moved to the market area and have easy access to water through pipes.

Access to clean water is also a problem for some hamlets because of the open source of water. For instance, women in Saingoan reported that since there is no tap and the source is open, children often put their hands in the water which makes the water dirty. They use utensils to collect water from the source. Unequal, unsafe and inadequate water access negatively affects women's health, work burden and

therefore, capabilities. Women lack entitlement to safe water because of cultural norms, social exclusion and lack of water infrastructure as well (Mehta 2014).

Access to irrigation water, in the studied hamlets, is not as simple as it appears on the ground. In normal terms, we heard explanations such as - we irrigate our fields on mutual decisions; we face minor verbal disputes but we solve it soon among ourselves. Gathered data shows that access is largely defined by land size, land location, land quality, labour availability, water infrastructure, resources to buy pipes, seeds, fertilisers on time, good social networks and access to water stakeholders.. Land distribution in terms of quality and quantity is shaped by history. Consequently, the bigger chunks of lands with good soil productivity and water access is owned by comparatively well-off groups in the village. The table below details the physical and social factors that determine inequities in terms of access to irrigation water.

Table 1: *Bio-physical and social factors determines unequal access to water resources*

Determinants of Access	Non-Marginalised Group	Marginalised Group
Land ownership and Size	Big	Small/landless
Land Quality	Khet (Irrigated lands)	Pakho (Steep rain fed lands)
Land Location	Near Water Source	Far from water source / Vulnerable to monsoon landslides
Labour Availability	Men are involved in government or NGO jobs, men return back during farming season, hire or exchange labour	Usually a migrant to India, returns back only after 2-3 years, women rely on village men for ploughing, exchange labour in the village.
Water Infrastructure	Ponds	No access to pond water
Resource Availability	Pipes, Seeds, Fertilisers, pumps, bullocks	Seeds, Fertilisers
Social Networks	Extended	Limited
Access to Institutions/Water stakeholders	Men	Women

(Source: Fieldwork, 2017)

In all the studied areas, technically, the one who sows gets the chance to irrigate the fields. Marginalised households without men, lack labour, equipment and resources to sow fields before the one who owns resources and labour.

> "We are mostly dependent on rainwater. If there is a lot of rain, we get water from the canal. At that time, 4-5 people can plant on the same day. If my field is ready, then I take

> water. I might be first or last, it does not matter when there is a lot of water. If there is less water, we have to take turn. The ones nearer to the canal are the first ones and the ones at the end receive water last". (Source: Female, Focus Group Discussion in Doti, 2017)

In some cases, it was also found that people do not get water to irrigate the fields even if they manage to sow the fields on time. In case of Punetola, those who have pipes and irrigation ponds have easier access to water than those who do not have means to buy pipes.

> "Few ponds are supported by the organisation but the landowners made it private. We have to ask the owner of the land to use the water". (Source: Focus Group Discussion in Doti, 2017

Labour availability is important not only in terms of preparing the fields sooner but also in communal activities that includes repair and maintenance of the canals during the planting season. Repair and maintenance is traditionally seen as a masculine activity, therefore limit women culturally from participating in it. Moreover, if they don't do it, they risk losing right to access water to irrigate their fields. Social networks also play role in determining individual access to water resources and infrastructure. Since water sector is run especially by men, it is men in the village who access information about projects and play role in decision making with regard to location and benefit from water infrastructure, trainings and other relevant information on extension services. With unpredictable and changed weather patterns the tensions around irrigation becomes rife during dry season, when water flow decreases substantially in springs and streams. Without required resources and men at home, women may suffer crop loss as shared by many in both Doti and Kailali.

> "The water source is dry, except in rainy season. The water in the stream has reduced. It rise only during rainfall. Rainfall was good in old days. It would rain the whole day and we would do plantation". (Source: Female, Focus Group Discussion in Doti, 2017)

Similarly, in a hamlet in Kailali a widow with migrant sons shared how this year she could not irrigate 10 kathas of land because there was no one to help her to carry the engine to her fields, located in the elevated lands near the Mohana River. Her crops were destroyed. In another hamlet, another woman with a migrant husband stated, "It is difficult to arrange everything. I was busy arranging the 'dunlop' (the cart) all morning, now I need to arrange bullocks and then I have to worry about getting a man to drive the cart and plough the fields. To get things done is not straightforward. We have to request several people, several times." Lack of access to water and destruction of harvest can translate into losses for instance, more debt, circular migration, cut offs in nutrition, less money to invest in next season farming, and greater vulnerabilities.

5.2. Gender, social capital and water resource management

5.2.1. Social networks

In the study sites, well-being is shaped by household capabilities to diversify sources of livelihood which in turn is determined by gender, class, caste, and age (GCCA). Among affluent households are primarily high caste (Chettri in Doti and Tharu in Kailali), with local jobs (teachers, army, police, NGO), hold an important leadership role in the community combined with local business (renting cars, hotels, shops), literate and men. The most common characteristics of such households in all three sites is the strong social ties that men share with men both inside and outside the village. Men share the privileged position as water managers and access the associated opportunities (job), training, information and meeting

since water management is typically seen as men's work both inside the village and in the organisations working in the water sector. We came across no female staff working at the sites. The absence of female staffs in the fields discourage women in the village to expand social networks. First, men usually contact men and not women and second, contact with men bring tag of an immoral image to women. Similar instances have also been reported by previous studies, for example, Ireland and Thomalla (2011) provide an example of male government staff refusing to meet women unless accompanied by men and how male local government employee reported the loss of his social status by interacting with women collective. These social norms act detrimental to the development of women's capabilities.

In addition, influential men in the village act as links for further contacts for the development actors and recommend men (women only when there is a compulsory criteria) in close contacts (basically sharing kinship) for jobs, position in user committees, meetings or training. This chain of benefit from individual social networks, benefit one single group and carry a risk of aggravating social and gender inequalities. The gathered data reveals that a strong social connection depends on common ethnicity people share in the village. For instance, Chettris have close social bonding with Chettis than with Dalits. This finding was similar in case of Kailali. For instance, Tharus share a strong social bond with Tharus and strongly disassociate themselves from Madhesi and Pahadis. Since Chettri is high in caste hierarchy than Dalit, in the hills Dalit was underprivileged. In the case below, a Dalit woman was boycotted and lost membership in social groups because a boy from her family married a Chettri girl.

Box 2 CASE: Common ethnicity counts for building social capital

A Dalit woman with a migrant husband was found not a member of any community group. When asked about the reason she seemed very reluctant. After several minutes of probing she shared that since her elder sister in law's son married a Chettri girl, everyone in the village boycotted her family. Her elder sister-in-law family were ostracized from the village. She faced fights in groups she was a member of. So, she left. She is not a member of any community group including women's saving and community forestry groups. She is forced to live an isolated life.

Engagement in community-level organisations increases trust and provides access to resources, income and improved well-being. However, in this example the Dalit woman lost the only means to build on informal networks provided her exclusion from women saving groups, which as we found to act as an important base of women's social capital in the villages. All other community groups are managed by men including forest groups. Women, in particular of households with no men or women with migrant husbands lack social networks because of less frequency of contacts with the outsiders. Men on the other hand responsible as bread earners are mobile and earn an opportunity to build wider relations with outside and inside actors. In such a context, women's capabilities to access water is often conditioned by their relations with male relatives (Movik 2012).

Research indicates an absence of social capital acting as an obstacle in management and development of collective commons. For instance, Bisung et al. (2014), explores the relationship between social capital and participation in collective action in the context of addressing water and sanitation issues in Western Kenya and finds that the lack of social capital is a barrier to collective action for community-based water and sanitation initiatives. In the context of Nepal, Lam (1999) compared 150 government and farmer managed irrigation systems and found that their success depended heavily on the social relations between farmers receiving water from the system. Similar to these studies, women's weak social capital in the research areas was found critical for women's non-participation in the collective management of water resources, thus severely limiting their capabilities to improved well-being.

5.2.2. Trust

Trust is integral to good social relations and cohesive societies. Cooperation can flourish when people trust each other (Uslaner 2002). Trust promotes participation and affiliation and therefore can affect capabilities (Murphy-Grahama and Lample 2014). According to Nussbaum (2011) affiliation denotes an ability to live with and toward others, to recognise and show concern for other human beings, and to be able to engage in various forms of social interaction. It also means self-respect and non-humiliation, the ability to be treated as equal and dignified being. In all the study areas, gathered data indicates lack of trust among community members and in particular with community leaders.

> "We have some leaders. A few years back they said they will convert this hamlet into a colony (everyone laughs)". (Source: Male, Focus Group Discussion in Doti, 2017)

When men and women do not trust leaders or mistrust each other, they are less likely to participate in committees. This could lead to weak law enforcement as could be seen in case of stealing of forest products or the existing forest conflicts between different hamlets in Doti. Similar evidence have also been provided from Uganda by Naiga and Penker (2014) where lack of trust caused reluctance from users to contribute to water user fees. Less participation also means no voice in decisions which impact the bodily health of men and women and therefore can impact their capabilities. The Dalit woman who was ostracised by the community, for example, lost all her group affiliations which reduced her access to forest products. She doesn't pay for the forest products but steals from the forest to meet her firewood necessities and also this has forced her to live in continuous fear of being caught. Similarly, no participation and no voice due to mistrust reduce capabilities of women for they could not access information and opportunities from water management projects.

> Q. From which organisation?
>
> We don't know
>
> Q. Why did not you get it?

In other villages, there are people who can speak, go and ask. Here, those who could speak migrated to Kathmandu. The remaining men just sit under the pipal tree. What can women do?

> "If things come in the woman's name, then we will get it, but it comes in the men's name". (Source: Female, Focus Group Discussion in Doti, 2017)

As could be inferred from the interview excerpts, trust on each other, trust in women's capabilities and self-trust by women themselves is important for effective women's participation and sustainable management of WUAs. It was found that trust and good leadership are two important factors that enable collective action. A hamlet in Kuti presents an example of well-managed water governance. The hamlet is inhabited by Tharus. The role of village head is prominent in big decisions. He is respected and followed by everyone in the village. Similar kinship has also kept the bond strong among the community members. Besides, there are leaders not in formal positions however with strong social networks who are working for the betterment of the community for example access to budget from District Development Committee to build stone-paved road, which would cause trouble of access during flood before.

> "The front road was made gravelled from MP fund. Mr Chaudhary is from Madheshi Forum. When they came for a survey, I had told him about the flood situation and the need for embankment". (Source: Male, Focus Group Discussion in Kailali, 2017)

With regard to irrigation water distribution, the rule is to charge the user a certain amount for using the borewell water and the machine. The user also needs to bear the cost of diesel in addition. However, the rule is different for those living within the hamlet. Borewell owners do not charge the user for water and machine. The user only buys the fuel. Again if the user is a relative then he/she only prepares snacks for everyone.

> "Within our hamlet, we usually do not charge for using borewell. The users bring their fuel. Before, it was charged Nrs.35/hour for the engine. However, we never charge our neighbours. Sharing water is a goodwill." (Source: Male, Focus Group Discussion in Kailali, 2017)

In other hamlets, although lesser amount, when compared to the outsiders, the user from the hamlet, is charged both for the machine, and the fuel. Social capital as such reduces the cost of irrigation for the users who do not own borewell. Nevertheless, in other hamlets, users without private borewell bear the higher cost of irrigation because they pay for engine, pipe and fuel as well.

> "We also rent from other hamlets. Sometimes we pump water from far distances using pipes. We are charged Nrs100/ hour. We need to bring fuel and pipe. Some people charge Nrs80 for using motor". (Source: Female, Focus Group Discussion in Kailali, 2017)

Good leaders play a critical role in facilitating collective action within the communities. In the stated hamlet, strong social capital and collective action are also evident from well-maintained common borewell which was provided by the government. As informed, the cost of machine and electricity meter installation was paid from the contribution from the users and they also share the cost of repair and maintenance among themselves. The installation of motor and meter became possible due to collective demand and leadership in the community.

An effective collective governance of the water resources requires good trust among the community members. Accountable leadership is missing in case of Doti which has created mistrust and weak collective social capital in the village. Unlike the hamlet of Kuti, both sites in Doti and remaining hamlets in Kailali reveal leadership void that has been created by the decade-long conflict, socio-economic differences and increasing men's migration as well. The negative impact is visible through the ineffective water and forest resource management at the sites. Traditionally men held leadership positions as village head or political leaders. With increasing men's migration women are the left behind who traditionally were excluded from leadership positions and lack capacity and social status to be accepted as leaders by the community. The existing leadership in the village is defined as individualistic and corrupt by the community members which provide fewer incentives to men and women to contribute to the maintenance of water and forest collectives.

5.2.3. Institutions

The problem is aggravated by development interventions which, despite having good intentions, have created unintentional unequal ownership and access to water resources. Inclusive participation and gender equality have become integral buzzwords to organisations, nevertheless, there are less structural changes that define control and benefit from water resource management. The formal-informal rules and norms for the selection of individuals for important positions include those who could keep records, carry good hold in Nepali language (observation), is mobile and can spend time for meetings and discussions. Women both in Doti and Kuti are not educated, not versed in the Nepali language, less mobile, and busy

with triple burden of work. In such a context, women are selected as members of the committee and with no time and budget devoted by the projects to build their capabilities, remain passive participants. These formal rules and norms support powerful groups' interests, rather than those of the weak and marginalised (Mehta 2014). This could be seen from the increasing privatisation of water sources and infrastructure in Doti, which the poor and marginalised women cannot access. Even the compulsory women quota has not succeeded to bring women in the committees. In Kuti for example, none of the women irrigators is members of the user group. Women who are in the group are close relatives of influential men in the village and do not irrigate fields themselves. Evidently, such water management arrangements have pushed marginalised women to vulnerable situations in terms of equal water access.

> "One pond belongs to Mr. K. If we ask, he would give us water but we have not asked because it is his personal pond. What about the pond in Punetola? – They don't provide us with water. It is sufficient for only Punetola. It was brought by an organisation. I do not know if the pond is leaking". (Source: Female, Focus Group Discussion in Doti, 2017)

Studies indicate that often the community contribution in infrastructure development becomes possible not because of social trust however due to NGOs/ the government who pay the community to construct the infrastructure (Bouma, Bulte and Van Soest 2008). Such cases usually reduce the collective incentives for the community to contribute. Our observations reflect similar findings as that of Ostrom (1994) which argue that ignoring the role of social capital and collective management of water resources by development organisations might have unwanted consequences as that could be seen in Mellekh and Punetola in the form of leaking and abandoned ponds or communal ponds turning into private ponds. Creating water infrastructure such as common ponds, taps and canals are popular among development organisations to encourage community management of watersheds and water systems. However, the sustainability of an externally induced collective project, not considering the social context, is increasingly debated (Adhikari and Goldey 2010, Lam 1996, Lam 1999, Lam and Ostrom 2010). Lam (1996), for instance, in Nepal showed that infrastructure interventions can erode the need for collective action and consequently fail to achieve the expected results. In all study sites, there are informal institutions managing irrigation water. However, as stated elsewhere women's access is not only determined by caste and class but also largely depends on women's relations with men relatives.

6. Conclusions

This study found that both biophysical and socio-economic aspects are influential in shaping access to water resources. However, most of the times it is the poor and the marginalised who suffer owing to the least means, networks, capabilities to better adapt to adverse circumstances. This study confirms findings from previous studies (Das and Hatzfeldt 2017) that gender norms are key to shaping water inequities at various intersections such as caste, class, age, disability, location and so on. The increasing norm of seasonal migration of men from the rural villages has added more to adversities especially for the left behind women from poor households who are responsible for triple nature of work. Not only women's work burden increases but migration defines women's dependency on other men for activities socially defined as masculine, and also to information and opportunities. We posit that migration does not necessarily prove positive to all but can have differential impacts on different women. In all the sites, women play nil or minimum role in decisions related to water management. Women's access to water is defined by their relation to men relatives.

Equitable water resource management requires not only an equal access to use the resource but also

the capabilities, trust and good relations to sustain it effectively in the longer run. We agree to Migheli (2011) and argue mutual interlinkages between social capital and capabilities. Social capital enhances new capabilities, which in turn creates new connections, access and networks which again allow individuals to attain new capabilities and functioning. However, since men and women share gendered spaces, linkages and resources to build social capital, women lack capabilities to contribute effectively to sustainable water resource management. Gender intersects with class, caste and other social differences determine ownership and mobilisation of capitals – physical, social, natural and human. Ownership and mobilisation of these capitals build individual capabilities and determines in turn access to resources (water, land, forest), infrastructures, opportunities (knowledge, skills, income, health) and institutions. The new capabilities again create newer capabilities and enhanced access to resources and opportunities.

In the study areas, gender relations not only determine the ownership of water sources equipment and infrastructure but also influence the location of water infrastructure to be constructed, leadership choice in key positions and income opportunities from water projects. This has a negative impact on marginalised women's capabilities and functioning. We argue that the existing configurations for water governance (re)produce gender and social inequalities. It is because of the following:

1) Despite increasing gender mainstreaming efforts, women are either not involved in local water governance or are involved without required capabilities to influence decision making. No interventions have been proposed to address power relations arising of GCCA in the group. Women, in most cases, hold treasurer post and influential men in the villages chair different important groups, which keep the gender belief intact that men are good at decision making and women are good at safeguarding the fund, however, hold no power or role in spending it. The relation of masculine and feminine traits to water governance remains intact. Men get involved in high earning activities such as supervision, tender, breaking stones and constructing irrigation ponds while women carry stones and earn less than men.

2) On one hand, if migration is considered as an important risk reduction strategy for the households, on the other hand, migration of men from the poor household has increased water insecurities for the left behind women. It is because, the maintenance and repair of the water source is still seen as men's job, that needs long hours walk to the source and physical strength to repair the damages. Households without men which cannot participate in the repair and maintenance work face constraints to reliable water access.

3) We find that migration of men from the most marginalised groups does not necessarily empower voiceless women in the local water decision making. There is a possibility that this may further marginalise them in terms of access to information and opportunities because influential men who do not migrate still act as gatekeepers to important information, training and development projects, therefore, give preference to women of their choice. This may increase disadvantaged women's struggle for well-being in the absence of proper social networks and result in no change in individual and household well-being.

4) The varied development interventions for increased access to water in the communities is praiseworthy, however, our observations indicate that such development interventions usually ignore the social and cultural complexities that shape an individual access to water resources. Social and economic inequalities are further aggravated by the development organisations which practically provide less attention to the GCCA differentiation and more effort is made to overcome the technical obstacle in the building of water infrastructures. This could be seen from

the delegation of leadership positions to influential persons (mostly businessmen, politicians or job holders), preference to individuals good at record keeping, speech making (good hold on the Nepali language) and with spare time. The adverse impact of this could be seen from the location of water infrastructures and also the unsustainable investment in water infrastructures evident in the form of leaking and abandoned ponds. In addition, there has been little done to strengthen the trust and work on collective commons. We presented examples of the cases where communal ponds are claimed as private and therefore limit water access to the poor households. Also, we found cases where water committee collapses as soon as the project ends.

7. Recommendations

Based on this study, we make the following policy recommendations:

- Policy on GCCA should go beyond 33% representation of women in WUAs and focus on how to build capabilities of women and the marginalised so that they can contribute effectively to collective water governance.
- Apportion time and budget to build skills and capacities of the marginalised groups to bring them to the leadership positions.
- Appoint female project staffs (technical and non-technical) so that women are comfortable to ask questions, access information and skills, take leadership positions and contribute better to sustainable water resource management.
- Encourage or create incentives for the staffs to consider GCCA while planning, implementation and monitoring. This is important to break the gate of influential gatekeepers who control major decisions in the villages.
- It is important to address intra-household gender relations. Young married women although literate and have the capacity to effectively contribute to the local water governance do not receive the opportunity because of gendered expectations of taking care of household affairs, bearing children and taking care of old and young. In the absence of proper support from the projects, it is difficult for a single voiceless woman with a migrant husband and young children to be part of the decision-making process.
- Finally, policies/activities should create an environment that enhances collective action through increased trust and social well-being in the community.

Acknowledgements: This study is made possible by the generous support of the American people through the United States Agency for International Development (USAID). The contents are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

References

Adhikari, K. P., P. Goldey (2010) Social Capital and its "downside": The impact on sustainability of induced community-based organisations in Nepal. World Development, 38, 184-194.

Ahmed, S. I. (2009). The water governance systems in Dhaka and metropolitan Manila: Marginalised women's capabiltieis and social justice In Political Science. US: Northern Arizona University.

Allan, J. A. (2005). Water in the Environment/Socio-Economic Development Discourse: Sustainability, Changing

Management Paradigms and Policy Responses in a Global System. Government and Opposition, 40, 181-199.
Bebbington, A. (1999). Capitals and Capabiltiies: A framework for analyzing peasant viability, rurual livelihoods and poverty. World Development 27, 2021- 2044.
Bisung, E., S. Elliott, C. Schuster-Wallace, D. Karanja, A. Bernard (2014). Social capital, collective action and access to water in rural Kenya. Soc Sci Med., 119, 147-54.
Bouma, J., E. Bultet, D. Van Soest (2008). Trust and Cooperation: Social Capital and Community Resource Management. Journal of Envrionmental Economics and Managment, 56, 155-166.
Cleaver, F. (1998). Choice, complexity, and change: Gendered livelihoods and the management of water. Agriculture and Human Values 15, 293-299.
Das, M. B., G. Hatzfeldt. (2017). The Rising Tide: A new look at water and gender Washington DC: International Bank for Reconstruction and Development/ The World Bank.
Dinda, S. (2014) Inclusive growth through creation of human and social capital. International Journal of Social Economics, 41, 878-895.
Fox, J., J. Gershman (2000) The World Bank and social capital: Lessons from ten rural development projects in the Philippines and Mexico. Policy Sciences 33, 399-419.
Giraud, G. C., H. Renouard, R. D. L'Huillier, L. Martini`ere, C. Sutter. (2012). Relational capability: A multidimensional approach., ed. H. Universit´e Paris1 Panth´eonSorbonne (Post-Print and Working Papers) halshs-00827690.
Helliwell, J. F., H. Huang, S. Wang (2013) Social Capital and Well-Being in Times of Crisis. Journal of Happiness Studies, 15, 145-162.
Ireland, P., F. Thomalla. (2011). The Role of Collective Action in Enhancing Communities' Adaptive Capacity to Environmental Risk: An Exploration of Two Case Studies from Asia. Department of Environment and Geography, Faculty of Science, Macquarie University.
Jaquet, S., G. Shrestha, T. Kohler, G. Schwilch (2016). The effects of migration on livelihoods, land managment, and vulnerability to natural disasters in the Harpan watershed in Western Nepal. Mountain research and development 36, 494-505.
Jepson, W., M. L. Harris, A. L. Pearson, J. Stoler (2017) Advancting Human Capabilties of Water Security: A relational approach. Water Security, 1, 46-52.
Lam, W. F. (1996) Improving the performance of small scale irrgation systems: The effects of technological investments and governance structure on irrigation performance in Nepal. World Development, 24, 1301-1315.
---. 1999. Governing irrigation systems in Nepal : Institutions, Infrastructure and Collective Action. . California, USA: ICS Press, Institute for contemporary studies (ICS).
Lam, W. F., E. Ostrom (2010). Analyzing the dynamic complexity of development interventions: Lessons from an irrigation experiment in Nepal. Policy Sciences, 43, 1-25.
Mehta, L. (2006). 'Water and Human Development: Capabilities, entitilements and power', background paper for the 2006 Human Development Report, 'Beyond scarcity: Power, pverty and the global water crisis'. UK: Institute of Development Studies.
Mehta, L. (2014) Water and Human Development. World Development, 59, 59-69.
Migheli, M. (2011) Capabilities and Functionings: The Role of Social Capital for Accessing New Capabilities. Review of Political Economy, 23, 133-142.
Molinas, J. R. (1998) The impact of inequality, gender, external assistance and social capital on local-level cooperation. World Development, 26, 413-431.
Moser, C. (1996). Confronting Crisis: A Comparative Study of Household Responses to Poverty and Vulnerability in Four Poor Urban Communities Washington, DC.
Movik, S. (2012). Fluid Rights: South Africa's Water Allocation Reform. . Cape Town: Human Sciences Research Council Press.
Murphy-Grahama, E., J. Lample (2014) Learning to trust: Examining the connections between trust and capabilities friendly pedagogy through case studies from Honduras and Uganda. International Journal of Educational Development, 36.
Naiga, R., M. Penker (2014). Determinants of users' willingness to contribute to safe water provision in rural Uganda. Lex Localis-Journal of Local Self-Government, 12, 695-714.
Naiga, R., M. Penker, K. Hogl (2017). Women's Crucial Role in Collective Operation and Maintenance of Drinking

Water Infrastructure in Rural Uganda. Society & Natural Resources, 30, 506-520.

Nassubaum, M. C. (2000). Women and Human development: The Capabilities Approach. Cambridge University Press.

Nussbaum, M. (2003) CAPABILITIES AS FUNDAMENTAL ENTITLEMENTS: SEN AND SOCIAL JUSTICE. Feminist Economics, 9, 33-59.

Nussbaum, M. (2011). Creating Capabilities: The Human Development Approach. Cambridge, MA: Belknap Press of Harvard University Press

Ostrom, E. (1994) Constituting Social Capital and Collective Action. Journal of Theoritical Politics, 6, 527-562.

Ostrom, E., T. K. Ahn. (2007). The meaninig of social capital and its link to collective action. Northampton, MA: Edward Elgar.

Partnership, G. W. (2002). Dialogue on effective water governance. Stockholm, Sweden: Global Water Partnership.

Pradhan, P. (2015). Gender Issues and Women Participation in Water Users Associations (WUAs) in Irrigated Agriculture in Nepal. Journal of Graduate Studies, 12, 262-297.

Prokopy, L. S. (2004) Women's participation in rural water supply projects in India: Is it moving beyond tokenism and does it matter? . Water Policy 6, 727-56.

Sen, A. (1992). Inequaluity Re-examined. Oxford: Clarendon Press.

---. (1999). Development as Freedom. New York: Knopf.

Sen, A. (2004) Capabilities, Lists, and Public Reason: Continuing the Conversation. Feminist Economics, 10, 77-80.

Silvey, R., R. Elmhirst (2003) Engendering Social Capital: Women Workers and Rural-Urban Networks in Indonesia's Crisis. World Development, 31, 865-879.

Syme, G. J., N. B. Porter, U. Goeft, E. A. Kington (2008) Integrating social well being into assessments of water policy: meeting the challenge for decision makers. Water Policy, 10, 323-343.

Upadhyay, B. (2003). Water, poverty and gender: review of evidences from Nepal, India and South Africa. Water Policy, 5, 503-511.

Uslaner, E. M. (2002). The Moral Foundations of Trust. . Cambridge, England: Cambridge University Press

Wambu, C. K., M. Kindiki (2015.) Gender disparities in water resources management projects in Njoro Sub-county, Kenya. International Journal of Social Sciences Studies, 3, 123-129

Westermann, O., J. Ashby, J. Pretty (2005). Gender and Social Capital: The importance of gender differences for teh maturity and effectiveness of natural resoruce managment groups. World Development.

THEME – II

Coping with Recurring Droughts and Floods in the Context of Climate Change

Water resources management in Himalayan region for food security and rural development in the context of climate change

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Abstract

Population growth, urbanization, industrialization, and climate change are the key drivers leading to water crisis. Given the typical nature of Himalayan watersheds, soil and water management is very necessary for irrigation, food security, and sustainable development. In this context, this paper highlights possible techniques for enhancing water availability and then providing irrigation services for three types of agriculture systems that are prevalent in the Himalayan watersheds. They include hill slope farming, river valley farming, and foothill agriculture. Finally, this paper presents a success story of river valley development and management with a case of Ramganga Valley in Uttarkhand, India.

Keywords: *foothill agriculture; hill slope farming; river valley farming; water resources*

1. Introduction

Water is a critical resource that can enhance economic growth, improve quality of life and ensure environmental sustainability. Population growth, climate change, and urbanization cum industrialization are the three main factors for water crisis. Population growth means more water required for drinking, domestic, sanitation and irrigation needs for food security of rising population. Climate change is affecting the availability of water; it will affect rainfall patterns, including intensity, in time and space. Temperature rise will affect the movement of air, its humidity and cloud dynamics, i.e. water vapor carrying capacity of atmosphere. Urbanization cum industrialization, on the other hand, has resulted in increasing demand of freshwater. Unabated discharge of industrial effluents into natural water bodies is further aggravating water scarcity by deteriorating its quality.

Hence, proper management of water resource is very necessary to address the issue of water crisis in the Himalayan region. The Himalayas are the youngest and very fragile mountain range whose aquifers are not well defined. Infiltration is the entry of rain water into the ground and addition of infiltrated water to the aquifer is known as recharge. There are two types of recharge. Natural recharge refers to infiltration of rainfall under the ground surface under natural conditions. Artificial recharge, on the other hand, refers to collection of precipitation artificially and channeling it into the aquifer by artificial means. The artificial recharge can be made through point recharge or diffuse recharge. The point recharge occurs at a specific location, whereas in the case of diffuse recharge, a large pond is created and recharge

occurs through a large surface area. Rainfall and snow melts are the main sources of water in the Himalayan region. Various watershed management techniques can be opted for harvesting rainwater and then recharging the groundwater. They include construction of check dams at suitable locations in the stream beds, and construction of sub-surface dykes at stream beds, among others. These techniques help saturate the voids and faults of ground and aquifers, thus, creating soil dam.

Himalayan region lies between 74°50' - 95°40'E longitudes and 26°20' - 35°40' N latitudes. It spreads from north-west (NW) to north-east (NE) of the Indian sub-continent. Its average length is 2,400 km and the width varies from 400 km in NW to 150 km in NE. It is spread in three parallel ranges. Its northern most range/greater Himalaya remains snow covered round-the-year, which is the main source of water for snowfed perennial rivers. Mid-range and outer range are populated. Himalayan people are very resource-poor due to their remote environment, degraded infrastructure, socio–economic backwardness and low land holdings. Agriculture is their main occupation which is mainly rainfed depending entirely on mercy of rains. Rainfall is very uneven in time and space and due to lack of irrigation facilities they face the vagary of rain in the form of low yield. The north-east (NE) region gets more rainfall than the NW. Its average rainfall is from 1500 to 3500 mm per year from NW to NE. Rainfall is sufficient for crop production but due to steep terrain, surface run-off is very high. As a result, soil erosion is significant, so, their production is subsistence in nature. Under these circumstances, soil and water management is very necessary for irrigation, food security, and sustainable development. Water management in Himalayan agriculture system can be broadly divided into three categories as discussed in the following sections.

2. Development and Management of Hill Slope Farming

Hill slope farming depends entirely upon rainfall and snow melt. Hill slopes are highly suitable for horticulture. Various forms of micro-irrigation techniques are generally adopted for hill slope farming. They include tank irrigation, sprinkler irrigation, drip irrigation, bamboo irrigation, and snow harvesting, among others. In addition, water availability in that region can be increased by retention and detention of runoff generated from rainfall and then recharging to groundwater using various types of watershed management methods such as grass land development; forest land development; tree plantation; gully plugging; contour bunding; land terracing/leveling; semi-circular trenches; raising boundary of farm; plantation of trees on boundary of farm; and other methods of watershed management as per the site condition. Retaining runoff, recharging to groundwater, and then using for irrigation as and when needed help attain food security and also alleviate poverty in the hills.

In the hilly region, rejuvenation of springs is another approach for enhancing water availability. Himalayan settlements are located near or around the springs due to convenient access to water. The springs are gradually drying up due to human interventions as well as climate change. Watershed development by on-site harvesting of rainfall and off-site harvesting of runoff will help recharge groundwater that will rejuvenate the springs in the Himalayan region. Some of the approaches for rejuvenating the springs are discussed hereunder;

- Large-scale afforestation with meaningful involvement of local communities and forest department in the upper reaches of hill slopes may help reduce velocity of runoff water, increase retention time in the watershed, and hence facilitate enhanced infiltration and subsequent recharge of groundwater
- Improved farming practices such as contour bunding, contour trenching, leveling of fields and plantation of trees/bushes/shrubs/herbs/grasses on the farm may help enhance groundwater

recharge due to retention and detention of runoff water

- Construction of structures for retention and detention of river flows such as series of check-dams, sub-surface dykes and weirs/barrages along the flow path of natural streams/rivulets/rivers in the upper reaches of the hill slopes may help enhance groundwater recharge by means of off-site diffusion. The recharge water will flow as sub-surface water, intensify discharge of springs in the lower reaches, and hence helps revive the springs.
- Construction of filter drains to re-stabilize (in its original form) the exposed aquifers due to the cutting of hill sides during road construction
- Applying isotope techniques in identifying the recharge areas for reviving the springs. Analyzing oxygen and hydrogen isotopes of rainwater, spring water, and river water can help identify potential areas that recharge the spring of interest. Once recharge areas are identified, strategies for protecting them as well as enhancing recharge using various approaches can be applied.

3. Development and Management of River Valley Farming

Agricultural land in the river valley is generally located on both banks of the river. Irrigation of the river valley depends on rainfall as well as on runoff of the river. Abundant water is available in the river during monsoon season (July – September) but very little or inadequate during winter (December – February). We have to manage the water for irrigation during Kharif as well as Rabi seasons. For that following techniques are generally adopted;

- Construction of a series of head regulators for diverting water in gravity channels/ contour channels for irrigation of crops near river sites
- Construction of lift schemes for those areas which are not covered by gravity flow in river valley sites
- Construction of hydrum schemes in those areas of river valley where river slope/ gradient is very steep, providing high head over a short flow length

Head in the system can be increased by one or more of the following means:

- Constructing a series of weirs/ barrages in the streams/ rivers in hill regions as per site condition for off-season irrigation
- Construction of sub-surface dyke cum check dams for collecting sub-surface flow of water
- Construction of reservoirs/small dams

The hydrum irrigation is very useful for providing irrigation facility in remote areas of Himalayan regions, where agriculture productivity from fertile land is suffering due to inadequate irrigation facilities. The basic requirements of hydrum irrigation are high discharge (Q) and high head (H), which are readily available in Himalayan streams. There is no need of any external energy to run the hydrum. It converts its kinetic energy into potential energy and lifts the water from streams located at lower elevation to farms located at higher elevations. It can lift the water three-times higher than its available head (H) for which it is designed. It can run continuously round the clock without any external source of energy. We can directly irrigate our fields or store the water in tanks for other purposes. The remote areas of the Himalayan region are most suitable for hydrum irrigation due to the steep slope and high discharge of the streams where other mode of irrigation is very expensive. Its installation is very simple and economical, maintenance cost is very cheap, and it can be operated by any farmer and therefore no need of any operator or mechanic to run the system. The existing water mills in the area may also be converted into the hydrum systems with small modifications in water mills.

The Ramganga Valley in Uttrakhand state in India can be considered a success story of development and management of river valley in the Himalayan region. Irrigation in the valley has helped for better production of crops for food security, poverty alleviation, and rural development of the region. The Ramganga Valley is situated in Kumaon region of Uttrakhand state in NW zone of Indian Himalayan Region. This valley ranges from Gairsair area of Chamoli district up to Kalagarh area of Pauri district via Almora district of Kumaon region of Uttrakhand state. The study area is the Chaukhutia block of Almora district. This area ranges from upstream of Chaukhutia to downstream of Bhikhiyasen in Almora district. This area is approximately 50 km in length and on an average 1 km wide, which covers an area of approximately 50 km^2. Eight percent of the area is cultivated. Kharif and Rabi are the main crop seasons. Due to availability of plenty of water in Ramganga River, water for irrigation is harvested in Kharif as well as in Rabi seasons. A series of water harvesting structures are constructed to pond the water in the river bed. Dry bunds are constructed with the help of available stones in river and gabion bunds with the help of G.I. wire crates and masonry head work. This pond water is used as diffuse recharging of groundwater as well as diversion of water in gravity/contour channels for irrigation of crops. In the monsoon season when plenty of water is available and water has a large quantity of silt and clay, the fields are flooded with this water via gravity/contour channels and the silts and clays are deposited in the field by sedimentation methods which act as natural fertilizer. With the help of assured irrigation, people get high yield and they adopt intensive farming for better livelihood, rural employment and poverty alleviation. This ultimately contributes in minimizing migration of rural people from the hills region, which is considered as a major problem of this region. Diffused recharge techniques help in rejuvenation of springs located in the downstream reaches of the pond, which is used for drinking, domestic use and in cattle rearing by the local people. It is found that the productivity of crops is three times more than rainfed agriculture and there is no impact of drought or climate change. The area therefore has assured irrigation and does not need to worry about food security.

4. Development and Management of Foothills Agriculture

Foot hills are the main agricultural areas to feed the Himalayan people. Following three techniques are generally used to increase water availability in these areas.

- Sub-surface dyke cum check dams: Himalayan foothill regions have a large number of natural streams, which are seasonal in nature but have sub-surface water. By construction of sub-surface dyke cum check dams at suitable locations in the natural streams, we can check the flow of subsurface water and harvest this water as surface water/pond water. That will recharge the groundwater system of the area, enhances water availability for tube wells, and therefore contributes for better irrigation.
- Artesian wells: This region has a great scope for artisan wells, which can ensure better water supply for all purposes. There are a series of artisan wells in Terai area of Nainital district in India and in Kohalpur area of Nepalgunj in Nepal.
- Reservoirs: The foothill areas are suitable for construction of small reservoirs to store water for multi-purpose uses such as irrigation, fisheries and hydropower projects.

5. Conclusions

Key conclusions are;

- Soil water management is essential for providing irrigation services, and securing food and livelihoods of people in Himalayan watersheds that have typical characteristics.
- The Himalayan watersheds can have three typical types of agriculture systems (i.e., hill slope farming, river valley farming, and foothill farming) and different water management approaches are required for each system.
- Micro-irrigation techniques are typically suited for hill slope irrigation; whereas hydrum irrigation systems are suited for river valley irrigation; and development of weirs, barrages and reservoirs are suited for foothill farming.
- Various forms of watershed management approaches can help retain and detain surface runoff, recharge groundwater systems, and help rejuvenate spring sources that are drying up gradually in many Himalayan watersheds.

A foresight for flood disaster management in Pakistan

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Abstract

Despite many years of experience and highly developed techniques, flood continues to play havoc in most parts of the planet. The frequency of floods occurrence in the region in general and in Pakistan in particular has considerably increased since past several years, because of global warming and rapid climate change. Pakistan is a country with diverse type of land and fluctuating pattern of climate. A significant variation in climate is observed in Pakistan since the last few years. Many districts and urban centers located along the rivers banks are ever on a great risk to confront with various types of floods such as riverine flood, flash flood and urban floods particularly in Punjab and Sindh provinces in Pakistan. Floods occur usually in summer (July - October) and therefore damages mainly the standing Kharif crops; however, inundation of lands for a longer period sometime may affect sowing of Rabi crops too.

After the large-scale damages by 2010 floods followed by 2011 and 2012 floods/rains, the need for investment in flood sector has gained importance. Federal Flood Commission has initiated efforts to formulate National Flood Protection Plan-IV (2016-25) in close consultation with all federal and provincial stakeholders. The planning strategies for that is focused on integrated flood management planning putting more emphasis on the non-structural measures such as reservoir operations; flood forecasting and early warning; flood risk zoning; watershed management; flood proofing and insurance; and disaster management among others. However, considering the uniqueness of the Indus Basin with its large integrated network of dams, barrages and canals, which form the lifeline of agriculture economy of the country, protection of infrastructure and irrigated areas will continue to be a focus like in the earlier three Flood Protection Plans. The cost of the Plan including both structural and non-structural measures is estimated at Rs 177.61 Billion in the next five years. It is the need of the hour to implement the flood mitigation measures under National Flood Protection Plan in all the provinces and federal line agencies as a stitch in time saves nine.

Keywords: *climate change; disaster; flood management; Pakistan*

1. Introduction

Despite many years of experience and highly developed techniques, flood continues to play havoc in most parts of the planet even today. The frequency of occurrence of floods in the region in general and in Pakistan in particular has considerably increased since past several years, because of global warming and rapid climate change. That is why Pakistan has faced series of flood events since 2010. It indicates that flood has now become a regular feature in the country. This is exacerbated by the factors such as inadequate surface water storage capacity for absorbing flood peaks; chronic and increasing threat of encroachments in flood plains; inadequate discharge capacity of some of barrages/bridges; inadequate budget allocation under Public Sector Development Programme (PSDP) and Provincial Annual Development Plan (ADP) for execution of flood projects; weakness in flood defenses due to improper maintenance of existing flood protection structures; and importantly a distorted natural drainage network.

There is a lack of effective coordination among institutions involved in flood management, caused in part by limitations of technical capacities such as dissemination of early warning, disaster preparedness measures, emergency response and structural measures for flood mitigation. The local communities do not have adequate disaster preparedness information and there is lack of general awareness raising, sensitization and education of the masses regularly affected by floods, focusing especially on populations residing within the active flood plains along major, secondary and tertiary rivers.

The riverine floods are generally caused due to heavy concentrated rainfall in catchment areas of the mainstream and their tributaries, which are sometimes augmented by snowmelt due to high temperatures and generate exceptionally high flood flows in rivers across the country. The torrential rains are caused due to monsoon currents originating from Bay of Bengal and resultant depressions (strong weather system) often cause heavy downpour in the catchment areas of major rivers and their tributaries including hill torrents, which is sometimes augmented by the Westerly Wave from Mediterranean Sea.

2. The Nature of Flood Hazard

The riverine floods take hours or even days to develop, giving ample reaction time to locals to prepare/evacuate. However, flash floods generate quickly in mountainous regions with little warning/reaction time for locals. Flash floods can be extremely dangerous, instantly turning a babbling brook into a thundering wall of water and sweeping everything on its way downstream. Floods occur in all types of rivers and their tributaries. Localized flooding may be caused or exacerbated by drainage obstructions such as landslides, ice, debris, or dam failure. The increase in flow may be the result of sustained rainfall, rapid snow melting, monsoon/ depression (weather system) or tropical cyclones. Rapid flood events including flash floods, more often occur on smaller rivers, rivers with steep valleys or rivers that flow for much of their length over impermeable terrain. The cause may be localized convective precipitation (intense thunderstorms) or sudden release from an upstream impoundment created behind a dam, landslide or glacier.

Disaster experts classify floods according to their likelihood of occurring in a given time period. A hundred-year flood, for example, is an extremely large, destructive event that would theoretically be expected to happen only once every century. But this is a theoretical number. In reality, this classification means there is a one-percent chance that such a flood could happen in any given year. Over recent decades, possibly due to global climate change, hundred-year floods have been occurring worldwide with frightening regularity.

Climate change is considered to be a critical global challenge and recurring flood events have demonstrated growing vulnerability to climate change. The impacts of climate change range from affecting agriculture

to further endangering food security, rising sea levels, accelerating erosion of coastal zones, increasing intensity of natural disasters (e.g., floods and droughts), endangering of species extinction, and spreading of vector-borne diseases.

It is generally recognized that complete prevention from floods is humanly impossible, but protection from floods is feasible and is a vital necessity. By proper planning, means can be devised to harness the fury of floods to safeguard human life and property. Floods with devoid power can be used in the service and the welfare of a community.

3. Floods in Pakistan

Pakistan is a country with diverse type of land and fluctuating pattern of climate. Climate is usually considered hot and dry in Pakistan but it has shown significant obvious variations in the last few years. Many districts and urban centers located along the river banks are ever on a great risk to confront with various types of floods such as riverine flood, flash flood and urban flood particularly in Punjab and Sindh provinces. Floods cause damages to a large swath of fertile agricultural lands, standing crops and affect adjoining abadies with monetary loss in billions of rupees.

The riverine floods are generally caused due to heavy concentrated rainfall in the river catchments, during monsoon season, which is sometimes augmented by snowmelt flows. Monsoon currents originating from Bay of Bengal and resultant depressions (weather system) often result in heavy downpour in the Himalayan foothills, which occasionally generate destructive floods in the main rivers and their tributaries. Sometimes exceptionally high flood flows in major rivers are generated due to formation of temporary natural dams by landslide or glacier movement and their subsequent collapse. Flooding of the Indus River and its tributaries represents the greatest hazard in Pakistan. Floods occur usually in summer season (July - October), therefore damages to agriculture sector are mainly to the standing Kharif crops. However, in some cases the inundated lands do not dry up in time and ultimately affects sowing of Rabi crops too.

The major rivers (Indus, Jhelum, Chenab, Ravi, Sutlej) and secondary rivers (Kabul, Swat, etc.) cause flood losses by inundating low lying areas around the rivers and subsequently damaging irrigation and communication network besides land erosion along the rivers banks. In the upper part of the Indus Basin (Punjab and Khyber Pakhtunkhwa), floodwater spilling over the high banks of the rivers generally turns back to the main rivers channel. In the lower parts of the country, i.e. Lower Indus Basin (Sindh province), River Indus is flows along the ridge, that is at higher elevation than the adjoining land. That is why flood embankments have been provided along both sides of the river. In case of a breach, the flood water does not return to the main river channel. This largely extends the area and period of inundation resulting in more damages to abadies, standing crops, and other private and public infrastructure.

4. History of Flood Events in Pakistan

So far, Pakistan has faced 24 severe historical flood events. They are floods of 1950, 1955, 1956, 1957, 1959, 1973, 1975, 1976, 1977, 1978, 19981, 1983, 1984, 1988, 1992, 1994, 1995, 2010, 2011, 2012, 2013, 2014, 2015 and 2016. The 2010 flood was the worst ever in the country. The floods of various magnitudes since 1950 to 2016 affected vast areas in the four provinces including Gilgit-Baltistan, FATA and Azad Jammu and Kashmir. Owing to adverse impacts of climate change, in the recent years, vulnerabilities of communities to coastal and urban flooding have also increased. Flood damages are caused mainly due to riverine flooding in main rivers and flash floods in secondary and tertiary rivers/hill; torrents, coastal

flooding due to cyclone; and urban flooding due to torrential rains and inadequate storm drainage facilities, besides glacial lake outburst floods (GLOFs) in the northern parts of the country.

The unprecedented flood of 2010 was the worst in the history of the country in which about 1,985 people lost their lives, 1.6 million houses were damaged/destroyed, and 17,553 villages with an area of 160,000 km^2 was affected. The Sindh province, particularly southeastern parts of the province was severely affected due to unprecedented rains and inadequate drainage facilities during the monsoon season of 2011. The 2012 rains/floods affected a total area of 4,746 km^2 in Southern Punjab, Sindh and Balochistan provinces. About 571 people lost their lives, 636,438 houses were damaged/destroyed and 14,159 villages were affected. There were about 333 casualties during 2013 rains/floods, with around 8,297 villages being affected, the total inundated area being around 4,483 km^2. The floods of 2014 affected cropped area of about 2.415 million acres (9,779 km^2) inundating 4,065 villages, claiming about 367 lives, fully damaging 107,102 houses and directly impacting a population of about 2.600 million. The 2015 floods affected more than 1,933 million inhabitants, 4,634 villages (damaging 10,716 houses) and claiming about 238 lives all over the country. Flood flows triggered by torrential rains affected various parts of country, especially Chitral valley in Khyber Pakhtunkhwa, Punjab, Balochistan and some parts of Sindh & Federally Administered Areas (Gilgit-Baltistan, FATA and AJK (Azad Jammu and Kashmir Areas of Pakistan)) The 2016-rains/ floods affected 43 villages, claiming 153 lives, 113 injured and damaging 1452 houses. Pakistan has suffered a cumulative financial loss of more than US$ 38.171 billion during the past seventy years. Around 12,502 people lost their lives, some 197,273 villages damaged/destroyed and an area more than 616,598 km^2 was affected due to major flood events. The historical flood events experienced in the past and their damages are given in the Table 1.

Table 1: *Historical flood events in Pakistan (Source: Federal Flood Commission of Pakistan)*

SN	Year	Direct losses (US$ million)	Lost lives (No)	Affected villages (No)	Flooded area (km^2)
1	1950	488	2,190	10,000	17,920
2	1955	378	679	6,945	20,480
3	1956	318	160	11,609	74,406
4	1957	301	83	4,498	16,003
5	1959	234	88	3,902	10,424
6	1973	5134	474	9,719	41,472
7	1975	684	126	8,628	34,931
8	1976	3485	425	18,390	81,920
9	1977	338	848	2,185	4,657
10	1978	2227	393	9,199	30,597
11	1981	299	82	2,071	4,191
12	1983	135	39	643	1,882
13	1984	75	42	251	1,093
14	1988	858	508	100	6,144

15	1992	3010	1,008	13,208	38,758
16	1994	843	431	1,622	5,568
17	1995	376	591	6,852	16,686
18	2010	10,000	1,985	17,553	160,000
19	2011	3730	516	38,700	27,581
20	2012	2640	571	14,159	4,746
21	2013	2,000	333	8,297	4,483
22	2014	440	367	4,065	9,779
23	2015	170	238	4,634	2,877
24	**2016**	**6**	**153**	**43**	-
25	**2017**	**-**	**172**	**-**	-
Total	**38,171**	**12,502**	**197,273**	**616,598**	

5. Flood Control Planning in Pakistan

Flood management planning in Pakistan is being carried out to essentially cover the following three specific objectives:

- To reduce or eliminate damages to existing properties;
- To prevent future increase in damages; and
- To mitigate the residual hazards.

In Pakistan, flood control planning is a complex problem and calls for great ingenuity and experience on the part of the planners. The nature of flood problems varies in each of the four provinces and federally administered areas due to varying physiographic, climatic, demographic, and socio-economic conditions. Even the characteristics of catchment areas of various rivers differ from each other. Flood problems related to various provinces are given as under:

Punjab: In Punjab, the flood protection marginal bunds have been generally constructed either to protect the headworks and other irrigation structures, or to safeguard certain towns, villages and adjoining agricultural lands. Due to general topography of the area, pre-determined breaching sections have been provided in the Right Marginal Bunds (RMBs) for operation for safety of headwork/barrages in case of exceptional high flood flows i.e. likely to exceed the designed level. In order to protect areas from erosion, spurs have been constructed in critical reaches. These spurs have protected vast areas and, in some cases, even large tracks of eroded lands have been reclaimed.

Sindh: The Indus River flows along a ridge in the Sindh Province and generally in surrounding areas (outside the flood embankments) are lower than the river bed. Hence, water once leaving the Indus River does not return to the main channel. The escaped water thus causes greater damage to widespread areas, and it persists for a longer period even after flood peaks are over. Sindh province is situated at the tail end, therefore, drains out all rivers. If flood protection measures adopted in the upper Sindh are not properly planned, severe damages are likely to occur in the province. In most of the reaches, a

double line of flood embankments has been constructed on both sides of the river from Guddu to a few kilometers short of Arabian Sea. These flood embankments have been further compartmentalized to contain widespread inundation.

Khyber Pakhtunkhwa: In Khyber Pakhtunkhwa, flash floods in the secondary rivers (Kabul, Swat, Panjkora, Kurram, etc.) are frequent and major hill torrents/flood flow generating nullahs having steep bed slopes greatly increase flood velocity and severely erode the banks. In Khyber Pakhtunkhwa, most flood protection walls/ embankments and short spurs have been constructed to save the areas from spill action and erosion. Around 40 spurs having considerable shank length and marginal bund have been constructed along the right bank of Indus River "Chashma Barrage – Ramak Reach" for protection of D.I. Khan City and adjoining area from devastating flood flows of Indus River. A large number of spurs and flood embankments/flood protection walls in critical locations have also been constructed along Kabul, Swat, Panjkora, and Kurram rivers and their tributaries including flood flows generating nullahs/ hill torrents.

Balochistan: Due to peculiar physiographic and climatic characterizes in Balochistan, the bed slopes of rivers and nullahs in this area are very steep; hence, generate flash flood flows with high velocity causing banks erosion and inundations of floodplains and low lying areas. Mostly flood protection walls/ embankments and short spurs have been constructed for protection of orchards, agricultural lands and abadies. Flood flows regulators/ flood diversion structures have also been constructed to dissipate the thrust of flood water and use the same for agriculture in the area.

Gilgit-Baltistan, FATA and AJK: The bed slopes of rivers and nullahs in Gilgit-Baltistan, FATA and AJK are very steep. The flash flood flows generated in main rivers and their tributaries cause severe banks erosion. Flood protection walls and short spurs in plain cement concrete (PCC) and gabion crates are constructed in order to check the spill and erosive action of flood flows in rivers/hill torrents. The main purpose of such interventions is to provide protection to abadies, agricultural lands and other private and infrastructure. Existing flood protection facilities are summarized in Table 2.

Table 2: *Existing flood protection infrastructures in Pakistan*

SN	Provinces / Federal Line Agencies	No. of Protection Works
1	Punjab	1,185
2	Sindh	261
3	Khyber Pakhtunkhwa	784
4	Balochistan	260
5	Gilgit-Baltistan	30
6	FATA	209
7	AJK	13
	Grand Total	**2,742**

6. Impact of Climate Change on Flood Management

Global warming causes climate change, which is a serious issue for the entire world. It is a serious threat to the third world as its impacts will not be felt equally across our planet. Developing countries including Pakistan are much more vulnerable to the impacts of climate change. The melting rate of glaciers in South Asia has increased, which may cause floods in Pakistan and surrounding countries in the coming years. Pakistan's economy has faced significant losses due to environmental damages and degradations.

Pakistan is amongst the top ten countries on the globe experiencing frequent and intense climatic events such as floods, droughts, cyclones, heavy rains, extremely high temperatures, etc. The average global temperature has increased due to increasing concentrations of carbon dioxide and other greenhouse gases in the atmosphere for many years. During the last century, it increased by 0.6°C and is likely to increase further by 1.0°C to 4.0°C till the end of this century.

The most recent extreme climatic events witnessed by Pakistan are frequent floods hitting various parts of the country during the monsoon season. Pakistan has experienced flooding almost every year since 2010 which has caused huge damages to life and property. Water security of the country is also threatened by climate change. Increasing temperatures in the northern mountains of the country are likely to result in glacier melting, thereby affecting the flows of Indus River System.

7. Integrated Approach in Flood Management

Flood management plays an important role in protecting people and their socio-economic activities in floodplains from flooding. The development in the river basins has been closely linked with successful implementation of flood control projects. In the past, exposure to flood risks has been handled largely through structural measures. However, strategies that rely largely on structural solutions unfortunately alter the natural environment of the river, which may result in loss of habitats, biological diversity and ecosystem productivity.

Further, structural approaches are bound to fail the moment an extraordinary or unforeseen event occurs. These traditional approaches, where the risks are merely transferred spatially, are likely to generate conflicts and inequities. Environmental degradation has the potential to threaten human security, including life and livelihoods, and food and health security. This realization has recently led to calls for a paradigm shift from traditional flood management to integrated flood management (IFM). The IFM is a concept that addresses issues of human security against flood risks and sustainable development within the framework of Integrated Water Resources Management (IWRM). Such an integrated approach to flood management can play an important role in sustainable development and poverty reduction. The IFM aims at minimizing loss of life from flooding while maximizing the net benefits derived from flood plains.

8. Floods and the Development Process

Historically, floodplains have been the preferred places for socio-economic activities as is evident from the very high densities of human settlement found there. Floods are a natural phenomenon, with both negative and positive impacts and generally should not be considered as a hindrance to economic development. Floods play a major role in replenishing wetlands, recharging groundwater and support agriculture and fisheries system, making flood plains preferred areas for human settlements and economic activities. Extreme demands on natural resources due to population growth have forced people and their

property to move closer to rivers in many parts of the world. Further, flood control and protection measures have encouraged people to utilize newly protected areas extensively, thereby increasing flood risks and consequent losses.

Recurrent and extreme flooding, however, pose grave risks to development and have negative impacts on lives, livelihoods and economic activity and can cause occasional disasters. Flood disasters result from the interaction between extreme hydrological events and environmental, social and economic processes. These disasters have the potential to put development back by five to ten years, particularly in developing countries. The spiraling economic losses in developed countries also have given rise to grave concerns.

The balancing of development needs and risks is essential. The evidence worldwide is that people will not, and in certain circumstances, cannot abandon flood-prone areas. There is a need, therefore, to find ways of making life sustainable in the floodplains. The best approach is to manage floods in an integrated manner.

9. National Flood Protection Plan - IV

Since its establishment, Federal Flood Commission (FFC) has so far prepared and executed three National Flood Protection Plans: National Flood Protection Plan-I (1978-88), Plan-II (1988-1998), and Plan-III (1998-2008) through Provincial Irrigation Departments and Federal Line Agencies. After the large-scale damages as a result of 2010 floods followed by 2011 and 2012-floods/rains, the need for investment in flood sector has gained importance. The FFC has initiated works on formulation of National Flood Protection Plan-IV (2016-25) in May 2013. The plan has been prepared in close consultation with all federal as well as provincial stakeholders. The planning strategy for development of National Flood Protection Plan-IV, in line with the current practices worldwide, is focused on integrated flood management planning laying more emphasis on the non-structural measures, such as;

- Reservoir operations
- Flood forecasting and early warning
- Flood risk zoning
- Watershed management
- Flood proofing and insurance
- Disaster management and other measures

However, considering the uniqueness of the Indus Basin with its large integrated network of dams, barrages and canals, which form the lifeline of agriculture economy of the country, the protection of this infrastructure as well as the irrigated area is focused on the Plan-IV too like in the earlier three Flood Protection Plans. The new plan has not ignored the maintenance, up-gradation and in some cases new construction especially in light of 2010 floods. The estimated cost of the Plan with category-wise breakdown into structural and non-structural measures is Rs 177.61 Billion. The cost provides for -

i- Rehabilitation and enhancement of flood passing capacity of barrages and bridges

ii- Restoration of adequate conveyance capacity within the river and urban channels by removing bottle necks and encroachments

iii- Up-gradation of Flood Early Warning System (FEWS-Pakistan) for inclusion of

  a- Catchment area upstream of Tarbela dam,

  b- Updated existing river and floodplain geometry,

c- Study on Radar calibrations,

d- Enhancement in reliability of Quantitative Precipitation Forecast (QPF) through meteorological studies to enhance lead time, and

e- Training of PMD professionals

iv- Expansion and up-gradation of existing gauging network, Radar network, telemetry network under PMD and WAPDA.

v- Repairing, strengthening and up-gradation of existing flood protection works

vi- Operation and Maintenance (O&M) of existing flood infrastructure

vii- Comprehensive studies for all existing breaching sections to ascertain their effectiveness and possible flow paths, flow depths, velocities and inundation extents of breach flood flows

viii- Formulation and implementation of watershed management policy for re-forestation, soil conservation and improvement in land use in the watersheds by undertaking necessary legislation at national level as well as provincial level

ix- A draft "River Act" for the rivers flood plains has been formulated during current NFPP-IV studies keeping relevant stakeholders on board for removing encroachments, permanent settlements and undue developments in the floodplains so that flood damages can be reduced

x- Capacity building and training of FFC, PIDs, NDMA, PDMAs, and other relevant agencies.

Category-wise summary for cost of structural and non-structural measures is presented in Table 3:

Table 3: *Flood protection measures (structural and non-structural) under National Flood Protection Plan-IV*

Description		Cost in Million Rupees
Non-structural Measures		
1.	Up-gradation & Expansion in Existing Flood Forecasting and Warning System of PMD	4,205
2.	Up-gradation, Installation & Expansion in Existing Gauging System of WAPDA.	2,297
3.	Study to be conducted for removal of Encroachments in major Rivers & Hill Torrents and Procurement of LiDAR's.	800
4.	Study and Implementation Cost of Development of Watershed Management in Upper Catchment Areas of Rivers & Hill Torrents.	4,500
5.	Disaster Management Activities by NDMA, Rescue and Relief.	6,500
6.	Feasibility/Technical Studies for Ramsar Sites	30
7.	Capacity Building for All Institutions Dealing with Flood Management in the Country.	1,380
Sub-Total		**20,012 (175 Million USD)**

Structural Measures		
1.	Completion of on-going Project/Liability	751
2.	Construction of Proposed Flood Protection Works	90,992
3.	Flood Management Structures Across Hill Torrents and Flood Generating Nullahs	26,371
4.	Feasibility & Detailed Design Studies of Barrages and Hydraulic Structures.	1,500
5.	Master Planning, Feasibility Studies, and Detailed Designing Studies.	3,000
6.	Physical Hydraulic Model Study for Major Railway Bridges and Improvements of Existing Flood Protection Facilities of Pakistan Railway.	450
7.	Physical Hydraulic Model Study for Selected Reaches of Major Rivers.	200
8.	Measures for GLOFs & Land Sliding in Hilly Areas.	1,000
9.	Remodeling & Proper Maintenance of Drainage System.	9,763
10.	Coastal Flood Protection Works.	1,622
11.	Flood Mitigation, Channelization and Execution of the Lai Nullah Project (Only Flood Component).	16,000
12.	Studies for Proper Town Planning in Future and Improving the Existing storm Drainage System of Urban Areas.	1,000
13.	Provision of Annual Funds under Provincial ADPs for Flood Fighting	5,000
Sub-Total		**157,649 (1400 Million USD)**

10. Conclusions

It is the need of the hour to implement flood mitigation measures under National Flood Protection Plan in all the provinces and federal line agencies as a stitch in time saves nine. Major benefits of the plan implementation are;

- Integrated flood management on country wide basis to ensure no adverse effects on upper/ lower riparian.
- Improved flood forecasting & warning system through models, radars and telemetry network.
- Reduction in damages through flood plain regulations.
- Significant improvement in relief and rescue operations.
- Flood reduction through watershed management.
- Reduction in flash flooding through management of hill torrents.
- Capacity building and institutional strengthening

Groundwater reservoir as a source of flood water storage: A case study from Punjab, Pakistan

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Abstract

Pakistan is the fourth largest user of groundwater in the world after India, USA and China, where groundwater is playing a vital role in the economy of the country and underpins the food security. In Punjab province of Pakistan groundwater has attained a significant potential in the national economy by contributing about 50% in cropwater requirements through 1.2 million tubewells installed by farmers. This has led to tremendous increase in cropping intensity from 67% to more than 150% during the last six decades. Besides this, groundwater is catering for more than 95% water requirements of industrial and domestic sectors as well. Ever increasing and unscientific use of groundwater has overburdened this finite natural resource resulting in extra financial pressure on the end users especially the small farmers at grassroot levels. Climate change is resulting in rise in frequency and intensity of extreme weather events such as cloudburst, floods and droughts, which have become a major threat for irrigated agriculture in developing countries putting livelihood of a multitude of tiny farming communities on risk. Groundwater quality and levels are changing abnormally due to these events, which subsequently cause water and land degradation, waterlogging and salinity, and spatial and temporal uncertainty in water availability, among others. Impacts of floods on irrigation network, society, economy and environment have been investigated intensively worldwide, however impacts of floods on regional shallow groundwater levels and quality are recorded and documented randomly. Punjab Irrigation Department has installed a network of piezometers to monitor the groundwater in the province. Impact of 2014-flood on groundwater has been evaluated in Rechna and Chaj Doabs (land between two rivers) in Punjab Province. Results have indicated that 0.77 ft. and 2.57 ft rise in water table in Chaj and Rechna Doabs, respectively. Volume of water recharged to aquifer has been estimated at 1.20 Million-Acre-Feet (MAF) and 1.90 MAF in Chaj and Rechna Doabs, respectively. Further potential of diversion and storage of flood water in both aquifers has been evaluated as 4 MAF and 14 MAF in Chaj and Rechna Doabs, respectively. It has been concluded that besides huge damages, floods are sources of groundwater recharge and artificial recharge can be opted as one of the flood mitigation measures.

Keywords: *flood; groundwater; Pakistan; Punjab; recharge*

1. Background

Agriculture is the single largest sector of Pakistan's economy contributing to about 21.8% of the Gross Domestic Product (GDP), and is the source of earning of 45% of the total employed manpower of the country. However, the potential of agricultural production and to bring more area under cultivation depends on availability of water. Whereas water is not evenly distributed over the year, due to large seasonal variations, droughts and floods create extreme situations. World population is expected to increase by 45% in the next thirty years. Groundwater is the world's most extracted raw material with withdrawal rates currently in the estimated range of 982 km3/year. Out of total earth's water, 99% is unusable for human beings while only 1 % is usable. Out of this usable (1%), 99% comes from groundwater while nearly 1 % world's groundwater is fresh and is accessible for consumption. Pakistan is the fourth largest user of groundwater after India, USA and China. Pakistan is blessed with plenty of water resources including a large groundwater reservoir underlying the Indus Basin. The extent of this large and highly transmissive aquifer is about 297,200 km2 with a length of 1,900 km. This natural resource is under serious threats and needs immediate measures for its sustainable utilization. In Pakistan, over 90% drinking water and almost 100% industrial water comes from groundwater. Groundwater has helped in increasing cropping intensity from 60% in 1947 to 150% or even more in 2015. Current per capita water availability (1200 m3/person) in Pakistan is low, which puts it in the category of high water stressed countries on the globe. UNESCO has predicted that by 2020 water shortage will be a serious worldwide problem. Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050 (WWAP, 2012). Groundwater quality depends on the climatic parameters, nature of the surface flow, topography, extent of seepage and irrigation with amendment practices. Groundwater in the Indus Basin contributes around 35% to the total water available for agriculture and water quality of the 60% area is marginal to brackish (World Bank, 1997; Ahmad and Rashida, 2001).

Pakistan is the eighth largest food producing country and economy heavily relying on agriculture sector which accounts for a quarter of its GDP and employs two-fifths of total labor force. The agriculture mainly depends on the Indus River System (IRS) for 90% of its irrigation needs, which is also a source of 30% of energy generation of the country. Pakistan's agricultural performance is closely linked with the supply of irrigation water. This natural resource is being utilized for drinking, agricultural, industrial, livestock, commercial and other uses and is continuously under threat. The other most obvious uses of water for people are drinking, cooking, bathing, cleaning, and for some watering family food plots. Irrigated agriculture contributes to over 90% of Pakistan's food production. Agriculture sector generates over 60% of foreign exchange. It is the second largest sector, accounting for over 22% of GDP, and remains by and far the largest employer, absorbing 45% of the country's total labor force. Around 63% of country's population living in rural areas is indirectly or directly linked with this sector for their livelihood. While on the other, it is a large market for industrial products such as fertilizer, pesticides, tractors and agricultural implements. According to Kaldor's (1978)'s two-sector model, agricultural and industrial sectors supply inputs to each other and provide market for their outputs but differ in a number of ways. The agricultural sector has disguised unemployment and produces consumer goods for competitive markets, while industrial sector produces investment goods which are sold in imperfectly competitive markets at mark-up prices. According to Duranton (1998), in order to transform from agriculture sector to industrial sector, a significant increase in the agricultural sector productivity is necessary. On the demand-side, the growth in agricultural production increases agricultural income which leads to increase in the demand for industrial products; whereas on the supply side, the increase

in the agricultural productivity shifts human resources from the agricultural to the industrial sector (Jorgenson, 1967). Chebbi (2010) evaluated the role of agriculture in economic growth and dealings with other sectors. Johansen's multivariate approach has been used to study the co-integration with the other sectors in its country economy and he deeply analysed how to overcome the problems of spurious regression.

The annual groundwater pumpage has increased from 4 billion m3 in 1959 to around 60 billion m3 in 1999-2000. About 79 % area in Punjab and 28% area in Sindh provinces has fresh groundwater suitable for agriculture (Afzal, 1999; Bhutta, 1999). In Punjab province, about 40-50% cropwater requirements are being met from groundwater through about 1.2 million tubewells installed by the farmers. Groundwater quality in the Punjab province is deteriorating with the passage of time and sweet water is becoming rare and out of reach of the common farmers who are dependent on groundwater for their livelihood. (Hassan et al, 2014).

The Indus Basin Irrigation System (IBIS) is the largest integrated irrigation system in the World. Historically IBIS has been fed through run-of-river supplies derived from Indus and its five major tributaries. For supplying water to Pakistan's irrigation network (the largest man-made canal system in the world), the Indus Basin Project (IBP) was designed and constructed to replace the waters of Eastern Rivers. Any reduction in those waters will put Pakistan's agriculture, food security and economy at great risk. Hassan et al (2013) during a study found that pollution in surface water bodies is affecting the groundwater quality in the underlying aquifer in Lahore city. They recommended to allow/arrange minimum flow in the river at least to meet the requirements of dilution of pollutants and to treat the wastewater before releasing it. Domestic and industrial effluents contain organic and inorganic pollutants, which deeply percolate to groundwater. Flow in Ravi River especially during the winter is remarkably insufficient to dilute and wash off wastewater pollution (Hassan et al, 2016). Pakistan is bestowed with a largest contiguous irrigation canal network, major part of which lies in Punjab Province. This network was started to be constructed by British during the early nineteenth century. The continuous expansion of the irrigation system over the past century significantly altered the hydrological balance of the Indus River Basin (IRB) in Pakistan (Hassan and Bhutta, 1996). This also posed severe impacts on aquifer equilibrium. Thus, the economy of Pakistan is agri-based for which water resources are required on sustainable basis to feed the ever increasing population of the country.

2. Experimental Setup and Study Area

For monitoring of groundwater levels about 3000 piezometers have been installed at different location scattered throughout the Punjab province as depicted in Fig. 1. This paper presents the results of different research studies carried out by IRI in the irrigated areas of Punjab in Pakistan. Two areas i.e. Chaj Doab (land between Jhelum and Chenab River) and Rechna Doab (land between Chenab and Ravi rivers) have been selected for evaluating the impact of 2014-flood on groundwater reservoir and potential of flood water storage in both areas has also been estimated. Location of IBIS in Pakistan showing the study areas is shown in Fig. 1 while map of piezometers in Punjab province is shown in Fig. 1-A.

Figure 1: *Indus Basin Irrigation System and location of study areas.*

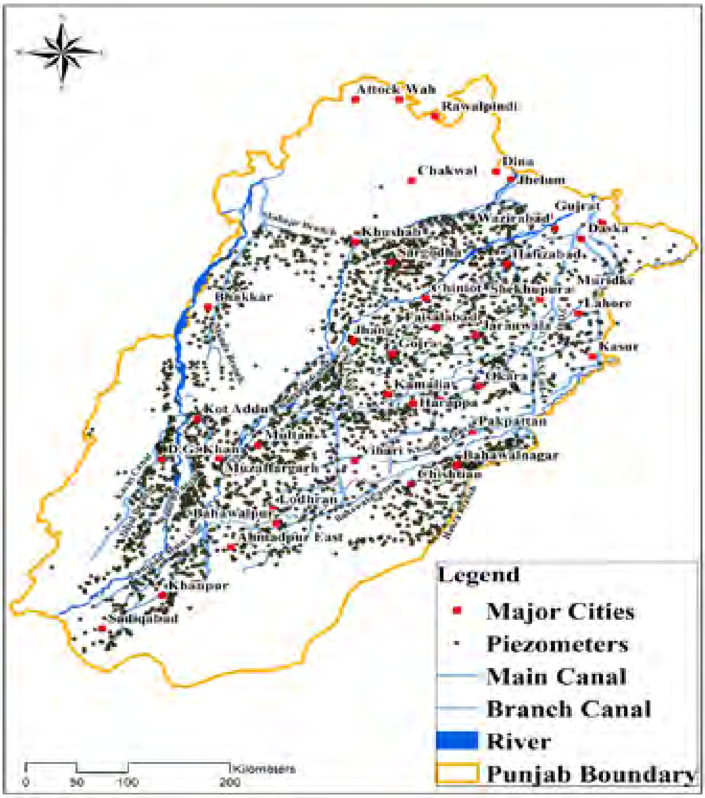

Figure 1-A: *Network of piezometers in Punjab province*

Groundwater levels have been measured using water level indicator from the piezometers biannually (pre-monsoon and post-monsoon). The observed data has been analysed to visualize and evaluate the aquifer behaviour in the study area. IRI (2009) and IRI (2013) conducted a field survey and investigation

study by installation of sixty exploratory boreholes in the field at various critical sites in Punjab to explorer the groundwater quality and soil stratification to observe the impact of surface water bodies and other potential threats for groundwater. It was observed that surface water bodies especially drains are playing a vital role in contamination of groundwater. A study was conducted for groundwater investigation in Faisalabad area (Rechan Doab) using MODFLOW, a groundwater model, where tile drainage and surface drainage networks are functional and groundwater is brackish for which one of the causes is heavy industrial pollution in the area (IRI, 2012).

3. Groundwater Recharge in Chaj Doab

The Chenab and Jhelum rivers bound the wedge-shaped area called "Chaj Doab". The flows of the Chenab and Jhelum rivers are regulated at four major head works to ensure adequate irrigation supplies to the Chaj Doab area and other areas of the Indus Basin. Map of Chaj Doab showing Irrigation network is shown in Fig. 2.

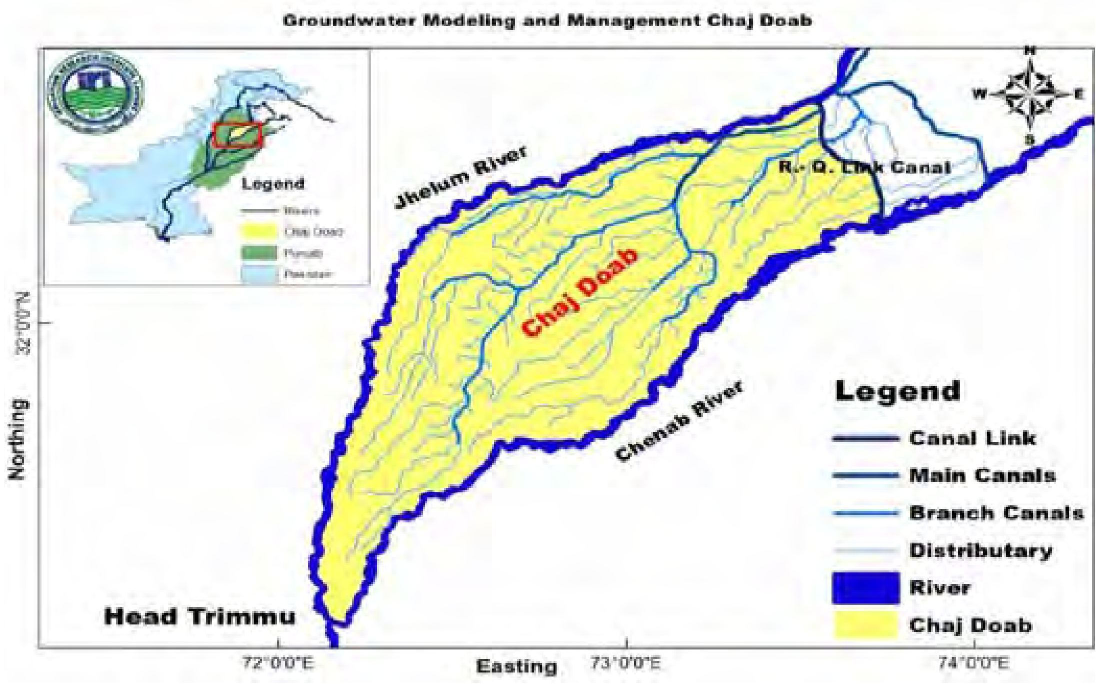

Figure 2: Irrigation network in Chaj Doab

Data observed from piezometers in Chaj Doab have been analysed to study the behaviour of aquifer. Different watertable depth ranges in Chaj Doab during October 2010 are given in Table 1 and groundwater recharge potential during October 2010 is given in Table 2. Different ranges of depth to watertable in Chaj Doab during October 2010 are plotted Fig. 3.

Table 1: *Different water table depth ranges in Chaj Doab during October. 2010*

Depth to Water Table Ranges (m)	Area		
	Acres	**Hectares**	**%**
< 1.5	303,580	122,907	8.80
1.5 – 3	834,823	337,985	24.21
3 – 6	1,420,871	575,251	41.20
6 – 9	760,020	307,700	22.04
9 – 13	128,489	520,20	3.73
13 – 18	882	357	0.03
>18			
Total Area	**3,448,665**	**1396221**	**100**

Table 2: *Groundwater recharge potential in Chaj Doab during October 2010*

Available potential for water **depth to be recharged (m)**	**Area**		**Specific yield**	**Volume of water (ha.m)**
	(ha)	(acre)		
1.5	575,251.4	1,420,871	0.2	172,575.4
4.5	307,700.4	760,020	0.2	276,930.4
8	52,019.8	128,489	0.2	83,231.7
12.5	357.1	882	0.2	892.7
Total Volume of Water which can be stored Hectare Meter (ha.m)				**533,630.2**
Million Hectare Meter (MHM)				0.53
Million Acre Feet (MAF)				4.32

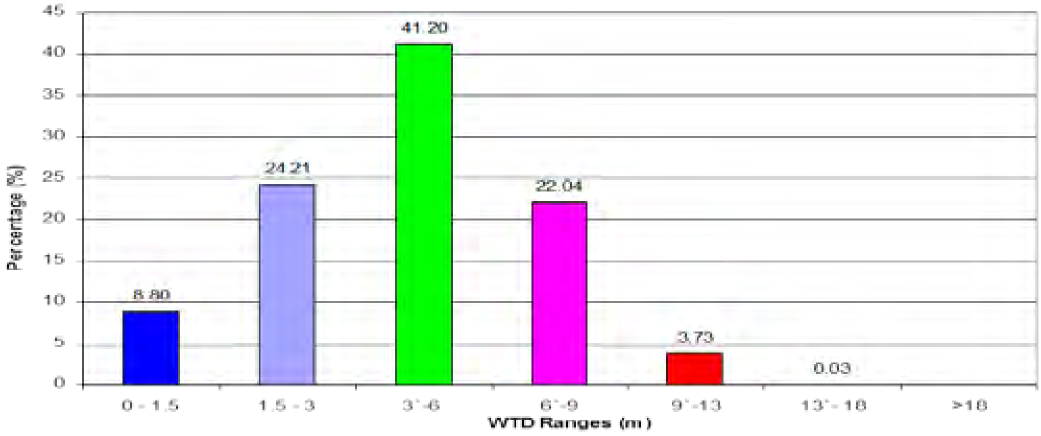

Figure 3: *Area under different depths to water table in Chaj Doab during October, 2010*

Watertable depth ranges of Chaj Doab during June 2012 is given in Table 3 and area (%) under different depth ranges in Fig. 4. Recharge potential in irrigated areas during June 2012 is given in Table 4.

Table 3: *Water table depth ranges of Chaj Doab during June 2012*

WTD Ranges (m)	Area			Classified as
	(Acres)	**(ha)**	**(%)**	
0 - 1.5	57,103	23,118.6	1.7	Waterlogged
1.5 – 3	809,235	327,625.5	23.5	Likely to be Waterlogged
3 – 6	1,663,234	673,374.1	48.2	Normal
6 – 9	781,698	316,476.9	22.7	Normal
9 -13	133,889	54,206.1	3.9	Likely to be depleted
13 -18	3,506	1,419.4	0.1	Depleted
> 18				Highly Depleted
Total	**3,448,665**	**1,396,221**	**100.0**	

Losses from irrigation system are the major sources of aquifer recharge in the irrigated areas. IRI conducted 24 seepage tests on 21 channels (distributaries and minors) in Lower Jhelum Canal (LJC) system in Chaj Doab. Seepage rate calculated through inflow outflow method on the specified locations were in the range from 1.183 to 13.293 (cfs/msf) (IRI, 1996). IRI also conducted 37 seepage tests on 25 channels (distributaries and minors) in the declared saline zone of Lower Jhelum canal (LJC) circle in Chaj Doab. Average seepage rate calculated through ponding test method on the specified locations were in the range from 0.669 to 6.874 (cfs/msf) (IRI, 1998). Flood water is another major source which contributes significantly towards recharging the aquifer.

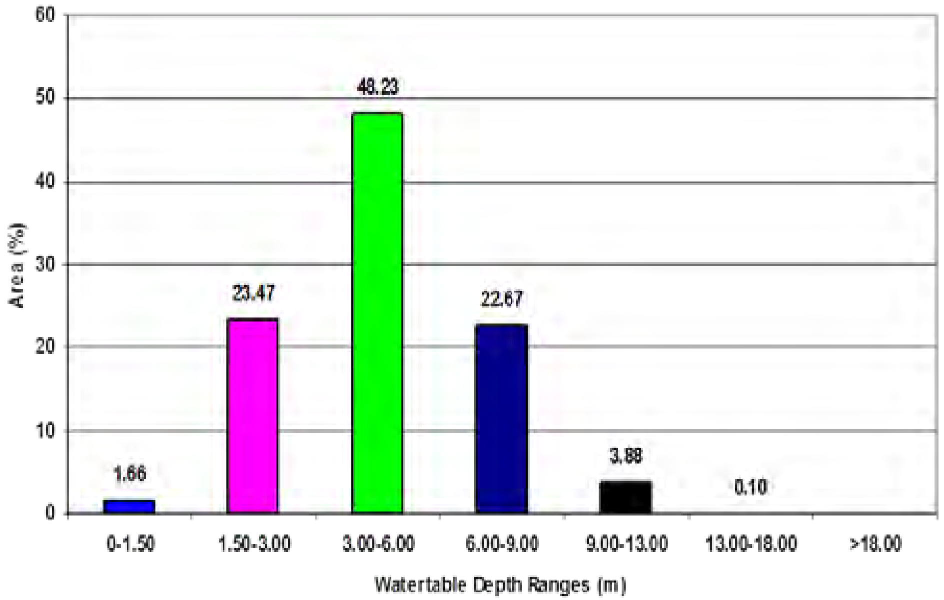

Figure 4: *Area under different depth to watertable ranges in Chaj Doab during June 2012*

Table 4: *Recharge potential in irrigated areas of Chaj Doab during June 2012*

Available potential for water depth to be recharged (m)	Area		Specific yield	Volume of water (ha.m)
	(ha)	(acre)		
1.5	673,374.1	1,663,234	0.2	202,012.2
4.5	316,476.9	781,698	0.2	284,829.2
8	54,206.1	133,889	0.2	86,729.7
12.5	1,409.7	3,482	0.2	3,524.3
Total Volume of Water Hectare Meter (ha.m)				577,095.5
Million hectare meter (MHM)				0.58
Million Acre Feet (MAF)				4.68

The depth of groundwater table between 5 and 10 feet is very important not only for agricultural produce, but it also changes the soil salinity and the soil moisture. The seasonal changes for Rabi seasons after monsoon makes large areas unfit for sowing and growth of winter crops. Location of installed piezometers in Chaj Doab is shown in Fig. 5.

Depth to watertable data at fifteen selected points in Chaj Doab over the period of 2011-15 has been plotted to depict the fluctuations of groundwater levels which have been shown in Fig.s 6 and 7.

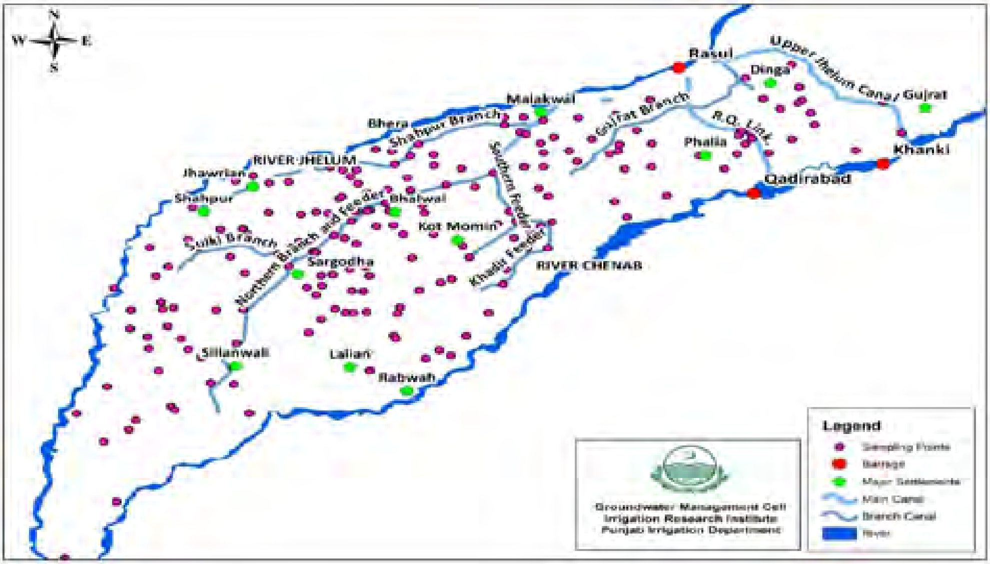

Figure 5: *Location of Piezometers in Chaj Doab*

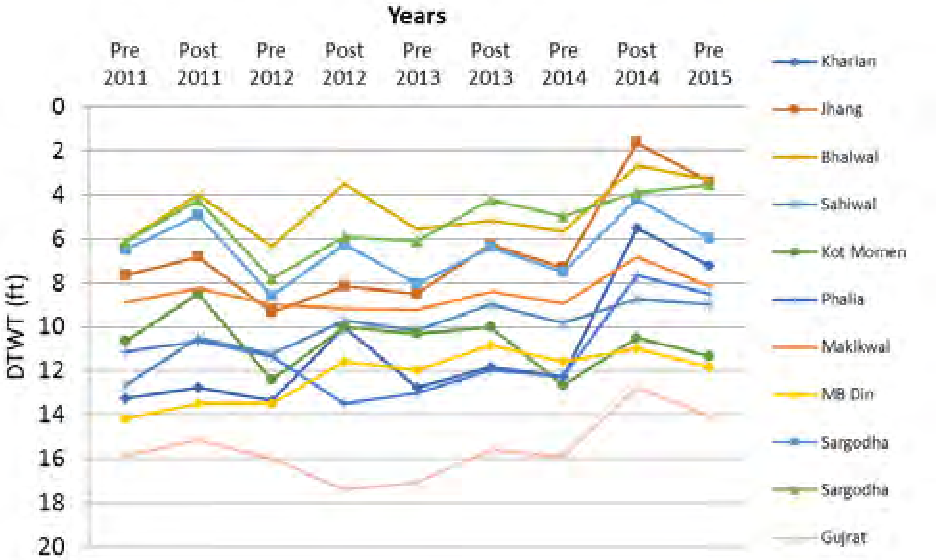

Figure 6: *Fluctuation in depth to water table (ft) from 2011 to 2015 in Chaj Doab*

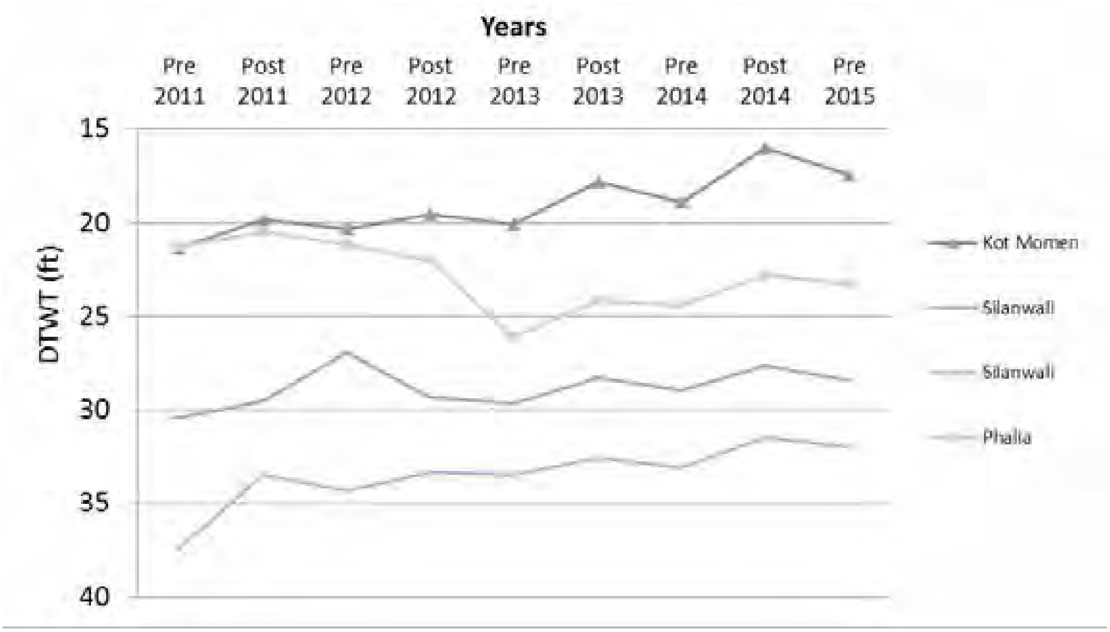

Figure 7: *Fluctuation in DTWT (ft) from 2011 to 2015 in Chaj Doab*

In Chaj Doab groundwater deeper than 20 feet showed nearly constant rise of 1.7 to 2.2 feet per year. During years 2011-2015, water levels in the Chaj Doab rose from 0.3 to 2.6 ft per year with average 0.9 ft. Groundwater level is in rising trend. Flood water contributes significantly towards recharging the aquifer average rise in Chaj Doab during flood 2014 is 0.77 ft/season. Total recharge of GW during flood season 2014 in Chaj Doab is 1.20 Million-Acre-Feet (MAF). Recharge potential of Chaj Doab during October 2010 and June 2012 were found out as 4.32 and 4.675 MAF respectively (IRI, 2016). The area under depth to watertable more than 30 feet was 95 km2 in pre-monsoon 2011 which decreased to 30 km2 in post-monsoon 2011 and it further decreased to 2.65 km2 in post-monsoon 2015 in Chaj Doab area as shown in Fig. 8-13.

To evaluate impacts of flood on recharge, the area of Chaj Doab was divided into 15 polygons (Thiessen Polygons using GIS) as shown in Fig. 14. DTWT data of 200 piezometers (pre and post flood 2014) were analyzed. Average rise/fall in each polygon were calculated and recharge was estimated by Specific yield Method

$$GWR = \sum_{i=1}^{n} (Ri \cdot Ai \cdot Syi)$$

where GWR is groundwater recharge, n is number of polygons, R is rise/fall in GWL, A is area of polygon, Sy is the specific yield. Total recharge of GW during flood season 2014 in Chaj Doab was estimated as 1.20 MAF.

Groundwater levels at selected points had been observed pre-and post-flood 2014, to see the impact of flood water on groundwater level fluctuations. It has been found that during 2014-flood, average water level raised in Chaj Doab was 0.77 ft in some areas as shown in Fig.15.

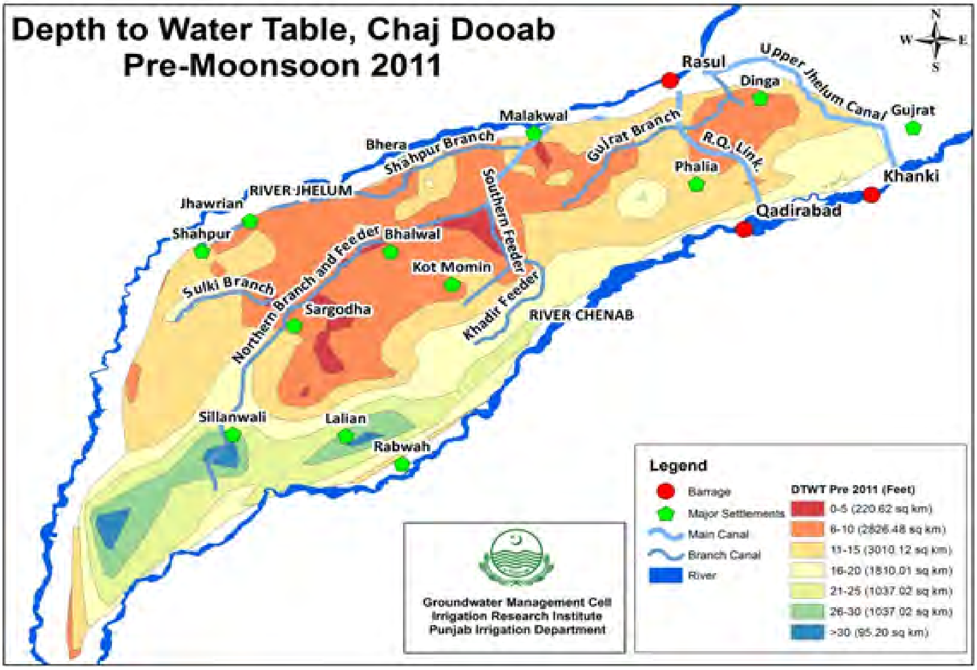

Figure 8: *Depth to watertable for Chaj Doab pre-moonsoon 2011*

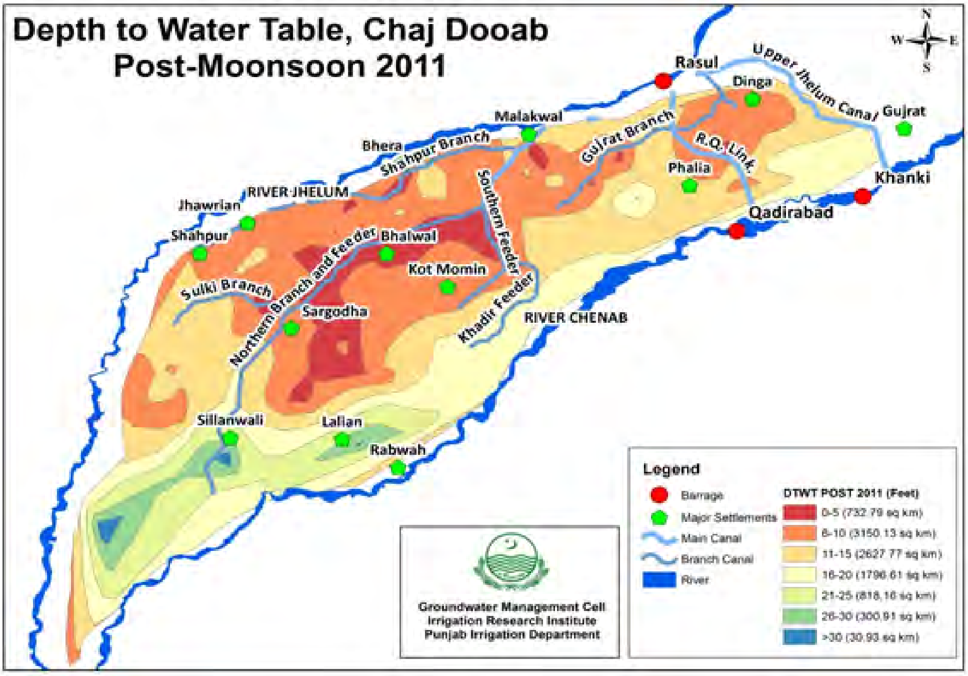

Figure 9 : *Depth to watertable for Chaj Doab post-moonsoon 2011*

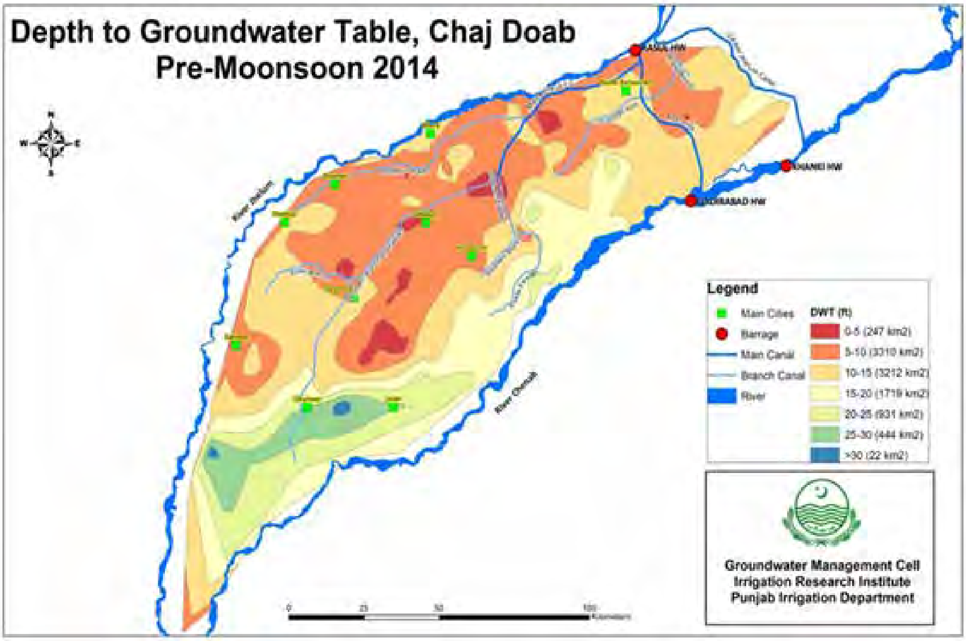

Figure 10: Depth to watertable for Chaj Doab pre-moonsoon 2014

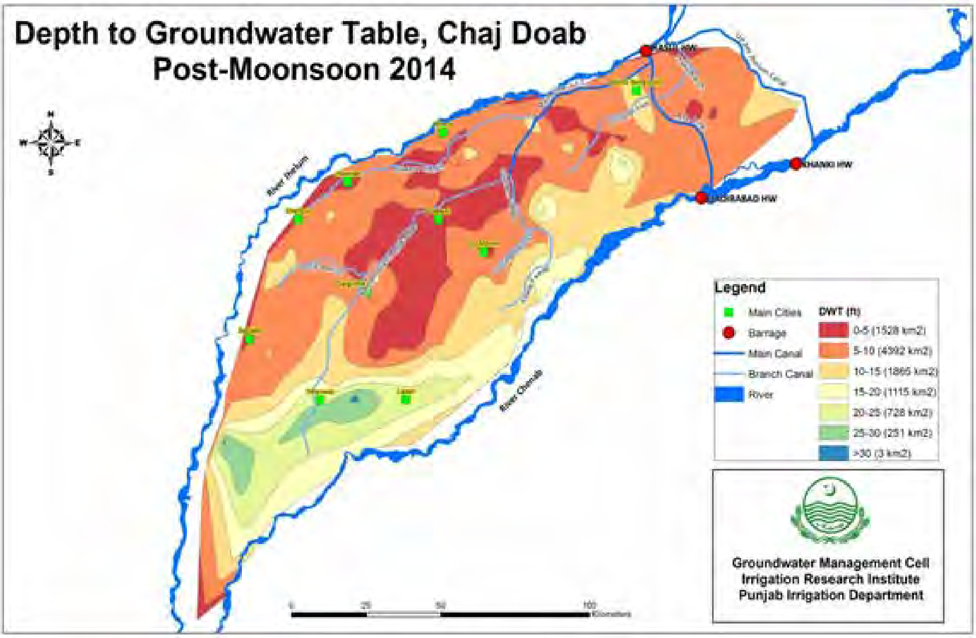

Figure 11: Depth to watertable for Chaj Doab post-moonsoon 2014

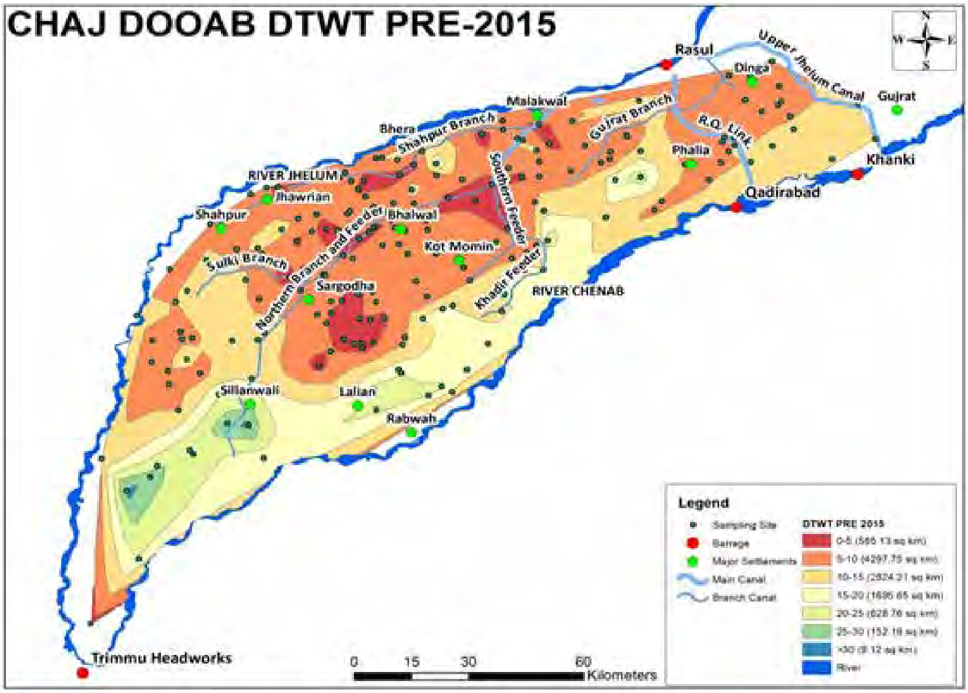

Figure 12: *Depth to watertable for Chaj Doab pre-moonsoon 2015*

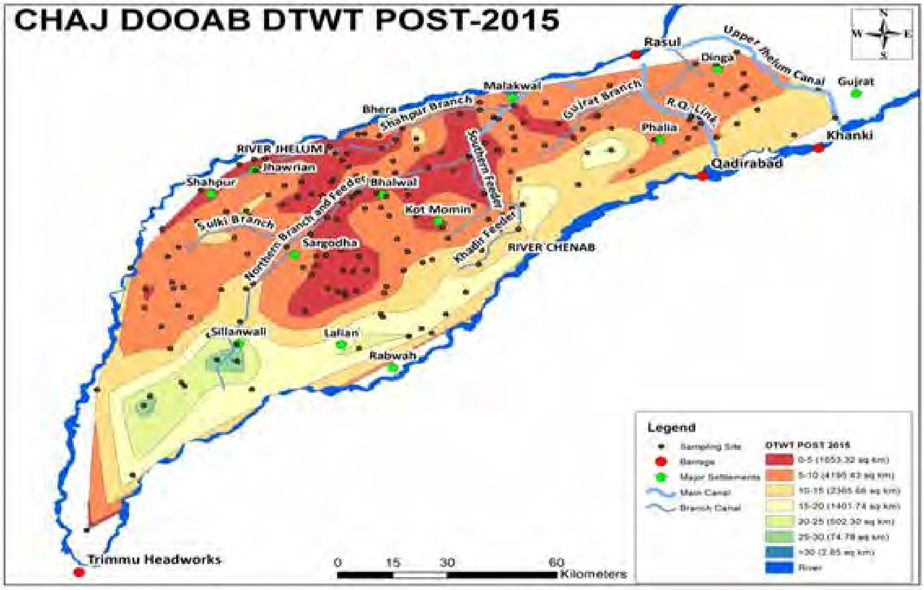

Figure 13: *Depth to watertable for Chaj Doab post-moonsoon 2015*

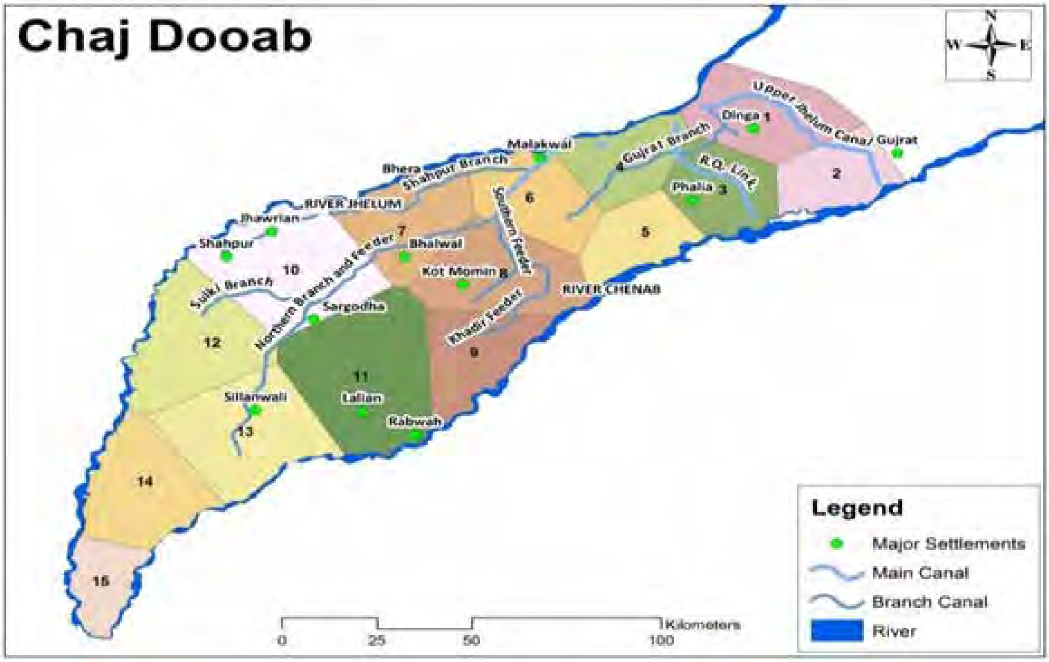

Figure 14: *Thiessen polygons using GIS of Chaj doab*

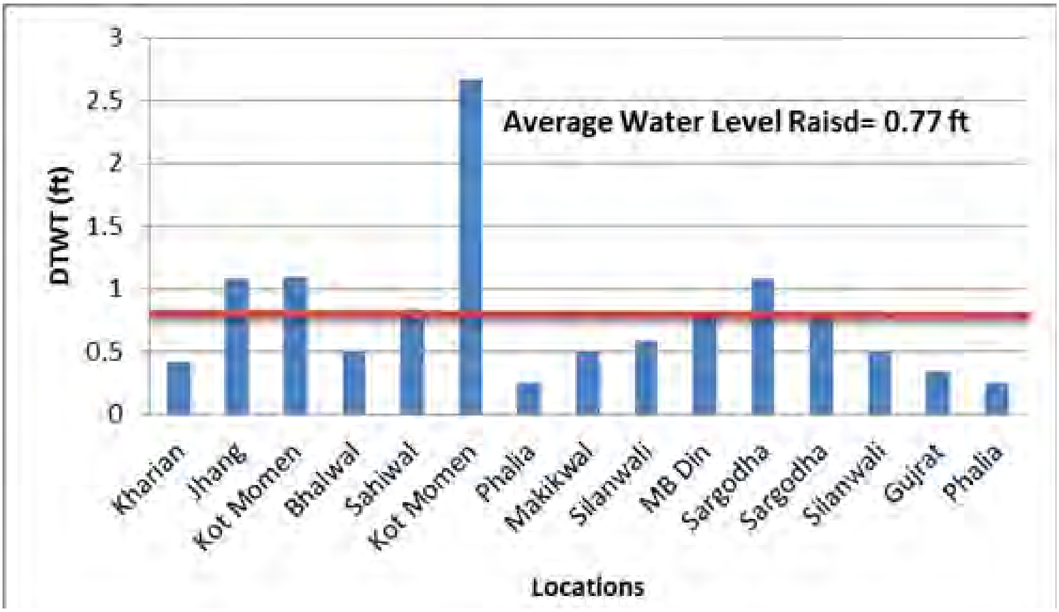

Figure 15: *Average water level raised (ft) in various areas in Chaj Doab after 2014 flood*

4. Groundwater Recharge in Rechna Doab

Fig. 16: shows the location of Rechna Doab and different irrigation divisions/network in the Rechna Doab.

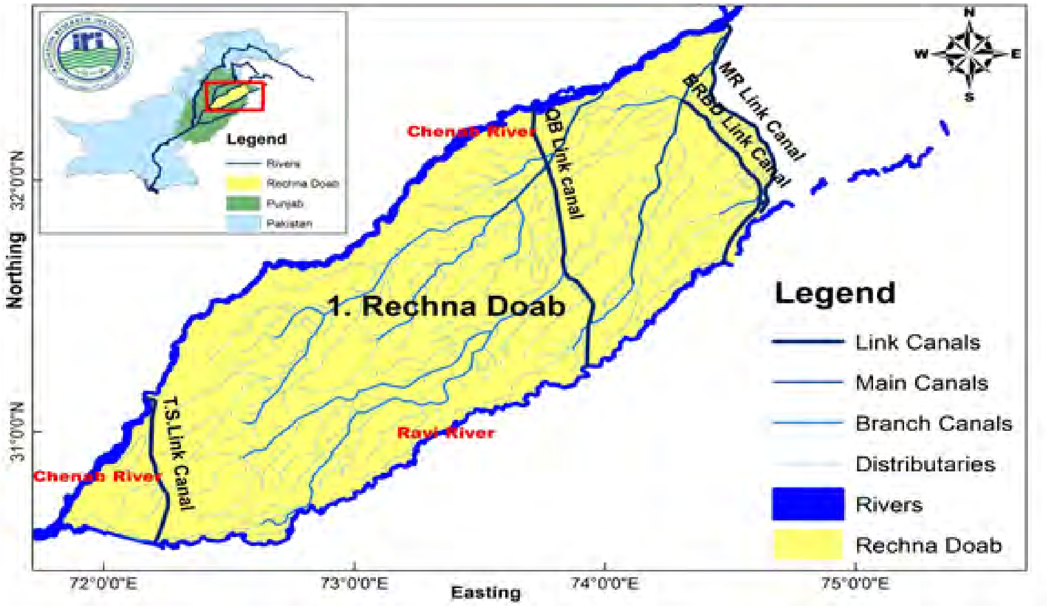

***Figure 16:** Irrigation network in Rechna Doab*

Different watertable depth ranges in Rechna Doab during October 2010 is given in Table 5. Ground-water recharge potential in Rechna Doab during October 2010 is given in Table 6. Areas (%) under different water table depth ranges in Rechna Doab during October, 2010 is shown in Fig. 17.

***Table 5:** Different water table depth ranges in Rechna Doab during Oct. 2010*

DTW Ranges (m)	Area		
	Acres	Hectares	%
0 - 1.5	140,318	56,809	2.04
1.5 - 3	657,550	266,215	9.57
3 - 6	2,900,574	1,174,321	42.23
6 - 9	2,073,790	839,591	30.19
9 - 13	748,958	303,222	10.90
13 - 18	332,382	134,568	4.84
>18	14,835	6,006	0.22
Total Area	**6,868,407**	**2,780,732**	**100**

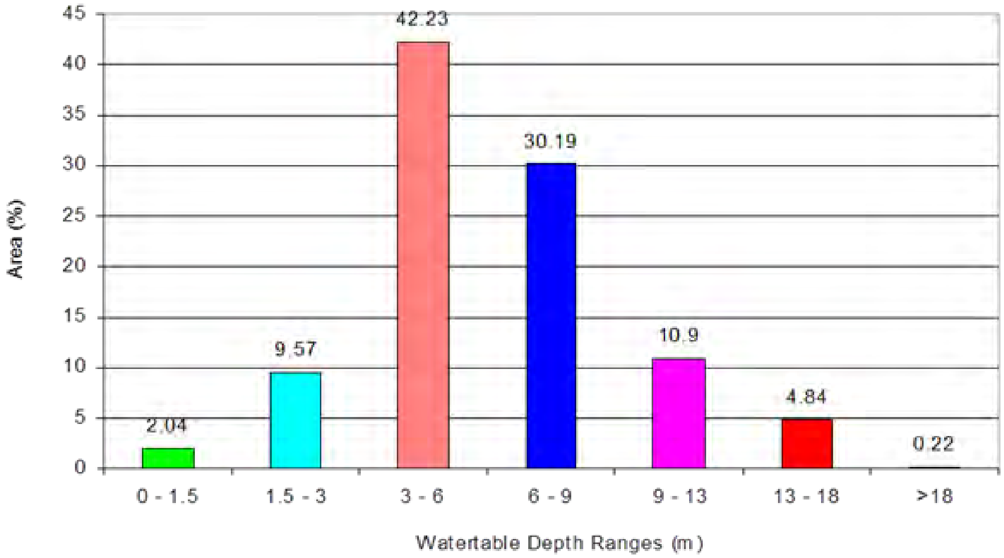

Figure 17: *Area under different depth to watertable ranges in Rechna Doab during October, 2010*

Table 6: *Groundwater recharge potential in Rechna Doab during Oct. 2010*

Depth to be Recharged (m)	Area		Specific yield	Volume of water (ha.m)
	Hectares	Acres		
1.50	1,174,321	2,900,574	0.20	352,296.3
4.50	839,591	2,073,790	0.20	755,631.9
8.00	303,222	748,958	0.20	485,155.2
12.50	134,568	332,382	0.20	336,420.0
17.50	6,006	14,835	0.20	21,021.0
Total Volume of Water Hectare Meter (ha.m)				1,950,524.4
Million hectare meter (M.Ha-m)				1.95
Million Acre Feet (MAF)				15.80

Watertable depth ranges percent area of Rechna Doab during June 2012 is shown in Fig. 18. Recharge Potential in irrigated areas of Rechna Doab during June 2012 is given in Table 7. Changes in water table depth at selected point during 2008-2014 are shown in Fig. 19-22.

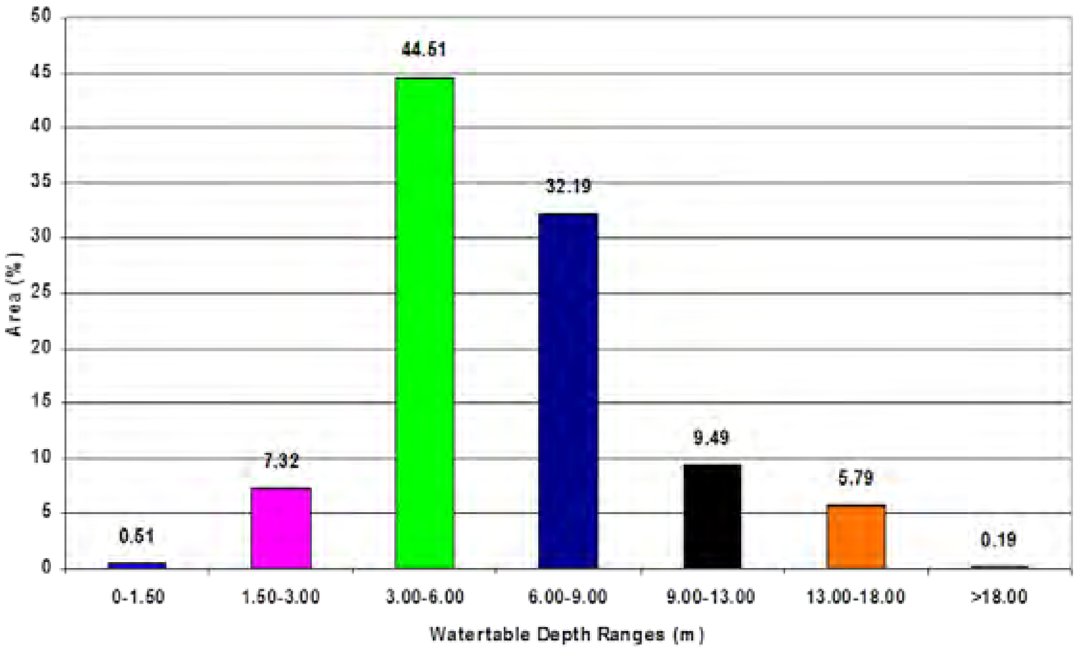

Figure 18: *Water table depth ranges percent area of Rechna Doab during June 2012*

Table 7: *Recharge Potential in irrigated areas of Rechna Doab during June 2012*

Depth to be Recharged (m)	Area		Specific yield	Volume of water (ha.m)
	Hectare	Acre		
1.50	1,239,234.0	3,060,908	0.20	371,770.2
4.50	896,170.9	2,213,542	0.20	806,553.8
8.00	264,283.0	652,779	0.20	422,852.8
12.50	161,063.2	397,826	0.20	402,657.9
17.50	5,173.7	12,779	0.20	18,107.89
Total Volume of Water Hectare Meter (ha.m)				2,021,943
Million hectare meter (MHM)				2.022
Million Acre Feet (MAF)				16.381

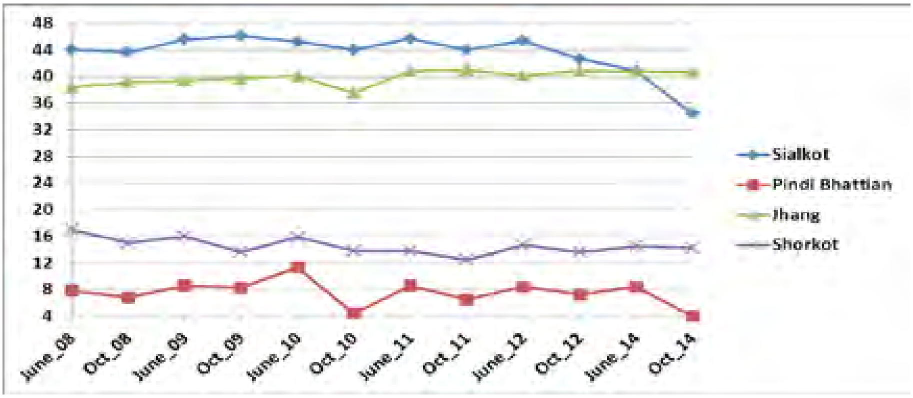

Figure 19:*Changes in depth to watertable (ft below NSL) at selected points in Rechna Doab (2008 to 2014)*

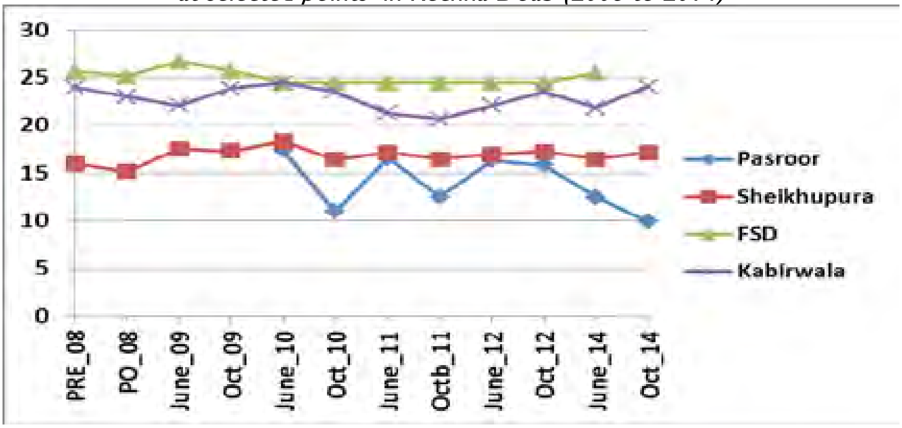

Figure 20: *Changes in depth to watertable (ft below Natural Surface Level (NSL) atselected pointsin Rechna Doab (2008 to 2014)*

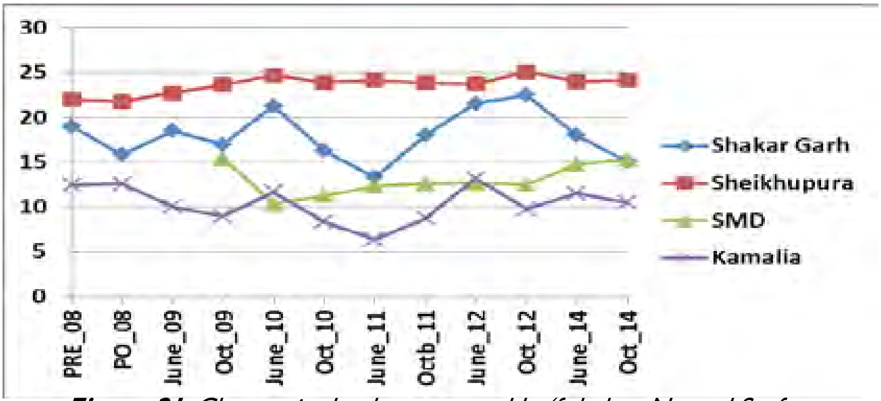

Figure 21: *Changes in depth to watertable (ft below Natural Surface Level (NSL) atselected points in Rechna Doab (2008 to 2014)*

Groundwater levels are falling at an average rate of 1-2 ft/year in some areas of Rechna Doab (bounded by two rivers, on the south and east by the Ravi River while on the North and West by the Chenab River). Recharge potential in Rechna doab during October 2010 and June 2012 were found out as 15.80 and 16.381 MAF respectively. Flood water contributes significantly towards recharging the aquifer average rise in Rechna Doab during flood 2014 is 2.57 ft/season. Total recharge of GW during flood season 2014 in Rechna Doab is 1.90 MAF (IRI, 2015). Research study carried out in Lower Bari Doab Canal (LBDC) has indicated that by increase of depth to water table from 40 ft. to 70ft the cost of pumping per acre-feet has increased 125% as showing Fig. 22-25.

Rechna Doab divided into 20 polygons (Thiessen Polygons using GIS) as shown in Fig. 26. DTWT Data of 200 piezometers (pre and post flood 2014). Average rise/fall in each polygon determined Recharge estimated by Specific yield Method. Total recharge of groundwater during flood season 2014 in Rechna Doab was 1.90 MAF.

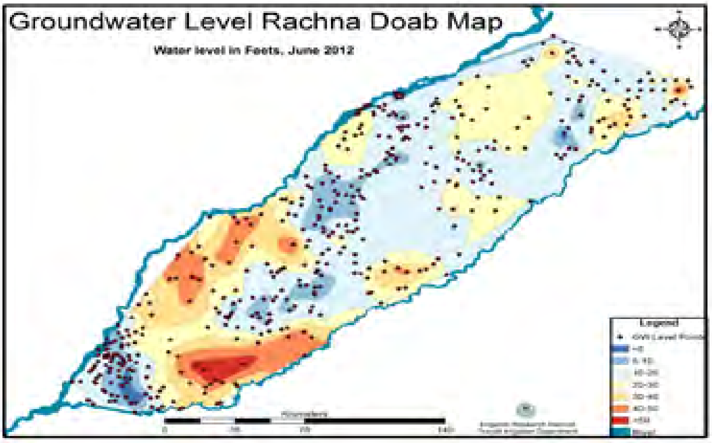

Figure 22: *Map of depth to watertable (ft) below Natural Surface Level (NSL) in Rechna Doab June 2012*

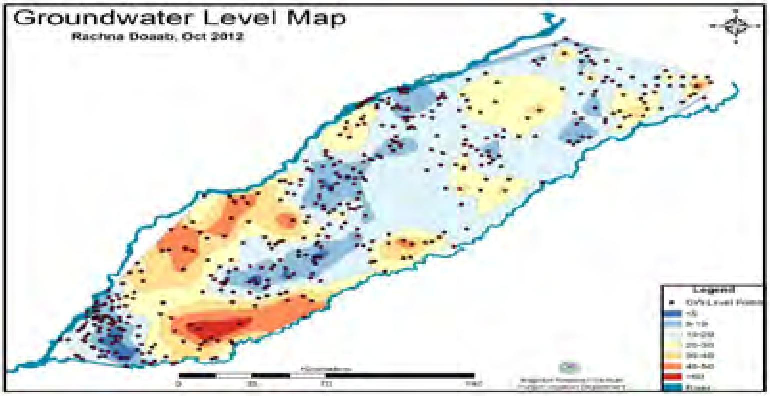

Figure 23: *Map of depth to water table (ft) below Natural Surface Level (NSL) in Rechna Doab October 2012*

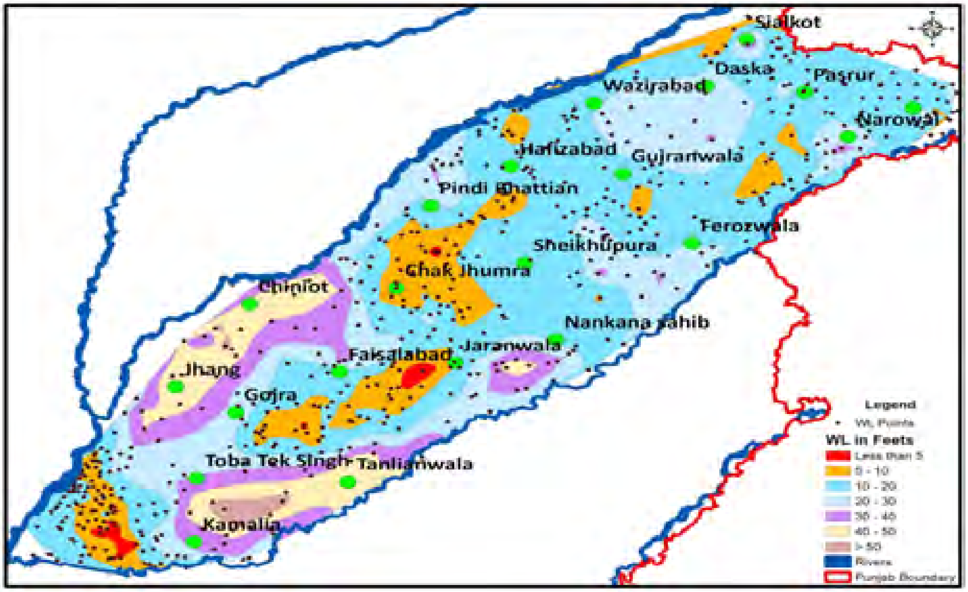

Figure 24: *Depth to watertable Pre-monsoon 2014 in Rechna Doab*

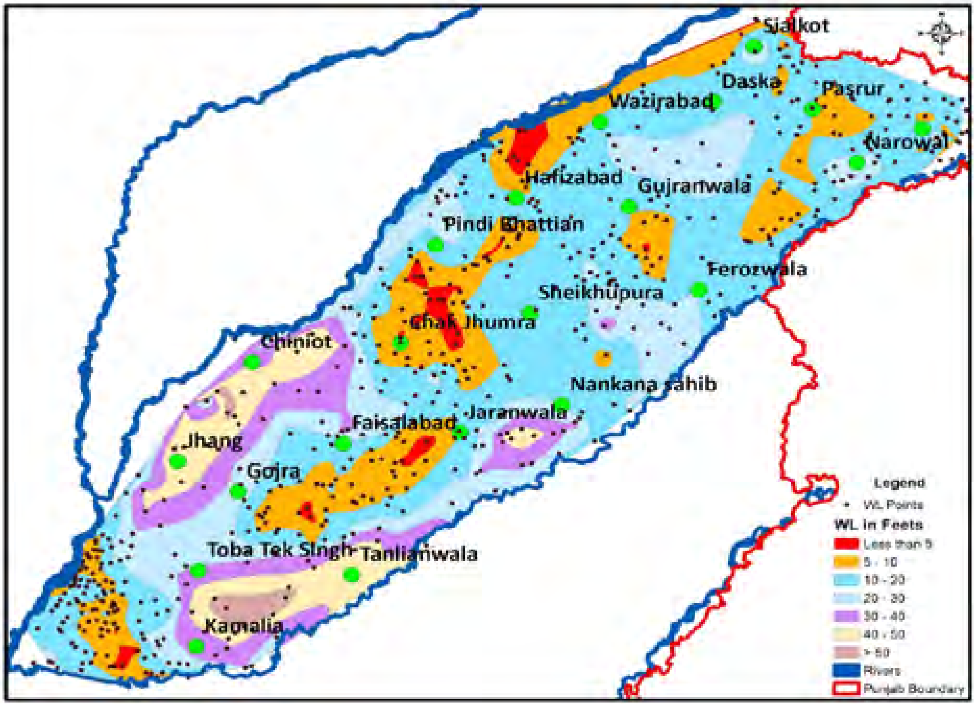

Figure 25: *Depth to watertable Post -monsoon 2014 in Rechna Doab*

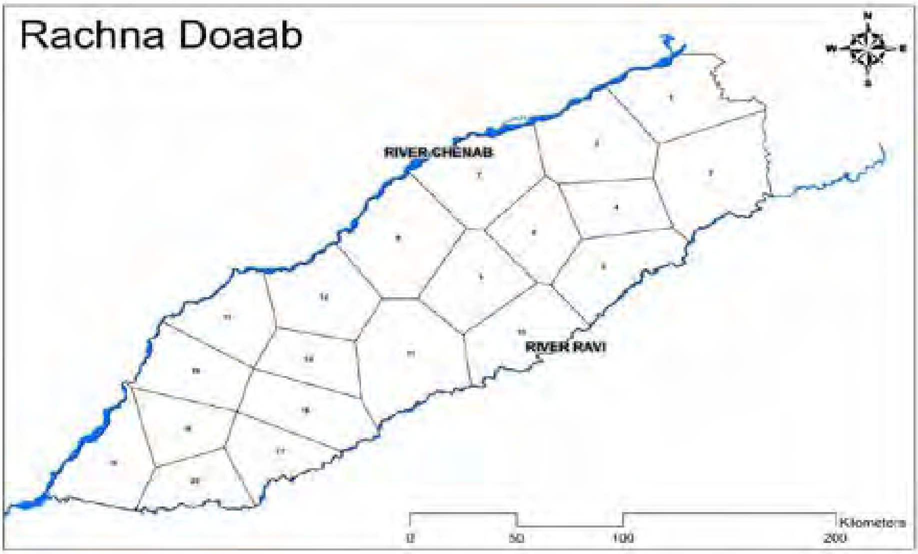

Figure 26: *Thiessen polygons using GIS of Rechna Doab*

Groundwater levels at selected points had been observed during pre- and post-flood seasons in 2014, to see the impact of flood water on groundwater level fluctuations. It has been found that during flood 2014, average water level raised in Rechna Doab was 2.57 ft in some areas as shown in Fig. 27. Groundwater recharge potentials under different depths are shown in Table 8, and areas (%) under them are shown in Fig. 28.

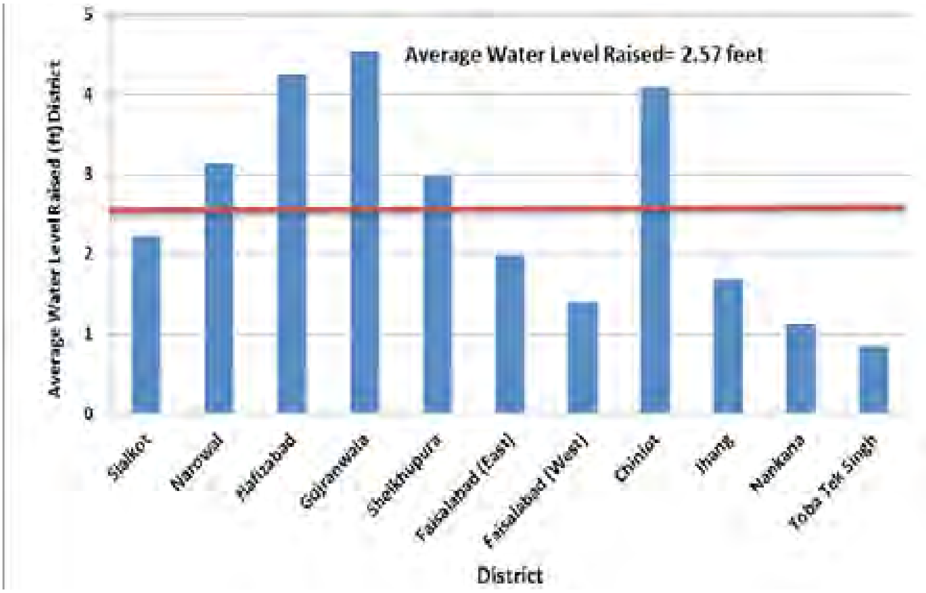

Figure 27: *Average water level raise (ft) in various areas in Rechna doab after flood 2014*

Table 8: *Groundwater Recharge potential in Rechna Doab*

DTWT (ft)	Km²	%age	Depth to be recharged (ft)	Potential for Recharge (MAF)
<10	2184	9	0	0.00
10-20	10596	43	5	2.62
20-30	7102	29	15	5.26
30-40	3129	13	25	3.86
>40	1762	7	30	2.61
Total				**14**

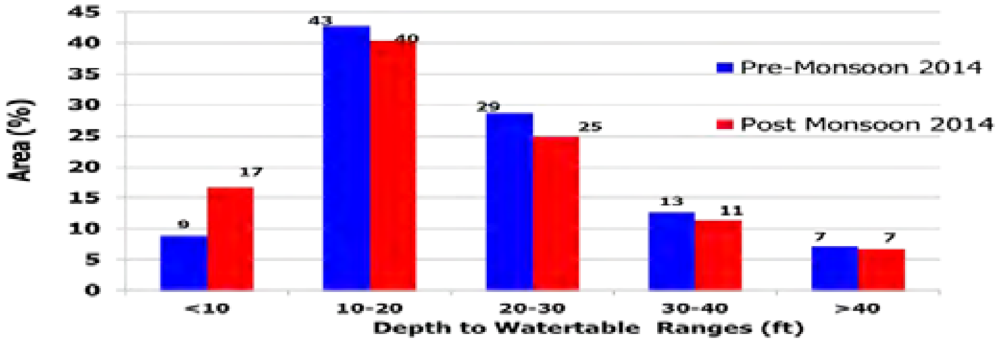

Figure 28: *Area under different depth to water table ranges in Rechna Doab (pre- and post-flood, 2014)*

5. Conclusions

- It has been observed that unplanned excessive pumpage, lack of awareness and capacity of stakeholders, lack of regulatory framework, and spatial/temporal uncertainty in surface water due to climatic changes (droughts and floods) are the major challenges for groundwater fluctuation.
- In Chaj Doab, the water table is showing a rising trend with an average rate of 0.9 ft/year. Total recharge of GW during flood season 2014 in Chaj Doab was 1.20 MAF. Flood water contributes significantly towards recharging the aquifer and average rise in Chaj Doab during flood 2014 was 0.77 ft/season. Groundwater quality in the aquifer is being deteriorated with the passage of time and sweet water is becoming rare.
- Groundwater recharge potential in Chaj Doab during October 2010 and June 2012 were found out as 4.32 and 4.675 MAF, respectively.

- In the Rechna Doab it has been observed the average depleting rate is 1-2 ft/year and over exploitation in certain areas is causing intermixing of fresh and saline water leading to overall deterioration of groundwater.
- Flood water played a significant role in recharging the aquifer during 2014-flood, an average rise of 2.57 ft in water table has been observed in Rechna Doab.
- Total recharge of groundwater during flood season of 2014 in Rechna Doab was 1.90 MAF.
- Estimated potential of flood water storage/recharge in Rechna Doab has been found to be 14 MAF.

References

Afzal, M. (1999). Water for agriculture. Paper for water Vision Pakistan.

Ahmad, S., Rashida, M. (2001). Indus basin irrigation system water budget and associated problems. J. Engineering and Applied Sciences. 20 (1),.69-75.

Bhutta, M.N. (1999). Vision on water for food and agriculture: Pakistan's perspective. Regional South Asia Meeting on Water for Food and Agriculture Development. New Delhi.

Chebbi, E.H. (2010). Agriculture and economic growth in Tunisia, 1&2, 63-78. Emerald Group Publishing Limited.

Duranton, G. (1998). Agricultural Productivity, Trade, and Industrialization. Oxford Economic Papers 50,pp. 220–236.

Hassan G. Z., Bhutta M N. (1996). A Water Balance Model to Estimate Groundwater Recharge in Rechna Doab Pakistan. Irrigation and Drainage System,10, 297-317, Kulwer Academic Publisher, Printed in Netherlands.

Hassan G.Z., Shabir G., Hassan F. R., Akhtar S. (2013). Impact of Pollution in Ravi River on Groundwater underlying the Lahore City. Paper 749, 72nd Annual Session of Pakistan Engineering Congress, Lahore, Pakistan.

Hassan G.Z., Hassan F. R., Akhtar S. (2014). Environment Threats to Groundwater in Lahore Area. World Environment Day, Pakistan Engineering Congress, Lahore Pakistan.

Hassan G.Z., Hassan F. R., Akhtar S. (2016). Environmental Issues and concerns of Groundwater in Lahore. Proceedings of the Pakistan Academy of Sciences :B: Life and Environmental Science 53(3), 163-178

IRI. (2009). Research Studies on Artificial Recharges of Aquifer in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute (IRI). Research Report No IRR-Phy/552.

IRI. (2012). Groundwater Investigation for Sustainable Water Supply to FDA City Housing Scheme, Faisalabad. Government of the Punjab, Irrigation Department, Irrigation Research Institute (IRI), Lahore, Pakistan. Research Report No IRR-Phy/577.

IRI. (2013). Research Studies on Artificial Recharges of Aquifer in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute (IRI), Lahore, Pakistan. Research Report No IRR-Phy/579.

IRI. (2015). Groundwater Behavior in Rechna Doab, Punjab, Pakistan. Groundwater Management Cell, Irrigation Department, Irrigation Research Institute (IRI), Lahore, Pakistan. Research Report No IRR-GWMC/101.

IRI. (2016). Challenges and Opportunities for Sustainable use of Groundwater in Chaj Doab, Punjab, Pakistan. Groundwater Management Cell, Irrigation Department, Irrigation Research Institute (IRI), Lahore, Pakistan. Research Report No IRR-GWMC/102.

Jorgenson, D. (1967). Surplus Agricultural Labour and Development of a Dual Economy. Oxford Economic Papers, 19,. 288–312.

Kaldor, N. (1978). Further Essays on Economic Theory. In M. Baskin (ed.) Economics and Human Welfare Essay in Honor of Tibor Scitovsky. New York: Academic Press.

WWAP (United Nations World Water Assessment Program) (2012). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwd

Climate and aridity change

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Abstract

Significant global warming occurred in the twentieth century and especially in the most recent decades. Climate change is a complex phenomenon, accompanied by a wide variety of effects. Rapid alternation, between severe heat wave/drought and abundant rainfall/ flooding, is more and more obvious. The article presents the annual and vegetation season meteorological conditions changes at Kaunas (Lithuania), Horki (Belarus), Sisak (Croatia) and Sarajevo (Bosnia and Herzegovina) between 1996-2016. According to the aridity index, based on temperature and rainfall as weather parameters, this study analyzed the climate dryness risk. This study demonstrates how climate change affects traditional temperature and aridity zones. The movement of temperature and aridity zones could trigger ecosystem migration and land use change. However, the evidence and velocity of ecosystem migration and adaptation in response to the shifting of temperature and aridity zones require more research.

Keywords: *aridity; climate change; meteorological parameters*

1. Introduction

Global climate change and associated impacts on water resources are the most urgent challenges faced by mankind today and will have enduring societal implications for generations to come. Potential impacts may include the changes in watershed hydrologic processes including timing and magnitude of surface discharge, stream discharge, evapotranspiration, and flood events, all of which would influence other environmental variables such as nutrient and sediment flux on water sources (Simonovic and Li, 2004). Changes in precipitation are the prime drivers of change in the availability of both surface water and groundwater resources (Beare, Heaney, 2002). The trends of precipitation extremes in Europe vary greatly and depend not only on the region but also on the indicator used to describe an extreme (Groisman et al., 2005). Climate change is altering the statistics of temperature and precipitation. More frequent and severer weather extreme events are anticipated to impose greater damages to ecosystems and agricultural systems (Choi et al., 2015; Wigley, 2009). Climate changes (temperature increase, precipitation decrease) may be related with the environmental pollution. In case of low temperature and low moisture, assimilation of nutrients goes on much worse; therefore, they are leached from the soil

with the drainage runoff more intensely (Root et al., 2003; Soussana and Luscher, 2007). Introduction of drainage has altered the time and frequency of high streamflows in particular. The decreasing number of low pulses suggests that an efficient hydrological connectivity with the groundwater in the river catchment may exist through tile drainage (Povilaitis et al., 2015). Precipitation distribution in a territory and their change within a year has a great impact on hydrological phenomena, soil formation and plant-growing seasons (Bukantis, 1994). Climate change impact on flora is receiving increasing attention around the world (Fuhrer, 2003). Climate change projections may result in reductions of average annual discharge up to 50%, challenging the whole socio-economic model which is based largely on water demanding activities: recreation, tourism and food production (Iglesias and Garrote, 2015). A number of studies have shown that annual river flows under climate change is expected to decrease in Southern Europe and increase in Northern Europe; changes are also expected in the seasonality of river flows with considerable differences over the European region. While some aspects of climate change such as increased precipitation may bring some localized benefits, there will also be a range of adverse impacts, including reduced water availability and more frequent extreme weather (Arnell et al., 2011). A change in climate may cause either or both precipitation and potential evaporation to change. A change in potential evaporation may be due to one or more of the following causes (Arora, 2002): i) change in temperature (e.g. due to climate warming), ii) change in net radiation associated with a change in albedo (e.g. due to land-use change), or iii) both. The one binding factor to all arid areas is aridity. Aridity is usually expressed as a function of rainfall and temperature. A useful description of aridity is the climatic aridity index (=precipitation (P)/potential evapotranspiration (PET)). Aridity results from the presence of dry, descending air (Some'e et al., 2013). A quite common method for quantifying the gap between rainfall contributions and water demand is the Aridity Index (AI) which, in the formulation adopted by United Nations Environment Programme (UNEP), Food and Agriculture Organization (FAO), and United Nations Convention to Combat Desertification (UNCCD), represents a simple but effective scientific investigation tool and an operational support to territorial monitoring and classification. The AI can be defined as a bio-climatic index, as it takes into account both physical phenomena (precipitation and potential evapotranspiration) and biological processes (plant transpiration) (Salvati et al., 2013).

2. Methodology

Data from Kaunas (Lithuania), Horki (Belarus), Sisak (Croatia) and Sarajevo (Bosnia and Hercegovina) meteorological stations (MS) (Table 1), were used for analysis of agro-hydrological balance components by Thornthwaite-Mather method (TM, Thornthwaite and Mather, 1957). Potential evapotranspiration (PET) calculated with Thornthwaite method was used as input for water balance calculation. Other input parameters used were monthly precipitation (P), monthly potential evapotranspiration (PET) and readily available soil water holding capacity of 100 mm (RAW). Climatic data (monthly air temperature and sum of precipitation) for four meteorological stations (middle Lithuania, Belarus, Croatia and Bosnia and Herzegovina), for the period of 1996 – 2016 were used for analysis of agro-hydrological balance components.

Table 1: *Location and details of meteorological data used in this study*

Meteorological stations		Longitude	Latitude	Elevation	Used time series	Total years
Kaunas	Lithuania	23°83'	54°88'	48 m.	1996-2016	21
Horki	Belarus	30°59'	54°17'	182 m.	1997-2016	20

Sisak	Croatia	16° 22´	45° 29´	98 m	1996-2016	21
Sarajevo	B&H	18° 25´	43° 52´	630 m.	1996-2016	21

PET calculated with Thornthwaite method (Thornthwaite, 1948) was used as input for water balance calculation.This method is used all over the world and is the most appropriate for the Balkan conditions (Vlahinić, 2004; Čadro et al., 2017; Čustović et al.,2011). Following equations were used:

$$ET_{0\,Thornthwaite} = 16\left(\frac{T_s}{I}\right)^a \quad (1)$$

$$I = \sum_{n=1}^{12}(0{,}2T_a)^{1.514} \quad (2)$$

$$a = 6{,}75 \times 10^{-7}I^3 - 7{,}71 \times 10^{-5}I^2 + 1{,}7912 \times 10^{-2}I + 0{,}49239 \quad (3)$$

where Ts is mean air temperature (°C); I is a thermal index imposed by the local normal climatic temperature regime, and the exponent "a" is a function of I.

The Aridity Index (AI) calculated by dividing the total annual precipitation (P) by the annual potential evapotranspiration (PET, Salvati, 2013):

$$AI = \frac{P}{ET_0} \quad (4)$$

AI values below 0.5 define arid or semi-arid, while values over 0.65 describe humid and values over 0.75 - hyper-humid zones.

3. Results

The monthly average temperature and precipitation data are presented in Table 2.The vegetation period starts in April in Sarajevo and Sisak and continues until November. One-month later vegetation period starts in Kaunas and Horki, and continues until October. The highest average yearly temperature was in Sisak (11.89°C) and the lowest in Horki (6.05°C). Yearly precipitation amount ranges from 650 mm (Horki) to 968 mm (Sarajevo).

Table 2: *Average climatic data for Kaunas, Horki, Sarajevo and Sisak period 1996 – 2015*

Month	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
	Kaunas		Horki		Sarajevo		Sisak	
I	-3.66	47	-5.89	33	0.63	75	1.18	67
II	-2.74	38	-6.62	37	1.81	69	2.92	57
III	0.94	35	-1.79	40	5.57	68	7.41	57
IV	7.70	35	6.67	40	10.36	76	12.40	71
V	13.10	56	12.83	67	14.99	86	17.14	86
VI	16.13	67	16.36	73	18.72	83	20.97	93
VII	18.75	93	19.05	81	20.56	73	22.42	87
VIII	17.80	83	17.62	79	20.34	62	21.54	82

IX	12.85	48	11.82	43	15.23	101	16.30	113
X	7.18	63	6.00	67	10.93	97	11.60	83
XI	2.92	49	0.54	50	6.38	90	6.94	93
XII	-1.51	44	-3.94	39	0.93	89	1.78	69
Average	7.46	-	6.05	-	10.54	-	11.89	-
Sum	-	658	-	650	-	968	-	958

The annual air temperatures for the 1996-2016 period showed increasingly variable patterns (Fig. 1). There is a clear tendency of increase in the average annual air temperature in all four meteorological stations. The highest air temperature at Sisak in 1996 was (12.9°C), at Sarajevo in 2014 (11.6°C), at Kaunas in 2015 (8.69°C) and at Horki in 2008 (7.1°C). The lowest temperature observed in 2016 at Horki was (4.8°C), in 1996 (5.0°C) at Kaunas, in 2005 at Sarajevo (9.1°C), and in 1996 at Sisak (10.1°C). The coefficient of correlation shows, that Sisak (0.47), Sarajevo (0.56) and Kaunas (0.45) indicate a moderate positive linear relationship, and only Horki (0.20) shows a weak positive linear relationship.

The annual precipitation for the period of 1996-2016 is shown in Fig. 2. The wettest year (about 30 % higher than that of the Climatic Normal (CN)) occurred in 2010 at Kaunas (849 mm), in 1999 at Sarajevo (1249 mm), in 2012 at Horki (931mm), and in 2014 at Sisak (1451 mm). The driest year (about 30 % less as CN) occurred in 1996 at Kaunas (462 mm), in 2011 at Sarajevo (692 mm), in 2002 at Horki (444 mm) and in 2011 at Sisak (555 mm). The linear trends are positive except in Sarajevo.

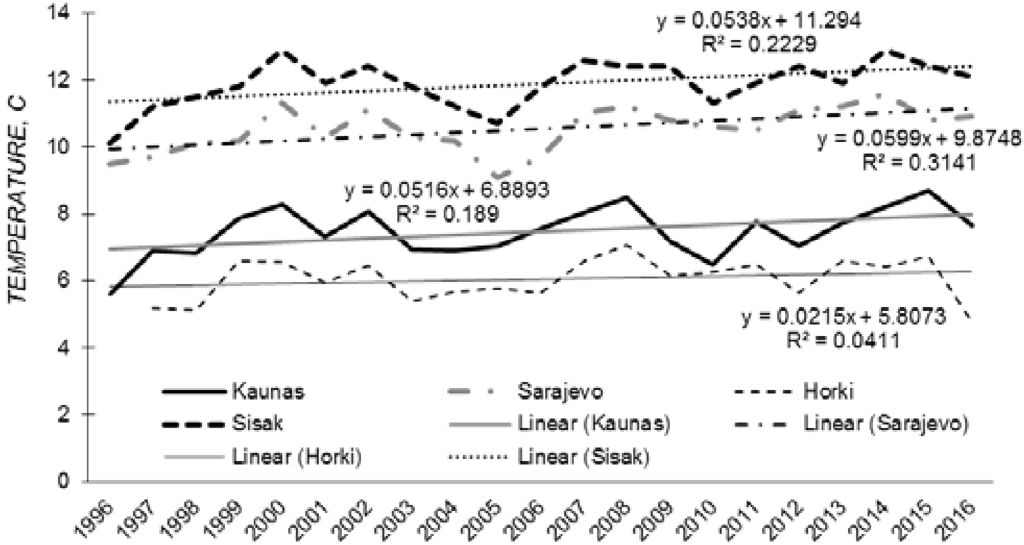


Figure 1: *Average yearly air temperature (°C) and linear trends*

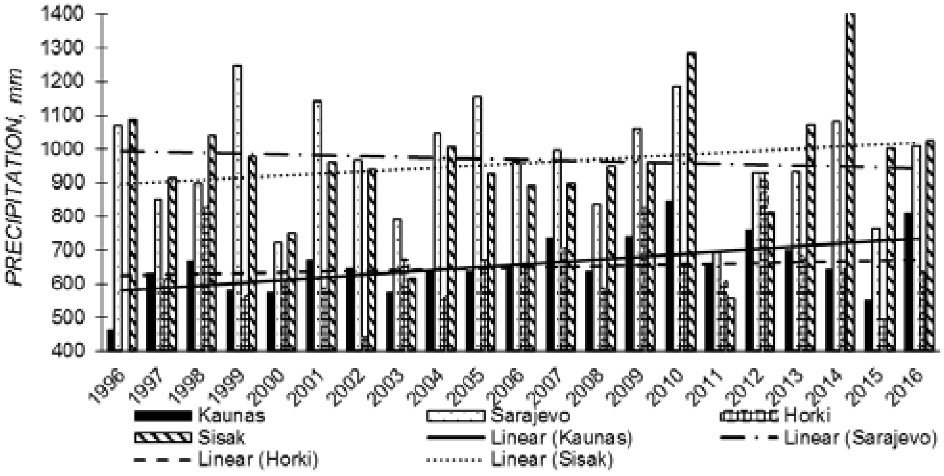
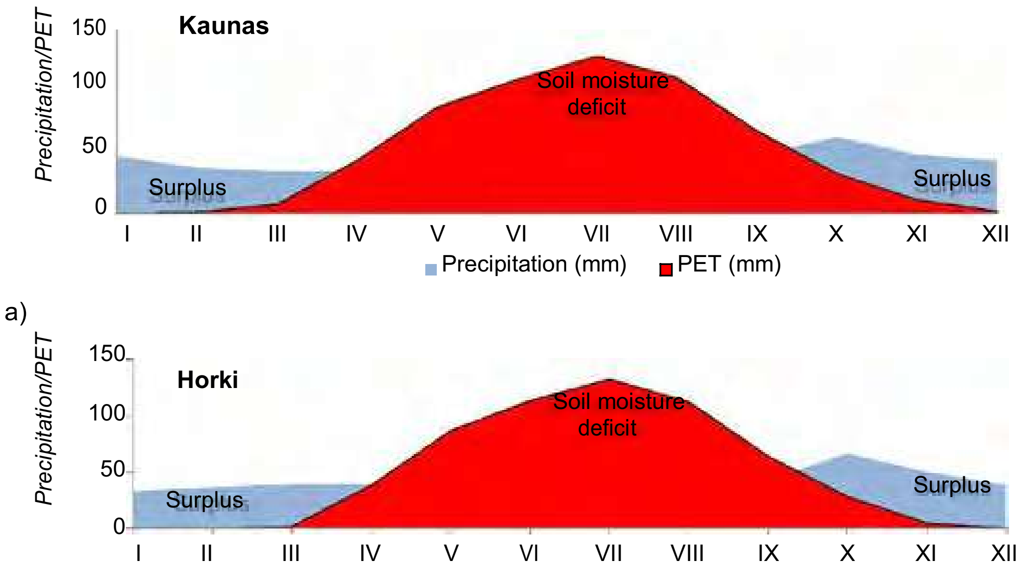
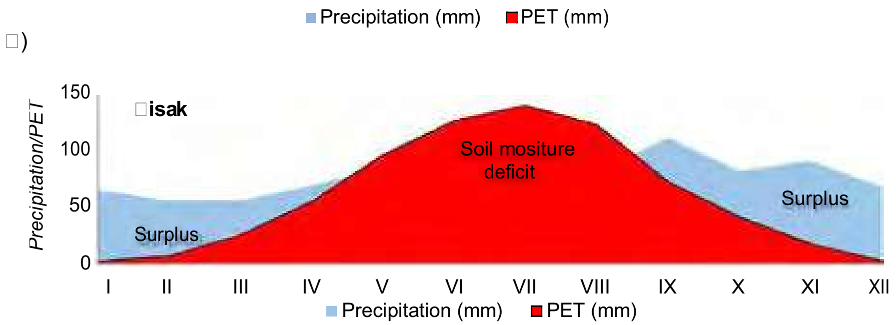


***Figure 2:** Sum of precipitation and liner trends*

Monthly soil water balances are negative at all the stations (Fig. 3): with higher negative values were found at Sisak and Sarajevo stations (43 mm and 48 mm in August), at Horki - 35 mm in July and at Kaunas station - 34 mm in August. Soil moisture deficit (2 - 35 mm) can be observed during the vegetation period (May-October) at Kaunas and Horki (Fig. 3 a, b). Soil moisture deficit is concentrated in summer months, from April to September, at Sarajevo and Sisak (Fig.s 3 c, d). Compared to Kaunas and Horki, at these locations, there is a bigger soil moisture deficit (1 - 48 mm) occurring in fewer vegetation months. The biggest monthly soil moisture deficit was in August (at Kaunas – 34 mm, Sisak - 43 mm, Sarajevo - 48 mm), and July (Horki - 35mm).





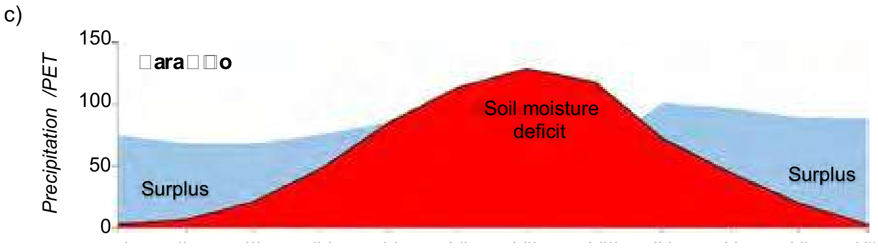


Figure 3: *Monthly soil water balance*

Average water balance, including annual PET is shown in Table 3 and soil water deficit is plotted in Fig. 4.

Table 3: *Average water balance*

Month	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Sum**	**Average**
							Kaunas							
Precipitation	47	38	35	35	56	67	93	83	48	63	49	44	*658*	*55*
PET	0	1	8	44	87	110	130	112	68	33	11	2	*606*	*51*
AET	0	1	8	44	87	103	102	78	49	30	11	2	*516*	*43*
Deficit	0	0	0	0	0	7	28	34	19	3	0	0	*91*	*8*
Surplus	43	34	27	5	0	1	0	0	0	2	6	23	*142*	*12*
	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.7	0.9	1.0	1.0		
AET/PET	0	0	0	0	0	4	8	0	2	2	0	0		*0.92*
		27.	4.5	0.8	0.6	0.6	0.7	0.7	0.7	1.9	4.2	19.		
P/PET	206	2	2	1	5	1	1	4	0	4	7	0		*22.29*
	0.9	0.9	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5		
Surplus/P	2	0	8	5	1	1	0	0	0	4	3	2		*0.29*
							Horki							

Precipitation	33	37	40	40	67	73	81	79	43	67	50	39	650	54
PET	0	0	2	39	87	113	133	112	64	28	5	0	584	49
AET	0	0	2	39	87	103	98	84	43	26	5	0	489	41
Deficit	0	0	0	0	0	10	35	28	20	2	0	0	96	8
Surplus	30	37	38	9	2	4	0	0	0	7	12	22	161	13
	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.6	0.9	1.0	1.0		
AET/PET	0	0	0	0	0	1	4	5	8	3	0	0		*0.92*
			20.	1.0	0.7	0.6	0.6	0.7	0.6	2.3	10.	88.		
P/PET	-	-	3	2	7	4	1	1	8	8	1	9		-
	0.9	1.0	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5		
Surplus/P	0	0	5	4	3	6	0	0	0	1	4	5		*0.34*
Sisak														
Precipitation	67	57	57	71	86	93	87	82	113	83	93	69	*958*	*80*
PET	3	8	26	56	98	128	142	125	74	43	19	4	*726*	*61*
AET	3	8	26	56	97	116	111	82	66	43	19	4	*630*	*53*
Deficit	0	0	0	0	1	12	31	43	8	0	0	0	*96*	*8*
Surplus	63	50	33	23	13	1	0	1	16	18	48	62	*327*	*27*
	1.0	1.0	1.0	1.0	0.9	0.9	0.7	0.6	0.8	1.0	1.0	1.0		
AET/PET	0	0	0	0	9	0	8	5	9	0	0	0		*0.93*
	19,	7,5	2,1	1.2	0.8	0.7	0.6	0.6	1.5	1.9	4.9	17.		
P/PET	9	1	9	5	8	2	1	6	2	4	3	2		*4.95*
	0.9	0.8	0.5	0.3	0.1	0.0	0.0	0.0	0.1	0.2	0.5	0.8		
Surplus/P	5	7	7	2	5	1	0	1	4	2	1	9		*0.39*
Sarajevo														
Precipitation	75	68	68	76	85	83	73	62	101	97	90	89	967	81
PET	3	7	21	49	86	114	129	118	72	45	20	3	668	56
AET	3	7	21	49	86	111	98	71	63	45	20	3	577	48
Deficit	0	0	0	0	0	3	31	48	9	0	0	0	91	8
Surplus	72	62	48	30	14	5	0	0	11	20	47	81	390	32
	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.6	0.8	1.0	1.0	1.0		
AET/PET	0	0	0	0	0	7	6	0	7	0	0	0		*0.93*
	23.	9.8	3.1	1.5	0.9	0.7	0.5	0.5	1.4	2.1	4.4	26.		
P/PET	9	9	8	4	9	3	6	2	0	6	3	3		*6.31*
	0.9	0.9	0.7	0.3	0.1	0.0	0.0	0.0	0.1	0.2	0.5	0.9		
Surplus/P	6	0	0	9	7	6	0	1	1	0	3	1		*0.41*

NOTE: AET/PET represents a drought coefficient; P/PET is an aridity index (AI); Surplus/P is a potential runoff coefficient

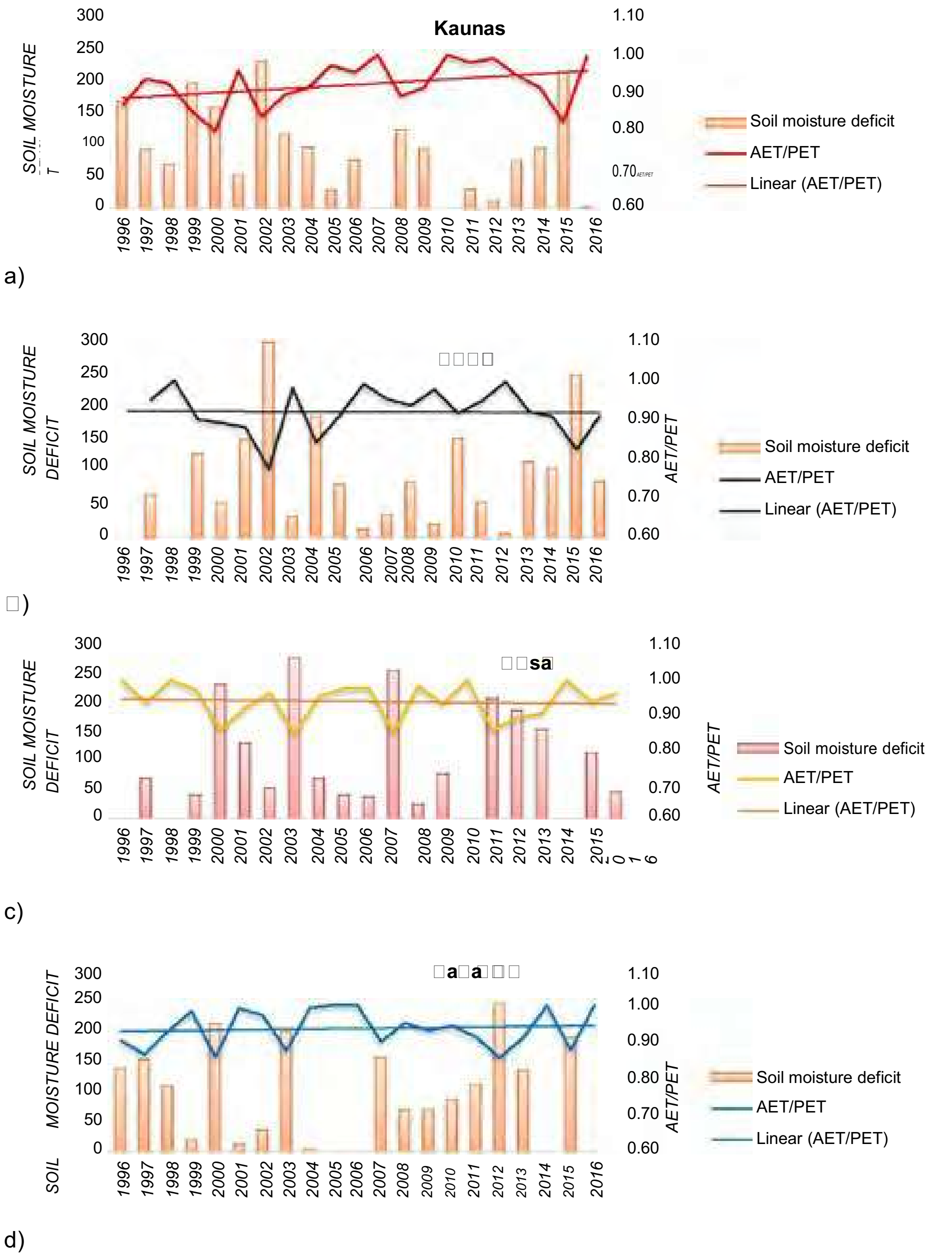


Figure 4: *Time series and liner trends of annual soil moisture defect and drought coefficient*

Yearly PET was highest at Sisak (726 mm) and lowest at Horki (584 mm) (Table 3). The highest monthly PET was in July at all the stations in the last 20 years, and the largest amount of precipitation was in July

at Kaunas and Horki too, at Sisak and at Sarajevo – in September. While the lowest AI was in May-June in Kaunas (0.65-0.61), in June – July in Horki (0.64, 0.61) and in July-August in Sisak (0.61, 0.66) and Sarajevo (0.56, 0.52). Aridity is found mostly in places where anticyclonic conditions are persistent, as is the case in the regions lying under the anticyclones of the subtropics (Some'e et al., 2013). But we can see, that the above mentioned months for which an AI value of over 0.5 were was classified as arid whereas those months in which AI is above 0.5 but less than 0.65 are classified as semi-arid.

Yearly soil moisture deficit was observed nearly each year at all meteorological stations too (Fig. 4). The highest soil moisture deficit was in 2002-2003 (about 200-300 mm) and 2015 (120-250 mm) in all the studied places, while the lowest average drought coefficient was in 2000 in Kaunas and Sarajevo (in Sarajevo – in 2012 too), in 2002 in Horki and 2003 in Sisak. It was found that the linear drought coefficient trend was increasing in Kaunas and Sarajevo in the last 20 years (Fig. 4 a, d), and decreasing in Horki and Sisak. Results showed increasing trends in surface air temperature (in all four meteorological station) and precipitation (except in Sarajevo - decreasing). The increase of aridity may be caused by the concurrent occurrences of negative precipitation trends and positive reference evapotranspiration trends (Some'e et al., 2013).

The annual summer P/PET of the study areas varied between 0.6 and 0.9. Results showed that research areas are with AI values higher than 0.5 (at Sarjevo, 0.56-0.52 in July-August), and drought coefficient are higher as 0.5. Information regarding changes in the P/ETo index as a result of climate change is necessary for policy makers and managers within the context of water resources management, hydrology, agriculture, and environment. Consequently, it indicates the need for more concentration to climate change and different aspects of its effect in the P/ETo regime of a given region (Some'e et al., 2013).

4. Conclusions

The annual air temperature for the 1996-2016 has tendency to increase in all four research meteorological stations. The coefficient of correlation shows, that Sisak, Sarajevo and Kaunas have a moderate positive trend, and Horki has a weak positive trend. The linear trend in annual precipitation is positive at Kaunas, Horki, and Sisak too, but at Sarajevo tendency are decreasing. Monthly soil water balance is negative at all the stations; with higher amount at Sisak and Sarajevo, but continuous longer period at Kaunas and Horki. Average annual soil moisture deficit was 8 mm at all selected meteorological stations. The highest monthly PET was in July at all the stations in the last 20 years, and the largest amount of precipitation was in July at Kaunas and Horki, in September at Sisak and Sarajevo. According to AI classification, the months of May-June at Kaunas (AI = 0.65-0.61), June-July at Horki (AI = 0.64, 0.61) and July-August at Sisak (AI = 0.61, 0.66) and Sarajevo (AI = 0.56, 0.52) were semi-arid.

References

Arnell, N.W., van Vuuren D.P., Isaac, M. (2011). The implications of climate policy for the impacts of climate change on global water resources. Glob. Environ. Change, 21, 592–603.

Arora, V. K. (2002). The use of the aridity index to assess climate change effect on annual runoff. Journal of Hydrology, 265 (1-4), 164–177.

Beare, S., Heaney A. (2002). Climate change and water resources in the Murray Darling Basin, Australia. Word Congress of Environmental and Resource Economists. p. 1-33.

Čadro, S., Uzunović, M., Žurovec, J., Žurovec, O. (2017). Validation and calibration of various reference evapotranspiration alternative methods under the climate conditions of Bosnia and Herzegovina. International

Soil and Water Conservation Research, 5(4), 309-324.
Choi, H.S., Schneider U.A., Rasche L., Cui J., Schmid E., Held H. (2015). Potential effects of perfect seasonal climate forecasting on agricultural markets, welfare and land use: A case study of Spain. Agric. Syst., 133, 177–189.
Čustović, H., Žurovec, O. (2011). Influence of soil water retention properties on hydrological cycle and water Budgeting module simulation. Agriculturae Conspectus Scientificus, 76(1), 65–69.
Fuhrer, J. (2003). Agro-ecosystem responses to combinations of elevated CO2, ozone and global climate change. Agriculture, Ecosystems and Environment, 97, 1–20.
Groisman, P., Ya., Knight, R.W., Easterling, D.R., Karl, T.R., Hegerl, G. C., Razuvaev, V.N. (2005). Trends in intense precipitation in the climate record. J. Climate, 18 (9), 1343– 1367.
Iglesias, A., Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management , 155, 113–124.
Povilaitis A., Lamsodis R., Bastiene N., Rudzianskait□ A., Misevičiene S., Miseckaite O., Gužys S., Baigys G., Grybauskiene V., Balevičius G. (2015). Agricultural drainage in Lithuania: a review of practices and environmental effects: Acta Agric. Scandinavica, Section B- Soil & Plant Sci. 65 (1), 14-29.
Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., Pounds, A. J. (2003). Fingerprints of Global Warming on Wild Animals and Plants. Nature, 421, 57–60.
Salvati, L., Zitti, M., Di Bartolomei, R., Perini, L. (2013). Climate aridity under changing conditions and implications for the agricultural sector: Italy as a case study. Geography Journal, 2013.
Simonovic, S.P., Li L. (2004). Sensitivity of the Red River Basin flood protection system to climate variability and change. Water Resources Management, 18(2), 89-110.
Some'e, B.S., Ezani, A., Tabari, H. (2013). Spatiotemporal trends of aridity index in arid and semi-arid regions of Iran. Theoretical and applied climatology, 111(1-2), 149-160.
Soussana, J. F., Luscher, A. (2007). Temperate grasslands and global atmospheric change: a review. Grass Forage Sc., 62, 127–134.
Thornthwaite, C.W. (1948). An Approach Toward a Rational Classification of Climate. The Geographical Review, 38, 55-94.
Thornthwaite, C.W., Mather, J. R. (1957). Instructions and Tables for Computing Potential Evapotranspiration and the Water balance, laboratory of Climatology, Publications in Climatology, 10 (3), pp 311.
Vlahinić, M. (2004). Land reclamation and Agrohydrological Monograph of Popovo Polje.
Wigley, T. M. L. (2009). The effect of changing climate on the frequency of absolute extreme events. Climate Change, 97, 67–76.

Spatio-temporal disintegration of different droughts in Nepal

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Abstract

Drought is an environmental disaster related to both meteorology and hydrology; the root cause of drought being the climate anomaly followed by human water use practices. Anomalies in climate result in meteorological and hydrological drought whereas human water use practice triggers agricultural and socio-economic drought. For efficient water resources management, it is important to quantify various forms of drought and disintegrate them based on their nature. This paper aims to characterize droughts based on the drought indices. For this, we used 41 years (1975-2015) data at stations across Nepal for characterizing meteorological drought. Standard Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) are used to measure the degree of drought severity. For all the stations, drought indices for four temporal scales are calculated. The temporal scales are one-month (SPI-1), 3-months (SPI-3), 6-months (SPI-6) and 12-months (SPI-12). Results showed that Dolpa has experienced drought compared to other stations; even though the severity and duration of the droughts are shorter. The intensity of SPI-3 is relatively lesser compared to SPI-6 and SPI-12 at all the stations. For Kaski and Dolpa, the year 1992 was one of the severe drought years where the severity crossed more than 2.0. Similarly, other stations have experienced drought beyond 2010 where the intensity of the drought severity is not much. The analysis of the PDSI reveals that all stations experience a certain degree of drought for most of the period. Some stations are also experiencing a higher degree of severity. The results can further be utilized for planning water resource and irrigation water management systems.

Keywords: *drought; irrigation water; Palmer Drought Severity Index; Standardized Precipitation Index; water resource management*

1. Introduction

Drought is considered as the natural hazard that is related to hydrology, meteorology, land use and water resource infrastructure. Those droughts are termed as hydrological, meteorological, agricultural and socio-economic droughts, respectively (Mishra and Singh, 2010; Rivera et al., 2017; Zargar et al., 2011).

Meteorological drought is defined as the lack of precipitation over a region for a longer period whereas hydrological drought is related with water supply being low in streams, reservoirs and groundwater levels, usually after a long period of meteorological drought (Duan and Mei, 2014). Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources while socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (Tallaksen and Lanen, 2004, Leng et al., 2015). The effect of the drought is diverse. It affects different sectors and causes huge economic losses thereby threatening the life of human and imbalance in the ecosystem (Bayissa et al., 2017). Being unknown of the onset and termination of the drought, the event is difficult to pinpoint and analyze. The way of quantitatively analyzing the drought is through the estimation of the drought indices. The different types of the drought indices are defined in Khanna (2010); Mishra and Singh (2010); and Vicente-Serrano et al. (2012). Standardized Precipitation Index (SPI) is used to evaluate the status of the meteorological drought in Nepal by a few earlier studies (Sigdel and Ikeda, 2011; Dahal et al., 2016)

The objective of this research is to disintegrate different types of droughts in Nepal over spatial and temporal scales. Nepal being an agricultural country, the amount of rainfall, time of sunshine duration and the runoff volume in streams play an important role in agricultural production. Lack of managed irrigation water systems such as irrigation canals, reservoirs and dams, gates and sluices always have an impact on the amount of crop production. An insufficient number of meteorological, hydrological and water resources infrastructures make it more difficult to deal with droughts. Irregularity in monsoon has also acted as a catalyst for poor yield in crops. Thus, this research tries to point out which kind of drought was occurred in the specific area for the specific period. This will help water resource managers and irrigation actioners such as farmers and institutions that provide services for irrigation. Stating thus, we quantify the type of the drought existed earlier via drought index.

2. Study Area

The study area, Nepal, lies in between $80^0 04'$ and $88^0 12'$ East and $26^0 12'$ and $30^0 27'$ North. The country covers a total area of 147,181 km^2 ranging the elevation from 60m in the south to 8848m in the north thereby demonstrating high variability in climate pattern. Agriculture is the main occupation of the people in Nepal. Agriculture depends on the monsoon period and is dependent on the amount of the rainfall. Karnali, Narayani, Koshi and Bagmati are the major rivers that flow within the country with the high amount of the river flow in monsoon period thereby citing as one of the water tower of Asia. Nepal experiences four different seasons as per English calendar and six seasons as per Nepalese calendar. Monsoon (Barsha) season experiences almost 80% of the rainfall thus leaving remaining three seasons as moderate and lesser rainfall seasons. In the Terai (southern Nepal), summer temperatures exceed 37°C and higher in some areas, winter temperatures range from 7°C to 23°C in the Terai. In mountainous regions, hills and valleys, summers are temperate while winter temperatures can plummet below zero. Kathmandu, the capital of the country, has a pleasant climate with average summer and winter temperatures of 19°C – 35°C and 2°C – 12°C respectively.

3. Materials and Methods

The data required for the computation were obtained from Department of Hydrology and Meteorology (DHM), Kathmandu, Nepal. Monthly temperature and precipitation data for 41 years (1975-2015) were

collected for the analysis. The missing precipitation data were filled using average station approach whereas missing temperature data were filled using linear interpolation. Fig.s 1 and 2 show the temporal and spatial distribution of monthly precipitation for the period of 41 years across respectively.

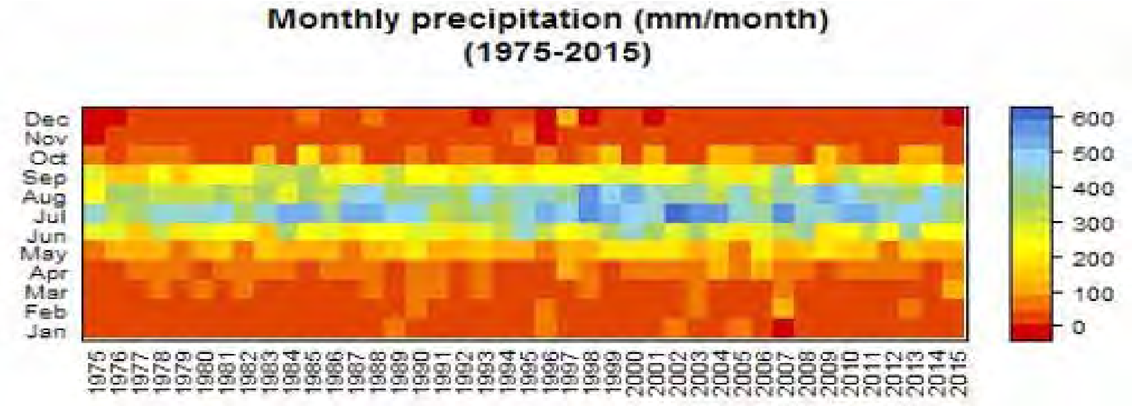


Figure 1: *Temporal distribution of monthly precipitation (mm/month) for 975-2015*

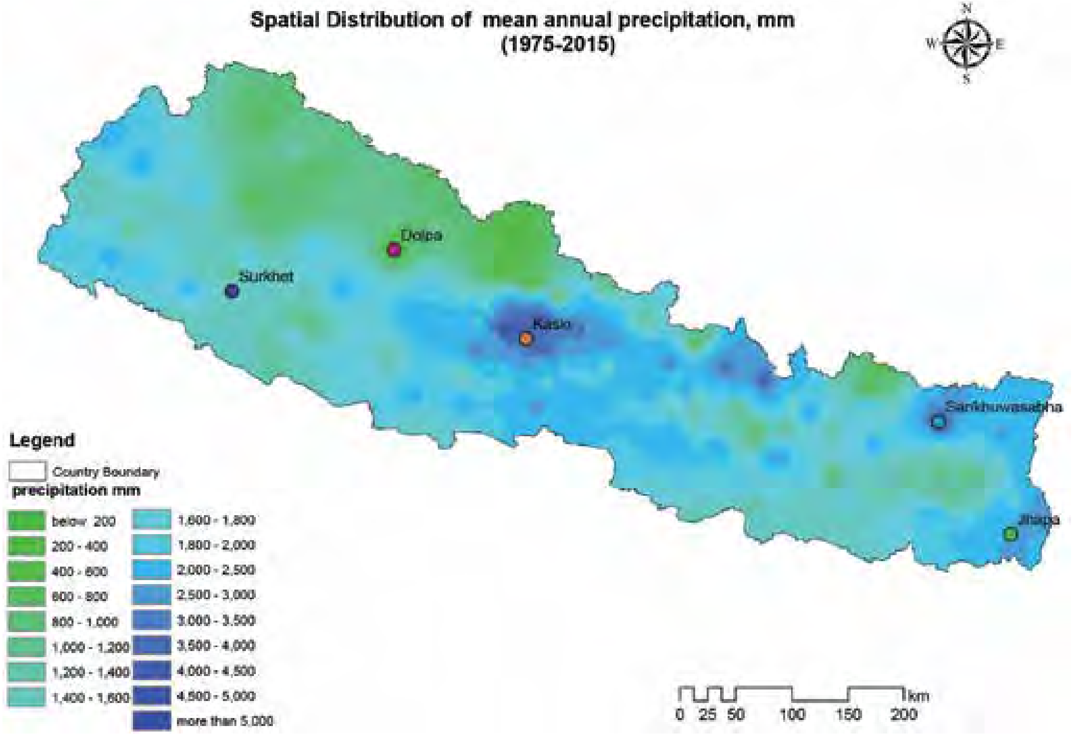


Figure 2: *Spatial distribution of annual precipitation (1975-2015)*

4. Drought Indices

Standardized Precipitation Index (SPI) is the widely used drought indices developed by (Mckee, Doesken and Kleist, 1993).The application of SPI is not only limited to drought but also used for frequency analysis and climate impact studies. As per the recommendation of the World Meteorological Organization (WMO), SPI is also termed as meteorological drought index as precipitation is the major influencing climatic parameter (Hayes, 2002).The SPI is defined as the number of standard deviations that observed cumulative precipitation deviates from the climatological average. The index value of SPI spans from -2 (dry) to +2 (wet). The index shows a different degree of severity as represented in Table 1.

Table 1: *Degree of severity based on SPI and PDSI values*

Category	Values
SPI	
Extremely wet	>= 2.00
Severely wet	1.50 ~ 1.99
Moderately wet	1.0 ~ 1.49
Near normal	-0.99 ~ 0.99
Moderate drought	-1.0 ~ -1.49
Severe drought	-2.00 ~ -1.50
Extreme drought	<= -2.00

Category	Values
PDSI	
Extreme wet	>= 4.00
Severe wet	3.00 to 3.99
Moderate wet	2.00 to 2.99
Mild wet	1.00 to 1.99
Incipient wet	0.50 to 0.99
Normal	0.49 to -0.49
Incipient drought	-0.50 to -0.99
Mild drought	-1.00 to -1.99
Moderate drought	-2.00 to -2.99
Severe drought	-3.00 to -3.99
Extreme drought	<= -4.00

(Source: Yang et al., 2017 for PDSI values)

The Palmer Drought Severity (PDSI) is a drought index that uses precipitation and evapotranspiration (or temperature, for computing potential evapotranspiration using method suggested by Thronwaite) and thereby estimates the supply and demand in two-layer soil model prior to use of only precipitation for the determination of SPI drought index (Heddinghaus and Sabol, 1991). The PDSI estimates relative dryness whose value spans from -10 (dry) to +10 (wet). Table 1 shows the degree of severity represented by PDSI values (Yang et al., 2017). The precipitation and temperature data provided by DHM and soil moisture depth from SOTER soil map and Food and Agricultural Organization (FAO) soil database were used for the computation. The temperature and precipitation for 31 years (1985-2015) were used in the analysis. Five different spatially located stations (Dolpa, Sankhuwasabha, Surkhet, Kaski and Jhapa) were chosen based on the intensity of the precipitation and temperature variability for the analysis. We used self-calibrating PDSI (Wells, 2003) developed by the National Agricultural Decision Support System, University of Nebraska-Lincoln as a computation tool. The tool is written on FORTRAN program and distributed for windows OS.

5. Results and Discussions

5.1 SPI calculation

SPI on four-time scale were plotted for 41 years (1975-2015) as shown in Fig. 3. The figure depicts the temporal distribution of SPI in four-time scales of 1, 3, 6, and 12 months, respectively. The average precipitation of all the stations were calculated and used for SPI calculation. The figure depicts that for all the SPI months, the year between 1992-2007 is wet whereas for the period before 1980 all SPI months it is dry. The high severity in the drought before 1980s might have caused because the precipitation values for some months were recorded zero. We performed the SPI calculation using SPEI package in R-platform (Beguería et al., 2017).

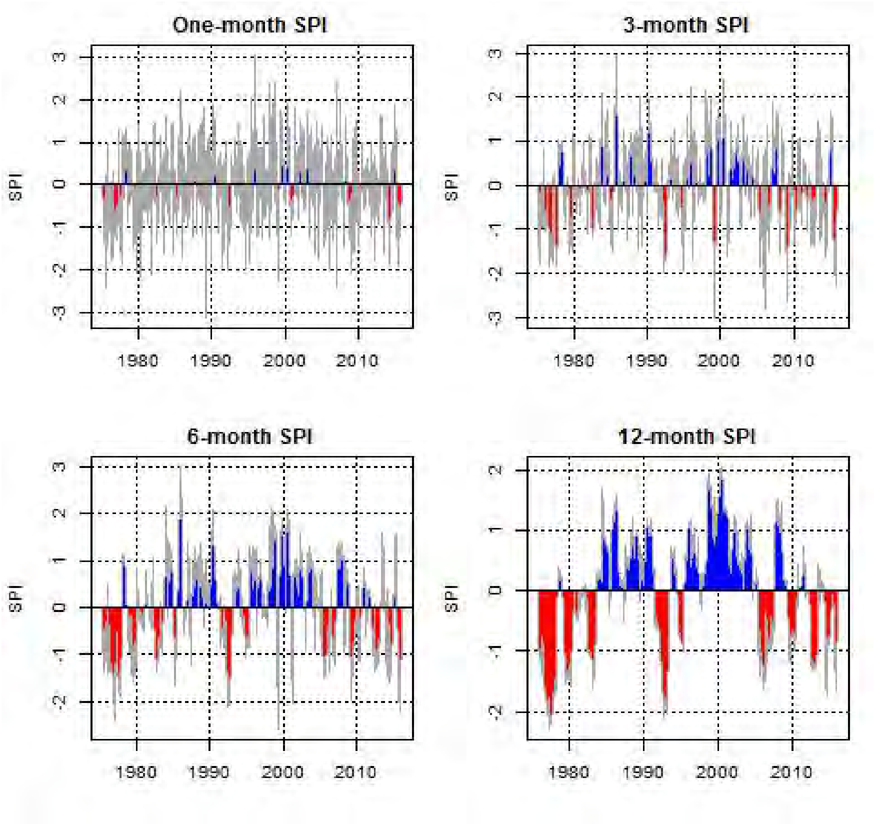


Figure 3: *SPI values for four different time scales*

For the analysis of the severity of the drought, we selected different regions based on the amount of the annual precipitation (shown in Fig. 2). Dolpa has low precipitation whereas Surkhet and Sankhuwasabha have moderate and high precipitations. The SPI values for 1, 3, 6 and 12-months for the five stations are shown in Fig.s 4-8. Temporal distribution of the SPI portrays that Dolpa is having a drought in between 2000 and 2010 with high severity of drought in 2002. Similarly, there is no severe drought in Sankhuwasabha for the past 41 years but the onset and termination of the drought are frequent i.e. it is in cyclic order.

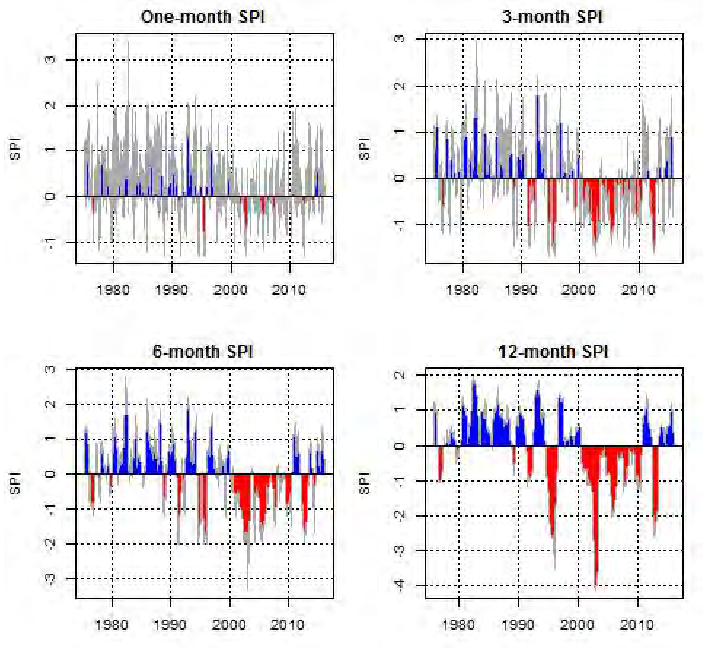


Figure 4: *Standardized precipitation index for Dolpa*

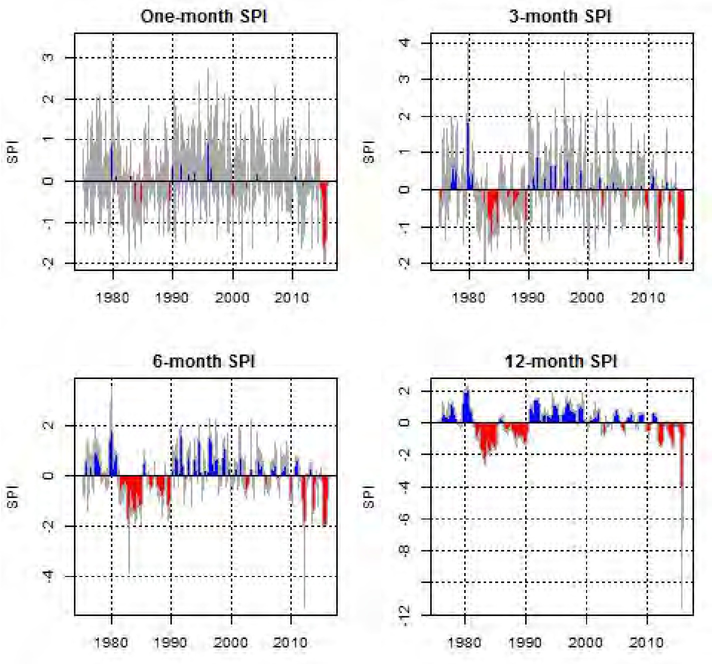


Figure 5: *Standardized precipitation index for Sanhuwasabaha*

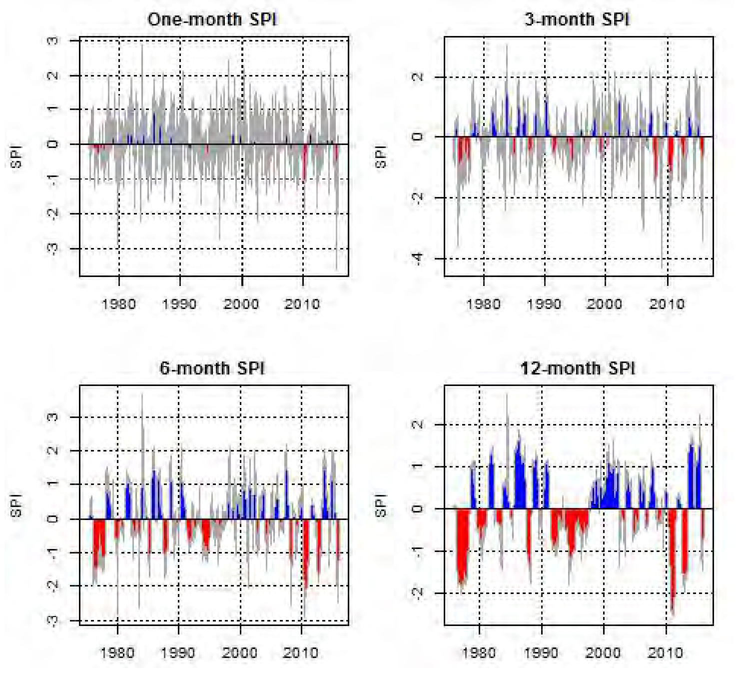


Figure 6: *Standardized precipitation index for Surkhet*

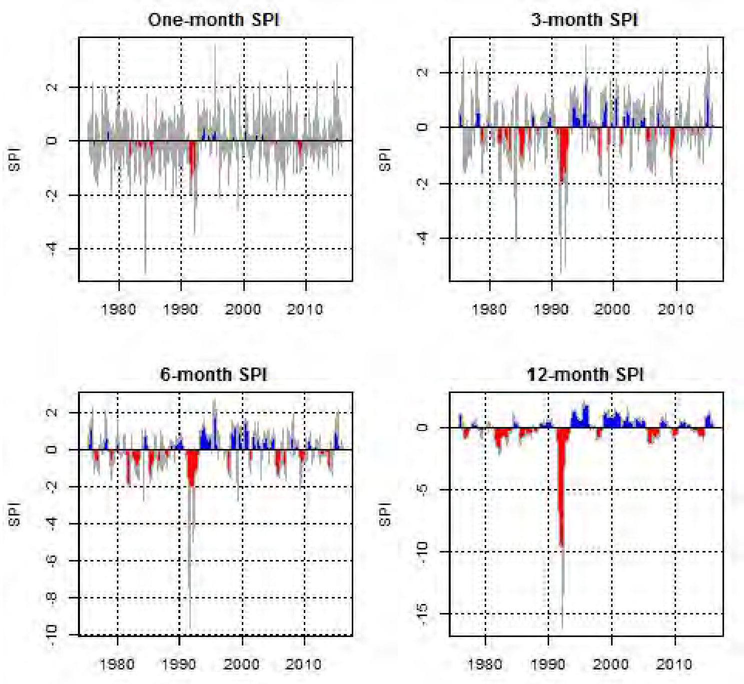


Figure 7: *Standardized precipitation index for Kaski*

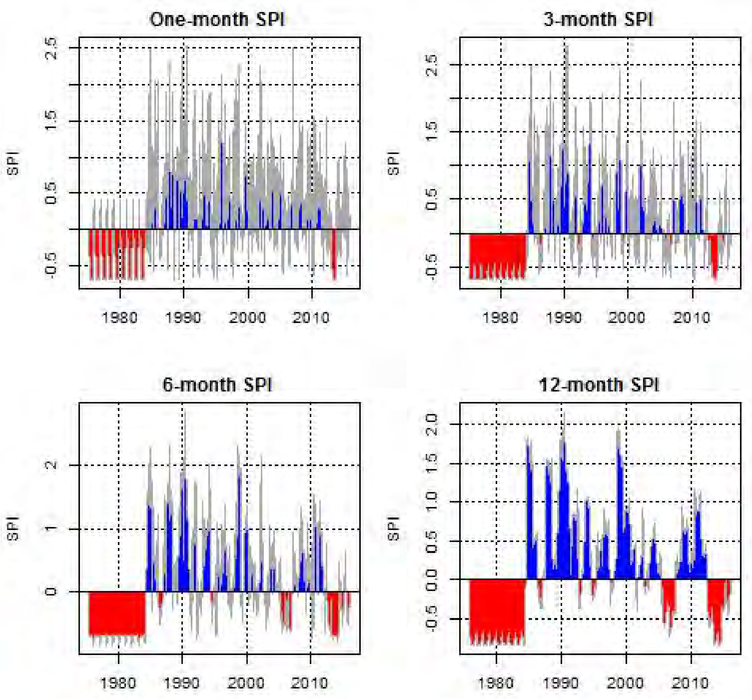
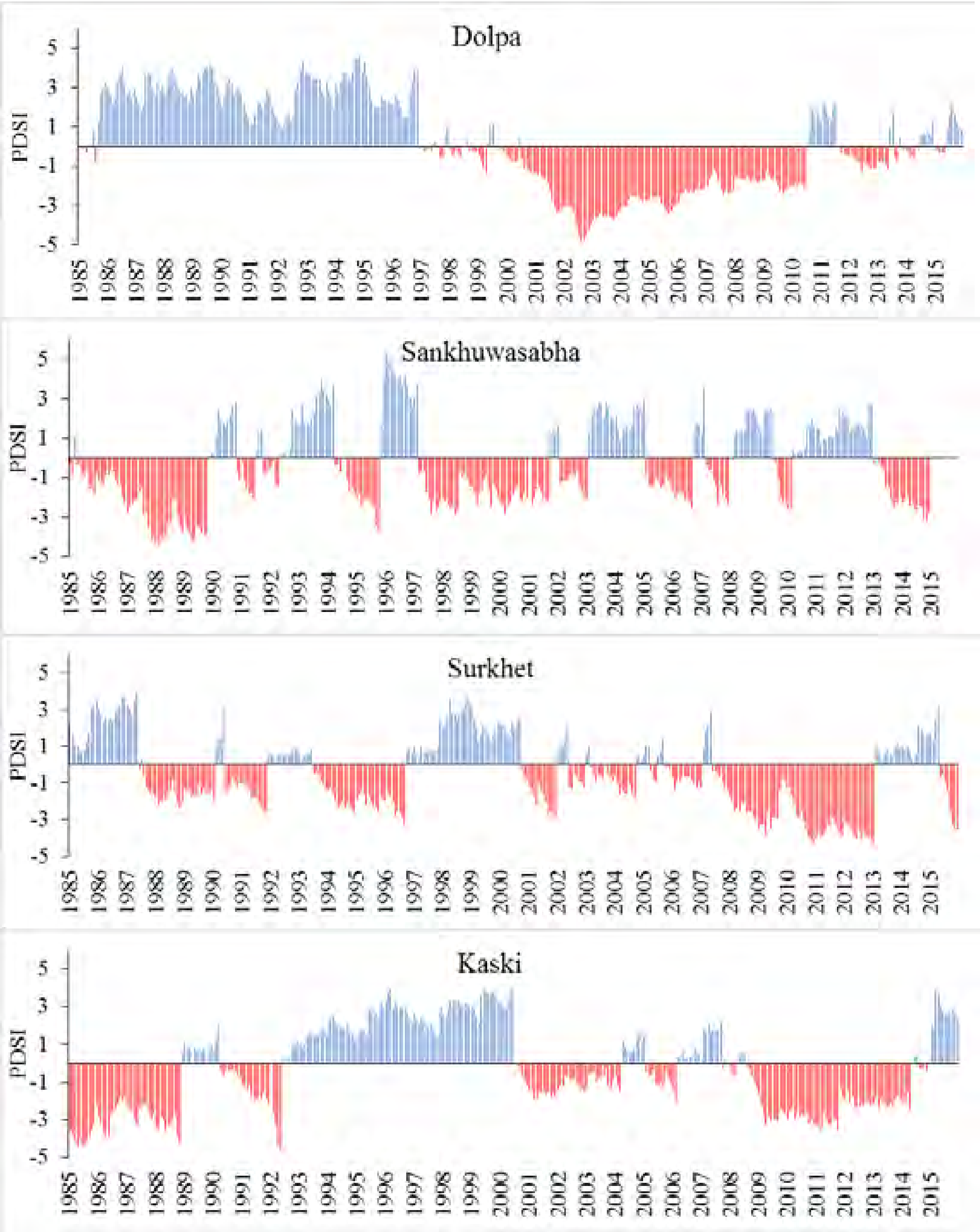


Figure 8: *Standardized precipitation index for Jhapa*

Surkhet area is having less time drought compared to other regions. It is observed that annual average precipitation at Kaski is high and at Jhapa is moderately high. For most of the monsoon period in between 1975-1985, the recorded precipitation is zero at Jhapa. It might be the reason for the drought for the first ten years in Jhapa. For other years, the case of severe drought is not observed in both Kaski and Jhapa regions. This fact reveals that these areas are having the possibility of rain-fed activities such as agriculture, hydropower production (where the head is available). Comparing all the regions, Dolpa is under drought but not the severe.

5.2. PDSI calculation

Results of this research reveal that at all the selected stations, the case of drought is more compared to the wet periods after 2000 as shown in Fig. 9. The case of extreme drought is relatively more for Dolpa and Jhapa. Jhapa is facing drought after 1990 almost all the time in 31 years of span. Though the drought is not too extreme, necessary actions are needed to be adopted for the watershed management and water resource management for sustainability. Results of both SPI and PDSI show that in the past, the observed stations were under the stage of drought to a certain level of intensity. Dahal et al. (2016) showed that the central Nepal, Gandaki basin, was under the tendency of drought in Nepal. Similarly, research conducted by (Wang et al., 2013) showed that the winter season droughts were more frequent in the western part of Nepal in the past.



Dolpa
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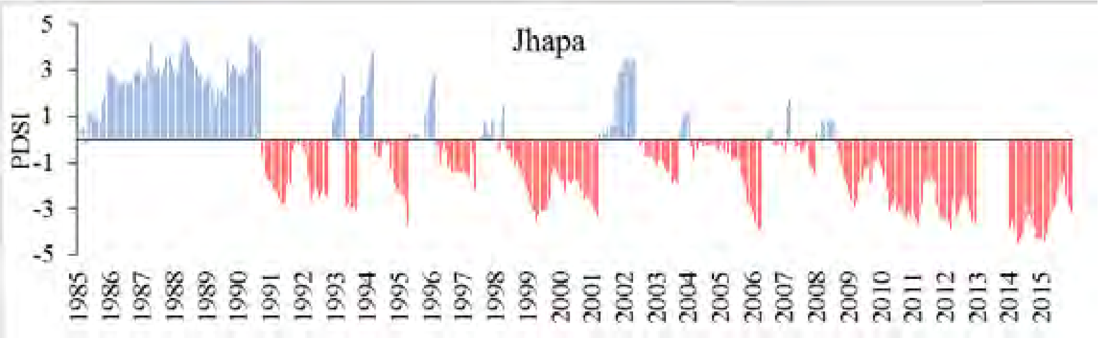

Figure 9: *Temporal distribution of PDSI at all the selected stations (1985-2015)*

6. Conclusions

Drought analysis for the selected stations of Nepal reveals that the situation of drought was not much severe in the past. But if the trend continues and proper mitigation approach is not adopted, the situation might lean towards severity and may cause an impact on water resource management. Hence, research on the drought impacted by climate change seems necessary.

7. Future Directions

In the future, we aim to disintegrate further different indices of drought throughout Nepal. This would help the planners and managers of the water resources to quantify the nature and status of the drought severity spatially, and further will strengthen temporal drought forecasting and consequently river basin management.

Acknowledgements: The authors would like to acknowledge DHM, Kathmandu, Nepal for providing climate data.

References

Bayissa, Y., Tadesse, T., Demisse, G., Shiferaw, A. (2017). Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia, Remote Sensing, 9(7), 1–17.

Beguería, S., Vicente-Serrano, S. M., Santiago Beguería, M. (2017). Calculation of the Standardised Precipitation-Evapotranspiration Index Description. Available at: http://sac.csic.es/spei (Accessed: 20 January 2018).

Dahal, P., Shrestha, N. S., Shrestha, M. L., Krakauer, N. Y., Panthi, J., Pradhanang, S. M., Jha, A., Lakhankar, T. (2016). Drought risk assessment in central Nepal: temporal and spatial analysis, Natural Hazards. Springer Netherlands, 80(3), 1913–1932.

Duan, K., Mei, Y. (2014). Comparison of Meteorological, Hydrological and Agricultural Drought Responses to Climate Change and Uncertainty Assessment, Water Resources Management, 28 (14), 5039–5054.

Hayes, M. (2002). Drought Indices, ppt, 23, p. 18. doi: 10.1002/joc.931.

Heddinghaus, T. R., Sabol, P. (1991). A Review of the Palmer Drought Severity Index and Where Do We Go from Here?, in Seventh conference on applied climatology. Available at: https://pdfs.semanticscholar.org/6951/2362983873d5a9ffbf816cd1d0ac014aa814.pdf (Accessed: 20 January 2018).

Khanna, M. (2010). Hydrological Drought Indices, Water Technology Centre, Indian Agricultural Research Institute. Available at: http://www.wamis.org/agm/meetings/wies09/S62-Khanna.pdf%5Cnfile:///K:/guilherme.mohor/OneDrive/SHS/Paper-Capitulo-2/Referencias/List of indices.pdf.

Leng, G., Tang, Q., Rayburg, S. (2015). Climate change impacts on meteorological, agricultural and hydrological droughts in China, Global and Planetary Change. Elsevier B.V., 126, 23–34.

Mckee, T. B., Doesken, N. J., Kleist, J. (1993).The relationship of drought frequency and duration to time scales, Eighth Conference on Applied Climatology, pp. 17–22. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.4342&rep=rep1&type=pdf (Accessed: 20 January 2018).

Mishra, A. K., Singh, V. P. (2010). A review of drought concepts, Journal of Hydrology. Elsevier B.V., 391(1–2), 202–216.

Rivera, J. A., Penalba, O. C., Villalba, R., Araneo, D. C. (2017). Spatio-temporal patterns of the 2010-2015 extreme hydrological drought across the Central Andes, Argentina, Water (Switzerland), 9(9), 1–18.

Sigdel, M., Ikeda, M. (2011). Spatial and Temporal Analysis of Drought in Nepal using Standardized Precipitation Index and its Relationship with Climate Indices, Journal of Hydrology and Meteorology, 7(1), 59–74.

Tallaksen, L. M., Lanen, H. A. J. van (2004).Hydrological drought : processes and estimation methods for streamflow and groundwater. Elsevier.

Vicente-Serrano, S. M., López-Moreno, J. I., Beguería, S., Lorenzo-Lacruz, J., Azorin-Molina, C. and Morán-Tejeda, E. (2012). Accurate Computation of a Streamflow Drought Index, Journal of Hydrologic Engineering, 17(2), 318–332.

Wang, S. Y., Yoon, J. H., Gillies, R. R., Cho, C. (2013). What caused the winter drought in western nepal during recent years?, Journal of Climate, 26(21), 8241–8256.

Wells, N. (2003). PDSI Users Manual , National Agricultural Decision Support System, University of Nebraska-London.

Yang, M., Xiao, W., Zhao, Y., Li, X., Lu, F., Lu, C., Chen, Y. (2017). Assessing agricultural drought in the anthropocene: A modified Palmer drought severity index, Water (Switzerland), 9(10)

Zargar, A., Sadiq, R., Naser, B., Khan, F. I. (2011). A review of drought indices, Environmental Reviews, 19, 333–349.

Agro-climatic atlas of Nepal: A tool for sharing climatic information for agricultural sector

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Abstract

Agro-climate zonation can provide better information for growing suitable crops as per the potential of the zones for maximum harvests. This study analysed 30 years (1986-2015) data from selected meteorological stations and interpolated spatially with due care for elevation as a dominant driver for the variability. The modified Thornthwaite's approach was carried out for the classification of agro-climates based on Soil Moisture Index (SMI). The annual SMI distribution is more or less analogous to the monsoon SMI distribution. Based on the annual SMI values, around 60 % of areal coverage falls under humid environment. SMI during monsoon season is undoubtedly higher compared to other seasons. As a common mountainous feature, the windward slopes of mountain receive higher precipitation compared to leeward sides and at the same time, air temperature during monsoon is quite high resulting in an increased evapotranspiration. Thus, on the leeward side of the mountainous areas lead to a lesser SMI values. The westerly-derived precipitation during the winter season is greater in the north-west. SMI also follows similar gradient resulting higher values in far western region whereas lower in the central and eastern region. The spatial variability of SMI in the country is attributed to the complex topographical settings and highly heterogeneous distribution of precipitation. The spatial and seasonal distribution of SMI can be helpful to assess the needs of the irrigational facility, choice of crops and their rotation, and finally to design the cropping calendar. This study has developed a tool in the form of the agro-climatic atlas of the country to present agro-climatic information. It is especially relevant to agricultural sectors, which might be helpful to agricultural commodity, practitioners, researchers and decision/policy-makers.

Keywords: *agro-climate; climatic classification; Nepal; soil moisture index*

1. Introduction

The purpose of climatic zonation is to organize a set of data or information about something to effectively communicate in an informative way. Climatic zonation can be done using various climate

elements. The aim, here, is directed towards agriculture. For any crop grown in an area, it is necessary to have information of physiography; availability of irrigational facilities and their types; soil types and their field capacities; and climatic characteristics of the area. The climatic zonation is necessary to identify features of climate that distinguish a region from neighbouring region, which helps to study the influence of a variety of climatic factors on human beings, animals and plant life confined to that particular area (Zaman and Rasul, 2004). The identification of climatic characteristics of a region helps in the assessment of the agro-climatic potential of the area; the plant and animal species suited to that area; selection of crop-varieties; and need of irrigational facilities and their types in order to achieve high yields.

In Nepal, Nayava (1975) classified the climates using Thornthwaite's model (Thornthwaite, 1931), which was further generalised into five major climatic groups based on humidity (i.e. wet, humid, sub-humid, semi-arid, and arid). The climatic data used in Nayava (1975) is limited to only 15 stations for a data period 1965-1969. Similarly, Jha and Karn (2001) classified the climates for the administrative districts of Nepal using the scheme of Thornthwaite (1948). The meteorological data of each administrative district was obtained from the book "Mechidekhi Mahakali' (HMG, 1975). Despite Koppen's method leaves undecided the problem of when the mountain climate exists, Karki *et al.* (2016) has classified the climates using Koppen-Geiger method (original and modified form), in a conjunction with a Spatial Interpolation (SI) taking into account the role of elevation. The climatic data used in Karki *et al.* (2016) is of 30 years (1981-2010) length for 240 stations for precipitation and 74 stations for air temperature. The study has attempted to use Thornthwaite's model to determine station-wise Soil Moisture Index (SMI) utilizing a large number of stations (75 stations, for the first time) for a recent 30-years (1986-2015) data distributed across the country. The SI used in this study has taken into consideration of elevation in order to replicate realistic spatial variation.

2. Material and Methods

2.1 Climate data

Daily data of 30 years (1986- 2015) period from the meteorological stations maintained by Department of Hydrology and Meteorology (DHM), Government of Nepal were utilized for the study. For a particular station, a year having data gap for more than 15 days were excluded from the analysis. After that, the data have been checked for outliers, errors and the sudden jump in the series. RclimDex was used for those aspects and homogeneity test was performed for monthly time series. For the present study, 71 stations are selected after the quality control. In addition to regular data of DHM, 4 high elevation stations data maintained by EVK2CNR (http://www.evk2cnr.org) with data availability for a shorter period of at least 5 years are also included in the analysis to fill the data gap in high altitude area from the network of DHM meteorological stations. The details of the meteorological stations (71 DHM stations and 4 EVK2CNR) used for the computation are presented in Table 1 and plotted in Figs. 1 and 2. This study is based on the values of monthly mean air temperature and precipitation data derived from daily data. In Nepal, four distinct climatic seasons can be recognized characterizing precipitation patterns. They are pre-monsoon (Mar-May), monsoon (Jun-Sep), post-monsoon (Oct–Nov) and winter (Dec–Feb). Therefore, seasonal and yearly analyses are carried out to develop agro-climatic atlas.

***Table 1**: Description of stations*

SN	Station Name	Lon (deg)	Lat (deg)	Elev (m)	SN	Station Name	Lon (deg)	Lat (deg)	Elev (m)
1	Dadeldhura	80.58	29.30	1848	39	Gorkha	84.62	28.00	1097
2	Mahendra Nagar	80.22	29.03	176	40	Chapkot	83.82	27.88	460
3	Chainpur(West)	81.22	29.55	1304	41	Malepatan (Pokhara)	84.12	28.12	856
4	Silgadhi Doti	80.98	29.27	1360	42	Lumle	83.80	28.30	1740
5	Tikapur	81.12	28.53	140	43	Khairini Tar	84.10	28.03	500
6	Dhangadhi(Atariya)	80.55	28.80	187	44	Chame	84.23	28.55	2680
7	Godavari(West)	80.63	28.87	288	45	Rampur	84.42	27.62	256
8	Dipayal (Doti)	80.77	29.10	652	46	Daman	85.08	27.60	2314
9	Jumla	82.17	29.28	2300	47	Hetaunda N.F.I.	85.05	27.42	474
10	Dipal Gaun	82.22	29.27	2310	48	Simara Airport	84.98	27.17	130
11	Simikot	81.83	29.97	2800	49	Parwanipur	84.97	27.07	115
12	Dunai	82.92	28.93	2058	50	Nuwakot	85.17	27.92	1003
13	Pusma Camp	81.25	28.88	950	51	Kakani	85.25	27.80	2064
14	Dailekh	81.72	28.85	1402	52	Godavari	85.40	27.58	1400
15	Chisapani(Karnali)	81.27	28.65	225	53	Khumaltar	85.33	27.67	1350
16	Surkhet(Birendra Nagar)	81.62	28.60	720	54	Kathmandu Airport	85.37	27.70	1337
17	Khajura (Nepalganj)	81.57	28.10	190	55	Panchkhal	85.63	27.68	865
18	Nepalgunj(Reg.Off.)	81.62	28.07	144	56	Dhunibesi	85.18	27.72	1085
19	Rani Jaruwa Nursery	81.35	28.38	200	57	Panipokhari(Kathmandu)	85.33	27.73	1335
20	Sikta	81.78	28.03	195	58	Nagarkot	85.52	27.70	2163
21	Tulsipur	82.30	28.13	725	59	Jiri	86.23	27.63	2003
22	Salyan Bazar	82.17	28.38	1457	60	Janakpur Airport	85.97	26.72	90
23	Chaur Jhari Tar	82.20	28.63	910	61	Manusmara	85.42	26.88	100
24	Musikot(Rukumkot)	82.48	28.63	2100	62	Okhaldhunga	86.50	27.32	1720
25	Ghorai (Dang)	82.50	28.05	634	63	Phatepur	86.93	26.73	100
26	Jomsom	83.72	28.78	2744	64	Rajbiraj	86.75	26.55	91
27	Thakmarpha	83.70	28.75	2566	65	Pakhribas	87.28	27.05	1680
28	Baglung	83.60	28.27	984	66	Dhankuta	87.35	26.98	1210
29	Butwal	83.47	27.70	205	67	Biratnagar Airport	87.27	26.48	72
30	Bhairahawa Airport	83.43	27.52	109	68	Tarahara	87.27	26.70	200
31	Dumkauli	84.22	27.68	154	69	Taplejung	87.67	27.35	1732
32	Khanchikot	83.15	27.93	1760	70	Kanyam Tea Estate	88.07	26.87	1678
33	Taulihawa	83.07	27.55	94	71	Gaida (Kankai)	87.90	26.58	143
34	Tamghas	83.25	28.07	1530	72	Pyramid *	86.82	27.97	5050
35	Simari	83.75	27.53	154	73	Namche *	86.82	27.92	3560
36	Khudi Bazar	84.37	28.28	823	74	Pheriche *	86.72	27.80	4258
37	Pokhara Airport	84.00	28.22	827	75	Lukla *	86.72	27.70	2660
38	Syangja	83.88	28.10	868		* : EVK2CNR Station			

2.2 Classification method

A wide range of approaches exists in the literature for climate classification. The modern climate classifications really began, and continue to this day, with the work of Wladimir Köppen (Köppen, 1900). The known climatic classifications include that of Basalirwa (1995),Geiger (1954), Köppen (1936), Kottek *et al.* (2006), Stern and DeHoedt (1999), Thornthwaite (1931, 1948), and many others. Among these Koppen's Classification (KC) and Thornthwaite's Classification (TC) have been widely accepted. Broadly, their classifications are based on average values of temperature and precipitation, but KC has limitations over the mountain climate. As Nepal is predominantly a mountainous country, TC is used. The main emphasis of KC is on the temperature limits, whereas TC on the effectiveness of rainfall. As soil forming processes are related to water surpluses and deficiencies (estimated with due consideration for soil moisture), TC has been preferred to other classification schemes by many soil scientists (Kyuma, 1971).

Thornthwaite (1948) introduced Potential Evapotranspiration (PET) and soil-moisture factor for climatic classification. Due to the complexity of soils in many areas, the combined index based on soil and climate might be difficult to use in classification. Reddy and Reddy (1973) proposed some modification to TC hereafter called modified Thornthwaite's Approach. In this method, the soil-term was eliminated in the computation of SMI using PET and Mean Monthly Precipitation (MMP) in monthly basis.

$$SMI = 100\ \frac{MMP-PET}{PET} \qquad (1)$$

Thornthwaite (1948) derived an empirical relationship for estimating PET on monthly basis in limited data inputs.

$$PET = k\ \times 16\left(\frac{10T}{I}\right)^{a} \qquad (2)$$

where, PET is in mm/month for a day length of 12 hours and a month of 30 days, k is the adjustment factor [$k = No.of\ days\ in\ the\ month\ being\ calculated(N)/30$], T is the mean monthly air temperature, I is the heat index which represents the sum of 12 monthly indices and may vary from 0 – 160 and a is the empirical exponent for a given location which may vary from 0 – 4.25.

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514} \qquad (3)$$

$$a = 6.75\ \times\ 10^{-7}I^3 - 7.71\ \times\ 10^{-5}I^2 + 1.79\ \times\ 10^{-2}I + 0.49 \qquad (4)$$

where, T_i is the mean monthly air temperature (^{0}C) of the i^{th} month.

Using this method, the station-wise SMI was determined and then, SI was utilised to develop the spatial variation of SMI. The categories of agro-climatic classification based on SMI is shown in Table 2 which has been used for making the agro-climatic atlas of Nepal.

***Table 2**: Categories and symbols of different agro-climates and their SMI limits*

Categories	Symbol	SMI limits (%)
Arid	A	< - 50
Semi-Arid	SA	- 50 to - 25
Dry Sub-Humid	SH1	-25 to 0
Moist Sub-Humid	SH2	0 to 25
	H1	25 to 50
Humid	H2	50 to 75
	H3	75 to 100
	PH1	100 to 200
Per-Humid	PH2	200 to 400
	PH3	> 400

2.3 Spatial interpolation (SI)

SI of precipitation, temperature and SMI was carried out considering the elevation as one of the important variables in the interpolation along with longitude and latitude to account for potential elevational and geographical trends. SI is performed at 1 km x 1 km horizontal resolution by kriging technique in R *gstat* package (R Development Core Team, 2011). The elevation used here is from 30 m x 30 m resolution ASTER Digital Elevation Model (DEM) further resampled to 1 km x 1 km resolution. The interpolation method predicts a value for a location with no-data based on the spatial dependency (i.e. autocorrelation) of observed values (Aalto et al., 2013). A general model of the spatial variability can be expressed as (Høst, 1999):

$$Z = \mu + r_e \tag{5}$$

where, Z is the predicted value at a given location, μ is the deterministic function for a trend component and r_e is the stochastically locally varying but spatially dependent residual errors. The trend was fitted using the least-squares method:

$$Z(x,y,z) = \theta_0 + \theta_1 x + \theta_2 y + \theta_3 z \tag{6}$$

where, x, y and z are the longitude, latitude and elevation. A cross-validation scheme was incorporated in the SI. The observations were randomly split into independent calibration (70%) and validation data (30%). Please refer Karki et al. (2016) and Aalto et al. (2013) for the detailed explanation.

3. Results and Discussions

The spatial variations of Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) in Nepal are shown in Figs. 1 and 2, respectively.

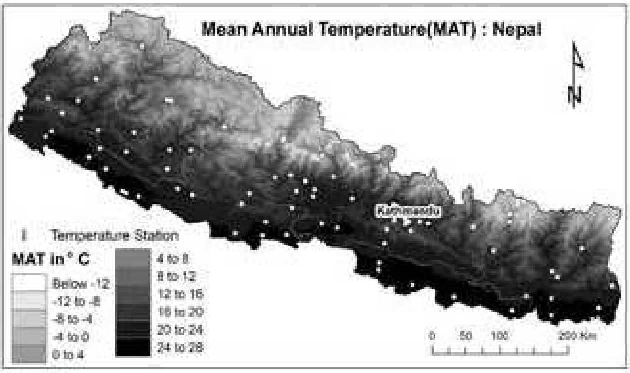

Figure 1: *Location of meteorological stations superimposed over spatial variation of MAT (^{0}C) in Nepal [1986-2015]*

Those patterns are broadly congruent with earlier studies (DHM/GoN, 2013, 2015; ICIMOD, 1996; Karki *et al.*, 2016; and Talchabhadel *et al.*, 2018). The variation of air temperature in the local features such as valley and mountains are well captured with SI. The North-South gradient of air temperature following the pattern of elevation is clearly depicted.

All the 3 high rainfall pockets presented in Karki et al. (2016) are not visible in this study but an overall pattern has been well captured. This is due to the fact that only 75 stations with both the parameters (i.e. precipitation and temperature) are used in this study. In the case of Karki et al. (2016), 240 precipitation stations were used to generate MAP distribution. The complex topographical setting of the country leads to a highly heterogeneous spatial distribution of precipitation. In general, the country receives more rainfall in the eastern region compared to the western region. As a common feature in mountainous terrain, the windward sides of the mountain receive higher precipitation compared to leeward sides.

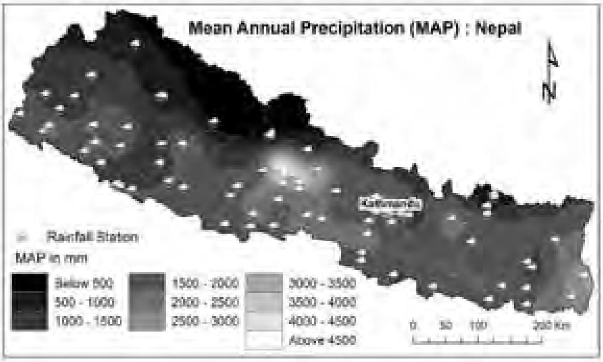

Figure 2*: Location of meteorological stations superimposed over spatial variation of MAP (mm) in Nepal [1986-2015]*

The results may not be well represented for higher mountains due to lack of data. The precipitation distribution is controlled by many factors besides elevation such as latitude, longitude, steepness of slope and orientations, the monsoonal system (east to west summer monsoon and west to east winter monsoon in context of Nepal), diurnal reversal of mountain wind flow and many others. To some extent, the data gap has been partially fulfilled by 4 higher elevation stations maintained by EVK2CNR in the eastern region of the country.

Based on the SI of SMI, an atlas of agro-climatic classification is presented in Fig. 3. The figure shows that three broad categories of agro-climate exist in Nepal. They are Sub Humid (SH1, SH2), Humid (H1, H2, and H3) and Per Humid (PH1). The study shows there are no locations with Arid (A) environment.

In a seasonal scale, humid to perhumid agro-climates are dominant in monsoon whereas semiarid to subhumid agro-climates are dominant in other seasons (i.e. pre-monsoon, post-monsoon and winter). Almost 80% of the precipitation in the country comes with warm and moist south-easterly winds from the Bay of Bengal in the form of summer monsoon precipitation. The annual SMI distribution is more or less analogous to the monsoon SMI distribution. Based on the annual SMI values, around 60 % of areal coverage falls under humid environment.

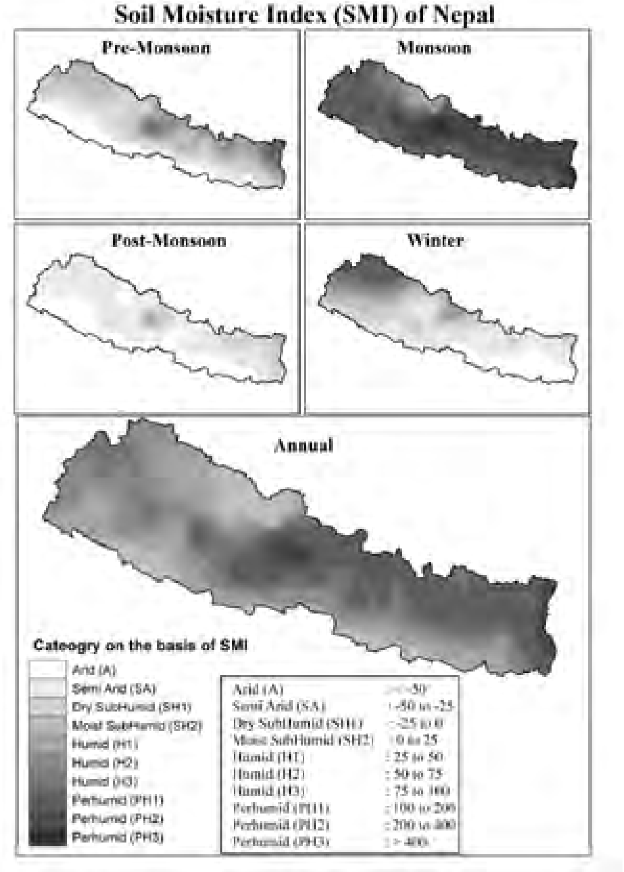

Figure 3: *Spatial variation of SMI in Nepal [1986-2015]*

SMI during monsoon season is undoubtedly higher compared to other seasons. The spatial distribution of SMI in monsoon shows highly heterogeneous distribution. The east-west gradient of summer monsoon precipitation is dominant as a result of which SMI has also a similar gradient. Additionally, as the moisture bearing monsoonal wind approaches Nepal from the south-east in SM season, heavier precipitation falls in the foothills of the mid-mountains and hills which are higher on the windward side and lower in the leeward side and river valleys. The lowest precipitation in Nepal is in Manang, Mustang and Dolpa region located at leeward sides of the mountain range as a result of which SMI values are also less (as can be seen in Fig, 3). Due to topographical locations with series of ranges of the mountain such as *Churia* in south and *Mahabharat* range in North, the precipitation enhances in windward sides and the leeward sides are barren. Such patterns result in double peak rainfall band in North-South sections. But at the same time, the air temperature during monsoon is quite higher and especially in river valleys resulting in an increased evapotranspiration. Thus, on the leeward side of the mountainous areas and around valleys, the values of SMIs are very low. Such patterns are seen in the study. The local effects of the broken topography of mountainous regions have been reflected in the study by utilizing SI.

In pre-monsoon, the country frequently experiences localized thunder shower due to the strong heating, moisture supply from local or other large-scale sources and orographic upliftments. In winter, the country experiences few spells of precipitation caused by extra-tropical cyclones, termed western disturbances, with the moisture supply from the Mediterranean, the Caspian, and the Arabian Sea. Since the system moves from the west towards the east guided by the upper air Rossby wave flow of mid-latitude, high mountains of the west are under the high influence of this system, resulting in the northwest to southeast precipitation gradient. SMI also follows similar gradient resulting higher values in far western region whereas lower values in the central and eastern region. Post-monsoon is generally dry and the temperature is also pleasant. The spatial variability of SMI in the country is attributed due to the complex topographical settings and highly heterogeneous distribution of precipitation.

To explore the monthly variability of SMI, monthly SMIs are shown in Fig. 4. As mentioned earlier, SMI is primarily following the pattern of precipitation distribution. Starting from the month of January, which is accompanied by cold temperature, the western region of the country is wetter than eastern region due to the west–east precipitation gradient of westerly disturbances. As the pre-monsoon starts, the eastern region becomes wetter from mid-March to early April and pronounces fully in the monsoon season. Monsoon enters from the eastern region of the country normally around the second week of June. The climate during these months from June to September is mostly hot and humid. The withdrawal of monsoon happens normally around the fourth week of September. As a result of which country experiences drier and cool environment in the month of October and November. From the start of December, the cold and chilling winter starts and the country again experiences few spell of precipitations from westerly disturbances. The typical monthly variations of SMIs of representative stations are shown in Fig. 5.

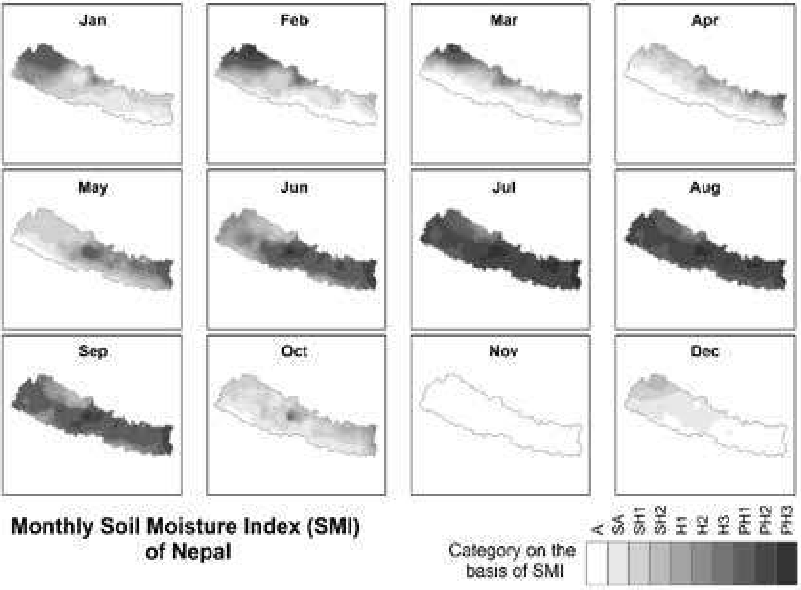

***Figure 4**: Spatial variation of monthly SMI in Nepal [1986-2015]*

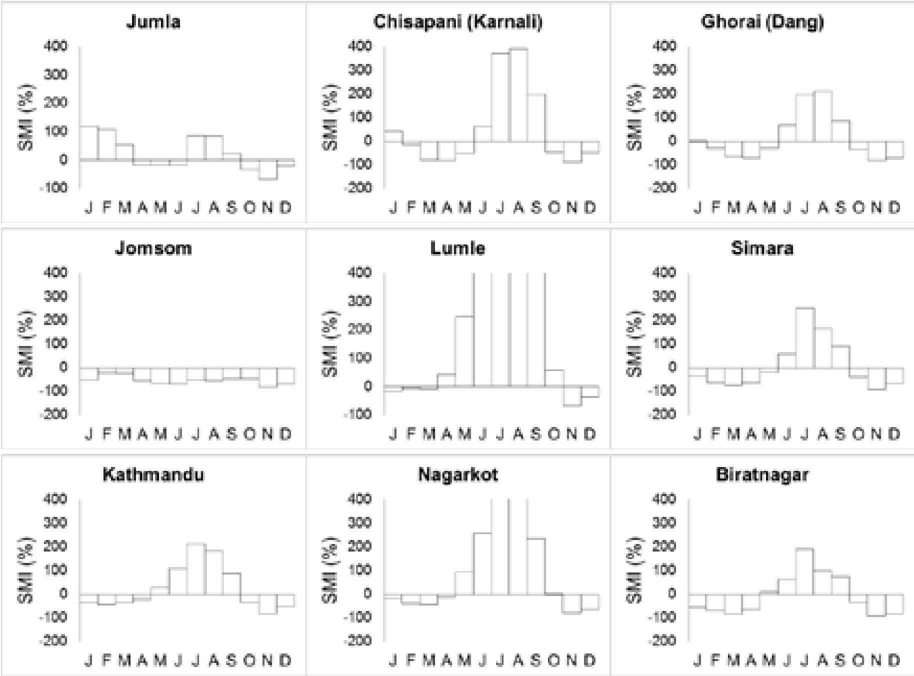

***Figure 5**: Mean monthly variation of SMI at selected stations in Nepal [1986-2015]*

Lastly, the areal coverage of different agro-climatic categories based on yearly SMI values and their elevation limits are presented in Table 3. In general, the country is dominantly in the humid environment. Due to the lack of meteorological stations in high elevation, the agro-climatic classification does not provide clear picture in high elevation areas. Importantly, the classification seems to provide a better general representation of agro-climates of Nepal.

***Table 3**: Categories, symbols, and areal coverage of different agro-climates in Nepal*

Categories	Symbol	Area (km^2)	Area (%)	
Arid	A	0.00	0.00	0.00
Semi-Arid	SA	0.00	0.00	0.00
Dry Sub-Humid	SH1	416.65	0.28	10.91
Moist Sub-Humid	SH2	15,649.29	10.63	
Humid	H1	30,059.15	20.42	59.20
	H2	33,887.05	23.02	
	H3	23,179.64	15.75	
Per-Humid	PH1	38,964.89	26.47	29.89
	PH2	4,983.11	3.39	
	PH3	41.23	0.03	

4. Conclusions

The modified Thornthwaite's Approach was applied for the classification of agro-climates in Nepal. Based on the classification, different types of agro-climates were observed in different seasons. The annual SMI distribution is more or less analogous to the monsoon SMI distribution. Based on the annual SMI values, around 60 % of the total area falls under humid environment. The spatial and temporal distribution of SMI can be helpful to assess the needs of the irrigational facility, choice of crops and their rotation, and finally to design the cropping calendar. This classification offers a powerful decision-making tool for other stakeholders; those directly or indirectly using the information in course of their respective business (construction, tourism, disaster risk reduction sectors etc.). This agro-climatic atlas developed here can serve as a valuable basis for the upcoming studies and research exploring the effects of change in agricultural practice and irrigational interventions in vegetation.

5. Recommendations

It is suggested to use crop evapotranspiration (ETo) instead of PET for better results in relation to natural vegetation. The study has firstly determined station-wise SMI and then interpolated to develop the agro-climatic atlas of the country. Therefore, our analysis was restricted with the number of stations having both temperature and precipitation data. It would be better if the interpolated gridded air temperature

and precipitation were used to generate gridded variables and finally the agro-climatic map which would give a more realistic picture of the rainfall variability. As the SI is known to be very sensitive to the spatial coverage of the observation network, the quality of the analysis could be further improved by incorporation of data from more stations.

Acknowledgements: The authors would like to thank the Department of Hydrology and Meteorology (DHM), Government of Nepal, for the permission to use meteorological data.

References

Aalto, J., Pirinen, P., Heikkinen, J., Venäläinen, A. (2013). Spatial interpolation of monthly climate data for Finland: comparing the performance of kriging and generalized additive models. Theoretical and Applied Climatology, 112(1), 99–111.

Basalirwa, C.P.K. (1995). Delineation of Uganda into climatological rainfall zones using the method of principal component analysis. International Journal of Climatology, 15(10), 1161–1177.

DHM/GoN. (2013). Agro-climatic atlas of Nepal. Department of Hydrology and Meteorology (DHM), the Government of Nepal (GoN): Kathmandu, Nepal.

DHM/GoN. (2015). Study of Climate and climatic variation over Nepal. Department of Hydrology and Meteorology (DHM), the Government of Nepal (GoN): Kathmandu, Nepal.

Geiger, R. (1954). Klassifikation der klimate nach W. Köppen. In: Bartels J and Bruggencate P (eds) Landolt- Börnstein – Zahlenwerte und Funktionen aus physik, chemie, astronomie, Geophysik und Technik, Alte Serie 3, 603-607.

HMG. (1975). Mechidekhi Mahakali (I-IV Volumes). Department of Information, Ministry of Communication.

Høst, G. (1999). Kriging by local polynomials. Computational statistics & data analysis, 29(3), 295–312.

ICIMOD (1996). Climatic and hydrological atlas of Nepal. International Center for Integrated Mountain Development (ICIMOD): Kathmandu, Nepal.

Jha S., Karn, A. (2001) Climatic Analogues for the Administrative Districts of Nepal. Tribhuvan University Journal, 55-64.

Karki, R., Talchabhadel, R., Aalto, J., Baidya, S.K. (2016). New climatic classification of Nepal. Theoretical and Applied Climatology, 125(3–4), 799–808.

Köppen, W. (1900). Versuch einer Klassifikation der Klimate, Vorzugsweise nach ihren Beziehungen zur Pflanzenwelt [Attempted climate classification in relation to plant distributions]. Geographische Zeitschrift, 6, 593–611, 657–679.

Köppen, W. (1936). Das geographische System der Klimate. Handbuch der Klimatologie (c), 7–30.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259–263.

Kyuma K. (1971). Climate of South and Southeast Asia according to Thornthwaite's Classification Scheme. The Southeast Asian Studies, 9(1), 136-158.

Nayava, J.L. (1975). Climates of Nepal. The Himalayan Review, VII, 9–12.

R Development Core Team. (2011). R: a language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Australia.

Reddy, S.J., Reddy, R.S. (1973). A new method of estimation of water balance. International Symposium On tropical Meteoroligical Meeting. American Meteorological Society: Nairobi, Kenya, 277–280.

Stern, H., DeHoedt, G. (1999). Objective classification of Australian climates. 8th Conf. on Aviation, Range and Aerospace Meteorology. American Meteological Society: Dallas, Texas, 87–91.

Talchabhadel, R., Karki, R., Thapa, B.R., Maharjan, M., Parajuli, B. (2018). Spatio-Temporal Variability of Extreme Precipitation in Nepal. International Journal of Climatology.

Thornthwaite, C.W. (1931). The climates of North America according to a new classification. Geographical Review Review, XXXI, 633–655.

Thornthwaite, C.W. (1948). An Approach toward a Rational Classification of Climate. Geographical Review, 38(1), 55–94.

Zaman Q.U., Rasul G. (2004). Agro-Climatic Classification of Pakistan. Quarterly Science Vision. 9, 59-66.

Climate change and water management impact on crop production in Bangladesh

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Abstract

Bangladesh is an agricultural country with an area of 147,570 km^2. It has a population of 160 million with the highest density in the world. A majority of the population depends on agriculture and natural resources for their livelihoods. Climate of Bangladesh is tropical with a mild winter from October to March and a hot humid summer from March to June. Agriculture is the most vulnerable sector and its productivity depends on climatic factors. In Bangladesh, the average annual rainfall is about 220 cm which is not eventually distributed in space. Due to geographic location, the country is one of the most flood-prone areas in the world. Natural calamities, such as drought, flood, cyclone, tornadoes and tidal bores occur almost every year. Water logging is responsible for decreasing the productivity of agricultural land. For agricultural production, necessary water management practices such as irrigation, drainage, salinity, river bank conservation, and erosion are important to minimize the damage from natural calamities. Irrigation is an important input for crop production all over the country. Therefore, groundwater abstraction has increased. The northwestern part of Bangladesh is prone to drought. River bank erosion as well as flash flood is another problem during the rainy season. Production cost of major crops due to natural calamities is high in Bangladesh. Optimum use of water management practices plays an important role to increasing agricultural production. It is essential to identify the best water management practices considering the socioeconomic condition of farmers in Bangladesh. Therefore, efficient and effective water management systems are required to mitigate climate change effects on agricultural production in Bangladesh.

Keywords: *climate change; crop production; flood; irrigation; water management*

1. Introduction

It is well known that climate is an important and independent factor in agriculture due to its effect on crops in terms of quality and quantity (Neenu et al., 2013). Climatic factors like temperature, rainfall, sunshine and carbon dioxide are closely related with crop production. Water management is important to maximize crop production. Bangladesh is situated in the South Asian sub-continent. The country is

mostly flat with only few hills in the southeastern and the northeastern part. Generally, ground slopes of the country extend from the north to the south and the elevation ranging from sixty meters to one meter above Mean Sea Level (MSL) at the north boundary and at the coastal areas in the south (MoDMR, 2014).This country is particularly vulnerable to climate change because of its geographic location between the north Himalayan Mountains and southern edge of the Bay of Bengal (Nasreen, 2008).The international community recognizes that Bangladesh ranks high in the list of most vulnerable countries (Climate Change Cell, 2008). Global climate has been changing due to natural forcing as well as anthropogenic activities. Besides, frequent disasters like drought, flood, tornado, cyclone and tidal surge, this country is also susceptible to sea-level rise and large scale inundation of its low lying land due to global warming (MoEF, 2005).The country experience floods, cyclones, droughts, river bank erosions, salinity intrusions, tornados and other natural calamities that have adverse effect on agriculture, fishery, infrastructure, water and health (ADPC and BCAS, 2008). Climate change is posing multiple threats on the communities and affected people are unable to perform their agro-based productions and face other occupational risks (Nasreen et al., 2016). Depletion and degradation of land and water resources pose serious challenges to agricultural production to sustain livelihoods. Rice is the main staple food in Bangladesh. Its production has been a major concern in recent years due to changing climatic conditions. Water availability situation over the year compels Bangladesh to address issues like irrigation, flood control and drainage. Large volume of water is available during June to September. Therefore, water environment forces this country for irrigated agriculture supported by flood control measures and provision of drainage facilities.The focus will have to be on increasing agricultural and water productivity with efficient and optimal use of available resources. Lack of continuity in policy supports, withdrawal of surface water at upstream, lack of timely availability of fuel, oil and electricity for smooth operation of irrigation systems, funds and interest for maintenance of flood control, drainage and irrigation (FCDI) systems are the major constraints to address issues of irrigation, flood control and drainage systems development and operation (Ghani, 2016). This will require adoption of improved agriculture practices, bringing more area under irrigation along with modernization of existing irrigation systems and strengthening of irrigated agriculture. Access to irrigation and drainage will play a significant role to enable more resilient household income for farmers, especially the smallholder farmers, since reliable access to water for crops can reduce vulnerability (NENCID, 2017). Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact (Chartzoulakis and Bertaki, 2015). The objective of this review is therefore to focus on the changing trend of climatic factors and water management practice that has impacts on crop production in Bangladesh.

2. Geography and Climate of Bangladesh

Bangladesh is situated in the north eastern part of South Asia between 20°34' and 26°38' north latitudes and between 88°01' and 92°41' east longitudes bordered by India and Myanmar. It is located at the apex of the Bay of Bengal with an area of 147,570 km^2. It has 230 rivers including 57 trans-boundary rivers, among them 54 originate from India including three major rivers - the Ganges, the Brahmaputra and the Meghna. Monsoon flood inundation of about 20-25% area of the country is assumed beneficial for crops, ecology and environment; however, inundation of more than that causes direct and indirect damages and considerable inconveniences to the population (BWDB, 2012). The climate of Bangladesh is tropical with a mild winter from October to March and a hot humid summer from March to June. The average temperature across the country usually ranges between 11^{0}C and 29^{0}C in winter months and between 21^{0}C and 34^{0}C during summer months. Annual rainfall varies from 160 cm to 200 cm in

the west, 200 cm to 400 cm in the southeast, and 250 cm to 400 cm in the northeast (Rashid, 1991). It is noted that the mean annual temperature in Bangladesh is about 26°C, mean annual rainfall is 254 cm and maximum summer temperatures varies between 38°C and 41°C (BBS, 2009). Temperature has been increasing predominantly over the recent 21 years (1990-2010) than the past 63 years (1948-2010) and monthly minimum temperature has increased significantly during the winter season (Hasan and Rahman, 2013). The total rainfall is increasing during monsoon and post-monsoon seasons, while winter rainfall has a decreasing trend and pre-monsoon rainfall has no significant change (Basak et al., 2013). Rainfall patterns have already changed across Bangladesh (Ahmed and Hussain, 2009; Selvaraju et al., 2006) but the total annual rainfall of the country has largely remained unchanged (Choudhury et al., 2003; Mondal and Hossain, 2009; Rahman et al., 1997).

3. Water Management Practices for Crop Production in Bangladesh

Water management comprises irrigation and drainage, depending considerably on the environmental conditions like soil, crops and climate. Water is one of the most important inputs essential for crop production. Plants need water continuously during their life. It influences photosynthesis, respiration, absorption, translocation and utilization of mineral nutrients and cell division besides some other processes. Both its shortage and excess affect the growth and development of a plant directly and consequently its yield and quality. Irrigation and water conservation are among the strong measures being taken to increase agricultural production for a fast growing population amid climate change conditions. For plants to grow well there has to be sufficient supply of water in the soil all the time. Normally this need is fulfilled by rain but when there is inadequate rainfall and insufficient water within the root zone area of the crops they wilt and die. During times of rain scarcity, the farmer must artificially supply irrigation water into the root area of the crops for sustainable growth of plant (Ssali, 2017). The area under cultivation and agricultural productivity are higher in the flood-prone districts of Bangladesh. Productivity increases during normal floods and in the post-flood months, while yield decline when floods assume extreme (Banerjee, 2010).

There are several issues that have connection with water management in changing adverse effects of global climatic conditions for crop production. The following sections have discussion some of them on water management system in Bangladesh.

3.1 Floods

Bangladesh has been facing prolonged and repeated floods in the northern and central regions (BCAS, 2008) with one-fifth of the country normally flooded each year. Over 35% of the country is submerged during extreme floods (Ahasan et al., 2010; *Banerjee, 2010*). This country receives an average rainfall of 2200-2500mm/y with most of the rainfall (80%) occurring during the monsoonal season (Hussain, 2004).Coastal flooding is common in Bangladesh due to high river discharge, low drainage capacity, and backwater effects with tidal surges from the Bay of Bengal (Ahmed and Diana, 2015). This is a land of rivers and heavy monsoon rains that subject to inundation by over bank spills due to drainage congestion, rainfall run-off and storm-tidal surges (Hossain et al., 1987; Milliman et al., 1989). With such high-intensity rains, floods are a normal occurrence with occasional high-intensity flooding inundating as much as 70% of the country's land mass. This is aggravated by the low and flat topography of the delta area (Okwany et al., 2016).

3.2 Drought

Drought is a lack of sufficient water to support satisfactory plant growth. The northwestern part of Bangladesh is prone to drought mainly due to rainfall variability in the pre-monsoon and the post-monsoon periods. Inadequate pre-monsoon showers, a delay in the onset of the rainy season or an early departure of the monsoon may create drought conditions in Bangladesh and adversely affect crop production. Since it puts severe strain on the land potential, it acts as a catalyst of land degradation through reduced soil moisture and water retention, increased soil erosion, decline in soil organic contents and overexploitation of sparse vegetation (MoEF, 2005).

3.3 River bank erosion

River bank erosion is a serious cause of land loss in Bangladesh. Every year large areas along riverbanks erode mainly during the monsoons taking away crop land, vegetation and human settlements creating acute socio-economic problems. There are many factors that may be responsible for riverbank erosion. Bank erosion is caused mainly due to strong river current enhanced by mechanized river traffic and/or channel diversion during the rainy season. About 1.7 million hectares of floodplain areas are prone to river bank erosion. The unique, natural geographic setting, the behavior of an alluvial channel, together with characteristics of the tropical monsoon climate, is mainly responsible for these ravages. An enormous volume of water comes from the melting of ice in the Himalayan range (Islam, 1986). River bank erosion results in displacement of people, who lose stability in their lives and social status (CUS, 1988).

3.4 Sedimentation over agricultural land

Another form of land degradation is deposition of sandy materials on agricultural land particularly in pediment areas of northern district. Land degradation by deposition of infertile soil on agricultural land also occurs by breach of embankment during floods. The soils eroded from the hills are usually deposited in the downstream areas. Siltation in the floodplains also contributes towards degradation of land due to flashflood and sediments accumulated from riverbank erosion. This phenomenon is the result of deforestation of the hills and faulty cultivation practice in the upper catchments areas (MoEF, 2005). The sediment transport is found up to 200×10^6 tons, the third highest yearly sediment load in the world (Schumm and Winkley, 1994). Bangladesh experiences levee breach flood more or less every year in different magnitudes due to the geographical position and obscured natural phenomenon. Levee breach causes serious disaster due to inundation and sediment deposition on the floodplain. Sediment deposition is occurred near the breach, and it decrease along the flow direction; and the depth of deposition is increased with the time (Islam and Tsujimoto, 2015).

3.5 Water logging from over-irrigation

Irrigation is the artificial application of water at field level to agricultural crops in dry areas or in periods of scarce rainfall to assure crop production. Irrigation is one of the most essential inputs for agricultural production. It is being used to grow high yielding variety rice in deferent seasons on the same field. In case the field is over-irrigation, the land remains waterlogged round the year. Water logging is responsible for decreasing of land productivity through rise in groundwater close to the soil surface irrigation practice, though yielding good harvest initially, degrades the soil due to continued absence of oxygen in the subsoil, chemical changes of soil materials by forming compounds toxic to plants, constant loss of soil

nutrients by percolation and incidence of pests and diseases associated with water-logged environment (MoEF, 2005).

3.6 Groundwater abstraction

Decline in the groundwater table is a self-explanatory form of land degradation, brought about through tube well pumping of groundwater, at the rate higher than the natural recharge capacity, for irrigation and other uses. In Bangladesh, groundwater abstraction has increased many-folds due to rapid expansion of irrigated agriculture (BARC, 1999). Withdrawal of river water and unbridled abstraction of groundwater have put the northern region at a risk of desertification through land degradation (MoEF, 2005). In Bangladesh, groundwater level on average drops by more than 5 meters every year as we rely more and more on the 5 million tube wells as our source for water (Access to Information, 2017).

3.7 Sea-level rise

Coastal Bangladesh is vulnerable to sea-level rise due to global warming and glacier melting in the Himalayas (Singh, 2001). Bangladesh is one of the largest deltas in the world which lies just less than 2 m above sea-level. Sea-level appears to be rising by 15.9–17.2 mm/yr in coastal Bangladesh (Schiermeier, 2014), while global sea-level rises 2-3 mm/yr (Pethick and Orford, 2013). Lives and properties along the Bay of Bengal are endangered by sea-level rise as the country has a 710 km long coastline (DoF, 2014). Sea-level rise will cause millions of people homeless (Dasgupta et al., 2010). One meter rise in sea-level would affect coastal Bangladesh, with the 'Sundarbans' mangrove forest completely submerged under the sea water (Agrawala et al., 2003).

3.8 Salinity

Salinity is one of the major natural hazards contributing towards land degradation in Bangladesh. About 30% of net cultivable area is in the coastal region of the country. The severity of salinity problem increases with the desiccation of the soil. Recently, salinity both in terms of severity and extent has increased much due to the intrusion of saline sea water because of the diversion of the Ganges water in the dry season. However, even in such cases, the expected yield reduces to a certain degree depending on the soil salinity concentration (Karim et al., 1990). As human-induced processes, these occur mainly through incorrect planning and management of irrigation schemes. Saline intrusion is a localized form of salinization which occurs as the result of the incursion of sea water into coastal soils arising from over-abstraction of groundwater (FAO, 1999). Salinity is a land degradation hazard that negatively affects the soil productivity.

3.9 Unplanned infrastructures

Many water development projects in Bangladesh have been implemented mainly for flood control and boosting the agriculture (Talukder and Shamsuddin, 2012). The main aim of these projects has been to increase agricultural production by providing protection from high level flooding and drainage facilities to dispose of excess rainfall during the monsoon season (Alexander et al., 1998). Flood Control Drainage and Irrigation (FCDI) projects are significant among all. These projects were implemented so as to support irrigation for high yielding varieties rice, but due to bad engineering construction some areas do not get irrigation facilities (Talukder and Shamsuddin, 2012). Construction of river embankments, flood control structures and roads, improper sluice gate management, increased irrigation for agriculture

and over exploitation of aquatic resources made huge negative impact. These enhance the loss of fish production and biodiversity in floodplain ecosystems. As a result, wetland dependent community people have lost their livelihoods (Hasan et al., 2013).

4. Climate Change Impact on Crop Production

The most important climatic factors that would affect agricultural productivity are changes in temperature, precipitation, carbon dioxide fertilization, short term weather variability and surface water runoff (Joshi and Amalkar, 2009). Changing pattern of rainfall in combination with the local environmental stress is being imposed on risk of agricultural crop production (Kabir and Golder, 2017). Variations in rainfall pattern over the growing period affect rice yield. Increasing temperatures have been found to reduce the duration of physiological maturity of the rice varieties (Basak et al., 2013). Maximum temperature is becoming the dominant variable continuously for *aman* rice production in Bangladesh (Zakaria et al., 2014). During the winter and pre-monsoon season (March-May) wheat and boro rice (December-April) mainly grow in the north and central parts of the country. Increase of winter temperature can reduce the environmental suitability for wheat, potato and other temperate crops grown in Rabi season (October- March). The trend of daily minimum temperature is higher in north and central parts of the country. Therefore, changes of climate will severely decline growth of various winter crops in the north and central parts of the country (Islam, 2009). Significant amount of rice yield may hamper for only fluctuations of climatic factors (Basak, 2010). A certain amount of boro rice production varied at different locations in Bangladesh for different climatic conditions and hydrological properties of soil. Comparing the simulation results of rice production on location wise, 'Rajshahi' district is the most vulnerable rice growing region due to significant fluctuation of day and night temperature in winter season (Basak, 2010). Wheat growing duration was reduced by about five days for each degree rise in temperature, irrespective of levels of irrigation water and nitrogen rates. Wheat yield would fall by 5-10% with every increase in 1°C (Pachouri, 2008). In general, there was yield reduction of 8.13, 16.77 and 24.97 % with increased temperature of 1°C, 2°C and 3°C, respectively (Sen et al., 2017).

5. Mitigation of Climate Change Effects on Agricultural Production

The patterns of alternative livelihood and other activities vary according to nature of disasters induced by climate change. The affected people are taking several strategies to cope with extreme climatic variability (Nasreen et al., 2016). Bangladesh should also prepare adaptation policies to minimize the adverse effects of climate change. Some agronomic practices, mechanical measures and afforestation can prevent the crop land degradation process. Tidal River Management (TRM), green afforestation belt, community-based adaptation, floating agriculture, homestead vegetable gardening, caged-fish culture, diversified saline, drought and flood tolerant crop varieties are good adaptation practices in Bangladesh (Sutradhar et al., 2015). The Government of Bangladesh has promulgated the national forest policy and approved the forestry sector master plan with the emphasis on the afforestation programs through co-ordinate efforts of GO-NGOs and active participation of the people. The cropping patterns need to be selected taking into consideration the seasonal rainfall availability and the water productivity with the varieties of the crops. Adoption of water stress resistant crop varieties and use of short cycle crops or varieties reduces the overall cropwater requirements; mulches protect the soil from direct impact of raindrops, thus controlling crusting and sealing processes. Conservation tillage helps to maintain high levels of organic matter in the soil thus it is highly effective in improving soil infiltration and controlling erosion. Increasing organic matter in the soil through adding organic matter and cultivating green manure provides soil

aggregation and increased water retention capacity of the soil.Appropriate control techniques need to be adopted to alleviate competition for water and transpiration losses by weeds (Chartzoulakis and Bertaki, 2015). Use of drought, salinity and flood tolerant crop varieties with proper management practices is important to mitigate the prevailing climate change situation. Bangladesh Rice Research Institute (BRRI) developed some varieties like BR23, BRRI dhan 40, BRRI dhan41, BRRI dhan53 and BRRI dhan54 possess salinity tolerance up to EC 8 dS m^{-1} for the wet season and BRRI dhan47, BINA dhan8 (developed by Bangladesh Nuclear Agriculture Institute), BRRI dhan53 and BRRI dhan55 for dry season. BRRI dhan47 can tolerate EC 12 to 14 dS m^{-1} salt stress (Islam and Gregorio, 2013). Drought tolerant rice varieties are BRRI dhan48, BRRI dhan56, BRRI dhan57, BRRI dhan55. Water logging resistant rice varieties are BRRI dhan49, BRRI dhan50, BRRI dhan51, BRRI dhan52. Salinity tolerance rice varieties are BR23, BRRI dhan40, BRRI dhan41, BRRI dhan53, BRRI dhan54 and BRRI dhan55. Irrigation is not sustainable if water supplies are not reliable. Especially in areas of water scarcity the major need for development of irrigation is to minimize water use. Effort is needed to find economic crops using minimal water, to use application methods that minimize loss of water by evaporation from the soil or percolation of water beyond the depth of root zone and to minimize losses of water from storage or delivery systems (Chartzoulakis and Bertaki, 2015). Localized irrigation (trickles or drip irrigation, micro-sprayers) is widely recognized as one of the most efficient methods of watering crops (Keller and Blienser, 1990). It is well known that crop yield increases with water availability in the root zone, until saturation level, above which there is little effect (Hillel, 1997).Adoption of drip irrigation technology has increased the net sown area, net irrigated area and thereby has helped in achieving higher cropping intensity and irrigation intensity (Kumar and Palanisamim, 2010).Environmental problems associated with the surface method of irrigation like water logging and salinity are also completely absent under drip method of irrigation (Narayanamoorthy, 1997). Drip method helps achieve saving in irrigation water, increased water-use efficiency, decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer-use efficiency (Namara et al., 2005; Qureshi et al., 2001; Sivanappan, 2002). Drip irrigation with mulch has an explicit role in increasing the land and water productivity of tomato (Biswas et al., 2015). The use of mulch with drip irrigation is a good option not only for water saving but also for improved yield (Jain et al., 2000). Excess withdrawal of groundwater has to be avoided for irrigation in dry land areas. Floating agriculture may be an effective way to combat the scarcity of cultivable land by increasing cropping intensity in wetland areas of Bangladesh (Hoque et al., 2016). Floating agriculture is a possible local knowledge-based technology which would help in attaining sustainable livelihood security in vulnerable waterlogged areas. The coastal areas of Bangladesh remain submerged for long periods every year, especially during the monsoon season. They have adopted a method of cultivation, referred to as 'floating agriculture'. The production rate is high from this kind of agricultural practice (Hossain, 2010). Floating gardening could be a useful option to tackle extended water logging by improving food security (IUCN, 2005; Practical Action, 2010). Recently, Bangladesh's floating gardens are designated as 'Globally Important Agricultural Heritage Systems' for innovation, sustainability and adaptability by Food and Agriculture Organization of the United Nations (FAO). This environment friendly traditional cultivation technique utilizes the natural resources of wetlands to grow vegetables and other crops almost all year round providing numerous social, economic, agricultural and ecological benefits to the local population (Ansarey, 2016). Producing vegetables in floating gardens can increase the income in some areas of Bangladesh during the post-flood months. The floating garden uses available natural resources, adjusts to wet conditions and helps the flood-prone people to earn a living and can be an adaptive response to frequent disaster events in Bangladesh (Pavel et al., 2014). Floating agriculture is a local innovative crop production technology for the submerged ecosystem of the southern region of Bangladesh. Bangladesh Agricultural Research Institute (BARI) has been working towards improving the traditional floating garden agriculture practices

for growing cucurbits or creeper type of vegetable crops. Recently, such improved technology has been developed and is termed as 'Floating Bed cum Trellis' (TECA-FAO). The sorjan cropping is a series of construction raised beds and lower sinks where dry land crops can be grown on the beds and wetland ones can be grown simultaneously in the sinks (Domingo and Hagerman, 1982). The farmers got wide success in crop production through floating cultivation with local technology totally in the unusable land submerged under water. Vulnerabilities assessment, disaster management, enhanced structure design, institutional reform and anti-extreme climate engineering are some feasible adaptation policies (Hasan and Rahman, 2013). TRM is the most effective method to raise land and make it cultivable, mitigate the water-logging crisis, increase the navigability of rivers, reduce salinity and protect coastal regions from sea level rise (Sutradhar et al., 2015) along with establishment of proper embankments with sluice gates in flood prone and coastal areas.

6. Conclusions

Agriculture intensification is expected to continue in Bangladesh in the context of ever-increasing population, climate change, and the need for food security. Prolonged water logging period is responsible for decreasing of land productivity. Sedimentation over the floodplains also contributes towards degradation of land due to flashflood and sediments accumulated from riverbank erosion. Withdrawal of river water and abstraction of groundwater have put the northern region at a risk of desertification. Forest degradation directly leads to lower rainfall and higher temperatures. The severity of salinity problem in Bangladesh has increased much due to the intrusion of saline sea water. Some agronomic practices, mechanical measures and afforestation can prevent the crop land degradation process. Conservation tillage and mulching practice can preserve top soils moisture. Excess withdrawal of groundwater for irrigation purpose in dry land areas should be avoided. Necessary action on an afforestation program should be taken in the country. The embankments construction should have proper design with sluice gates in flood prone and coastal areas. Localized irrigation is one of the most efficient methods for water supply to the crops**.** The farmers have got success in crop production through floating cultivation with local technology in the unusable land as submerged under water. The land productivity increases with adoption of long-term land and water management strategies which will also ensure crop production sustainability.

References

Access to Information. (2017). Programme of the Prime Minister's office of Bangladesh. [Available at: http://www.thedailystar.net/country/a2i-challenge-fund-use-surface-water-irrigation-launched-1446082 (Accessed 01 January, 2018)].

ADPC and BCAS (Asian Disaster Preparedness Centre and Bangladesh Centre for Advance Studies). (2008). Draft Disaster Management Information Link Report. Ministry of Food and Disaster Management, Government of Peoples Republic of Bangladesh, Dhaka, Bangladesh.

Agrawala, S.; Ota, T.; Ahmed, A.; Smith, J., Aalst, M. (2003). Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans. Organization for Economic Cooperation and Development, Paris France.

Ahasan, M.; Chowdhary, M., Quadir, D. (2010). Variability and trends of summer monsoon rainfall over Bangladesh. J. Hydrol. Meteorol., 7(1), 1-17.

Ahmed, N., Diana, J. (2015). Coastal to inland: Expansion of prawn farming for adaptation to climate change in Bangladesh. Aquaculture Reports 2, 67-76.

Ahmed, A., Hussain, S. (2009). Climate Change and Livelihoods: An Analysis of Agro-ecological Zones of Bangladesh.

Dhaka: Campaign for Sustainable Rural Livelihoods and Centre for Global Change.

Alexander, M.; Rashid, S.; Shamsuddin, D., Alam S. (1998). Flood Control, Drainage and Irrigation Projects in Bangladesh and Their Impact on Soils: An Empirical Study, Land Degradation & Development, 9,. 233- 246.

Ansarey, F. (2016). Floating Garden: Globally recognized Bangladeshi Sustainable Farming System. BIOLIFE. 1(45).

Banerjee, L. (2010). Effects of Flood on Agricultural Productivity in Bangladesh. [Available at: https://www.researchgate.net/publication/227622150_Effects_of_Flood_on_Agricultural_Productivity_in_Bangladesh (Accessed 10 January, 2018)].

BARC (Bangladesh Agricultural Research Council). (1999). Land Degradation Situation in Bangladesh, Soils Division, BARC, Farmgate, Dhaka, Bangladesh.

Basak, J. (2010). Climate Change Impacts on Rice Production in Bangladesh: Results from a Model. Unnayan Onneshan-The Innovators, Dhanmondi, Dhaka-1209, Bangladesh.

Basak, J; Titumir, R., Dey, N. (2013). Climate Change in Bangladesh: A Historical Analysis of Temperature and Rainfall Data. Journal of Environment, 2 (2), 41-46.

BBS (Bangladesh Bureau of Statistics) (2009). Compendium of Environment Statistics of Bangladesh-2009. Ministry of Planning, Peoples Republic of Bangladesh.

BCAS (Bangladesh Centre for Advance Studies). (2008). Community Risk Assessment of Disasters and Risk Reduction Action Plan in Madhukhali Upazila, Faridpur. Ministry of Food and Disaster Management, Government of Peoples Republic of Bangladesh.

Biswas, S.; Akanda, A.; Rahman, M., Hossain, M. (2015). Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato. Plant Soil Environ.61(3), 97-102.

BWDB (Bangladesh Water Development Board) (2012). Flood Forecasting and Warning Center, Bangladesh Water Development Board. Annual Flood Report 2012, p.1.

Chartzoulakis, K., Bertaki, M. (2015). Sustainable Water Management in Agriculture under Climate Change.Agriculture and Agricultural Science Procedia. 4, 88-98.

Choudhury, A.; Quadir,D.; Neelarmi, S., Ahmed, A. (2003). Climate Change and its Impacts on Water Resources of Bangladesh. In Climate Change and Water Resources in South Asia: Proceedings of Year-end Workshop, Kathmandu, Nepal. January 2003. pp. 21-60.

Climate Change Cell. (2008). Economic Modeling of Climate Change Adaptation Needs for Physical Infrastructures in Bangladesh Department of Environment, Ministry of Environment and Forests. Component 4b, Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management, Bangladesh.

CUS (Center for Urban Studies). (1988). Composite Score map of Socio-economic Development of Bangladesh by Upazila, Center for Urban Studies, Dhaka University, Dhaka, Bangladesh.

Dasgupta, S.; Huq, M.; Khna, Z.; Ahmed, M.; Mukherjee, N.; Khan, M., Pandey, K. (2010). Vulnerability of Bangladesh to cyclones in a changing climate: Potential damages and adaptation cost. Policy Research Working Paper; No. WPS 5280. World Bank.

DoF (Department of Fisheries). (2014). National Fish Week Compendium. Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh.

Domingo and Hagerman. (1982). Sorjan Cropping System Trial in Irrigated Wet Land Conditions. Phillip. J. Crop Sci,. 7(3),.154-161.

FAO (Food and Agriculture Organization). (1999). Poverty Alleviation and Food Security in Asia: Land Resources. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific. P. 26.

Ghani, M. (2016). Water management for agricultural development [Available at:http://www.thedailystar.net/supplements/25th-anniversary-special-part-4/water-management-agricultural-development-211999(Accessed 5 January, 2018)].

Hasan, A., Rahman, M. (2013). Change in Temperature over Bangladesh Associated with Degrees of Global Warming. Asian Journal of Applied Science and Engineering, 2 (2), 62-75.

Hasan, M.; Hossain, M.; Bari, M., Islam, M. (2013). Agricultural land availability in Bangladesh. Soil Resources Development Institute (SRDI), Dhaka, Bangladesh.

Hillel, D. (1997). Small-scale irrigation for arid zones: Principles and options. FAO Technical Paper 2, Rome, Italy.

Hoque, M.; Haque, M.; Afrad, M., Islam, M. (2016). Effectiveness of Floating Agriculture for Adapting Climate Change in Southern Bangladesh.International Journal of Economic Theory and Application,3(1),.14-25.

Hossain, M. (2010). Indigenous technology for adapting to water logging situation for sustainable livelihood security in low lying areas of Bangladesh. 19th World Congress of Soil Science, Soil Solutions for a Changing World. 1-6 August, 2010, Brisbane, Australia.

Hossain, M.; Islam, A., Seha, S. (1987). Floods in Bangladesh-Recurrent Disasters and People's survival, university research centre, Dhaka.

Hussain, I. (2004). Pro-Poor Intervention Strategies in Irrigated Agriculture in Asia: Poverty in Irrigated Agriculture-Issues and Options, Bangladesh. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Islam, A. (2009). Analyzing changes of temperature over Bangladesh due to global warming using historic data. Proceedings of the Young Scientists of Asia Conclave: Pressing Problems of Humankind: Energy & Climate held at Bangalore, January 15-17, 2009, TWAS-ROCASA, India.

Islam, M. (1986). Alternative Adjustment to Natural Hazards; Implication for Bangladesh, Presidential Address at the 11th Annual Bangladesh Science Conference, Rajshahi, Bangladesh.

Islam, M., Gregorio, G. (2013). Progress of salinity tolerant rice variety development in Bangladesh. SABRAO Journal of Breeding and Genetics. 45 (1), 21-30.

Islam, M., Tsujimoto, T. (2015). Numerical Simulation on Breach Evolution Process of a River Levee by Overtopping. Journal of Emerging Trends in Engineering and Applied Sciences, 6(1), 12-18.

IUCN (The International Union for the Conservation of Nature), Bangladesh. (2005). Baira: The Floating Gardens for Sustainable Livelihood, IUCN Bangladesh Country Office, Dhaka, Bangladesh, pp. 1-61.

Jain N.; Chauhan H.; Singh P.; Shukla K. (2000): Response of tomato under drip irrigation and plastic mulching. In: Proceeding of the 6th International Micro-irrigation Congress, Micro-irrigation Technology for Developing Agriculture, 22-27 October 2000, South Africa.

Joshi, N., Amalkar. (2009). Contingency crop planning for dry land areas in relation to climate change. Indian J.Agron., 54(2), 237-243.

Kabir, H., Golder, J. (2017). Rainfall Variability and Its Impact on Crop Agriculture in Southwest Region of Bangladesh. J Climatol Weather Forecasting, 5, 196.

Karim, Z.; Hussain, S., Ahmed. M. (1990). Salinity problems and crops intensification in the coastal region of Bangladesh, Bangladesh Agricultural Research Council, Dhaka, Bangladesh.

Keller J., Blinser R. (1990). Sprinkle and trickle irrigation. Van Nostrand Reinhold, New York, USA.

Kumar, D., Palanisamim, K. (2010). Impact of Drip Irrigation on Farming System: Evidence from Southern India. Agricultural Economics Research Review, 23, 265-272.

Milliman, J.; Broadees, J., Global, F. (1989). Environmental and Economic Impact of raising sea level and subsiding deltas. The Nile and Bengal Examples, Bangladesh Quest, 1.

MoDMR (The Ministry of Disaster Management and Relief). 2014. Flood Response Preparedness Plan of Bangladesh, p. 4. [Available at: https://www.sheltercluster.org/sites/default/files/docs/flood_response_preparedness_plan_of_bangladesh_june_2014.pdf (Accessed 11 January, 2018)]

MoEF (Ministry of Environment and Forest). (2005). National Action Programme (NAP) for Combating Desertification. Department of Environment, Ministry of Environment and Forest Government of the People's Republic of Bangladesh.

Mondal, M., Hossain, M. (2009). Characterizing Long-term Changes of Bangladesh Climate in Context of Agriculture and Irrigation. Climate Change Cell, Dhaka, Bangladesh.

Namara, R.; Upadhyay, B., Nagar, R. (2005). Adoption and Impacts of Micro irrigation Technologies: Empirical Results from Selected Localities of Maharashtra and Gujarat States of India, Research Report 93, International Water Management Institute, Colombo, Sri Lanka.

Narayanamoorthy, A. (1997). Drip irrigation: A viable option for future irrigation development, Productivity, 38(3), 504-511.

Nasreen, M. (2008). Sustainable Development and Impacts of Climate Change: A Gender Perspective. ITN, BUET.

Nasreen, M., Hossain, K. and Azad, M. (2016). Climate Change and Livelihood in Bangladesh: Experiences of People Living in the Coastal Regions.Climate Change Vulnerability: Cases from CIRDAP Member Countries. Published by: Centre on Integrated Rural Development for Asia and the Pacific (CIRDAP), Dhaka, Bangladesh.

Neenu, S.; Biswas, A., Rao, A. (2013). Impact of Climatic Factors on Crop Production-A Review.Agri. Reviews, 34 (2), 97-106.

NENCID. (2017) [Available at: http://nencid.org.np/wp-content/uploads/2017/06/call.pdf (Accessed 8 December, 2017)].

Okwany, R.; Prathapar, S.; Bastakoti, R., Mondal, M. (2016). Shallow subsurface drainage for managing seasonal flooding in Ganges floodplain, Bangladesh. Irrigation and Drainage, 65, 712-723.

Pachouri, R. (2008). Saving Planet Earth, TOI, 2/6/08, New Delhi, India.

Pavel, M.; Chowdhury, M., Mamun, M. (2014). Economic evaluation of floating gardening as a means of adapting to climate change in Bangladesh. Int'l J. of Env. Studies, 71(3), 261-269.

Pethick, J., Orford, J. (2013). Rapid rise in effective sea-level in southwest Bangladesh: its causes and contemporary rates Global Planet. Change, 111, 237-245.

Practical Action. (2010). Coping with Disasters, Practical Action, Bangladesh, Dhaka, pp. 1-60.

Qureshi, M.; Wegener, M.; Harrison, S., Bristow, K. (2001) Economic evaluation of alternate irrigation systems for sugarcane in the Burdekin delta in North Queensland, Australia, In: Water Resource Management, Eds: C.A. Brebbia, K. Anagnostopoulos, K. Katsifarakis and A.H.D. Cheng, WIT Press, Boston, pp. 47-57.

Rahman, M.; Salehin, M., Matsumoto, J. (1997). Trend of monsoon rainfall pattern in Bangladesh. Bangladesh Journal of Water Resource Research, (14-18), 121-138.

Rashid, H. (1991). Geography of Bangladesh. University Press Limited. Dhaka.

Schiermeier, Q. (2014). Holding back the tide. Nature, 508, 164-166.

Schumm, S., Winkley, B. (1994). The Character of Large Alluvial Rivers, In: The Variability of Large Alluvial Rivers(Ed. by S. Schumm and B. Winkley), American Society of Civil Engineers, New York, pp. 1-13.

Selvaraju, R.; Subbiah, A.; Bass, S., Juergens, I. (2006). Livelihood Adaptation to Climate Variability and Change in Drought-prone Areas of Bangladesh: Developing Institutions and Options. Asian Disaster Preparedness Center (ADPC) and Food and Agriculture Organization of United Nations.

Sen, R.; Choudhury, A.; Akhter, S.; Ishtiaque, S.; Jahan, M.; Ahmed, F.; Biswas, J.; Maniruzzaman, M.; Miah, M.; Rahman, M.; Kalra, N.; Aziz, M.; Khan, A. (2017). Simulating Nitrogen and Irrigation Effects on Wheat Production in Bangladesh under Changing Climate. American Journal of Plant Sciences, 8, 1593-1606.

Singh, O. (2001). Cause-effect relationships between sea surface temperature, precipitation and sea level along the Bangladesh coast. Theor. Appl. Climatol., 68, 233-243.

Sivanappan, R. (2002). Strengths and weaknesses of growth of drip irrigation in India, In: Proc. of Micro Irrigation for Sustainable Agriculture. GOI Short-term training 19-21 June, WTC, Tamil Nadu Agricultural University, Coimbatore, India.

Ssali, M. (2017). Irrigation for increased crop production [Available at: http://www.monitor.co.ug/Magazines/Farming/Irrigation-for-increased-crop-production-/689860-4192768-q4rx1v/index.html (Accessed 6 January, 2018)].

Sutradhar, L.; Bala, S.; Islam, A.; Hasan, M.; Paul, S.; Rhaman, M.; Pavel, M., Billah, M. (2015). A Review of Good Adaptation Practices on Climate Change in Bangladesh. 5th International Conference on Water & Flood Management (ICWFM-2015).

Talukder, B., Shamsuddin, D. (2012). Environmental Impacts of Flood Control Drainage and Irrigation (FCDI) Projects in a Non-Irrigated Area of Bangladesh: A Case Study. The Journal of Transdisciplinary Environmental Studies, 11(2).

Zakaria, M.; Aziz, M.; Hossain, M., Rahman, N. (2014). Effects of Rainfall and Maximum Temperature on Aman Rice Production of Bangladesh: A Case Study for Last Decade. International Journal of Science & Technology, 3 (2), 131-137.

Optimal cropping pattern for sustainable agriculture under drought conditions

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Abstract

Odisha is predominantly an agrarian state of India, with erratic climate. The western part of the state is more prone to droughts. The KBK region is a part of Odisha which consists of eight districts, namely, Koraput, Malkanagiri, Nowrangpur, Rayagada, Bolangir, Subarnapur, Kalahandi and Nuapada. More than 80% of the people in this region live in rural areas and depend on agriculture. As per the cropping pattern in the region, cereals production is in excess than the demands, whereas there is a deficit in the production of pulses, oilseeds and vegetables. Deficiencies of rainfall during drought years result in decline in surface water availability and subsequently affect adversely in agricultural production in the form of total crop failure or loss in crop yield. Therefore, there is a need to develop a methodology to suggest suitable cropping pattern for the respective agro-climatic zones of the region. This study has developed an optimal cropping model for 8 KBK districts comprising of 80 blocks. The model provides a cropping pattern scenario for drought conditions till 2051 with the aim of keeping water requirements to the minimum for self-sustenance. The model incorporates various constraints like food grain demand, availability of water and land resources, land use pattern, existing cropping pattern in the region, type/category of land, etc. In addition, crop suitability to the region's agro-climatic zones has also been duly taken care of in the model. Water availability at 75% and 50% dependability has been estimated from the rainfall pattern in drought years. The model is expected to help minimize the crop loss and improve socio-economic status of the people in the region.

Keywords: *drought; optimal cropping pattern; Odisha; sustainable agriculture*

1 Introduction

Climate change is a change in the mean values of a meteorological element (e.g., temperature, precipitation) over a decade or a longer period (World Meteorological Organization, 1992). Agriculture is strongly influenced by climate change, which is a well-recognized, man-made, global environmental challenge (Hillel and Rosenzweig, 2011; Kang and Banga, 2013). Food production and water resources are regulated

due to climate change (National Research Council (United States), 2010). In case of developing countries, climate change will make it difficult for achieving food security according to the Intergovernmental Panel on Climate Change (IPCC) (Catford, 2008). Yield is projected to decrease in case of tropical and sub-tropical countries because of the generally predicted negative impacts on agriculture (Parry et al., 2004, Stern and Treasury, 2007). Increased climate variability has made rainfall patterns more inconsistent and unpredictable (Kumar et al., 2005).

Extreme weather events such as droughts and floods are projected to increase in future, in both frequency and intensity (IPCC, 2007). These weather events are decisive weather phenomenon for ensuring or threatening our food security (Kumari et al., 2014). In order to devise strategies for minimizing the risk to sustainable production, characterization of rainfall and drought events would be helpful. Management and allocation of water for agricultural purpose is complex as it depends on social, environmental and political factors. In case of drought-prone areas, management and allocation of water has been performing far below its potential as a result of which the agricultural production and irrigation benefit become economically inadequate (Raju and Kumar, 1999). Water need in agricultural sector is going to be very high, as several thousand tonnes of water is required to produce each metric ton of food grain. The demand of water in other sectors specially to meet the increasing demand for rapid growing industrialisation and urbanisation will dwindle the share of water available for agriculture in the future (Mandal et al., 2015). In order to minimize the crop damages, there is a need for effective monitoring of agricultural drought (Patel and Sastri, 2004). Knowledge of frequency and intensity of drought is essential for crop selection, their management and overall agricultural planning of a region (Kumari et al., 2014).

Adaptation strategies can help reduce risks to climate change to a great extent for the agricultural sector (Deressa et al., 2011; Reidsma et al., 2010, Smit and Wandel, 2006). In agriculture, adaptation is evolutionary (Nelson et al., 2007) and farmers do adapt to reduce their vulnerability to climate change. Most of those studies have been done in the African countries (Armah et al., 2011, Deressa et al., 2011). In case of India there is a dearth in literature that addresses the climate change problem taking adaptation explicitly (Guiteras, 2007, Kumar and Parikh, 2001).

Mandal et al (2015) studied about the crop planning for Kharif rice in Sagar Island, India by considering the monsoon rainfall variability. Mane et al. (2016) studied the probability of dry and wet spells as well as rainwater availability for planning of the rice crop at Dapoli, India. Crop planning in Daspalla region in Odisha is designed by analysing the rainfall using probability distribution and Markov chain models (Mandal et al., 2015). The conjunctive use policies of surface water and groundwater resources are developed for minimizing water shortage in an irrigation district subject to constraints on groundwater withdrawals and crop planning capacities (Montazar, 2013). A mathematical programming model developed by Montazar (2013) in order to determine a stable conjunctive use policy for irrigation in a reservoir aquifer system in Iran. Armah et al (2011) mentioned the importance of various strategies such as expansion of irrigated agricultural areas, crop improvement and specialisation and improvement of cropwater productivity in order to adapt the climate change for achieving food security. Poor economic condition, poor infrastructure facility in the area in terms of unavailability of irrigation water and lack of extension service are the major barriers for the farmers to adapt to climate change (Mishra and Sahu, 2014). Knowledge of frequency and intensity of drought is essential for crop selection, their management and overall agricultural planning of a region (Kumari et al., 2014).

Odisha predominantly is an agrarian state of India. The state is generally frequently affected by erratic climate and the western part of Odisha is more prone to droughts. More than 80% of the people of KBK region (8 contiguous districts, Koraput, Malkanagiri, Nowrangpur, Rayagada, Bolangir, Subarnapur,

Kalahandi and Nuapada) live in rural areas and depend on agriculture. The agricultural land was 287000, 127000, 180000, 143000, 330000, 107000, 360000 and 161000 ha and the irrigation potential created up to the year 2009 was 101720, 79989, 31951, 65436, 64104, 77045, 142978 and 42701 ha for Koraput, Malkanagiri, Nowrangpur, Rayagada, Bolangir, Subarnapur, Kalahandi and Nuapada districts, respectively. The cropping pattern followed in the KBK districts indicate that the production of cereals is much more than the present demand and even it is more than the future demand, whereas there is a deficit in the production of pulses, oilseeds and vegetables. During drought years, due to deficiencies in rainfall, the situation gets worsened due to the reduction in the surface water availability and hence the agricultural operations also get affected adversely resulting in either total crop failure or suffer reduction in crop yield. Thus, there is a need to develop a methodology to suggest suitable cropping pattern for the respective agro-climatic zones of the region to meet the growing food grain demand of people in the future. Therefore, in this study, an optimal cropping model is developed for 8 KBK districts comprising of 80 blocks. The model provides a cropping pattern scenario for drought conditions till the year 2051 with the aim of keeping water requirements to the minimum for self-sustenance.

2 Material and Methods

This study is carried out in the KBK districts of Odisha, India. At present there are eight districts (Koraput, Malkangiri, Nowrangpur, Rayagada, Bolangir, Subarnapur (Sonepur), Kalahandi and Nuapada) and eighty blocks under the KBK region (Fig. 1). The total geographical area of the KBK region is 47,646 km^2. The Koraput district is encompassed between latitude of 82° 5' N and 83° 23' N and longitude 18° 13' E and 19° 10' E. The geographical area of the district is 8,807 km^2. The district Malkangiri lies between latitude of 17° 40'N and 18° 43' N and longitude 81° 22' N and 82° 25' N. The geographical area of the district is 5,791 km^2. The Nowrangpur district encompasses between latitude of 19° 09' N and 20° 05' N and longitude 81°52' E and 82°53' E. The geographical area of the district is 5,291 km^2.

The Rayagada district is encompassed between latitude of 19° 00' N and 19°58'N and longitude 82° 54' E and 84° 02' E. The geographical area of the district is 7,073 km^2. The Bolangir district is encompassed between latitude of 20° 09' N and 21° 05' N and longitude 82° 41'E and 83° 42'E. The geographical area of the district is 6,575 km^2. The Subarnapur district is encompassed between latitude of 20° 30' N and 20° 10' N and longitude 83° 27' E and 84° 15' E. The geographical area of the district is 2,337 km^2. The Kalahandi district lieis between latitude of 19° 08' N and 0°25'N and longitude 82° 32' E and 83° 47' E. The geographical area of the district is 7,920 km^2. The Nuapada district is encompassed between latitude of 20° 00' N and 21° 05' N and longitude 82° 20' E and 82° 53' E. The geographical area of the district is 3,852 km^2. Normal annual rainfall and temperature range of the KBK districts are presented in Table 1.

Figure 1: *Geographical map of KBK region of Odisha*

Table 1: *Normal annual rainfall and temperature range of KBK Districts*

District Name	Normal Annual Rainfall (mm)	Temperature Range (°C)
Koraput	1231	11-37
Malkangiri	1341	13-37
Nowrangpur	1367	11-44
Rayagada	1098	13-38
Bolangir	1041	13-42
Subarnapur	1130	7-40
Kalahandi	1155	11-42
Nuapada	976	13-42

The irrigation potential calculated up to the year 2009 was 101720, 79989, 31951, 65436, 64104, 77045, 142978 and 42701 ha for Koraput, Malkanagiri, Nowrangpur, Rayagada, Bolangir, Subarnapur, Kalahandi and Nuapada districts, respectively. Monthly rainfall and temperature data of the eight districts of KBK is collected from the Water Resource Department of Odisha.

2.1 Water availability in drought years

Khosla's formula for estimation of runoff is quite applicable in semi-arid and arid regions which are frequently prone to droughts and where rainfall-runoff models cannot be developed due to inadequacy of sufficient observed flow data. The Khosla's formula takes into account mean monthly temperatures and rainfall in the region to give runoff (R) during a month as,

$$R_m = P_m - 0.48*T_m \text{ if } R>0 \quad (1)$$

where, R_m = Monthly runoff in mm, P_m = Rainfall during the month in mm and T_m = Mean monthly temperature in °C.

The surface runoff available in the area is estimated by Khosla's formula using the long-term monthly rainfall data and mean monthly temperatures of the region. Runoff available at 50% and 75% dependability has been worked out from the long-term rainfall series and is considered as the surface runoff available in the area under consideration. This analysis has been done separately for normal years as well as for drought years. The 50% and 75% dependable runoff in normal years and in drought years has been worked out for each of the eight districts and in all the 80 blocks of KBK region. The cropwater requirement for different crops being cultivated in the area has been computed on the basis of procedure recommended by Food and Agriculture Organization (FAO). The cropwater requirement for various crops per unit ha. of cultivation in different districts is indicated in Table 2.

Table 2: *Crop water requirement (mm/ha) for different crops in KBK region*

District	Kharif					Rabi				
	Paddy	Other cereals	Pulses	Oil seeds	Vegetables	Paddy	Other cereals	Pulses	Oil seeds	Vegetables
Koraput	880	320	300	350	320	1890	530	410	420	420
Malkangiri	805	320	300	350	320	1900	540	430	420	430
Nowrangpur	860	320	300	350	320	1870	510	410	410	430
Rayagada	1030	320	300	350	320	1840	510	400	400	410
Bolangir	980	310	300	350	310	1870	470	370	370	390
Subarnapur	930	310	300	350	310	1880	470	370	380	390
Kalahandi	900	310	300	350	310	1900	510	430	410	450
Nuapada	1040	320	300	350	320	1900	500	430	400	440

The cropping pattern being followed at present (average of last 9-10 years) in eight districts of the KBK region under irrigated and rain-fed conditions will indicate that, farmers have a general tendency to grow paddy, wherever irrigation facilities exist. In irrigated areas, 81% of the area is covered under paddy in Kharif season whereas in rain-fed areas, only 50% of the area is covered under paddy on an average. Percentage of area grown under pulses, oilseeds and vegetables hardly range from 7-10% in irrigated condition and 4- 6% in rainfed condition in Kharif season in the KBK region. Similarly, in Rabi season, about 29% of the area is covered under paddy crop where irrigation facilities exist on an average, where as it is 0% in rainfed areas in different districts of KBK region.

The percentage of area under pulses, oilseeds and vegetables is relatively more in rain-fed areas (because of the residual moisture available after harvest of paddy crop) in comparison to areas wherever irrigation facilities exist. This is the reason why the production of cereals in the present scenario is much more than the demand and even more than the estimated future demand of 2051. There is a deficiency in the production of pulses, oil seeds and vegetables in comparison to the demand in the present scenario. This situation will further worsen due to rapid growth in population in the future scenario (2051). Paddy crop depends on the availability of water in sufficient quantity. Due to timely nonoccurrence of rainfall in the rainy season in drought years, the farmers who have a tendency to grow routine paddy crops almost every year, sustain huge crop loss.

Thus, there is a need to develop a mechanism to suggest suitable cropping pattern to the respective agro-climatic zones of the region under consideration for food security to meet the growing food grain demand of people in the future scenario (2051). Also, it is necessary to suggest an alternate cropping pattern limiting to the water availability in drought years for self-sustenance apart from meeting the water demand for domestic and livestock population to maintain healthy living conditions and to help prevent people migrating to neighboring districts/ states in search of work in drought situations. Keeping in view the water availability in drought years, a model has been developed for suggesting the cropping pattern to be followed under drought conditions with an aim to keep the water requirement to the minimum as per availability for self-sustenance.

2.2 Development of optimal cropping model under drought conditions

Minimization of Water requirement to suggest cropping pattern to be followed in drought like situations for self-sustenance.

Minimize Water requirement (Z_w)

Equation (2) was formulated as the objective function to minimize water requirement (Z_w):

Minimize water requirement (Z_w) = $\alpha_{k1}*w_{k1}+\alpha_{k2}*w_{k2}+\alpha_{k3}*w_{k3}+\alpha_{k4}*w_{k4}+\alpha_{k5}*w_{k5}+\beta_{k1}*w_{k1}+\beta_{k2}*w_{k2}+\beta_{k3}*w_{k3}+\beta_{k4}*w_{k4}+\beta_{k5}*w_{k5}+\alpha_{r1}*w_{r1}+\alpha_{r2}*w_{r2}+\alpha_{r3}*w_{r3}+\alpha_{r4}*w_{r4}+\alpha_{r5}*w_{r5}+\beta_{r1}*w_{r1}+\beta_{r2}*w_{r2}+\beta_{r3}*w_{r3}+\beta_{r4}*w_{r4}+\beta_{r5}*w_{r5}$ (2)

where, α_{k1} = area under rice in ha, α_{k2} = area under other cereals in ha, α_{k3} = area under pulses in ha, α_{k4} = area under oilseeds in ha, α_{k5} = area under vegetables, β_{k1} = area under rice in ha, β_{k2} = area under other cereals in ha, β_{k3} = area under pulses in ha, β_{k4} = area under oilseeds in ha, β_{k5} = area under vegetables, α_{r1} = area under rice in ha, α_{r2} = area under other cereals, α_{r3} = area under pulses, α_{r4} = area under oilseeds, α_{r5} = area under vegetables, β_{r1} = area under rice in ha, β_{r2} = area under other cereals, β_{r3} = area under pulses, β_{r4} = area under oilseeds, β_{r5} = area under vegetables, w_k and w_r represent water requirement of respective crops in Kharif and Rabi season respectively.

Constraints

The above equation was subjected to the following constraints:

i) Total cultivable area constraint

$\alpha_{k1} + \alpha_{k2} + \alpha_{k3} + \alpha_{k4} + \alpha_{k5} + \beta_{k1} + \beta_{k2} + \beta_{k3} + \beta_{k4} + \beta_{k5} \leq$ Total cultivable area (3)

ii) Total Irrigated area constraint

$\alpha_{k1} + \alpha_{k2} + \alpha_{k3} + \alpha_{k4} + \alpha_{k5} \leq$ Total Kharif irrigated area in ha (4)

$\alpha_{r2} + \alpha_{r3} + \alpha_{r4} + \alpha_{r5} \geq$ Rri (sum of area of other rabi crops in irrigated area) (5)

iii) Land type constraint

$\alpha_{k1} + \alpha_{k2} + \alpha_{k3} + \alpha_{k4} + \alpha_{k5} + \beta_{k1} + \beta_{k2} + \beta_{k3} + \beta_{k4} + \beta_{k5} \leq$ (sum of high, medium and low lands) (6)

iv) Water availability constraint

$\alpha_{k1} * w_{k1} + \alpha_{k2} * w_{k2} + \alpha_{k3} * w_{k3} + \alpha_{k4} * w_{k4} + \alpha_{k5} * w_{k5} + \beta_{k1} * w_{k1} + \beta_{k2} * w_{k2} + \beta_{k3} * w_{k3} + \beta_{k4} * w_{k4} + \beta_{k5} * w_{k5} + \alpha_{r1} * w_{r1} + \alpha_{r2} * w_{r2} + \alpha_{r3} * w_{r3} + \alpha_{r4} * w_{r4} + \alpha_{r5} * w_{r5} + \beta_{r1} * w_{r1} + \beta_{r2} * w_{r2} + \beta_{r3} * w_{r3} + \beta_{r4} * w_{r4} + \beta_{r5} * w_{r5} \leq$ Total water availability (7)

v) Other constraints

a) Irrigated & rainfed area constraints

$\alpha_{k1} + \alpha_{k2} + \alpha_{r1} + \alpha_{r2} + \beta_{k1} + \beta_{k2} \geq$ Total cereal crop in Kharif and rabi irrigated and rainfed area (8)

$\alpha_{k3} + \beta_{k3} \geq$ present crop area under pulses in Kharif in irrigated and rainfed areas (9)

$\alpha_{k4} + \beta_{k4} \geq$ present crop area under oilseeds in Kharif in irrigated & rainfed areas (10)

$\alpha_{k5} + \beta_{k5} \geq$ present crop area under vegetables in Kharif in irrigated & rainfed areas (11)

$\alpha_{r3} + \beta_{r3} \geq$ present crop area under pulses in Rabi season in irrigated/rainfed areas (12)

$\alpha_{r4} + \beta_{r4} \geq$ present crop area under oilseeds in Rabi season in irrigated/rainfed areas (13)

$\alpha_{r5} + \beta_{r5} \geq$ present crop area under vegetables in Rabi season in irrigated/rainfed areas (14)

b) Irrigated area constraints

$\alpha_{k3} + \alpha_{k4} + \alpha_{k5} \geq$ present crop area in Kharif under pulses, oilseeds and vegetables in irrigated areas (15)

$\alpha_{k1} + \alpha_{r1} \geq$ Total paddy crop area in Kharif and Rabi irrigated areas (16)

$\alpha_{k3} + \alpha_{r3} \geq$ Total crop area under pulses in Kharif and Rabi irrigated areas (17)

$\alpha_{k4} + \alpha_{k5} \geq$ Total crop area under oilseeds/vegetables in Kharif in irrigated areas (18)

(c) Rain fed area constraints

$\beta_{k3} + \beta_{k4} + \beta_{k5} \geq$ present crop area in Kharif under pulses, oilseeds and vegetables in rainfed areas (19)

$\beta_{k1} + \beta_{r1} \geq$ Total crop area under paddy in Kharif and Rabi in rain fed areas (20)

$\beta_{r3} + \beta_{r4} \geq$ Total crop area under pulses and oilseeds in Rabi in rain fed areas (21)

$\beta_{r3} + \beta_{r5} \geq$ Total crop area under pulses and vegetables in Rabi in rain-fed areas (22)

3. Result and Discussions

3.1 Cropping pattern under drought conditions for self-sustenance of KBK districts

Table 3 shows the total water availability (50 and 75% dependability), total domestic and livestock water demand, cropping pattern to be followed under drought conditions for self-sustenance, total water utilization and groundwater contribution required for eight KBK districts. Maximum amount of total water is available in Koraput district for both 50% (275285 in hectares-meter, ham) and 75% (250034 ham) dependability. Demand of total domestic and livestock water is highest (9421 ham) for Bolangir district and least demand (2962 ham) in case of Subarnapur district by 2051. Maximum area (85000 ha) of Paddy crop can be grown in Koraput District, other cereals (48000 ha) in Nowrangpur District, pulses (69100 ha), Oil seeds (51313 ha) in Koraput and Vegetables (29820) for Rayagada District. Minimum area (15000 ha) for Paddy, Malkanagiri (20604 ha) Pulses, Oil seeds (13085 ha) in Subarnapur and Vegetables (7338 ha) for Subarnapur district. Maximum area of paddy (352000 ha) crop grown in eight of the KBK districts whereas least area cropped under other cereals (100000 ha).

Cultivation of all the crops is maximum (239163 ha) for Kalahandi district whereas minimum (71577 ha) is in Subarnapur district. No groundwater contribution is required, if we will consider 50% depletion whereas for 75% depletion, groundwater contribution varied from 6-14% for all the districts except for Koraput district.

3.2 Surface water resources of KBK districts

It can be observed from Fig. 2 that, maximum surface water resources are available in Borigumma, Korkonda, Kasagumuda and Kashipur blocks of Koraput, Malkangiri, Nowrangpur and Rayagada district respectively for both 50% and 75% dependability. Narayanpatna, Podia, Dabugaon and Chandrapur blocks of Koraput, Malkangiri, Nowrangpur and Rayagada district have minimum surface water resources. Patnagarh, BM pur, Bhawanipatna and Nawapara block of Bolangir, Subarnapur, Kalahandi and Nuapada district have highest availability of surface water resources (Fig. 3). It can be observed from Fig. 3 that, minimum surface water resources are available in Gudvella, Binka, Karlamunda and Sinapalli blocks of Bolangir, Subarnapur, Kalahandi and Nuapada district respectively.

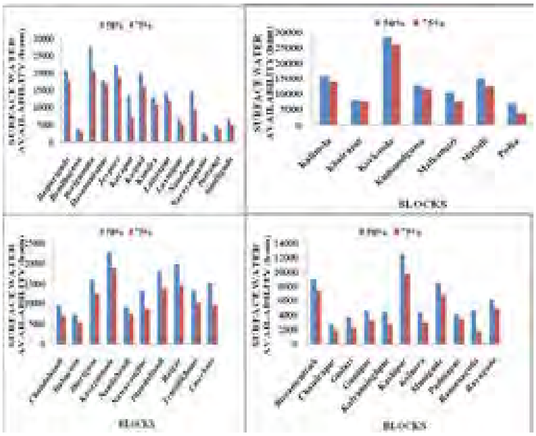

Figure 2: *Surface water resources of Koraput (Top Left), Malkangiri (Top Right), Nowrangpur (Bottom Left) and Rayagada (Bottom Right) district*

Table 3: Crop pattern and water utilization for drought conditions for self-sustenance in KBK districts

District	Surface water availability (ham)		Ground water resources (ham)	Total water availability (ham)		Domestic water demand (ham) in 2051	Livestock water demand (ham) in 2051	Total of domestic and livelihood water demand (ham) = (7) + (8)	Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utilization for irrigation purpose (ham)	Total water utilization for all uses (ham) = (9) + (15)	Groundwater contribution required	
	50 % Dep.	75 % Dep.		50 % Dep.	75% Dep.				Paddy	Other cereals	Pulses	Oil seeds	Vegetables			50 % Dep.	75 % Dep.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
KORAPUT	193149	168168	82136	275285	250304	5724	3305	9029	85000	0	31956	51313	26137	114715	123744	0	0
MALKANGIRI	91366	79334	32880	124246	112214	3406	2274	5680	60000	10000	20604	37060	12490	78391	84071	0	14
NOWRANGPUR	121094	89315	48103	169197	137418	3073	2629	5702	52000	48000	26596	15174	14743	88707	94409	0	11
RAYAGADA	66279	45484	62882	129161	108366	4464	2154	6618	15000	5000	33056	14086	29820	45123	51741	0	10
BOLANGIR	133943	79137	71349	205292	150486	5357	4064	9421	35000	7000	69100	32727	20056	78955	88376	0	13
SUBARNAPUR	59201	33408	29940	89141	63348	1902	1060	2962	15000	10000	26154	13085	7338	33272	36234	0	9
KALAHANDI	168010	128250	89520	257530	217770	6151	2991	9142	70000	20000	82125	47882	19156	124620	133762	0	6
NUAPADA	58656	44731	36729	95385	81460	2814	1406	4220	20000	0	30000	22221	12032	44516	48736	0	11

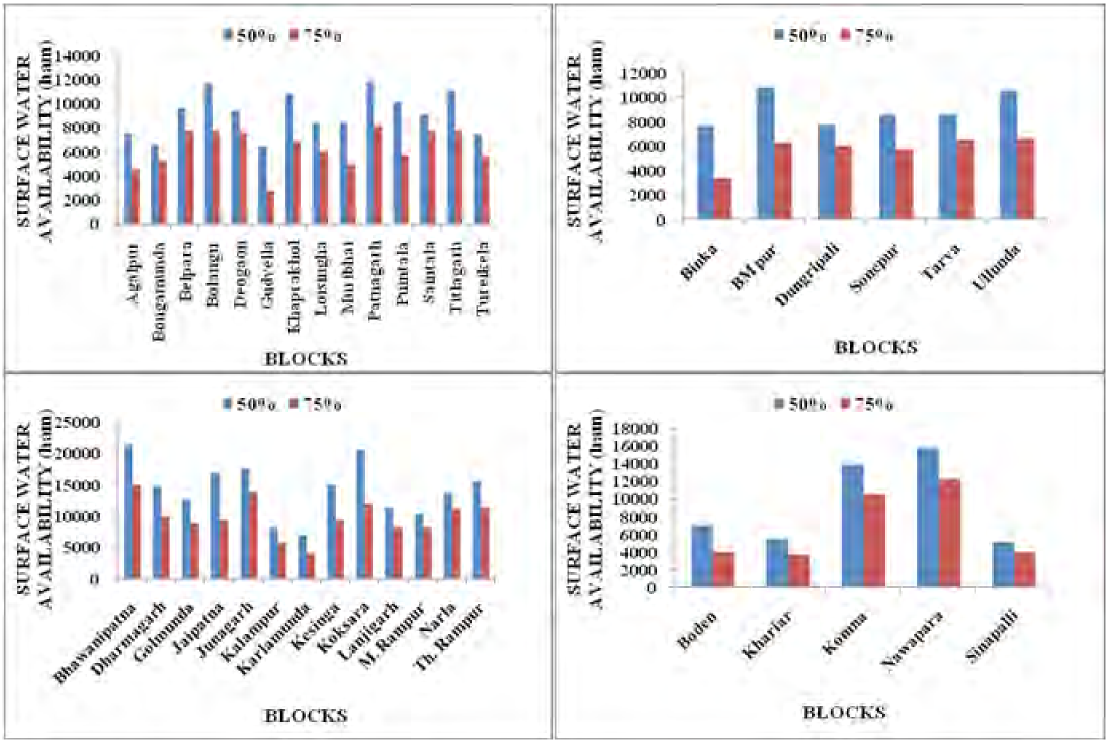

Figure 3: *Surface water resources of Bolangir (Top Left), Subarnapur (Top Right), Kalahandi (Bottom Left) and Nuapada (Bottom Right) district*

3.3 Ground water resources of KBK districts

Fig. 4 shows the groundwater resources available for all the blocks of Koraput, Malkangiri, Nowrangpur and Rayagada districts. Maximum amount of groundwater is available in Baipariguda (11648 ham), Kalimela (6847 ham), Raigar (8860 ham) and Gunupur (13371 ham) blocks whereas least amount of groundwater is present for Narayanpatna (1144 ham), Khairaput (1277 ham), Dabugaon (2335 ham) and Chandrapur (709 ham) blocks of Koraput, Malkangiri, Nowrangpur and Rayagada district respectively. It can be observed from Fig. 5 that, maximum amount of groundwater is available in Patnagarh (7002 ham), Dungripali (6123 ham), Junagarh (11252 ham) and Nawapara (17078 ham) blocks whereas least amount of groundwater is present in Gudvella (2946 ham), Tarva (4114 ham), Kalampur (3963 ham) and Boden (3608 ham) blocks of Bolangir, Subarnapur, Kalahandi and Nuapada district respectively.

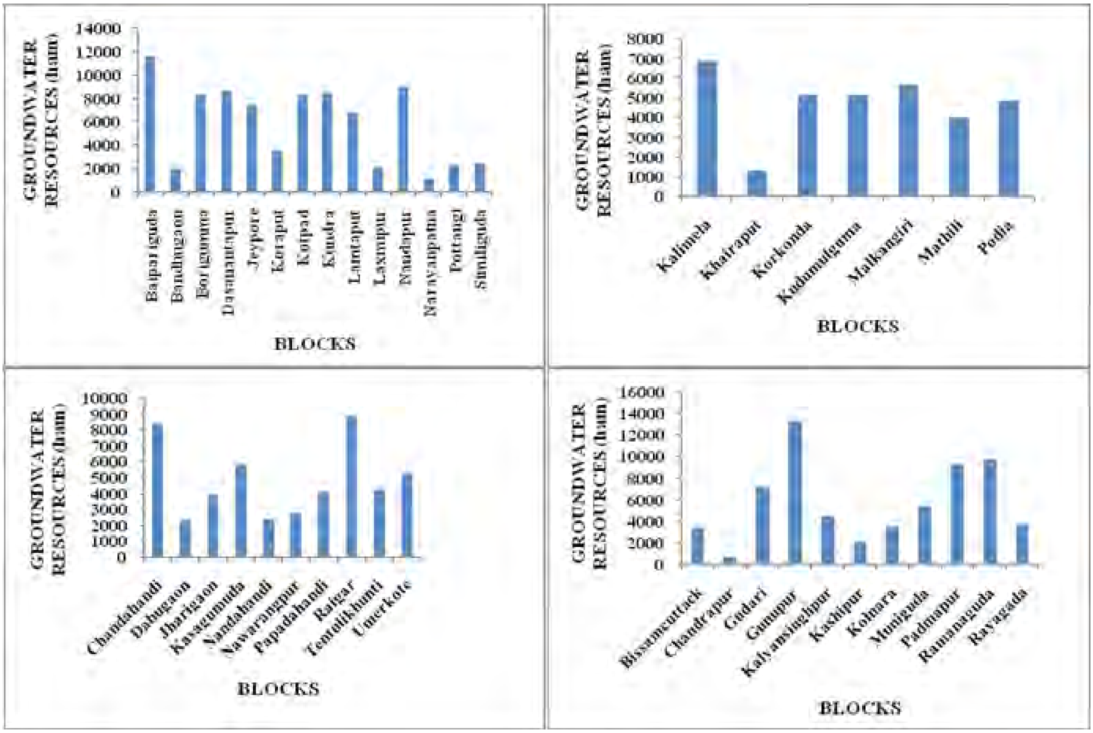

Figure 4: *Groundwater resources of Koraput (Top Left), Malkangiri (Top Right), Nowrangpur (Bottom Left) and Rayagada (Bottom Right) district*

3.4 Cropping pattern under drought conditions for self-sustenance of all the blocks of KBK districts

Total water availability (ha-m) as well as crop area (ha) to be followed under drought conditions for self-sustenance in 2051 along with the total water utilization and balance water available for domestic and other uses (ha-m) of all the blocks of Koraput district is presented in Table 4. Availability of total water is maximum in case of Borigumma block for 50% dependability and Baipariguda block in case of 70% dependability whereas minimum for Bandhugaon block of Koraput district. Maximum crop area (67336 ha) should be grown under pulses and minimum crop area (21591 ha) for other cereals in 2051. Cultivation of all the crops will be maximum for Dasanantapur block and minimum in case of Narayanpatna block. No groundwater contribution is required for all the blocks of Koraput District in order to grow the crops under drought condition for both 50% and 75% dependability. Availability of total water is maximum in case of Korkonda block whereas minimum for Podia block (Table 5). In case of Malkangiri district, maximum crop area (40153 ha) should be grown under oil seeds and minimum crop area (13000 ha) for other cereals in 2051. Maximum area is under cultivation for Korkonda block whereas minimum crop area will be grown in Podia block. No groundwater contribution is required for the growing of crops in all the blocks of Malkanagiri district.

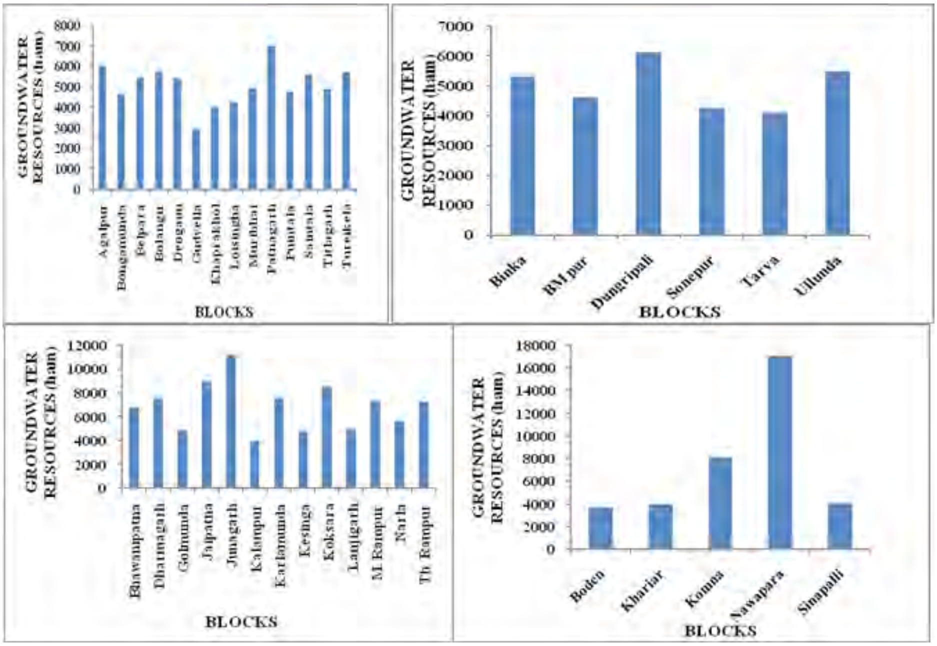

Figure 5: *Ground water resources of Bolangir (Top Left), Subarnapur (Top Right), Kalahandi (Bottom Left) and Nuapada (Bottom Right) district*

Table 4: *Total area, cropping pattern, and total water utilized for different blocks of Koraput district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utilization (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegetables		50% Dep.	75% Dep.
Baipariguda	32512	29073	3500	0	6651	6000	5000	13569	18943	15504
Bandhugaon	5977	5111	500	0	3000	1601	2688	3069	2908	2042
Borigumma	35778	28976	9000	3000	7784	7960	3911	15239	20539	13737
Dasanantapur	26246	25085	6500	2000	17025	5522	2835	9865	16381	15220
Jeypore	29964	26169	15000	4000	4675	4582	4662	18586	11378	7582
Koraput	16672	10724	2500	500	3937	4288	1889	7094	9578	3630

Kotpad	28321	24286	8000	3000	6231	3946	5420	12628	15694	11659
Kundra	21368	19426	3000	2000	3754	4845	2259	6869	14498	12556
Lamtaput	20994	18574	3000	1000	4371	6837	1783	9127	11867	9447
Laxmipur	8693	7343	3000	1500	1504	2288	2416	5212	3481	2131
Nandapur	23630	18394	4500	1000	4046	4823	2615	9244	14386	9151
Narayan-patna	3840	2967	500	1000	664	921	1240	1799	2041	1167
Pottangi	7379	6128	2500	591	1566	1343	1292	3841	3538	2288
Similiguda	9144	7618	2000	2000	2128	3334	1841	5073	4072	2545

Table 5: *Total area, cropping pattern, and total water utilized of different blocks of Malkangiri district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utili-zation (ham)	Balance water available for do-mestic & other uses (ham)	
	50% Dep.	75% Dep.	Pad-dy	Other cere-als	Puls-es	Oil seeds	Vege-tables		50% Dep.	75% Dep.
Kalimela	22691	20769	8500	500	3996	7493	4665	13217	9474	7552
Khaira-put	9331	8896	2000	2000	3524	3038	831	5783	3548	3113
Korkon-da	33614	31239	5500	2500	7082	11324	4522	13915	19699	17324
Kudu-mulguma	17767	16760	3000	0	5283	3935	1529	8504	9263	8257
Malkan-giri	16086	13274	2500	4000	3946	5176	2158	7596	8490	5679
Mathili	19050	16553	4000	2000	5950	7026	2035	11067	7983	5485
Podia	11560	8549	1000	2000	759	2161	2955	3719	7841	4830

Total water availability is maximum in case of Raigar and Kasagumuda block for 50% and 75% dependability respectively whereas minimum in case of Dabugaon block for both 50 and 70% dependability (Table 6). In case of Nowrangpur district, maximum crop area (45750 ha) should be grown under paddy crop and minimum crop area (15749 ha) for other cereals. Maximum area under cultivation should be for Kasagumuda block whereas minimum crop area should be grown in Dabugaon block. No groundwater contribution is required for the growing of crops in all the blocks of Nowrangpur district.

Availability of total water is maximum in case of Gunupur block whereas minimum for Chandrapur block for both 50% and 75% dependability (Table 7). In case of Rayagada district, maximum crop area (32251ha) should be grown under oil seeds and minimum crop area (11750 ha) for Paddy crop. Maximum area under cultivation observed for Kashipur block whereas minimum crop area will be grown in Chandrapur block. No groundwater contribution is required for the growing of crops in all the blocks of Rayagada district. Availability of total water is maximum in case of Patnagarh block whereas minimum for Gudvella block for both 50% and 75% dependability (Table 8). In case of Bolangir district, maximum crop area (55551ha) should be grown under pulses and minimum crop area (17302 ha) for Other Cereals. Maximum area under cultivation observed for Belpara block whereas minimum crop area will be grown in Gudvella block. No groundwater contribution is required for the growing crops in all the blocks of Bolangir district.

Table 6*: Total area, cropping pattern, and total water utilized of different blocks of Nowrangpur district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utili-zation (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegetables		50% Dep.	75% Dep.
Chandahandi	17826	15305	3500	1201	2173	4000	3589	6836	10990	8469
Dabugaon	9505	7552	1750	750	1791	1300	2400	5193	4312	2359
Jharigaon	19734	16155	5000	1000	3884	3002	3021	12215	7518	3940
Kasagumuda	28631	24695	8000	3000	6825	4375	3447	17971	10661	6725
Nandahandi	11389	9615	4500	1000	2908	2159	2980	6845	4544	2770
Nawarangpur	15717	11433	3500	1000	3137	3111	2974	8612	7106	2821
Papadahandi	22063	18082	5000	2000	5106	4348	2622	13793	8269	4288
Raigar	28808	23457	5500	1000	5605	3676	2649	14515	14293	8942
Tentulikhunti	17157	14225	4000	1000	2640	1805	1582	9931	7227	4294
Umerkote	20322	14793	5000	3798	3607	3200	4566	9520	10802	5273

Table 7: *Total area, cropping pattern, and total water utilized of different blocks of Rayagada district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utilization (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegetables		50% Dep.	75% Dep.
Bissamcuttack	12403	10748	2500	1669	4394	3966	2230	7225	5177	3523
Chandrapur	3416	2642	500	0	1000	1383	746	1889	1526	753
Gudari	10818	9492	500	1000	1651	1241	944	2241	8577	7251
Gunupur	17955	16569	1000	1000	1890	1440	1630	3189	14766	13380
Kalyansinghpur	8880	7136	750	1250	1000	1466	1467	2629	6251	4507
Kashipur	14466	11778	500	0	8000	12842	2716	9000	5466	2777
Kolnara	7784	6391	500	1500	1600	1700	1771	2891	4894	3500
Muniguda	13866	12061	2000	3500	4053	3097	2274	6517	7349	5544
Padmapur	13251	12741	1500	1000	1466	1481	1388	3467	9784	9274
Ramanaguda	14327	11490	500	500	800	1000	1000	1705	12622	9785
Rayagada	9869	8620	1500	2500	2879	2635	1962	4880	4989	3740

Table 8*: Total area, cropping pattern, and total water utilized of different blocks of Bolangir district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utilization (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegetables		50% Dep.	75% Dep.
Agalpur	13514	10552	1500	2500	3751	1869	1500	4492	9022	6060
Bongamunda	11249	9918	2500	1181	3000	1757	1883	5209	6040	4709

Belpara	15119	13194	2500	500	6000	4000	3273	7721	7397	5472
Bolangir	17410	13422	4000	1000	5000	3005	1835	7649	9761	5773
Deogaon	14809	13008	4000	1000	4000	3248	2367	7544	7265	5463
Gudvella	9359	5705	1000	1000	1500	1249	1345	2694	6665	3011
Khaprak-hol	14783	10863	2500	500	4000	3814	2521	6803	7981	4061
Loisingha	12663	10292	3500	500	2500	2100	2000	6015	6648	4277
Muribhai	13377	9828	1500	1390	3500	2055	1364	4917	8460	4911
Patnagarh	18867	15101	4000	1000	4500	2799	3846	8016	10851	7086
Puintala	14897	10442	3000	500	3300	1993	1847	5669	9228	4773
Saintala	14639	13278	3500	1000	4500	2520	1660	7680	6959	5598
Titlagarh	15966	12581	2500	3731	6000	2964	3199	7679	8286	4901
Tureikela	13149	11217	1500	1500	4000	3000	3000	5405	7744	5812

Total water availability is maximum in case of BM pur and Dungripali block for 50% and 75% dependability respectively whereas minimum in case of Tarva and Binka block (Table 9). In case of Subarnapur district, maximum crop area (24452 ha) should be grown under pulses and minimum crop area (10534 ha) for oil seeds. Maximum area under cultivation observed for BM pur block whereas minimum crop area will be grown in Binka block. No groundwater contribution is required for the growing of crops in all the blocks of Subarnapur district.

***Table 9**: Total area, cropping pattern, and total water utilized of different blocks of Subarnapur district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utili-zation (ham)	Balance water available for do-mestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vege-tables		50% Dep.	75% Dep.
Binka	12987	8746	1000	2000	1463	1500	2232	3415	9571	5330
BM pur	15428	10884	2000	3500	5517	1589	2809	6194	9234	4690
Dungri-pali	13905	12205	3500	2000	2057	2028	2225	5979	7926	6226
Sonepur	12840	10063	3000	3000	2500	1884	2419	5779	7061	4283
Tarva	12725	10691	2500	500	6904	1533	2704	6468	6257	4223
Ullunda	16013	12143	2500	2000	6011	2000	2772	6531	9481	5612

Total water availability is maximum in case of Koksara and Bhawanipatna block for 50% and 75% dependability respectively whereas minimum in case of Kalampur block for both 50% and 75% probability (Table 10). In case of Kalahandi district, maximum crop area (85032 ha) should be grown under Pulses and minimum crop area (33289 ha) for Other Cereals. Maximum area under cultivation observed for Junagarh block whereas minimum crop area will be grown in Karlamunda block. No groundwater contribution is required for the growing of crops in all the blocks of Kalahandi district.

***Table 10**: Total area, cropping pattern, and total water utilized of different blocks of Kalahandi district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utilization (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegetables		50% Dep.	75% Dep.
Bhawanipatna	28184	21833	5500	2807	10000	8378	1480	14902	13282	6931
Dharmagarh	22370	17549	4000	3000	8147	3208	3599	9829	12541	7720
Golmunda	17551	13816	6500	1500	3901	2500	2049	8932	8619	4883
Jaipatna	25944	18429	6500	3500	4110	2484	2008	9435	16509	8994
Junagarh	28918	25001	5500	7000	5540	5152	7060	13601	15318	11401
Kalampur	12208	9785	0	5000	7425	763	2218	5729	6479	4056
Karlamunda	14496	11733	1500	2000	3104	1627	1625	4158	10338	7576
Kesinga	19806	14133	4500	3000	6000	4000	3056	9320	10486	4813
Koksara	29123	20518	4500	1500	9000	6050	5221	11300	17823	9218
Lanjigarh	16326	13135	4000	1000	5500	3539	3000	8141	8185	4994
M. Rampur	17585	15543	4000	1732	6305	2727	2000	7858	9727	7685
Narla	19462	16852	4750	750	10000	6328	1754	10982	8479	5870
Th. Rampur	22911	18782	2500	500	6000	2961	1224	8263	14649	10519

Total water availability is maximum in case of Koksara and Bhawanipatna block for 50% and 75% dependability respectively whereas minimum in case of Kalampur block for both 50% and 75% probability (Table 11). In case of Nuapada district, maximum crop area (15500 ha) should be grown under Paddy and minimum crop area (8500 ha) for Other Cereals. Maximum area under cultivation observed for Nawapara block whereas minimum crop area will be grown in Khariar block. No groundwater contribution is required for the growing of crops in all the blocks of Nuapada district.

***Table 11**: Total area, cropping pattern, and total water utilized of different blocks of Nuapada district under drought conditions for self-sustenance*

BLOCK	Total water availability (ham)		Crop area to be followed under drought conditions for self-sustenance (ha)					Total water utili-zation (ham)	Balance water available for domestic & other uses (ham)	
	50% Dep.	75% Dep.	Paddy	Other cereals	Pulses	Oil seeds	Vegeta-bles		50% Dep.	75% Dep.
Boden	10607	7570	500	1500	2500	2542	2931	3931	6676	3639
Khariar	9468	7666	1000	1000	2000	1978	2177	3692	5776	3974
Komna	21974	18622	5500	1500	4000	4086	4653	10522	11452	8100
Nawapa-ra	32868	29403	8000	2000	4000	3200	3500	12260	20608	17143
Sinapalli	9126	8038	500	2500	2500	2168	2075	3892	5234	4146

4. Conclusions

In order to meet the growing demands for food grain of people and to achieve food security under the future scenario (2051) in KBK districts, there is a need to develop a mechanism to suggest the cropping pattern suitable to the respective agro-climatic zones of the region. It is also necessary to suggest an alternate cropping pattern limiting to the water availability in drought years for self-sustenance apart from meeting the water demand for domestic and livestock population to maintain healthy living conditions. This will prevent people migrating to neighboring districts/states in search of work in drought situations. Keeping in view the water availability in drought years, one optimal cropping pattern model has been developed to suggest the cropping pattern during drought conditions. This will keep the water requirement to the minimum as per availability. This model was developed by considering constraints as total cultivable area, total irrigated area, land type, irrigated and rainfed area. The model suggested the cropping pattern comprising of paddy, cereals, pulses, oilseeds and vegetables to be followed limiting to the water availability at 75% dependability with minimum supplementation from groundwater resources (0, 14, 11, 10, 13, 9, 6 and 11% for Koraput, Malkanagiri, Nowrangpur, Rayagada, Bolangir, Subarnapur, Kalahandi and Nuapada districts, respectively), and no groundwater contribution is required for 50%

dependability in drought conditions for self-sustenance in KBK regions. The prediction of this model will help in minimizing the crop loss and also improve the socio-economic status of the people of the region. This model covers five agro-climatic zones comprising eight KBK districts. Therefore, this model may be suitable for other areas/regions having similar type of agro-climatic conditions. The model may not be adopted for other climatic zones because of the variation in the constraints as well as the cropping pattern and climatic parameters varies.

References

Armah, F.A., Odoi, J.O., Yengoh, G.T., Obiri, S., Yawson, D.O., Afrifa, E.K.A. (2011). Food security and climate change in drought-sensitive savanna zones of Ghana. Mitigation and Adaptation Strategies for Global Change, 16, 291-306.

Catford, J. (2008). Food security, climate change and health promotion: opening up the streams not just helping out downstream. Health Promotion International, 23, 105

Deressa T.T., Hassan R.M., Ringler C., (2011). Climate change and agriculture Paper-Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. Journal of agricultural science, 149, 23-31.

Guiteras, R. (2007). The Impact of Climate Change on Indian Agriculture. Working Paper, Department of Economics, MIT.

Hillel, D., Rosenzweig, C., (2011). Climate change and agro ecosystems: key issues. In: Hillel, D., Rosenzweig, C. (Eds.), Handbook of Climate Change and Agroecosystems: Impacts, Adaptation and Mitigation. Imperial College Press, London, pp. 1–5.

IPCC (2007). Climate change 2007—Impacts, adaptation and vulnerability. Contribution of working group ii to the fourth assessment report of the IPCC. Cambridge University press, Cambridge

Kang, M.S., Banga, S.S. (2013). Global agriculture and climate change: a perspective. In: Kang, M.S., Banga, S.S. (Eds.), Combating Climate Change: An Agricultural Perspective. CRC Press, Boca Raton, FL, pp. 11–25.

Kumar, K., Parikh, J. (2001). Indian agriculture and climate sensitivity. Global environmental change, 11, 147-154.

Kumar, R., Singh, R.D., Sharma, K.D. (2005). Water resources of India. Current Science, 89(5), 794–811.

Kumari, P., Ojha, R.K., Wadood, A., Kumar, R. (2014). Rainfall and drought characteristics for crop planning in Palamau region of Jharkhand. Mausam, 65(1), 67-72.

Mandal, K.G., Padhi, J., Kumar, A., Ghosh, S., Panda, D.K., Mohanty, R.K., Raychaudhuri, M. (2015). Analyses of rainfall using probability distribution and Markov chain models for crop planning in Daspalla region in Odisha, India. Theoretical and Applied Climatology, 121, 517-528.

Mandal, S., Choudhury, B.U., Satpati, L.N. (2015). Monsoon variability, cropwater requirement, and crop planning for kharif rice in Sagar Island, India. International Journal of Biometeorology, 59, 1891-1903.

Mane, M.S., Jedhe, S.H., Kadam, U.S., Patil, S.T. (2016). Probability of dry/wet spell and rainwater availability at Dapoli for rice crop planning. Journal of Agrometeorology, 18(1), 165-167.

Mishra, D., Sahu, N.C. (2014). Response of farmers to climate change in Odisha: An empirical investigation. International Journal of Environmental Sciences, 4(5), 786-800.

Montazar, A. (2013). A decision tool for optimal irrigated crop planning and water resources sustainability. Journal of Global Optimization, 55, 641-654.

National Research Council (US) (2010). Advancing the science of climate change. America's Climate Choices: Panel on Advancing the Science of Climate Change, The National Academies Press, Washington, DC.

Nelson, D. R., Adger, W. N., Brown K. (2007). Adaptation to environmental change: Contributions of a resilience framework. Annual review of environment and resources, 32, 395-419.

Parry, M., Rosenzweig, C., Iglesias, A., Livermore, M., Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change, 14, 53–67

*Patel, S. R., Sastri, A. S. R.A. S. (2004). Drought management in rainfed rice (Oriza sativa L.). Journal of Agrometeorology, **6(**1), 147-149.*

Raju, K.S., Kumar, D.N. (1999). Multi-criterion decision making in irrigation planning. Agricultural Systems, 62, 117–129.

Reidsma, P., Ewert, F., Lansink, A.O., Leemans, R. (2010). Adaptation to climate change and climate variability in

European agriculture: The importance of farm-level responses. European journal of agronomy, 32, 91-102.
Smit, B., Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. Global environmental change, 16, 282-292.
Stern, N., Treasury, G. (2007). The economics of climate change: The Stern review. Cambridge University Press.
World Meteorological Organization (1992). International Meteorological Vocabulary. seconded, WMO, Geneva, Switzerland.

Calibration of an annual crop growth model in order to simulate growth and water use efficiency

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Abstract

Iran is a dry and semi-arid country due to inadequate precipitation as well as uneven spatial and temporal distributions. Agriculture is the largest water use sector in the country accounting for 93% of the total water use. Therefore, optimal use of the available water resources, especially in agriculture, is an indispensable necessity. Considering the current status of water resources in the country, one of the most effective ways to deal with water crisis and enhance (quantitative and qualitative) agricultural production is to improve agricultural water productivity. So far, many models have been developed and expanded to simulate crop growth. This study has used WOFOST model. The model was calibrated by using meteorological data (2014-2015) from Shahrekord station and wheat data from Shahrekord Agricultural Research Center. Simulation results of crop growth period and the total amount of production were compared with the observed data. Wheat growth chart was extracted and compared with Shahrekord's weather conditions. Also, the water use efficiency of wheat was compared with the rate of water use efficiency in the Shahrekord area. The simulated water utilization rate was higher than the actual rate, possibly due to low irrigation efficiency as well as weakness in wheat management. According to these conditions, cultivation of the late varieties is recommended in Shahrekord.

Keywords: *agriculture; water use efficiency; wheat; WOFOST mode*

1. Introduction

Water resources are becoming increasingly defenseless world-wide as a result of intensified demand arising from the increasing population; the need for escalated food production; degradation of quality due to various anthropogenic activities; industrialization and climate change (Hasnain and Rahman, 2017). Food and agricultural production are the largest water users and are directly constrained by water scarcity (Yang *et al*., 2006). One of the main factors that limits further expansion of food production for the increasing population will be water (Falkenmark, 2007). The demand for freshwater is doubled every 20 years as the population increases and living standard improves while the supply of freshwater is reducing at a similar rate as a result of population, climate change and sea water intrusion (Rogers, 2009). Research has shown that by improving water productivity, we will have enough water for agriculture,

the environment, industry and domestic use (Ehsani and Khaleghi, 2003). The concept of agricultural water productivity is the correct use of water, along with increased agricultural production. So far, many models have been developed and expanded to simulate crop growth and agricultural productivity. Crop modeling systems are designed to assist in analyzing the growth and development of crops and the environmental variables to which they are exposed (Amiri *et al.*, 2014). Crop modeling procedures try to represent the interaction between environmental and plant factors, allowing for more detailed study and prediction of the processes of interest (Amiri, 2016). As many physiological and morphological processes change with the phenological stage of the plant, accurate quantification of phenological development is essential in any crop model. To date, crop growth models are recognized as valuable tools in agricultural research and development (Larijani e*t al,* 2011). Crop simulation models are the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Mathews *et al*., 2000). Over the past decade, several crop simulation models have been developed to simulate and to predict crop growth, development and yield as a function of weather conditions, soil conditions, crop management and cultivar coefficients (Amiri e*t al*, 2015). This study has used WOFOST growth simulation model. It is a mechanistic model that simulates crop growth based on the underlying processes, including photosynthesis, respiration, and the effect of environmental conditions such as soil, climate, and fertilization on these processes (Wolf, 2002. Bouman *et al*, 2001). The model can be applied using two modes: (a) a potential mode, in which crop growth is driven solely by temperature and solar radiation, and in which no growth limiting factors are taken into consideration; and (b) a water-limited mode, in which crop growth is limited by the availability of water. The difference in yields between the potential and water-limited modes can be interpreted as the effect of drought. Currently, no other yield-limiting factors (e.g. nutrients, pests, weeds, farm management) are taken into consideration (Allard *et al*, 2012). The WOFOST model has been widely applied to many crops in the world across a wide range of climatic and management conditions (Matthews and Stephens, 2002; Wu *et al*., 2005). China, using the WOFOST model, achieved an average simulated potential yield of winter wheat in the northern region as 9.7 t/ha and in the southern regions as 7.5 t/ha. (Marleto et al., 2007). The study also simulated the growth of winter wheat in terms of water constraints, grain yield, and plant growth using weather data and the WOFOST vegetation model. Amiri and Rezaei (2011) used the WOFOST model to simulate the growth and development of rice. Also Rotter *et al*. (1997) calibrated and validated the WOFOST model for maze in Kenya and concluded that the model predicts the yield productivity with a ±15% error. This model was used to simulate maize and wheat in China (Yang et al., 2004; Song et al., 2006) and wheat in northern Italy (Marletto et al., 2007). Amiri et al (2011) used WOFOST to evaluate a data set of field experiments. Results concluded that the model generally overestimated the leaf area index (LAI) compared to the actual measured value. Zhou et al (2012) developed a fully coupled hydrological crop growth model to optimize an irrigation scheme under various environmental conditions. WOFOST was coupled to a hydrologic model (HYDRUS) as a calculation tool and applied to a wheat field experiment in the middle reach of Heihe river in Northwest China. Results showed that a good agreement was achieved between the model simulations and field measurements under water-limited conditions.

2. Materials and Methods

In order to calibrate the model, weather data was collected from meteorological station of Shahrekord for the year 2014-2015. The wheat crop data was collected from Shahrekord Agricultural Research Center. The crop and weather files were converted into the model prescribed format and data was entered using "crop" tab of the WOFOST (Fig. 1).

To be able to deal with the ecological diversity of agriculture, three hierarchical levels of crop growth can be distinguished: potential growth, limited growth and reduced growth. Potential production represents the absolute production ceiling for a given crop when grown in a given area under specific weather conditions. It is determined by the crop's response to the temperature and solar radiation regimes during the growing season. In this study simulation was performed by selecting the simulation of potential crop growth level (Fig. 2).

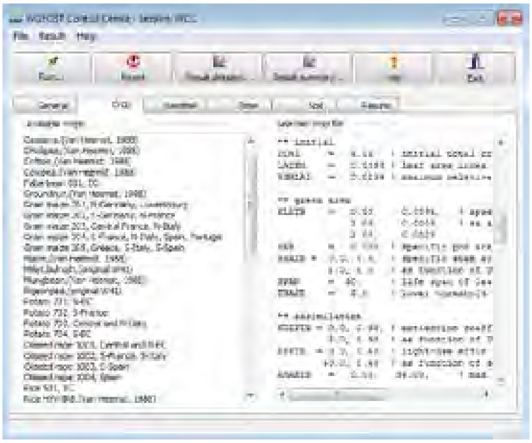

***Figure 1:** WOFOST "crop" tab*

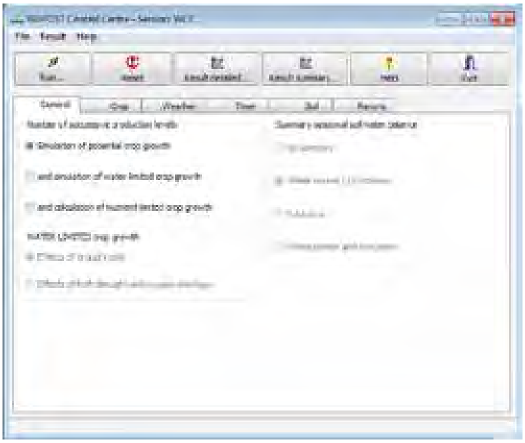

***Figure 2:** Selecting potential production level*

The simulation results were compared with the available data. The harvesting date of wheat simulated by the model was August 2, which differs from the observed data of July 22 (Fig. 3).

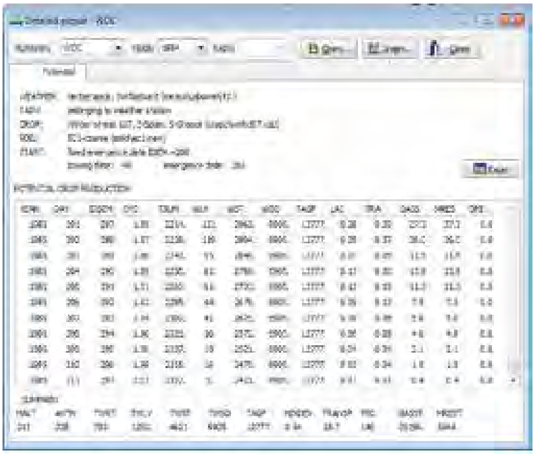

***Figure 3:** Output data*

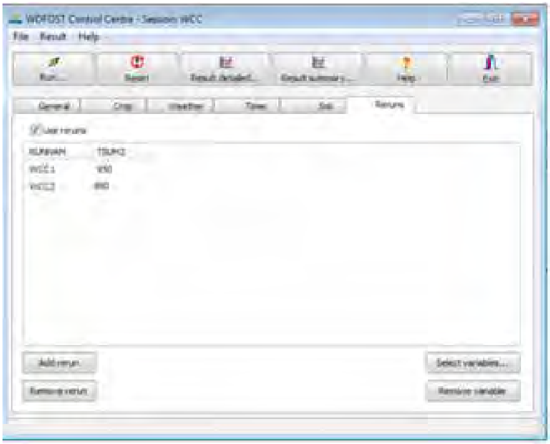

***Figure 4:** Re-running the model*

With the re-run file, a series of consecutive WOFOST-runs can be defined by providing a set of new values for one or more variables for each consecutive run. By re-running the model, the thermal time required from flowering to maturity (TSUM2) was determined with several runs as shown in Fig. 4.

In the next simulation, simulated date of crop maturity was matched to that of the observed (Fig. 5). In addition, the simulated wheat production in the Shahrekord was found to be 12500 kg/ha whereas the observed was 2,200 kg/ha (Fig. 5).

Once again, the mode Re-run was used. For this purpose, maximum rate of leaf assimilation (AMATXB parameter) was determined by trial and error as shown in Fig. 6.

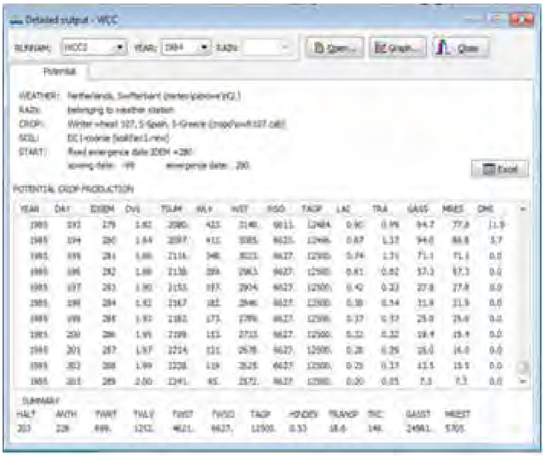

Figure 5: *Output data with re-running*

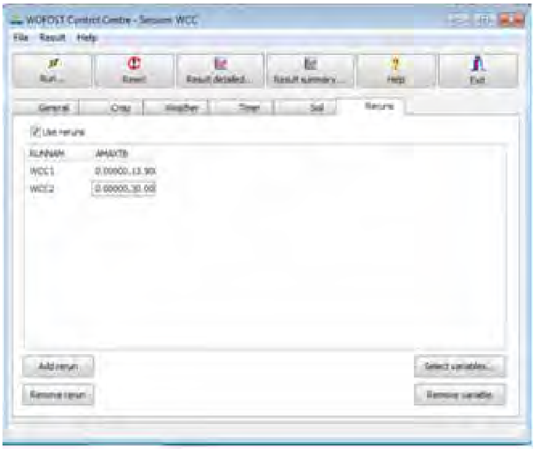

Figure 6: *Re-running the model*

In the next simulation results, the total amount of simulated wheat production was matched to the observed value (Fig. 7).

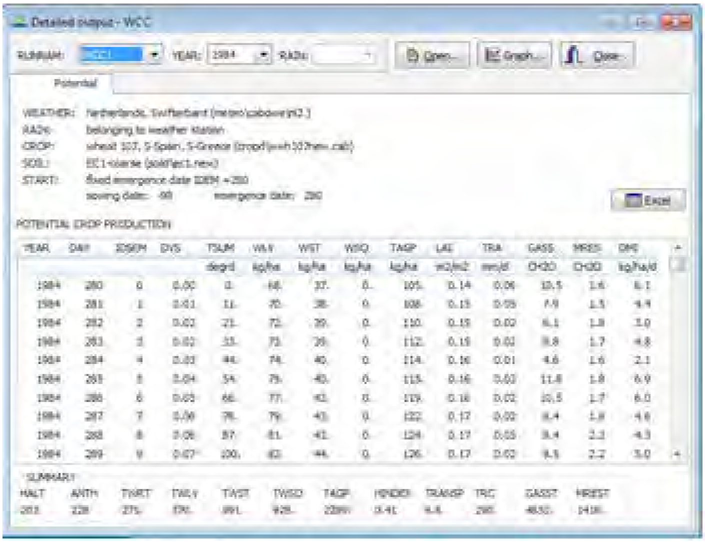

Figure 7: *Final output data*

In this way, the wheat crop file for Shahrekord was saved in WOFOST such that the data can be used in future studies to calculate the amount of crop production in water-limited level or nutrient-limited crop growth levels.

3. Results, Discussion, and Conclusion

In this paper, the WOFOST model was calibrated for wheat in Shahrekord. The crop growth diagram of wheat was extracted from the model, which is shown in Fig. 8. The amount of above ground production was increased since the 88th day of the year (March 9) with the maximum value on the 180th year (29th of June). The LAI graph is shown in Fig. 9. There is an increasing trend since the 85th day of the year (March 27) until the 215th day (August 3) after which it is decreasing.

The water use efficiency simulated by the model was 3.5 kg/m^3, while this rate according to an earlier study (Mirahmadi, 2012) for Shahrekord was 0.82 kg/m^3. Low irrigation efficiency and poor management of irrigation can be considered as two valid reasons of lower water use efficiency in Shahrekord compared to the simulated ones. Also, the model has run at the potential level; if there is a real shortage of water and food and pathogenic effects and more, the results will vary. According to these conditions, cultivation of the late varieties of wheat is recommended for the Shahrekord region. The generated model files can be used in the future to carry our research and irrigation planning studies in Shahrekord's conditions.

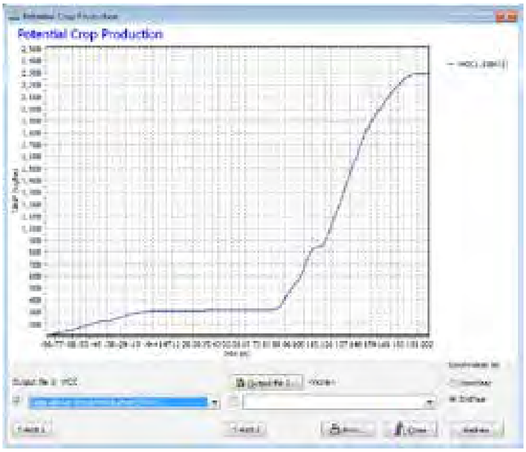

Figure 8: *Growth diagram of wheat*

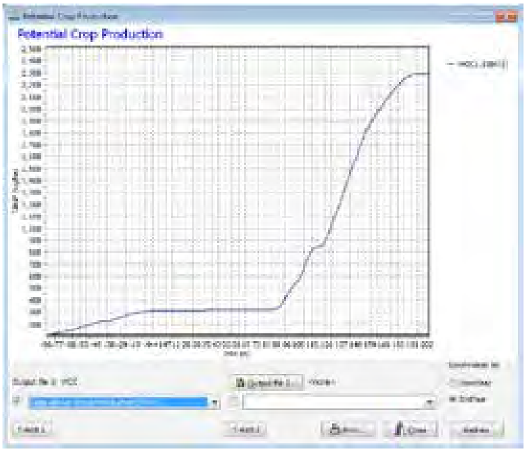

Figure 9: *Leaf area index graph*

References

Amiri, L. B., Sarvestani, Z.T., Nematzadeh, G. H., Manschadt, A.M., Amiri, E. (2011). Simulating phenology, growth and yield of transplanted rice at different seedling ages in Northern Iran using ORYZA2000. Rice Science, 18(4), 321-334.

Amiri, E., Rezaei., M., Eyshi, E.R., Bannayan, M. (2014). Evaluation of Ceres-Rice, Aquacrop and Oryza2000 Models in Simulation of Rice Yield Response to different Irrigation and Nitrogen Management Strategies. Journal of Plant Nutrition, 37 (11), 1749-1769.

Amiri, E., Abdzad G.A., Mianabadi, A. (2015). Evaluation of water schemes for peanut, using CSM-CROPGRO-Peanut model. Archives of Agronomy and Soil Science, 61 (10), 1439-1453.

Amiri, E. (2016). Calibration and Testing of the Aquacrop Model for Rice under Water and Nitrogen Management.

Communications in Soil Science and Plant Analysis, 47 (3), 387-403

de Wit, A., Duveiller, G., Defourny P. (2012). Estimating regional winter wheat yield with WOFOST through the assimilation of green area index retrieved from MODIS observations. Agricultural and Forest Meteorology, 164, 39-52.

Bouman, B.A.M., Kropff, M.J., Tuong, T.P., Wopereis, M.C.S., ten Berge, H.F.M., van Laar, H.H. (2001). ORYZA2000: Modeling lowland rice. IRRI, Manila, Philippines.

Amiri, E., Rezaei M. (2011). Evaluation of the crop growth model WOFOST under irrigation management. Agronomy Journal (Pajouhesh & Sazandegi), 90, 9-17

Ehsani, M., Khaleghi, H. (2003). Agricultural water productivity. ICID.

Falkenmark, M. (2007). Shift in thinking to address the 21st century hunger gap, moving focus from blue to green water management. Water Resource Management, 21(1), 3-18.

Hasnain, Z., Rahman, M.A. (2017). Managing water resources. DAWN. September 5, 2017. https://www.dawn.com/news/1355728/managing-water-resources

Mattews R.B., Stephens W., Hess T., Mason T., Graves A.R. (2000). Applications of crop/soil simulation models in developing countries. Final Report. PD 82. Cranfield Univ. at Silsoe, UK.

Marletto, V., Ventura, F., Fontana, G., Tomei, F. (2007). Wheat growth simulation and ield prediction with seasonal forecasts and a numerical model. Agriculture Meteorology, 147, 71–79.

Matthews, R.B., Stephens, W. (2002). Crop–soil simulation models: Applications in developing countries. CAB Int., Wallingford, UK.

Rotter, R., van Keulen, H. Jansen, M.J.W. (1997). Variations in yield response to fertilizer application in the tropics: I. quantifying risks for small holders based on crop growth simulation. Agric. Systems, 53, 41-68.

Rogers, P. (2009). Confronting the Global Water Crisis", Project Syndicate, www.project-syndicate.org, 05, 2009. With the continuous population growth and related developments, water resources have become increasingly scare in a growing number of countries and regions in the world.

Song, Y. I., Chen, D. L., Dong, W. J. (2006). Influence of climate on winter wheat productivity in different climate regions of China, 1961–2000. Clim. Res., 32, 219–227.

Wolf, J. (2002). Comparison of two potato simulation models under climatic change: I. Model calibration and sensitivity analysis. Clim. Res., 21, 173–186.

Wu, D., Yu, Q., Lua, C., Hengsdijk, H. (2005). Quantifying production potentials of winter wheat in the North China Plain. Journal of Agronomy, 24,.226–235.

Yang, H., Wang, L., Abbaspour, K., Zehnder, A. (2006). Virtual water and the need for greater attention to rain-fed agriculture. Water Magazine Int. Water Assoc., 21, 14-15.

Yang, H. S., Dobermann, A., Lindquist, J. L., Wolters, D. T., Arkebauer, T. J., Cassman, K. G. (2004). Hybrid-maize—A maize simulation model that combines two crop modeling approaches. Field Crops Res., 87, 131–154.

Zhou, J., Cheng., G., Li., X., Hu, B, X., Wang, G. (2012). Numerical Modeling of Wheat Irrigation using Coupled HYDRUS and WOFOST Models. Soil Science Society of America Journal, 76 (2), 648-662.

Crop water demand, climate variables and their effect on seed cotton yield in semi-arid region of India: A case study of Gujarat and Maharashtra

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Abstract

Nearly 76% of the available water resources is being diverted to improve livelihood of the farmers and agriculture-related industries. Hence an assessment of cropwater demand (evapotranspiration ETo) and its effective utilisation is imperative to boost food/commercial crop production particularly in rainfed regions of a country. In this paper the cropwater demand as ETo has been estimated by Hargreaves method for the period from 2001 to 2012 by taking daily meteorological data of the two cotton growing states of India (i.e., Gujarat and Maharashtra). Based on the daily water demand scenarios, the influence of water stress and climatic variables on seed cotton yield at different crop growth stages has been analysed and illustrated. In Maharashtra, the cotton crop is cultivated under rainfed condition (97.3 % of the total area) in light, medium and heavy soils and the water demand (ETo) of the cotton crop during June 20 to December 31, ranges from 765.7 to 1,011.2 mm. The rainfall received during the corresponding period varies from 558.5 to 1,051.1 mm. Some of the farmers continue their cotton crop up to April under drip irrigation system and harvest good seed cotton yield. During the period from January to April, the cropwater demand ranges from 527.7 to 738.6mm. As the rainfall received during the corresponding period is quite low (only 28.9 mm to 176.0 mm), farmers use groundwater for irrigation. In Gujarat, the cropwater demand and the rainfall received during the period from June to December is comparable with Maharashtra state except in Vadodara and Anand districts, where, the amount of rainfall is higher than the cropwater demand. The cropwater demand during the period from June to December in different districts ranges from 661.9 to 947.4 mm and the rainfall amount during this period ranges from 490.2 to 1150.5 mm. In case of the extended crop growing period from January to April the ETo ranges from 413.7 to 686.6 mm and the rainfall ranges from 5.5 to 34.9 mm. The total cropwater demand from June to April ranges from 1,075.6 to 1,595.8 mm and the rainfall received during the corresponding period ranges from 442.2 to 1210.5 mm. In this state the water resources structures are developed on a large scale and the farmers are harvesting good seed cotton yield using the irrigation facilities as compared to Maharashtra state. The multiple regression analysis between seed cotton yield and climatic variable (i.e. rainfall, crop ETc) at four critical crop growth stages (initial period 31 days,

crop development 50 days, mid-season 55 days, late stage 45 days after sowing on 20th June) were carried out by considering the seed cotton yield as dependent variable and climatic parameter (rainfall) and crop ETc as independent variables. In different districts of Gujarat, the correlation between rainfall and ETc on seed cotton yield was found to be 51 % to 92 %(R^2). The effect of rainfall during crop development and mid-stage was highly significant as it is expressed with as the crop was in flowering to boll development stages. Similar pattern was also recorded in different districts of Maharashtra where rainfall pattern and crop ET were regressed with cotton yield by considering ten years daily data.

Keywords: *cropwater demand; Gujrat; Maharashtra*

1. Introduction

One of the great challenges for the world's poor farmers is to provide food security and also ensure sustainability of food, fibre production and consumption. Among all fibre crops, cotton is a very important cash crop to the world's farmers. This crop is being commercially grown in more than 70 different countries in the longitudinal band between 37 ^{0} N and 32 ^{0} S. Cotton is widely adopted in semi-arid and arid environment, and is either grown in irrigated or rain-fed condition. About 53% of the world's production comes from supplemental irrigation or full irrigation and remaining 47% comes from rain-fed area (ICAC, 2013). At the global level, the cultivated area is increasing at a faster rate because of more earning from this fibre crop; however, the total production is not able to match the demand of cotton at global level. During 1950-51, the total cultivated area was 28.5 Million-Hectares (Mha) and it was increased to 33.5 Mha (17.5%) during 2010-11. Now the total production has also been increased at an alarming rate from 6.674 Million tonnes in 1950-51 to 25.368 Million tonnes (280%) in 2010-11. The productivity at the global level has also been improved substantially from 234 kg/ha in the year 1950-51 to 759 kg/ha (224 %) in 2010-11(ICAC, 2013). However, the magnitudes of productivity in different countries are changing significantly with the passage of time because of adoption of improved crop production technology, changing climatic variables and degree of resources utilization by the farmers. In Asia, this crop is being grown in 12 countries and the share of cultivated area, production and consumption is 66.4%, 68.0 % and 80.4 %, respectively over the world cotton scenario. Among the 12 Asian countries, three viz. China, India and Pakistan are contributing their major share in area, production and productivity.

Water is the primary and very important resource controlling plant growth. At the global level, water scarcity in the agriculture sector has severely hampered the overall outcome and the socio-economic status of the farmers. With the help of GlobWat model (Global Water Balance) by using AQUASTAT (data base) of FAO 2013, Hoogeveen et al. (2015) have reported that there will be a significant reduction of water for irrigation as 70 % of the freshwater is withdrawn in agriculture alone and the consumptive use of water in irrigated agriculture is 90% due to human intervention. As irrigated agriculture is the main component of water demand and driver of freshwater in any region of the world, it is thus highly essential to make effective use of water in the agriculture sector. In India, this crop is being cultivated predominantly in arid and semi-arid regions of the country over an area of 11.99 Mha. (Anonymous, 2011) However, the productivity is quite low as only 35.3 % of the cultivated area is under irrigation. In irrigated area (93.5 to 100 %) of the states like Punjab, Haryana, Rajasthan, the productivity is comparatively more than rainfed areas. In states such as Gujarat, the productivity is comparatively higher than other rainfed areas of the country. To improve the productivity of cotton in rainfed areas, there is an urgent need to make water resources structures at the plot level so that the supplemental irrigation during long dry

spell in monsoon season as well as after receding of monsoon will support cotton growth, and prevent the crop from suffering with moisture stress as well as occurrence of aberrant weather parameters. Basically, six weather parameters (i.e., temperature maximum, minimum, sunshine period, wing speed, relative humidity, and rainfall) influence crop growth, however maximum/minimum temperature and rainfall plays major role on growth/development of cotton in arid and semi-arid regions of the country.

1.1 Impact of climatic variables on crop growth

Cotton, being a perennial shrub, grows well under semi-desert area and requires warm temperature, but excessively high temperature during flowering and early boll development stages reduce yield substantially (Oosterhuis, 1999). The thermal kinetic windows (TKW) for enzymic activity strongly correlate with optimal temperature and general metabolism. The TKW of cotton is between 23.5 to 32 ^{0}C (Burke et al., 1988). If daily temperature exceeds this limit, then crop development and productivity is reduced. The optimum temperature for stem and leaf growth is about 30 ^{0}C and if the temperature reaches about 35 ^{0}C, growth rate and photosynthesis of cotton start decreasing (Hodges et. Al, 1993, Bibi et al., 2008, 2010). Reddy et al. (1991) reported that if day/night temperature exceed 40/20 ^{0}C, the reduction in total biomass is 50%. Reproductive stage is highly sensitive to higher temperature before and after anthesis. High temperature hastens appearance of first square, first flower and first mature boll. Temperature in excess of 30/20 ^{0}C in day/night results in to low retention of bolls. Cool temperature is the major limitation on crop productivity in temperate region. Gipson and Joham (1968) reported that the cool temperature below 20 ^{0}C at night hinders boll development. Reddy et al. (1992) reported that as plant canopy temperature exceeds 40 ^{0}C, production of bolls is reduced considerably. Three weeks' exposure to 40 ^{0} C for 6 hours resulted to only 40% boll retention and at same temperature (40 ^{0}C) for 14 hours resulted to 0% boll retention. Miller et al. (1996) ran multiple regression analysis by considering rainfall and temperature as independent variables and cotton yield as the dependent variable. They found that 50% variation in the yield was shared by weather parameters and remaining 50 % by management practices. They further identified that the most important factor for flower and boll production is evaporation, sunshine duration, humidity and surface soil temperature. Desired level of weather parameters for growing of cotton crop in arid and semi-arid region in India, is available, however, rainfall pattern is quite erratic, due to which the productivity is declining at a higher magnitude particularly in light to medium type of soils where water retentive capacity is very low. Hence it is highly essential to assess cropwater demand of cotton and provide suitable alternatives to the cotton growing farmers of arid and semi-arid region to increase its productivity.

The climate variables and concentration of carbon dioxide in the atmosphere are very important in cotton production. Houghton et. al. (2001) have reported that due to the anthropogenic activities, the concentration of carbon dioxide in the atmosphere has increased by more than 28% over the present level of 360 ppm and it may further aggravate if suitable management practices are not adopted well in advance. In the 21 st century, the concentration of carbon dioxide may increase to the tune of 970 ppm as industrial revolution is liberating more carbon dioxide in the atmosphere. As a result of higher concentration of carbon, the global temperature may increase in the range of 1.4 to 5.8 ^{0} C over the normal temperature. The high temperature increases male sterility in cotton flowers, bud shedding, alter boll development and size and reduces the availability of carbohydrate and maturity period considerably (Fisher, 1975; Reddy et. al., 1999, Loka and Oosterhuis, 2010). Dubey et al. (1995) have reported that the relative humidity directly or indirectly affects yield of crops. More relative humidity increases infestation of sucking pest and damages the cotton crop subsequently if adequate quantity of pesticides spraying

is not done in proper time (Singh et. al., 2009). Wind speed, sunshine hours also plays a significant role for harvesting quantity of cotton yield. High wind speed during the initial crop growth period in arid climate regions, damages the cotton seedling, increases the water requirement of the crop and reduces the humidity within crop canopy as well as surrounding areas of crop.

In India, Kumar (2015) analysed long-term meteorological data and reported that the surface air temperature has increased by 0.4 ^{0}C linearly in the past century. The warming trend at present has been observed in West Coast, Central India, Interior Peninsula and North Eastern India. Based on this projection, the agriculture sector is being badly affected with respect to more water demand as increased surface air temperature increased evaporative demand of crop. He further analysed and projected the production scenario of cereal crops and reported that every 1 ^{0}C rise in temperature may reduce the wheat production by 4 to 5 million tonnes by the end of the 21st century and the total food grain production will be reduced by 10 to 40%. Such heavy loss of food grain production due to increase in surface air temperature may affect the livelihood of the farmers who are fully dependent on agriculture.

1.2 Impact of Irrigation water

Ziao et al. (2000) conducted pot experiment on cotton crop by imposing four irrigation regimes and reported that when the cotton crop was grown in pots by applying irrigation water at 0.85, 0.70, and 0.55 or at 0.40 ET, the fruit bearing branches, squares, boll numbers, and boll size were increased with increasing water supply. Similarly, Barbour and Farquhar (2000) reported that in greenhouse when cotton was grown at 43 or 76 % relative humidity and sprayed daily with abscisic acid (ABA) or distilled water; the plants had higher transpiration rate and low stomatal conductance in lower relative humidity (RH). In Texas (USA), plant growth and yield of rainfed cotton (Pima cotton cv. S-6) were less in humid area than in an arid area with low humidity (Guo et al. 1994), because under the arid condition, higher vapour pressure deficit shows high transpiration rate, low leaf water potential.

Considering the major constraints of cotton production and productivity in India, the impact studies with regards to climatic variables and water demand scenarios under selected soil types has been carried with the help of daily meteorological data of cotton growing districts of Gujarat and Maharashtra.

2. Materials and Methods

The daily meteorological data of cotton growing districts of the two states were collected from Indian Meteorological Department (IMD) for the period from 2001 to 2012 and the reference evapotranspiration (ETo) was calculated using temperature-based ET method of Hargreaves and Samani (1985) as per the following equation:

$$ET_0 = 0.0023 R_a (TC + 17.8) TR^{0.50} \qquad \text{------------------(1)}$$

Where,

ETo = reference evapotranspiration (mm day^{-1})

R_a = extra-terrestrial radiation (mm day $^{-1}$)

TR = Tmax.-Tmin. (^{0} C)

TC = mean temperature (^{0} C); mean temperature =(T max+Tmin)/2

The monthly reference ETo and the rainfall pattern was prepared from 20th June every year as the monsoon rainfall is received during 11 June to 17 June and the farmers take up the sowing of cotton crop

thereafter. Under the rainfed condition, the farmers finish their boll picking operation up to December end and those who are having irrigation facility, they continue their cotton crop up to March-April. Based on ETo and rainfall pattern water, surplus and deficit period was indentified without soil water storage. Thereafter, the climatic water balance was computed by Thornthwaite and Mather (1955) procedure by considering the storage capacity of the soils of Gujarat as an example to assess the magnitude of soil moisture surplus and deficit during the crop growing period. The equation for the water balance is given below for reference. In this equation water is stored in the soil reservoir until the soil water content (*SW*) exceeds the available water capacity (*AWC*). at which point the excess goes into storage (*S*) or runoff is the provision of storage is not made at field level. Determining the soil water budget requires keeping the track of the accumulated potential water loss (*APWL*) and the amount of water in the soil (*SW*). In this equation three conditions of the soil water movement occurs due to ETo, rainfall and the soil water available in the profile.

Situation at field level	SW	APWL	Excess
Soil is drying $\Delta P < 0$	$= AWC \exp\left(\frac{APWL_t}{AWC}\right)$	$= APWL_{t-1} + \Delta P$	= 0
Soil is wetting $\Delta P > 0$ but $SW_{t-1} + \Delta P \leq AWC$	$= SW_{t-1} + \Delta P$	$= AWC \ln\left(\frac{SW_t}{AWC}\right)$	= 0
Soil is wetting above capacity $\Delta P > 0$ but $SW_{t-1} + \Delta P > AWC$	$= AWC$	= 0	$= SW_{t-1} + \Delta P - AWC$

When P>PET, AET =PET   When P<PET, AET = dSW + P

AWC = Available Water Capacity(field capacity-wilting point)X(soil depth)

SW = Available Soil Water (i.e., above wilting point.)

APWL = Accumulated Potential Water Loss (negative)

ΔP = Net rainfall amount; *P - PET*

P = Rainfall

PET = Potential Evapotranspiration

A*ET* = Actual Evapotranspiration

Deficit=defined when PET>AET

Surplus=defined when SW>AWS

Based on the output of the above equations, the daily monitoring of available soil moisture was performed and the suggestions have been given to the farmers for irrigation at various magnitudes of available soil moisture depletion. Generally, in the farmers' field, the irrigation is date is suggested when 50 % of the available soil moisture is depleted in case of surface flood irrigation and at 8-10 % depletion in case of drip irrigation method.

Table 1: *Soil Texture and water retention capacity of two major soils of Gujarat and Maharashtra*

Depth (cm)	Percentage of			Soil moisture retention (%)at		Available soil moisture (%)	Available soil moisture (mm)
	Sand %	Silt %	Clay %	33kPa	1500 kPa		
Clay Soil [at Ahmadabad, Modasar Series]							
0-18	26	29	45	30.5	14.2	16.3	29.34
18-55	23	25	52	28.4	13.5	14.9	53.64
55-82	22	38	40	29.3	13.9	15.4	40.04
82-145	20	38	42	31.5	14.5	17.0	108.80
Mean	22.75	32.5	44.75	29.93	14.03	15.87	Total 231.82
Sandy Loan Soil [at Ahmadabad, Block Sanand]							
0-18	62.1	20.1	17.8	15.4	6.4	9.0	16.20
18-46	57.9	22.7	19.3	16.8	7	9.8	27.44
46-73	59	23.9	17.1	16.3	6.4	9.9	26.73
73-105	59.2	23.9	16.9	16.3	6.4	9.9	31.68
105-150	58	25.2	16.8	16.6	6.4	10.2	45.9
Mean/Total	59.24	23.16	17.58	16.28	6.52	9.76	Total 146.5

So, considering the water demand and supply scenario, the effect of moisture stress and the climatic variables on seed cotton yield of two cotton growing states has been analysed and the possible technological intervention has been suggested to the planners/ researchers and irrigation engineers / hydrologists for further studies on development of water resources structures for irrigating cotton crop during long dry spell period.

3. Result and Discussion

3.1 Crop water demand in Maharashtra

In the major cotton-growing districts of Maharashtra, the cropwater demand and rainfall pattern vary considerably during the crop growth period. In Vidarbha region (Table 2 a, b), the cotton crop is cultivated under rainfed condition in light to heavy type of soil, however, the potential seed cotton yield is not achieved due to the erratic distribution of rainfall which is received during monsoon season. The farmers take sowing of the cotton crop once sufficient monsoon rain is received. Thereafter, it is continued

even up to the last week of December but under irrigated situation some of the farmers continue their cotton crop till April under pressurised irrigation system. It was observed that under the rainfed condition, the water demand (ETo) of the cotton crop from June 20 to December 31, ranged from 765.7 mm to 1011.2 mm, and the rainfall received during the corresponding period varied from 558.5 mm to 1051.1 mm. But the rainfall distribution within different month is not quite good. During the peak rainy months (July to September), the amount of rainfall is quite higher than the water demand. The magnitude of rainfall received during the period of these three months ranged from 103.4 mm to 354.7 mm and the water demand is 113.6 to 138.4 mm. Hence the excess rain water generally causes the severe problem of water logging in heavy type of soil, where drainage is poor. In the light type of soil, however, prolonged dry spell adversely affect the crop growth due to faster depletion of available soil moisture.

After receding of monsoon rain in the last week of September, cotton crop needs the very high amount of water during October to December as the crop is in full growth stages. However, the amount of rainfall received during this period is very low and the available soil moisture this time cannot support the crop for long period particularly in the light type of soil and hence the crop suffers from moisture stress and the final yield is reduced considerably (Table 2 a, b). Similarly, in the month of January to April the cropwater demand is very high (554.1 to 738.6 mm) as against the amount of rainfall (64.4 mm to 132.1 mm) and the deficit amount of water is being fulfilled through irrigation whereever it is available . During this dry months period the farmers are invariably using pressurised irrigation system and saving significant amount of irrigation water as against surface irrigation method.

In central and north Maharashtra where cotton crop is being cultivated under rainfed situation, the amount of rainfall received during monsoon season as well as to some extent in non-rainy season but it is comparatively low as compared to Vidarbha region except in Amarawati district (Table 2 c, d). The cropwater demand during June to December was in the range of 707.4 mm in Ahmednagar to 921.0 in Jagaon district, however, the amount of rainfall was in the range of 472.3 mm in Jalgaon to 885.1 mm in Nanded distrct. During the month of July, August and September, the rainfall amount is comparatively higher than the cropwater demand and hence these excess rainfall needs to be effectively managed through various water conservation measures and utilised during October onwards as the rainfall during October to December months is not enough to grow the cotton crop with potential supply of available soil moisture in profile. In subsequent period (January to April) also, cropwater demand is quite high and those farmers who are having irrigation facilities, are growing cotton crop and harvesting more cotton than the farmers who are taking their field crop under rain fed condition.

***Table 2 (a)**: Crop water demand (ETo) and rainfall scenario during cotton growing period in Nagpur, Wardha, Yeotmal areas in Vidarbha region, Maharashtra*

Period	Nagpur 2001-2012		Wardha 2001--2012		Yeotmal 2001-2012	
	ETo	Rainfall	ETo	Rainfall	ETo	Rainfall
June 20 to 30	49.9	103.3	56.1	40.8	59.7	98.5
July 1 to 31	134.4	271.6	138.2	166.3	143.8	271.1
Aug1-31	123.2	238.2	129.5	243.6	124.3	316.4
Sep 1-30	140.3	159.0	131.7	160.3	137.0	103.4

Oct 1-31	200.5	33.7	138.0	49.5	143.7	66.9
Nov 1-30	184.4	18.0	108.5	15.7	122.2	51.0
Dec 1-31	178.5	6.0	110.4	5.2	114.1	7.4
Total	1011.2	829.7	812.2	681.3	844.9	914.5
Jan 1-31	180.1	50.1	107.8	82.0	117.5	47.9
Feb 1-29	172.8	17.8	109.3	8.6	130.7	18.7
Mar 1-31	189.3	28.1	147.3	20.4	184.9	19.5
Apr 1-30	196.4	13.8	197.6	21.1	208.3	13.7
Total	738.6	109.8	561.9	132.1	641.4	99.8
Grand Total	1749.8	939.5	1374.2	813.4	1486.3	1014.3

***Table 2 (b)**: Crop water demand (Eto) and rainfall scenario during cotton growing period in Chandrapur, Buldhana, and Amrawati areas in Vidarbha region, Maharashtra*

Period	Chandrapur (2001-2009)		Buldhana (2001-2010)		Amrawati (2001-2009)	
	ETo	Rainfall	ETo	Rainfall	ETo	Rainfall
June 20 to 30	60.5	101.8	55.4	127.4	55.7	75.1
July 1 to 31	138.4	340.3	130.4	193.4	132.4	128.7
Aug1-31	113.8	354.7	113.6	302.6	122.3	156.1
Sep 1-30	114.3	135.3	121.8	129.3	120.3	96.9
Oct 1-31	130.5	61.2	133.5	77.3	133.3	38.2
Nov 1-30	121.4	13.7	111.4	40.7	104.2	62.6
Dec 1-31	121.2	8.2	111.0	2..0	97.6	1.0
Total	800.2	1015.1	777.0	872.6	765.7	558.5
Jan 1-31	128.9	43.4	115.1	13.7	104.8	14.0
Feb 1-29	143.9	10.7	131.5	12.4	109.6	5.6
Mar 1-31	167.8	25.5	171.4	124.5	158.7	33.1
Apr 1-30	205.5	34.7	191.4	25.3	181.1	11.8
Total	646.2	114.3	609.4	176.0	554.1	64.4
Grand Total	1446.4	1129.4	1386.4	1048.6	1319.9	623.0

***Table 2 (c)**: Crop water demand (ETo) and rainfall scenario during cotton growing period in Nanded,*

Parbhani, and Aurangabad in Marathwada region, Maharashtra

Period	Nanded (2001 - 2007)		Parbhani 2001-2012		Aurangabad 2001-2012	
	ETo	Rainfall	ETo	Rainfall	ETo	Rainfall
June 20 to 30	58.8	99.5	60.4	74.0	56.0	73.8
July 1 to 31	149.1	275.3	148.5	285.7	142.4	171.6
Aug1-31	133.5	246.0	128.8	199.2	128.5	186.9
Sep 1-30	137.5	151.3	135.4	113.6	130.1	190.8
Oct 1-31	144.7	84.1	151.2	88.4	147.3	62.6
Nov 1-30	130.9	24.7	130.7	34.4	128.9	30.4
Dec 1-31	123.5	4.3	126.5	1.8	124.5	4.5
Total	878.0	885.1	881.5	797.1	857.7	720.6
Jan 1-31	122.9	13.2	130.9	16.1	127.0	3.4
Feb 1-29	149.8	0.0	146.2	7.3	140.7	4.4
Mar 1-31	197.5	4.5	197.3	22.7	190.1	12.6
Apr 1-30	210.1	15.1	214.8	7.0	206.1	8.5
Total	680.2	32.8	689.2	53.0	663.8	28.9
Grand Total	1558.2	917.8	1570.8	850.1	1521.5	749.5

***Table 2 (d)**: Crop water demand (ETo) and rainfall scenario during cotton growing period in Central Maharashtra (Ahmednagar) and Northern Maharashtra(Jalgaon)*

Period	Ahmednagar (2001 - 2012)		Jalgaon 2001-2008)	
	ETo	Rainfall	ETo	Rainfall
June 20 to 30	51.9	66.3	62.0	66.3
July 1 to 31	131.1	63.5	153.8	63.3
Aug1-31	111.3	108.9	133.5	108.9
Sep 1-30	100.6	163.0	141.2	163.0
Oct 1-31	113.2	58.7	161.9	58.7
Nov 1-30	93.3	12.7	141.1	12.7
Dec 1-31	106.1	0.3	127.5	0.3
Total	707.4	473.2	921.0	472.2
Jan 1-31	107.2	0.0	125.7	0.0

Feb 1-29	109.1	7.7	146.3	7.7
Mar 1-31	142.1	33.9	202.6	33.9
Apr 1-30	169.3	9.7	223.8	9.7
Total	527.7	51.2	698.3	51.2
Grand Total	1235.1	524.4	1619.4	524.4

3.2 Crop water demand in Gujrat

In East-Central part of Gujarat, the estimated cropwater demand and the rainfall received during the period from June to December is comparable except in Vadodara and in Anand districts (Table 3a). But in Kheda district, the quantity of the rainfall received is 48.3 % less than the cropwater demand. As far as the monthly distribution of rainfall against the cropwater demand is concerned, the rainfall received during the monsoon period (July to September) is 74.0% higher than ETo (421.1 mm) in Ahmedabad, 90.4 % higher than ETo (427.3 mm) in Anand, and 148.1% higher than ETo (399.3 mm) in Vadodara districts. Hence the excess amount of rainfall during these three months needs to be conserved/stored effectively and utilised during non-monsoon period. But in Kheda district, the rainfall amount and cropwater demand during the above period are quite comparable (385.9 mm ETo and 384.9 mm rainfall) (Table 3b) and hence only in-situ conservation measures are enough, provided the rainfall distribution is satisfactory. In subsequent crop growth period (October to December), the cropwater demand in these districts is quite high as compared to the rainfall amount received and hence, the crop needs supplemental irrigation to harvest potential crop yield (Table 3a, b). In subsequent period also (January to April) when the farmers continue their cotton crop, a huge amount of irrigation water is required (627.3 mm to 647.9 mm) as against very minimum amount of rainfall received (6.0 mm to 60.1 mm). Generally, the farmers exploit ground water / surface water for irrigating their field crops during the rainless period and harvest very good crop yield as it has been experienced by the irrigated area and the lint yield recorded by the Directorate of Economics and Statistics, Ministry of Agriculture, the Government of India during 2014. In remaining areas / region of the Gujarat state, similar cropwater demand scenarios and rainfall pattern are recorded (Table 3c) and hence the adequate water conservation techniques / methods are required to use rain water and irrigation water effectively.

***Table 3** (a): Crop water demand (ETo) and rainfall scenario during cotton growing period in Ahmedabad, Anand, and Vadodara areas, East-Central Gujarat*

Period	Ahmedabad (2001 to 2011)		Anand (2001 to 2011)		Vadodara (2001 to 2011)	
	ETo	Rainfall	ETo	Rainfall	ETo	Rainfall
June 20 to June 30	65.1	60.7	62.8	112.9	59.6	127.8
July 1 to 31	149.4	293.2	145.2	338.4	140.6	387.3
Aug1-31	133.7	333.7	139.2	325.1	127.4	423.6
Sep 1-30	138.0	105.8	142.9	152.0	131.3	179.8
Oct 1-31	157.8	8.9	157.4	35.5	154.2	17.9

Nov 1-30	127.6	9.4	131.4	19.0	127.7	10.4
Dec 1-31	109.1	1.1	110.4	0.0	111.2	3.6
Total	880.9	812.8	889.3	982.8	852.0	1150.5
Jan 1-31	110.7	1.5	112.0	0.0	114.3	2.2
Feb 1-29	129.8	6.4	132.7	14.0	131.5	50.4
Mar 1-31	184.9	4.1	187.6	0.8	187.1	0.7
Apr 1-30	209.0	6.0	215.5	0.0	210.2	6.8
Total	634.4	17.9	647.9	14.8	643.1	60.1
Grand Total	1515.3	830.7	1537.2	997.6	1495.0	1210.5

***Table 3** (b): Crop water demand (ETo) and rainfall scenario during cotton growing period in Nadiadi (Kheda), Amreli, Bhaunagar, Rajkot and Dwarka areas, East-Central Gujarat*

Period	Nadiad(Kheda) (2001 to 2011)		Amreli (2001 to 2011)		Bhaunagar (2001 to 2011)	
	ETo	Rainfall	ETo	Rainfall	ETo	Rainfall
June 20 to June 30	50.8	28.2	60.2	188.1	64.1	152.2
July 1 to 31	132.0	142.0	145.7	248.8	156.1	232.8
Aug1-31	123.4	142.9	130.9	176.5	141.8	195.3
Sep 1-30	130.5	100.3	140.6	153.3	137.1	158.2
Oct 1-31	159.8	10.3	163.3	31.0	153.5	18.4
Nov 1-30	134.7	4.3	136.0	22.8	125.2	18.5
Dec 1-31	112.8	8.3	124.7	0.8	111.1	0.0
Total	844.0	436.3	901.5	821.4	889.0	775.5
Jan 1-31	115.6	1.4	125.2	0.0	113.0	0.8
Feb 1-29	130.8	4.6	142.7	0.0	130.1	3.8
Mar 1-31	185.7	0.0	197.5	8.0	179.5	5.1
Apr 1-30	195.2	0.0	221.2	0.4	201.2	8.0
Total	627.3	6.0	686.6	8.4	623.8	17.7
Grand Total	1471.3	442.2	1588.1	829.8	1512.8	793.1

Period	Rajkot (2001 to 2011)		Dwarka (2001 to 2011)	
	ETo	Rainfall	ETo	Rainfall
June 20 to June 30	62.7	99.7	38.4	43.0
July 1 to 31	148.8	308.9	103.8	225.6
Aug1-31	134.8	262.3	99.3	197.1

Sep 1-30	143.1	161.4	99.1	150.9
Oct 1-31	161.7	12.1	119.0	19.6
Nov 1-30	130.6	30.4	107.9	14.8
Dec 1-31	112.3	1.0	94.2	1.5
Total	894.0	875.8	661.9	652.3
Jan 1-31	117.8	0.0	96.2	1.0
Feb 1-29	133.3	1.3	94.2	8.3
Mar 1-31	189.6	1.1	110.4	4.0
Apr 1-30	217.4	3.1	112.8	0.0
Total	658.0	5.5	413.7	13.3
Grand Total	1552.1	881.2	1075.6	665.7

Table 3 *(c): Crop water demand (ETo) and rainfall scenario during cotton growing period in Banaskantha and Bhuj areas in Northern Gujarat*

Period	Desa (Banaskantha) (2001 to 2011)		Bhuj (2001 to 2011)	
	ETo	Rainfall	ETo	Rainfall
June 20 to June 30	64.7	16.5	59.6	37.6
July 1 to 31	171.1	266.6	146.1	152.7
Aug1-31	147.8	242.4	133.8	178.3
Sep 1-30	150.7	104.9	141.4	78.2
Oct 1-31	169.8	13.3	157.2	1.9
Nov 1-30	132.9	35.6	122.0	40.7
Dec 1-31	110.4	0.9	101.6	0.8
Total	947.4	680.1	861.7	490.2
Jan 1-31	112.1	7.6	103.5	2.0
Feb 1-29	129.8	20.8	123.0	1.8
Mar 1-31	189.3	2.0	178.4	6.2
Apr 1-30	217.3	4.5	202.5	0.0
Total	648.4	34.9	607.4	9.9
Grand Total	1595.8	715.0	1469.1	500.1

3.3 Effect of climatic variables and crop ET during different crop growing period

The multiple regression analysis between seed cotton yield and climatic variables (i.e. rainfall and crop ETc) at four critical crop growth stages (initial period =31 days, crop development period =50 days, mid-

season period =55 days, and late stage period =45 days after sowing on 20th June) were carried out by considering the seed cotton yield as dependent variable and climatic parameter (rainfall) and crop ETc as independent variables. The effect of the climatic parameters on crop yield was significant particularly during reproductive stages. In different districts of Gujarat state, the response of the rainfall and ETc on seed cotton yield was found to be 51 % to 92 %(R^2). The effect of rainfall during crop development and mid stage was highly significant as it is expressed with as the crop was in flowering to boll development stages. Similar pattern was also recorded in different districts of Maharashtra where rainfall pattern and crop ET was regressed with cotton yield by considering ten years daily rainfall pattern and crop ET. The details of analysis are presented in Table 4a and Table 4b.

***Table 4 a**: Regression analysis (yield versus rainfall (Average 2001 to 2012)*

Location and name of variables	Parameters	Equations and Coefficients						
		Inter-cept	initial stage (20 Jun - 20 Jul =31 days)	crop develop-ment (21 Jul - 8 Sep = 50days),	mid-sea-son(9 Sep - 2 Nov =55 days)	late season 3 Nov - 18 Dec =45 days)	R^2	F value
Ahmad-abad i) yield x rainfall	Coefficients	119.2	+ 0.065 X_1	+ 0.18X_2	+ 0.14 X_3	+ 6.22X_4	0.70	3.48
	SE	72.4	0.21X_1	0.11	0.29	2.25		
	T – Value	1.60	0.31	1.55	0.48	2.76		
	P – Value	0.16	0.77	0.17	0.65	0.06		
Amreli i) yield x rainfall	Coefficients	145.3	+ 0.21	+ 0.71	+ 0.64	+ 1.92	0.66	2.43
	SE	136.6	0.26	0.38	0.44	2.16		
	T – Value	1.1	0.82	1.86	1.44	0.88		
	P – Value	0.34	0.45	0.12	0.21	0.42		
Baroda i) yield x rainfall	Coefficients	240.3	+ 0.01	+ 0.13	+ 0.48	+ 14.3	0.37	0.89
	SE	177.2	0.27	0.18	0.81	7.82		
	T – Value	1.35	0.05	0.68	0.59	1.82		
	P – Value	0.22	0.96	0.52	0.57	0.12		
Bhavnagar i) yield x rainfall	Coefficients	225.6	- 0.11	+ 0.45	+ 1.39	+ 3.04	0.62	2.42
	SE	285.5	0.45	0.65	0.50	3.73		
	T – Value	0.79	- 0.24	0.69	2.77	0.82		
	P – Value	0.28	0.17	0.13	0.01	0.08		

Desa – Banaskantha yield x rainfall	Expected yield (y)	331.2	- 0.1	+ 0.69	+ 0.75	- 3.50	0.55	1.82
	SE	138.1	0.54	0.27	0.68	- 2.41		
	T – Value	2.40	- 0.19	2.56	1.10	- 1.47		
	P – Value	0.05	0.85	0.04	0.32	0.19		
KHEDA Rainfall xYield	coefficients	429.9	- 0.03	+ 0.08	+ 0.56	+ 13.9	0.26	0.53
	SE	111.2	0.60	0.32	1.50	17.5		
	T – Value	3.7	- 0.05	0.25	0.37	0.79		
	P – Value	0.01	0.96	0.74	0.72	0.46		
Rajkot Rainfall x yield	Coefficients	51.3	+ 0.26	+ 1.29	+ 1.01	- 5.58	0.62	2.50
	SE	239.1	0.62	0.51	0.66	3.19		
	T – Value	0.21	0.42	2.51	1.52	- 1.8		
	P – Value	0.84	0.69	0.05	0.18	0.18		
Anand rainfall x yield	Coefficients	578.8	- 0.5	+ 0.1	+ 1.8	- 2.2	0.53	1.39
	SE	119.4	0.4	0.2	1.1	3.6		
	T – Value	4.8	- 1.4	0.4	1.7	- 0.6		
	P – Value	0.0	0.2	0.7	0.2	0.6		

Table 4 b: *Regression analysis (yield versus crop ETo) (Average 2001 to 2012)*

Location	Parameters	Equations and Coefficients						
		Inter-cept	Initial stage (20 Jun - 20 Jul =31 days)	Crop devel-opment (21 Jul - 8 Sep = 50 days),	Mid-sea-son (9 Sep - 2 Nov =55 days)	Late season 3 Nov - 18 Dec =45 days)	R^2	F value
Ahmed-abad Yield x ET crop	Coefficients	859.9	+ 4.41	+3.32	- 2.45	- 4.65	0.92	16.99
	SE	316.5	2.31	1.35	1.03	2.13		
	T – Value	2.71	1.91	2.45	- 2.38	2.18		
	P – Value	0.03	0.10	0.05	0.05	0.07		

Amreli yield x ET crop	Coefficients	- 1384	+ 15.6	+ 9.24	- 6.38	+ 0.54	0.51	1.30
	SE	2471.8	21.0	8.54	3.23	7.33		
	T – Value	- 0.56	1.22	1.08	- 1.97	0.07		
	P – Value	0.60	0.28	0.33	0.11	0.94		
Bhavnagar yield x ET crop	Coefficients	6215.3	-4.08	+2.8	-10.13	-17.5	0.89	12.63
	SE	825.0	4.2	4.60	3.3	4.99		
	T – Value	7.53	-0.97	0.61	-3.1	-3.5		
	P – Value	0	0.37	0.56	0.02	0.01		
Baroda yield x ET crop	Coefficients	1336.1	+ 13.6	+ 4.37	- 4.37	- 7.57	0.89	12.5
	SE	1125.8	8.82	2.53	1.11	3.59		
	T – Value	1.18	1.54	1.72	- 3.94	- 2.10		
	P – Value	0.28	0.17	0.13	0.01	0.08		
Desa–Basankan-tha Yield x ET crop	Coefficients	400.0	+ 8.16	+ 1.21	- 2.4	+7.1	0.50	1.48
	SE	866.2	7.1	4.0	4.4	7.8		
	T – Value	- 0.5	1.1	0.3	- 0.5	0.9		
	P – Value	0.7	0.3	0.8	0.6	0.4		
Kheda yield x ET crop	Coefficients	- 287.1	+ 22.8	+ 2.4	+ 0.2	- 6.0	0.47	1.32
	SE	1476.6	14.1	3.9	2.6	2.1		
	T – Value	- 0.2	1.6	0.6	0.1	- 0.4		
	P – Value	0.9	0.2	0.6	0.9	0.40		
Rajkot yield x ET crop	Coefficients	4851.3	+ 18.6	- 4.0	- 15.0	+ 3.9	0.58	2.11
	SE	4145.1	32.4	12.1	5.8	18.5		
	T – Value	1.2	0.6	- 0.3	- 2.6	0.21		
	P – Value	0.3	0.6	0.8	0.04	0.8		
Anand yield x ET crop	Coefficients	1457.4	+ 2.1	+ 3.1	- 4.8	+ 0.6	0.63	2.17
	SE	464.2	3.8	2.4	2.3	4.0		
	T – Value	3.1	0.6	1.3	- 2.1	0.2		
	P – Value	0.0	0.6	0.3	0.1	0.9		

3.4 Climate water balance studies

In case of heavy soil where the clay content is quite high, the water storage capacity is 231.7 mm in 145 cm soil depth. Due to continuous rainfall, the soil profile was reached to 231.7 mm on 31 July and the rainfall of about 187.64 which was received during 1 to 16 August was found to be in excess (Fig. 1) and this excess amount of rainfall can be effectively stored in small reservoir and it can be used once the depletion available water occurred to the extent of 50%.

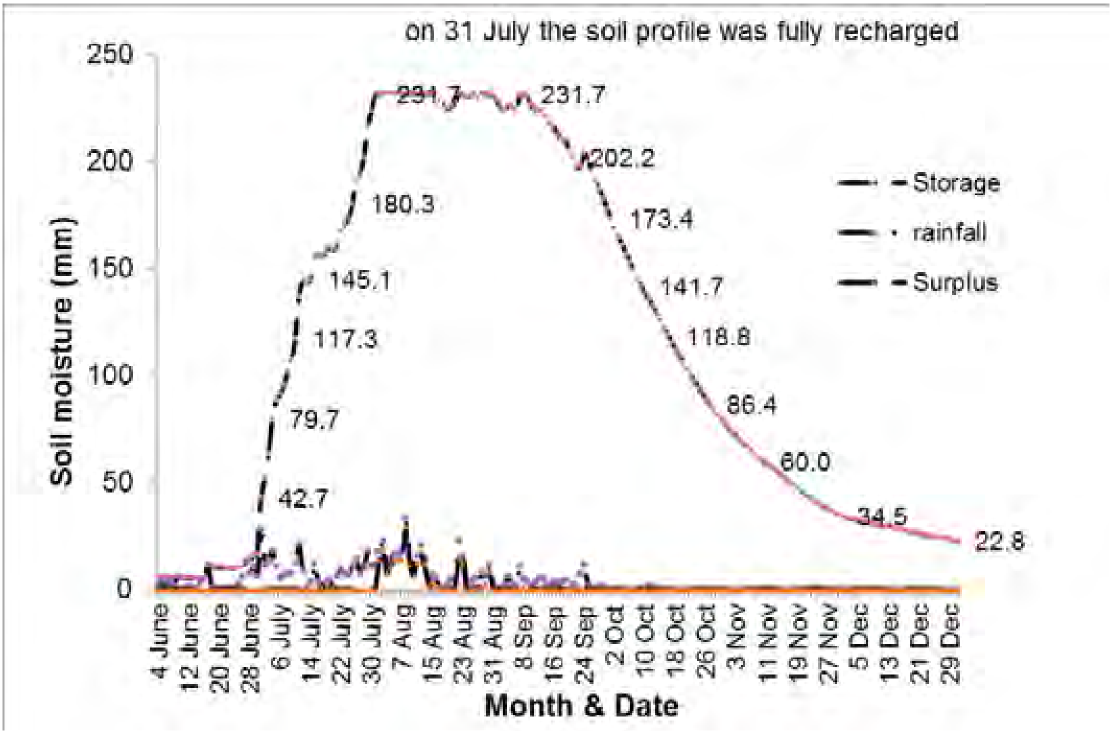

Figure 1: *Changes in soil moisture storage with time (average of 2001 to 2012) during cotton growing period in Ahmadabad district (clay soil)*

As per the computation of climatic water balance, 50% depletion was found on 16 October. If the farmers use the excess water during this period where the Bt cotton crop is in the flowering to boll development stages, they can harvest very good seed cotton yield. In case of sandy loam soil where the water storage capacity is 146.7 mm in 150 cm soil depth, the soil profile was fully recharged on 26 July and the rainfall amount of 188.3 mm which was received up August 16, was totally non effective. Thereafter the depletion of soil moisture occurred due to no rainfall. In the month of October, the crop suffers from moisture stress but due to low water retentive capacity of the soil and fast drying nature, the crop suffers from moisture stress early as compared to heavy soil. Hence it is suggested that in light soils, early maturing Bt hybrids can be advocated to the farmers (Fig. 2).

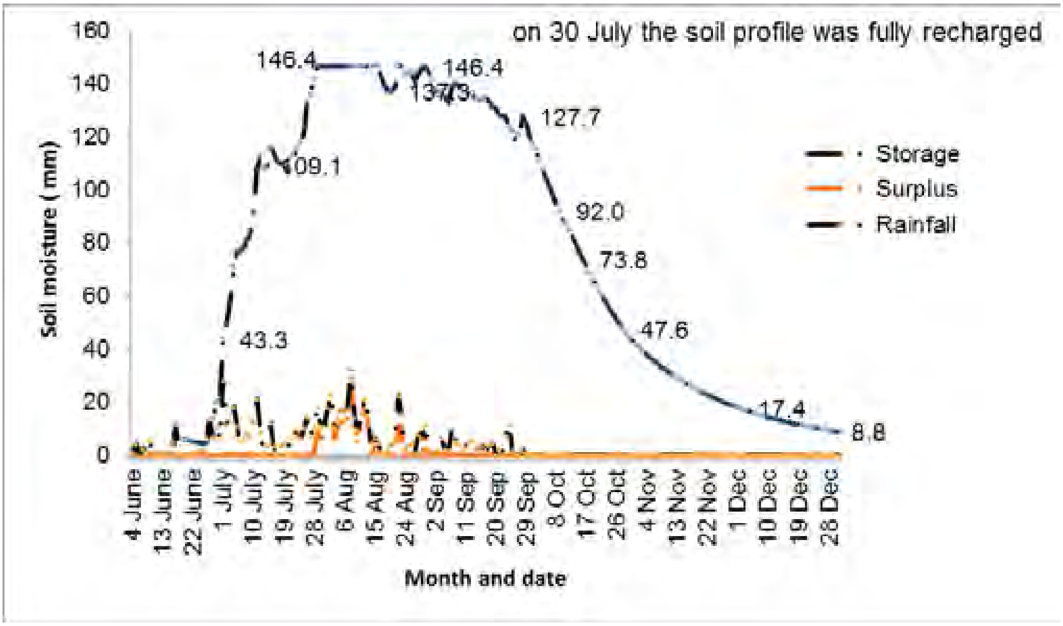

Figure 2: *Changes in soil moisture storage with time (average of 2001 to 2012) during cotton growing period in Ahmadabad district (sandy loam soil).*

4. Conclusions

Cotton, being a long duration crop, needs significant amount of water throughout the growing period. After sowing, it sustains on rainfall received during the monsoon period. During monsoon, , the crop is in flowering to boll development stage, however from October onwards, when the monsoon is withdrawn, the crop suffers from moisture stress and the seed cotton yield is adversely affected. In irrigated areas, farmers provide supplemental irrigation in October and November months and harvest satisfactory seed cotton yield particularly in the state of Gujarat where 56.7% cotton area is under irrigation. But in the state of Maharashtra where maximum cotton area is rainfed (2.7%), farmers are harvesting very low yield. Hence the assessment of water demand scenarios through these studies may help the planners, irrigation engineers and irrigation agronomists to properly plan rainwater harvesting and effective use of such harvested rainwater through pressurised irrigation system instead of the conventional aflood irrigation methods. The weather parameters also play a very important role in crop growth and development and increase in temperature substantiates significant amount of water demand in the crop growing period and effective planning and development of water resources structure may recoup the water needs of the crop, particularly during the dry period.

References

Anonymous (2011). Annual Report of Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare Govt. of India.

Barbour M.M., Farquhar G.D. (2000). Relative humidity and ABA induced variation in carbon and oxygen isotope ratios of cotton leaves. Plant Cell environment, 23, 473-485

Bibi, A.C., Oosterhuis, D. M., Gonias E.G. (2008). Photosynthesis and quantum of photosystem II and membrane leakages as affected by high temperature in cotton genotypes. J. Cotton Science, 12,150-159,

Bibi, A.C., Oosterhuis, D. M., Gonias E.G. (2010). Exogenous application of ameliorates the effect of high temperature in Gossipium hirsutum L. flower and fruit development. J. Agron. Crop Sci., 196, 205-211

Burke, J.J., Mahan, J. R., Hatfield, J. L. (1988). Crop specific thermal kinetic windows in relation to wheat and cotton biomass production. Agron. J., 80, 553-556.

Dubey, R. C., Choudhary, A., Kale, J.D. (1995). The estimation of cotton yield based on weather parameters on Maharashtra. Mausam, 46, 275-278.

Fisher, W. D. (1975). Heat induced sterility in Upland in cotton. In Proc. 27th Cotton Improvement Conference 1975, p.85.

Gipson, J. R., Joham, H, E. (1968). Influence of night temperature on growth and development on cotton (Gossipium hirsutum L.) I. fruiting and boll development. Agron. J., 60, 292-295.

Guo, Y., Landivar, J.C., Hanggelar, J. (1994). Response of leaf water potential and transpiration to water vapour deficit and salinity under arid and humid climate condition. In: Proceedings Beltwide Cotton Conferences: January 5-8, San Diego, California USA Memphis. USA National Cotton Council, pp.1301-1308.

Hargreaves, G.H., Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. Applied Engr. Agric., 1, 96-99

Hodges, H.F., Reddy, K. R., McKinnon, J.M., Reddy, V. R. (1993). Temperature effect on cotton. Mississippi Agri.and Forestry Exp. Sta. Mississippi State University, Missicippi.

Hoogenveen, J., Faures, J.M., Peirer, B.J. (2015). GlobWat- a global water balance model to assess water use in irrigated agriculture. Hydrological Earth System Science,19, 3829-3844.

Houghton, J.T. Ding, D. Griggs, D.J., Noguer, M., van der Lindon, P.J., Dai, X., Maskell, K., Johnson, C.A. (Eds.) (2001). Climate change 2001: the scientific basis, Contribution of Working Group I to the III rd Assessment Report of the IPCC, Cambridge University Press, Cambridge

ICAC (2014). International Cotton Advisory Committee Report 2013. The World Cotton Production Scenarios. ICAC Recorder, 13 (3). September 2014.

Kumar, A. (2015). Statistics related to Climate changes –India 2015. Ministry of Statistics and Programme Implementation. Central Statistics Office, Social Statistics Division, Govt. of India, New Delhi, pp.1-204.

Loka, D., Oosterhuis, D.M. (2010). Effect of high night temperature on cotton respiration, ATP levels and carbohydrate content. Environ. Exp. Bot., 68, 258-263.

Miller, J. K. Krieg, D, R., Patterson, R. E. (1996). Relationship between dry land cotton yields and weather parameters on the Southern hill plains. In Proc. Beltwide cotton conference Jan 9-12, Nashville T.N., USA, Memphis. USA National Cotton Council. pp 1165-1166.

Oosterhuis, D. M. (1999). Yield response environmental extreme in cotton. pp.30-38. In: Oosterhuis D. M.(ed.) Proc. 1999. Cotton Research Meeting Summery Cotton Research in Progress Report 193 Arkansas Agric. Exp. Stn., Fayetteville, AR.

Reddy, V. R., Baker, D. N., Hodges, H. F. (1991). Temperature effect on cotton canopy growth, photosynthesis and respiration. Agron. J., 83, 699-704.

Redd, V. R., Hodges, H. F., Reddy, V. R. (1992). Temperature effect on cotton fruit retention. Agron. J., 84, 26-30.

Reddy, K.R., Davidonis, G., Johnson, A., Vinyard, B. (1999). Temperature regime and carbon dioxide enrichment alters cotton boll development and fibre properties. Agron J., 91, 851-858.

Singh, S.P., Sekhon, B.S., Brar, J.S., Dhaliwal, I.K., Chahal S.K. (2009). Effect of Weather parameters and crop geometry on sucking pest dynamics in Bt and non Bt cotton. J. of Agro meteorology, 11, 129-234.

Thorntwaite, C.W., Mather, J. R. (1955). The water balance. Publ. Climatol. 8(1).

Ziao, J. F., Liu Z. G., Yu, X. G., Zhang, J. Y. (2000). Effect of different water application on lint yield and fibre quality of cotton under drip irrigation. Acta Gossipii Sinica, 12, 194-197.

Estimating paddy rice yield change considering climate change impact on cropping period

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Abstract

Intergovernmental Panel on Climate Change IPCC has projected an increase in temperature and precipitation due to climate change in South Korea which impacts paddy rice cultivation in terms of water use and rice production. It would have a significant impact on paddy rice cultivation including change in crop growth period, crop factors and crop varieties and farming methods which are highly dependent on weather conditions. Previous studies have estimated agricultural water according to the climate change scenarios, but most of them do not take into consideration the cropping period and the farming method. In this study, change in paddy rice yield is estimated considering climate change impacts on the cropping period and to subsequently identify impact in the food security of South Korea. The aim of this study is to simulate change in the cropping period by future climate change scenarios and to estimate the future paddy rice yield and agricultural water requirement using a crop growth model. Two study areas were selected in central and southern regions of South Korea. Future weather data was generated using representative concentration pathways (RCP) scenarios. Then the agricultural water requirement and the yield of future paddy rice were simulated using the CERES-Rice model. Weather, soil, crop data, cultivar and experiment data were the input to the model. Results showed that optimum transplanting date would be delayed in 2100 in all the tested scenarios. The optimum transplanting date for RCP 8.5 scenario would be delayed significantly compared to RCP 4.5. Also, paddy rice yield and growing period would be decreased and consumptive water use and irrigation water requirement would be decreased for RCP 4.5 scenario.

Keywords: *agricultural water use; climate change; cropping period; paddy rice yield*

1. Introduction

Carbon dioxide emissions from human activities are the major cause of climate change and greenhouse gas emissions are increasing every year. According to the fourth report of the Intergovernmental Panel on Climate Change (IPCC, 2007), global warming has reported an increase of about 0.74 °C globally from 1906 to 2005. The impacts of climate change on the global hydrological cycle are expected to vary

the patterns of demand and supply of water for agriculture - the dominant user of freshwater (Hong et al., 2009). Agriculture is a climate-dependent industry and closely linked to weather conditions, so climate change is expected to result in changes in the crop growth environment. In addition, paddy rice accounts for more than 90% of the domestic grain production and is sensitive to weather conditions such as temperature, precipitation and sunshine hours. Changes in the weather can significantly affect the cropping system, yield and evapotranspiration (Yun et al., 2011; Chung, 2012). This study aims to assess the impact of climate cha nge on the cropping system and yield in connect to water resources and food security of South Korea.

2. Material & Method

2.1 Study area

In this study, two meteorological sites were selected in the central (Chuncheon) and southern (Daegu) regions of South Korea where the crop factors, cropping periods and irrigation schedules differ according to the growing season.

Table 1: *Geographical characteristic of study stations*

Station name	Station number	Latitude (°N)	Longitude (°E)	Altitude (m)
Chuncheon	101	37.54	127.44	77.70
Daegu	143	35.53	128.37	64.10

2.2 RCP scenario

Studies are being conducted using the Representative Concentration Pathway (RCP) scenario presented in the IPCC Fifth Assessment Report. The SRES scenario included only the effects of greenhouse gases and aerosols on anthropogenic climate change factors, but the RCP scenarios also include impacts due to land-use change. The RCP scenarios correspond to the amount of radiative forcing, the amount of influence that changes the equilibrium of energy with greenhouse gases (CCIC, 2012).

2.3 Crop growth simulation model

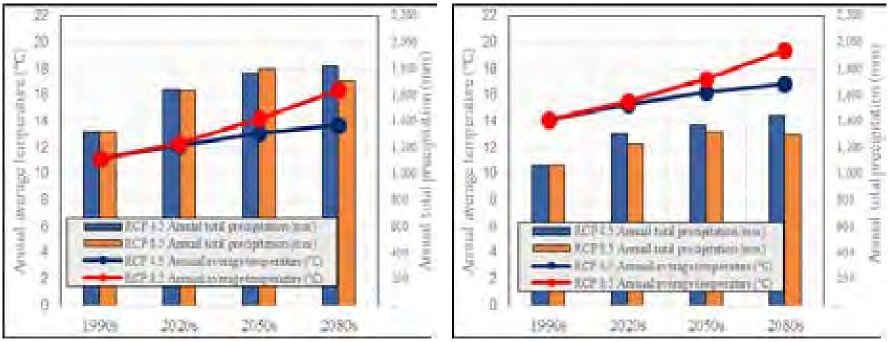
CERES (Crop-Environment Resource Synthesis) -Rice was developed in the USA and widely spread internationally by IBSNAT (International Benchmark Site Network for Agro-technology Transfer) project. This model considers the interactions between cultivated environmental components such as weather, soil, moisture, and nitrogen, which affect the growth and development of rice, and is considered to be in a practical stage beyond the laboratory level (Lee et al., 2012). In order to conduct the CERES-Rice model, it requires weather, soil, and farming-related information.

3. Results and Discussion

3.1 Future climatic characteristics

Meteorological data of Chuncheon and Daegu for the period of 1980-2099 was classified into four

time windows each of 30 years. 1980 to 2009 was set as the baseline period (Baseline, 1990s), and past observation meteorological data was applied from the Korea Meteorological Administration for this period. Future 30-years' time windows considered were 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099).



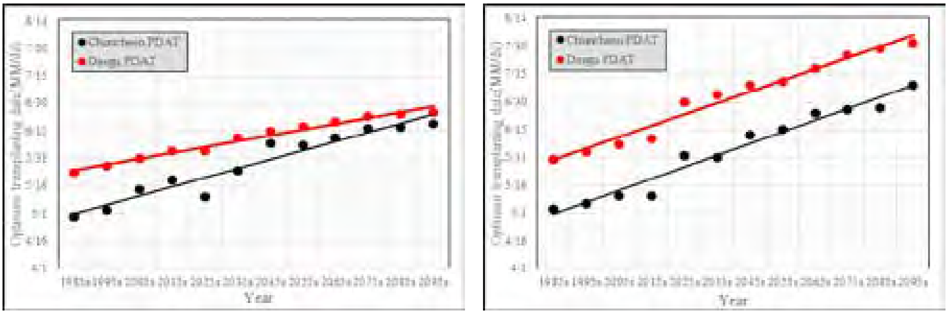
(a) (b)

Figure 1: *Annual change of average temperature and total precipitation (Blue: RCP 4.5, Red: RCP 8.5; (a) Chuncheon, (b) Daegu)*

3.2 Cropping period change

Rice paddy has a series of distinct growing stages in its cropping period, namely, transplanting, heading and harvesting. The cropping period is determined by the minimum temperature and the average temperature. Since the yield is influenced by the temperature in the heading period and after the heading, assessing the change in the cropping period as an effect of climate change is important for predicting agricultural productivity (Matthews et al., 1997).

Therefore, the optimum heading date and optimum transplanting date were estimated in this study for the climate change scenarios. The optimum heading date was estimated as for a period in which the accumulated temperature for 40 days from the reference date is above 840°C and below 920°C. Optimum transplanting date was estimated as the consumptive reference temperature of rice variety which was inversely estimated from the optimum heading date.



(a) (b)

Figure 2: *Optimum transplanting date by RCP scenario ((a): RCP 4.5, (b): RCP 8.5)*

Table 2: *Optimum transplanting date (month/date) at study station by RCP scenario*

Scenario	Year	Chuncheon	Daegu
RCP 4.5	1990s	5/5	5/27
	2020s	5/17	6/6
	2050s	6/8	6/17
	2080s	6/17	6/24
	Slope	4.9	3.1
RCP 8.5	1990s	5/6	6/3
	2020s	5/24	6/24
	2050s	6/17	7/12
	2080s	6/30	7/28
	Slope	6.3	6.2

The simulation results show that for the RCP 4.5 scenario, the transplanting date would be delayed by 43 days from 5/5 to 6/17 in Chuncheon and by 28 days from 6/3 to 7/28 in Daegu when compared to the baseline period.

For the RCP 8.5 scenario, the optimum transplanting date would be delayed 55-60 days in both the study stations. Regardless of the RCP scenario, the difference in optimum transplanting date between the central and southern regions is about 30 days. The optimum transplanting date in RCP 8.5 scenario is delayed considerably in comparison to RCP 4.5 scenario, which is a result of accelerated temperature rise due to the change in greenhouse gas concentration change of characterized by the RCP scenarios.

3.3 Paddy rice yield

The crop simulation model CERES-Rice generated paddy rice yield and growing period in RCP 4.5 scenario applying the transplanting date and heading date estimated by the RCP scenario into the model simulation.

Table 3: *Paddy rice yield and growing period results under RCP 4.5 scenario*

Region	Scenario	Rice Yield (kg/ha)	Growing period (day)	Region	Scenario	Rice Yield (kg/ha)	Growing period (day)
Chun cheon (101)	1990s	6,191	135	Daegu (143)	1990s	5,188	117
	2020s	5,595	130		2020s	4,578	114
	2050s	5,343	126		2050s	4,121	111
	2080s	5,270	123		2080s	4,052	109

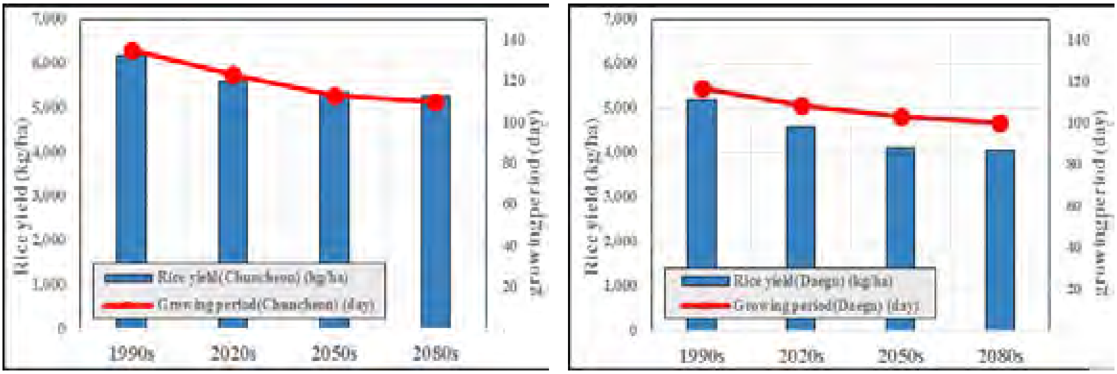
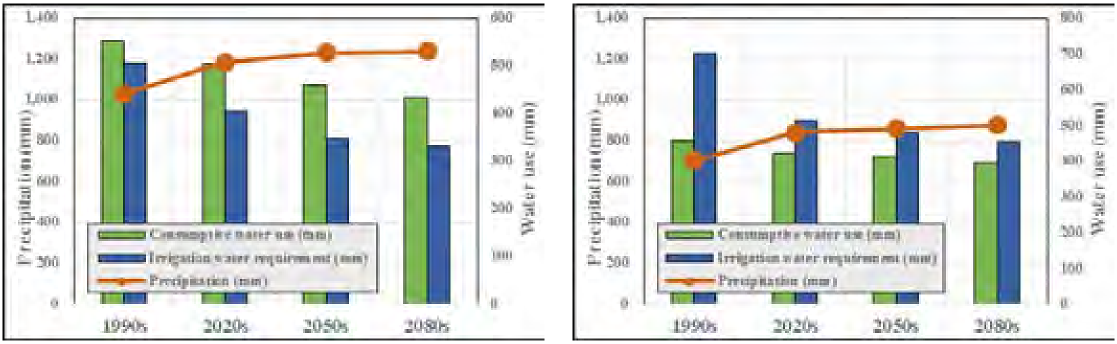


Figure 3: *Paddy rice yield and growing period under RCP 4.5 scenario*

As a result of paddy rice yield, in the case of RCP 4.5, it would be decreased to about 900-1,000kg/ha in Chuncheon and 900kg/ha in Daegu. Similarly, the growing period would be decreased to about 25 days in Chuncheon and 17-18 days in Daegu under the RCP 4.5 scenario.

3.4 Agricultural water use



(a) (b)

Figure 4: *Consumptive water use and irrigation water requirement under RCP 4.5 scenario ((a) Chuncheon, (b) Daegu)*

Fig. 4 shows the results of consumptive water use and irrigation water requirement under RCP 4.5 scenario. Consumptive water use would be decreased about 100-120mm; irrigation water requirement would be decreased about 170-220mm in Chuncheon. It is considered that because total precipitation increased during growing season, effective rainfall would be increased. In the southern region, consumptive water use is less than in Central region. Especially, in Daegu, there is little change in the consumptive water use in the future, irrigation water requirement is significantly more than other areas. It seems that because total precipitation is relatively less than other regions, the rate of increase in precipitation is the lowest, so the effective rainfall is less.

4. Conclusions

The purpose of this study is to estimate the changes in growing period according to climate change and to estimate the future paddy rice yield and agricultural water use in relation to the change of growing period. As a result, it was projected that firstly, optimum transplanting date and cropping period would be delayed as an effect of climate change. Compared to RCP 4.5 scenario, optimum transplanting date under RCP 8.5 scenario would be delayed significantly. Secondly, In the future, paddy rice yield and growing period would be decreased. It seems that due to climate change, temperature increases, and the effects of high-temperature injury and crop respiration increase are critical. Finally, regarding the consumptive water use and irrigation water requirement, in RCP 4.5 scenario, consumptive water and irrigation water requirement would be decreased because of the increase in effective rainfall.

Acknowledgements: This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01343502)" Rural Development Administration, Republic of Korea.

References

IPCC (2007). Climate Change 2007: Impacts, adaption and vulnerability. Cambridge University Press, Cambridge, UK

Hong, E.M., Choi, J.Y. Lee, S.H. Yoo, S.H., Kang, M.S. (2009). Estimation of paddy rice evapotranspiration considering climate change using LARS-WG, Journal of the Korean Society of Agricultural Engineers, 51(3), 25-35 (in Korean)

Yun, D.K., Chung, S.O., Kim, S.J. (2011). Climate change impact on paddy water requirement, Journal of the Korean Society of Agricultural Engineers, 53(4), 39-47 (in Korean)

Chung, S.O. (2012). Projection of paddy rice consumptive use in the major plains of the Korean peninsula under the RCP scenarios, Journal of the Korean Society of Agricultural Engineers, 54(5), 35-41 (in Korean)

Matthews, R.B., Kropff, M.J., Horie, T., Bachelet, D. (1997). Simulating the impacts of climate change on rice production in Asia and evaluating options for adoption, Agricultural Systems, 54(3), 399-425

CCIC (2012). RCP Scenarios. http://ccs.climate.go.kr

Lee, T.S., Choi, J.Y., Yoo, S.H., Lee, S.H., Oh, Y.G. (2012). Analyzing consumptive use of water and yields of paddy rice by climate change, Journal of the Korean Society of Agricultural Engineers, 54(1), 47-54 (in Korean)

Evaluation of combating-desertification strategies

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Abstract

Desertification is considered as a global problem that particularly affecting the developing countries. The challenges and threats of water scarcity to dry land populations are set to extend in magnitude and scope. As the world's population has reached to over 6 billion, some countries have already reached the limits of their water resources use. With the current climate change scenario, nearly half of the world's population will live in high-stress areas by 2030. Additionally, the scarcity of water in some arid and semi-arid regions will displace between 24 and 700 million people. The causes of desertification are complex and vary greatly from one case to another, thus solutions won't perpetually be easy. Social, cultural and economic issues need to be addressed together with the physical aspects of land management. Whereas cooperation at the national and international levels is required, action at the local community level has the ability to instantly improve the state of the environment. With respect to increasing importance of desertification and its complexity, the necessity of attention to the optimal combating-desertification alternatives is crucial. Selecting appropriate strategies according to all effective criteria to combat the desertification process are often helpful in rehabilitating degraded lands and avoiding degradation in vulnerable fields. This research discussed and evaluated effective ways to fight desertification.

Keywords*: climate change; desertification; management; strategies.*

1. Introduction

Desertification is defined as a process of land degradation in arid, semi-arid and sub-humid areas due to various factors including climatic variations and human activities. Alternately, desertification results in persistent degradation of dry land and fragile ecosystems due to man-made activities and variations in climate. Desertification, in short, is when land that was originally of another type of biome turns into a desert biome because of changes of all sorts. A huge issue that many countries have is the fact that there

are large pockets of land that are going through a process that is known as desertification (Nwokocha, 2017).

According to UNESCO, one-third of the world's land surface is threatened by desertification; it affects the livelihood of millions of people who depend on the benefits of ecosystems that dry lands provide. Desertification is another major environmental concern and a major barrier to meeting human basic needs in dry lands and is being constantly threatened by increases in human pressures and climatic variability (Ahmad and Pandey, 2017)

Based on the United Nations' information, at present, desertification has already affected one-fifth of the world's population and one-third of global terrestrial land. Desertification has brought serious catastrophe to the global environment and people's lives and very survival in many developing countries. It has become an important factor as a cause of poverty and a hindrance to economic and social sustainable development (Ci, 2000).

Desertification and land degradation lead to serious food safety issues in the countries affected. In the face of this phenomenon, the world governments started to seek for solutions under the leadership of the United Nations. In 1992 at the Rio Summit, intergovernmental officials agreed on three conventions; to stop desertification, to limit activities that impact climate change and to reduce loss of biological diversity. The United Nations Convention on Desertification, Land Degradation and Drought was ratified in 1994 in Paris and was introduced in 1996 (Nwokocha, 2015).

In this article, we are going to discuss what the causes of desertification are, the effects that desertification has, and what we can do in order to deal with this problem at hand.

2. Causes of Desertification

- **Overgrazing:** Animal grazing is a huge problem for many areas that are starting to become desert biomes. If there are too many animals that are overgrazing in certain spots, it makes it difficult for the plants to grow back, which hurts the biome and makes it lose its former green glory.
- **Deforestation:** When people are looking to move into an area, or they need trees in order to build houses and do other tasks, then they are contributing to the problems related to desertification. Without the plants (especially the trees) around, the rest of the biome cannot thrive.
- **Farming Practices:** Some farmers do not know how to use the land effectively. They may essentially strip the land of everything that it has before moving on to another plot of land. By stripping the soil of its nutrients, desertification becomes more and more of a reality for the area.
- **Urbanization and other types of land development:** As mentioned above, development can cause people to go through and kill the plant life. It can also cause issues with the soil due to chemicals and other things that may harm the ground. As areas become more urbanized, there are less places for plants to grow, thus causing desertification.
- **Climate Change:** Climate change plays a huge role in desertification. As the days get warmer and periods of drought become more frequent, desertification becomes more and more eminent. Unless the impacts of climate change are minimized, huge areas of land will become desert; some of those areas may even become uninhabitable as time goes on.

- **Stripping the land of resources:** If an area of land has natural resources like gas, oil, or minerals, people will come in and mine it out. This usually strips the soil of nutrients, which in turn kills the plant life ultimately leading to desertification.
- **Natural Disasters:** There are some cases where the land gets damaged because of natural disasters, including drought. In those cases, there isn't a lot that people can do except work to try and help rehabilitate the land after it has already been damaged by nature.

3. Effects of Desertification

- **Farming becomes next to impossible:** If an area becomes a desert, then it's almost impossible to grow substantial crops there without special technologies. This can cost a lot of money, so many farmers will have to sell their land and leave the desert areas.
- **Hunger:** Without farms in these areas, the food that those farms produce will become much scarcer, and the people who live in those local areas will be a lot more likely to face hunger problems. Animals will also go hungry, which will cause even more of a food shortage.
- **Flooding:** Without the plant life in an area, flooding is a lot more likely. Not all deserts are dry; those that are wet could experience a lot of flooding because there is nothing to stop the water from gathering and going all over the place. Flooding can also negatively affect the water supply.
- **Poor Water Quality:** If an area becomes a desert, the water quality is going to become a lot worse than it would have been otherwise. This is because the plant life plays a significant role in keeping the water clean and clear.
- **Overpopulation:** When areas start to desertify, animals and people will go to other areas where they can actually survive. This causes crowding and overpopulation, which will, in the long run, end up continuing the cycle of desertification that started this whole thing anyway.
- **Poverty:** All of the issues that we've talked about above (related to the problem of desertification) can lead to poverty if it is not kept in check. Without food and water, it becomes harder for people to thrive, and they take a lot of time to fetch the things that they need.

4. Desertification in Iraq

Most of the central and southern parts of Iraq are located in the arid conditions, where the rainfall rate does not exceed 400 mm/year, and the northern parts of it are located in the semi-arid conditions, so it falls within the desertification territory. The combination of inadequate rain and high temperatures turned most of the land to desert. In addition to human malpractices that lead to degradation of natural vegetation as shown in Fig 1. The practice of marginal agriculture in non-rainfall regions has caused severe degradation of natural vegetation and created certain opportunities for dust storms due to wind erosion and therefore the formation of sand dunes, particularly in the central and southern regions, covering an area of 4 million dunums. Therefore, it is necessary to give this serious environmental problem an utmost importance, which requires the development of plans to address the reduction of degradation of natural vegetation and consequent occurrence of dust storms and sand dunes. Desertification and sand dunes represent the majority of Iraq, and there are other areas threatened by desertification each year if measures are not taken to prevent and reduce the effects of this phenomenon.

The report on environmental statistics for 2009 indicates the intensification of land desertification in the country. The percentage of land threatened by desertification is about 92% of the total area of Iraq. Moreover, there is a real scarcity of water resources due to the lack of water imports from neighboring

countries.

Shrinking of the green cover in front of the creeping desert expansion and the intensification of dust storms threaten the public health, lead to widespread poverty, disease and migration from the countryside, cause significant environmental and economic damage and eliminate biodiversity in the environment. Immediate action is required to implement a long-term program plan to resist and stop the spread of desertification in Iraq.

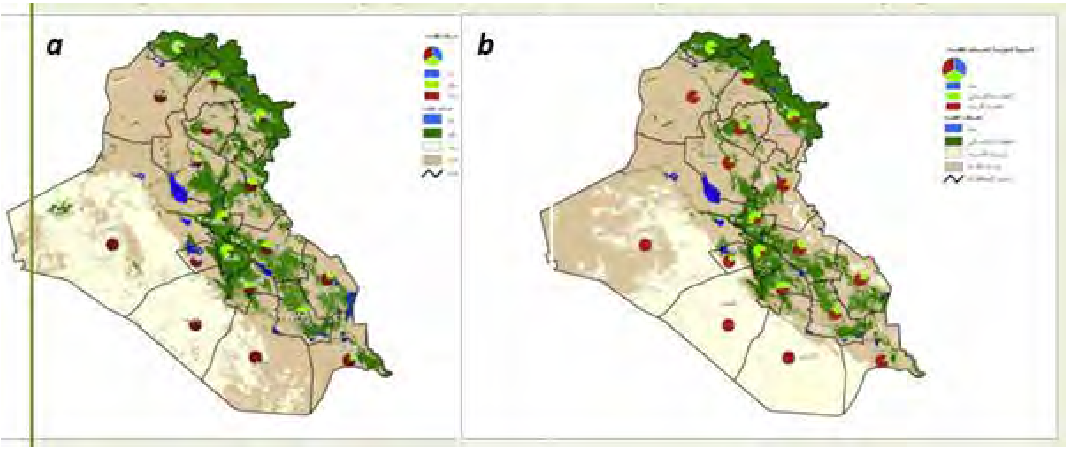

***Figure 1**: The natural vegetation in Iraq (a) in January 2009, and (b) in January 2012.*

The experience of the world has proved that the process of stopping desertification is more feasible than the process of rehabilitation of desertified land at a later stage because many of the desertification damage is always irreversible and cannot restore the soil properties, or the restoration of episodes and vital elements that have been lost. Therefore, preventive measures to combat desertification in the field are more effective to protect the interests of society and the state, as well as being a national, humanitarian and legal duty binding on the UNCCD member states. Directly put in place, the strategy of combating poverty and preventing migration and migration from the countryside because it provides elements of social and economic stability, foremost of which are job opportunities for thousands of citizens, especially in fragile areas. According to the extent of damage and complexity of desertification process, selecting appropriate alternatives considering all effective desertification criterions is one of the main concerns of Iraq in the field of natural resources (Katyal and Vlek, 2000).

5. Adopted Strategies to combat Drought and Desertification

- **Awareness programs of the government on drought and desertification:** Information is no doubt key to combating drought and desertification. However, empirical evidence points to the fact that the way governments have managed awareness, has limited effect on the people. Studies showed that government awareness activities in relation to programs on drought and desertification do not get to the people and they don't know about it. That means the government is yet to raise enough awareness on drought and desertification, which supposedly will provide people with the understanding of the causes and consequences of the phenomena so as to stop all possible actions that encourage the situation and prevent further degradation of the soil.

- **Tree planting and the ongoing campaign on desertification:** One of the strategies of combating drought and desertification is the planting of shelter-belt trees across the Sahara. Seedlings of the trees are meant to be distributed to local farmers in the zone. However, studies show that most of the farmers within the zone are not aware that tree planting is a part of the ongoing campaign aimed at combating desertification. Communication is an essential ingredient for effective implementation of public policy. If awareness is not properly created on the activities of government, how then will the farmers get to know and be part of the tree planting exercise? This again can aid indiscriminate felling of trees since the people are not involved. As part of the policy, implementation strategy is the involvement of host communities in the tree planting processes. This is important as it gives communities involved a sense of ownership and thus helps them ensure the survival of such project.
- **Awareness of laws prohibiting the cutting down of trees:** Effective policy implementation strategies include also the provision of requisite laws that will deter offenders from acting in a manner capable of destroying or limiting the effectiveness of such policy or strategies put in place. The government has not been able to enforce the laws on indiscriminate cutting down of trees or have not educated the people enough. This means that the policymakers and executing officials need to look beyond capacity building; policy must entail building the right political attitude and sense of dedication to ensure enforcement of conservation policies. There is also the role of education that is missing as most of the citizens are not aware of the laws and invariably act in a manner inimical to the environment.
- **Maintenance of water infrastructures by government as at when due:** Sequel to the provision of building water infrastructure for the control of drought, the government is also obligated as part of policy strategy to maintain it. The issues of requisite manpower to manage the various institutions of the government saddled with the responsibility of implementing policies as well as poor funding are at the base of program abandonment by the government.
- **Sustainable management of land and water:** Sustainable management of land and water and for the purpose of soil conservation and treatment of its problems depends mainly on the management and rationalization of water use and the efficiency and modernization of farming systems. In order to achieve this, these components must be put into practice and activating the instructions governing water disposal and modernizing farming methods, relying on the scientific and technological development of soil and water. It is also necessary to seek effective alternatives to water shortages, such as the use of wastewater after treatment in agriculture.

5. Conclusions

This research has shown that the strategies so far adopted by the government in combating drought and desertification have been more of rhetoric than reality. The research has also revealed that citizens' participation is the key for effective implementation of any strategy adopted by the government to combat drought and desertification in any part of the world. Governments have the obligation to adopt the hybrid approach of policy-making and implementation where all parties are involved; thus, giving a sense of ownership to the stakeholders. Education is also key to minimize drought and desertification. Thus, there is a need for serious citizen education on the challenges, in a local dialect. This is because most of the citizens drastically affected by desertification are local farmers who are most often on the farm. There is also an urgent need to try to find alternatives to water shortages due to climate change as well as from the lack of water discharge from the upstream countries.

References

Ahmad, N., Pandey, P. (2017).Assessment and Monitoring of Land Degradation Using Geospatial Technology in Bathinda District , Punjab , India. J. Solid Earth Discuss, 3, 1–28.

Ci, L. J. (2000). Combating Desertification. Chines Acad. For.II, pp.1–10.

Katyal, J. C., Vlek, P.L.G. (2000). Desertification - Concept, Causes and Amelioration. Zent. für Entwicklungsforsch. Cent. Dev. Res. pp. 1–73.

Nwokocha, C. (2015). Effect of Desertification on Environmental Managements in Northern Nigeria. Arab. J. Bus. Manag. Rev,.3, 7–13.

Nwokocha, C. O. (2017). Review of Public Administration and Management An Appraisal of the Strategies Implored by Government to Combating Drought and Desertification in the North-East Geo-Political Zone , 2004-. Rev. Pub Admintration Manag, 5, 1–6.

UNCCD (2013). Economic and Social Impacts of Desertification, Land Degradation and Drought.

Post-ECRRP integrated irrigation management in southern coastal Bangladesh – Case studies of success in Polder55/2D

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Abstract

The Cyclone SIDR hit southern Bangladesh in November 2007 and caused enormous environmental casualties to 30 coastal embankment Polders[1] beyond the normal framework of coastal management. Damages to lives and property in the districts of Patuakhali, Barguna, Pirojpur and Bagerhat were estimated at around US$ 1.7 Billion (Bangladesh Taka 136 Billion). The World Bank supported the governments' effort for the recovery of the damages and building long-term preparedness through strengthened disaster risk reduction management. The project was under implementation from 2009 by Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources with the objective of preventing saline water inundation of crops and properties and by reducing cyclonic storm damages. The project covered rehabilitation of embankments and water control structures in 29 Polders under three different IDA credits with a total amount of US$ 95.0 million. Embankments and water management structures in Polder 55/2D, located in Patuakhali district having an area of around 8,500 hectares, was one of the candidate subproject for rehabilitation. Immediately after SIDR, the Polder embankments and other infrastructures were in devastated condition. The project rebuilt the damaged 26 kilometers of embankment and 15 water management structures (sluices) by June 2017 resulting in large benefit to crop production. Compared to the pre-project (after cyclone) crops situation, local farmers reported production of average two crops after the embankments and structures were rebuilt. This has been possible through irrigation water management and the incremental annual cereal crop production was reported to be around 10,000 tons. This paper (case study of Polder 55/2D) investigated the irrigation benefit through interviewing farmers (male and female) and field data collection from agriculture extension officials. There are 139 such Polders built around mid-sixties along the southern coastline of the country. The rehabilitation benefit of the case of Polder 55/2D has encouraged the government, people (direct beneficiaries) and donors to consider further investment in integrated coastal management for the overall wellbeing of the people through sustained crop production and restoration of sound living environment. The paper has provided further insight into tidal sweet water irrigation benefit where the crop fields' land levels

1 Polder is an area built with embankments all around the peripheral rivers like an island for the purpose of tidal flood water management.

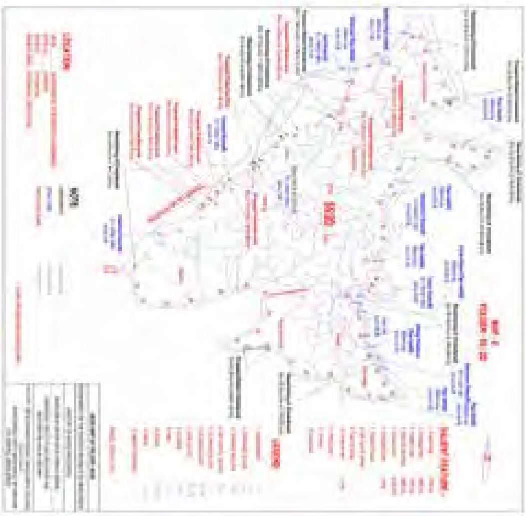
permit gravity irrigation twice a day as tidal front pushes water levels up at high tide and drains out at low tide.

Keywords: Aman; Aus; Dyke; Mug; Polder; SIDR.

1. Introduction

One hundred and thirty-nine Polders (EPWAPDA, 1961) were built around mid-sixties along the southern coastline of Bangladesh to protect crops and properties of coastal residents from saline tidal flooding and cyclonic storm surges. While building the dykes[2], the channels were provided with sluices / regulators for the management of storm water drainage and irrigation water to crop land. Cyclones in the Bay of Bengal, usually occur almost every 3- 5 years causing enormous dislocation of Polder residents, mostly farmers and fishermen. The Cyclone SIDR (measured as Category IV) hit southern coastal Bangladesh on 15 November 2007 and brought enormous devastations to 30 coastal Polders beyond the normal framework of coastal embankment management. Damages to earthen dykes, irrigation water management structures and lives and properties of the people in the four districts (i.e., Patuakhali, Barguna, Pirojpur and Bagerhat) (Map 1) were estimated at around US$ 1.7 billion (equivalent BDT 136 billion) in the 2009 conversion rate (JDLNA[3]). The World Bank supported the governments' effort for the recovery of the damages and building a long term preparedness through strengthened disaster risk reduction management and the project was implemented from 2009 by Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources (MoWR) with targeted completion by December 2017 (later extended to June 2018).

Map 1: ECRRP Polder Map



Map 2: Polder 55/2D

2 Dyke is used to mean embankment built from locally available earthen material compacted to 90% dry density to prevent cross seepage.

3 Joint Damage Loss and Need Assessments (JDLNA) that were conducted by the Government of Bangladesh (GoB) with the support from the International Development Partners

The project initially covered rehabilitation of embankments and water management structures such as regulators /sluices, irrigation inlets /outlets in 29 Polders under three different IDA credits with a total amount of US$ 95.0 million. Embankments and water management structures in Polder 55/2D, located in Patuakhali district having a gross area of around 8,500 hectares, was one of the candidate Polders for rehabilitation. Immediately after the cyclone, the Polder infrastructures were in devastated condition. Of the 64.5 kilometers peripheral embankments, the project rebuilt the damaged 26 kilometers of embankment and 15 water management structures by June 2017 resulting in large benefit to crop production. Compared to the pre-project situation after the cyclone with less than two crops, farmers reported production of over two crops after rehabilitation of the damaged flood management dykes and other infrastructure. The incremental production was possible through wider coverage of tidal sweet water irrigation management. The paper is based on a case study of Polder 55/2D in DasminaUpazila (sub-district) in Patuakhali District, in the southern coast of Bangladesh.

2. Project Description

Polder 55/2D is located in Dasmina Upazila (sub-district) in the southern coastal district of Patuakhali in Bangladesh between 22°08' and 22°22' north latitudes and 90°28' and 90°39' east longitudes along the right bank of Tetulia River. The Polder has a gross area of around 8,500 hectares, with a cultivated land of around 6800 hectares having a population of around 125,000 people with male and female almost the same ratio (percentage of female population is slightly high). The major crops of the area are Mug beans followed by Aus rice and then transplanted Aman variety. Polder has a peripheral dyke of around 64.5 kilometers with 15 water management /irrigation structures across the dyke to flush in surface water for irrigation to Aus and Aman rice field and to drain storm water to peripheral rivers when the tidal level permits. Mug beans is a rabi crop grown in winter months (December - March) and Aus rice is a pre-monsoon quick grown crops (around 90 days) transplanted in May – June and harvested in July–August followed by Aman rice transplanted in September- October and harvested in April – May. Immediately after cyclone SIDR in November 2007, around 26 kilometers of the peripheral dykes were damaged by breaching and overtopping and cultivated lands were unsuitable for production due to intrusion of saline water through breached embankments and damaged water management structures. After rehabilitation of the dykes and repair / reconstruction of the water control structures, the farmers were able to regain access to land cultivation through irrigation management. The methods of irrigation are tidal surface water inundation and lifting water by individually owned Low Lift Pumps (LLPs). The cyclone damaged scenario (pre-project) crop production and the crop production statistics after rehabilitation (post-project) is presented in Tables 1 and 2 and also shown graphically in Fig.1.

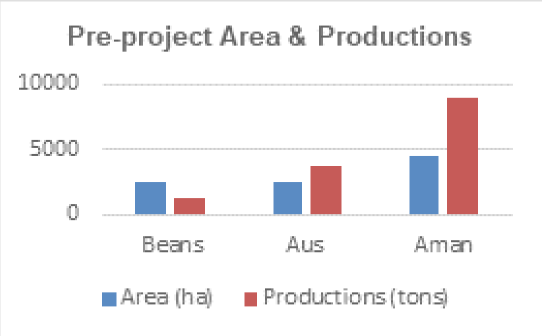
Table 1: *Pre-project crop production and yield after cyclone (2010)*

Major Crops	Cultivated Area (ha)	Gravity Irrigation (ha)	LLP Irrigation (ha)	Yield / ha (tons)	Production (tons)
Mug Beans	2,500	500	2000	0.500	1,250
Aus	2,500	1,000	1500	1.50	3,750

Aman	4,500	4,000	500	2.00	9,000
Fruits/Vegetables	1,000	100	900	2.00	1,500
Total	11,500				15,500

***Table 2:** Post-project crop production and yield (2017)*

Major Crops	Irrigated Area (ha)	Gravity Irrigation	LLP Irrigation	Yield / ha(tons)	Production (tons)
Mug Beans	3,500	500	3,000	0.50	1,750
Aus(transplanted)	3,500	2500	1,000	1.50	5,250
Aman (transplanted)	6,500	6000	500	2.50	16,250
Fruits/Vegetables	1,000	700	300	2.00	2,000
Total	14,500				25,250



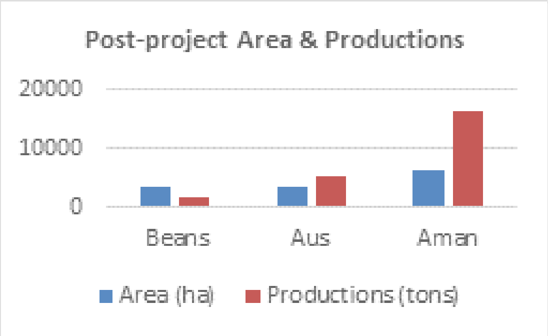


***Figure 1**: Pre- and post-project areas and productions*

2. Study Methodology

As mentioned above, Polder 55/2D is one of the subprojects of the 29 Polders for rehabilitation under the ECRRP program. Both the author and co-author are directly affiliated with the project. For this study, questionnaire survey was carried out to get feedback from local stakeholders such as farmers and Upazila Agriculture Officers (UAO) and Block Supervisors (BS) who are providing support services to the farmers with irrigation equipment, fertilizers and agricultural training on crop cultivation (UAO, 2017). The interviews were designed to find out the percentage of area cultivated in different crop season and per hectare yield of the major crops after the Polder was severely damaged by cyclone (pre-project) and the present day cultivated area and corresponding yield after rehabilitation works are nearly completed. Area under irrigation coverage (both gravity and pump irrigation) was estimated through the interview and the number of pumps used by the farmers. The farmers used mostly 1 cusec low lift pumps

(LLPs) where gravity irrigation was not possible. There are over 250 individually owned LLPs in the area. Deep tube wells (DTWs) / shallow tube wells (STWs) are not used as there is salinity in the ground water (source: local farmers). Tidal gravity irrigation is the most popular irrigation method in the project area. Even though, the project area is close to Bay of Bengal (around 50 kilometers away), the water in the surrounding rivers is not saline except during the months of March to May, in the dry period. As soon rain starts to pour in June, salinity level starts reducing.

3. Analysis and Findings

The study analyses resulted in large production benefit to the Polder community through increased area under irrigation resulting in increased yield. After the cyclone SIDR in November 2017, the tidal flood protection embankments and irrigation structures were in devastated condition and the area irrigated for the four major crops was around 11,500 hectares (Table 1) and the total production of beans, rice and winter vegetable was estimated at 15,500 tons. The Polder was taken up for rehabilitation in 2014 under an ICB contract package comprising rehabilitation of seven Polders awarded to BHARTIA-MBEL JV construction company. By December 2017, the Contractor BHARTIA-MBEL JV completed the repair work of 26 kilometers of embankment, 15 water management structures and 4500-meter embankment protective works to provide protection of the Polder against erosion of mighty Tetulia River surrounding the Polder. As the repair works were done, farmers got noticeable benefit from these interventions. Due to check in tidal flooding and increased irrigation area coverage, the cultivated area under the four major crops increased from 11,500 hectares to 14,500 hectares (an increase of 26%). Considering the total cultivated land of 6,800 hectares, the cropping intensity has gone up from 169 to 213% (an increase of around 44%). Cereal production increased by around 9,750 tons from 15,500 to 25,250 tons (an increase of around 63%). Rice production increased by 8,750 tons from 12,750 to 21,500 (an increase of 68%) which is considered remarkable. The project is completed by June 2018, and it is expected that the area under irrigation benefit will stand at 16,500 hectares for the two major rice crops and the cropping intensity will shoot to around 243%.

4. Lessons Learned

The lessons learnt during the course of rehabilitation of Polder 55/2D through interactions with the local stakeholders and BWDB officials, contractors and most importantly with the subproject beneficiaries and local agriculture support providers are important for future planning process. The cyclone SIDR occurred in November 2007 and the Polder rehabilitation works were taken up in 2014, almost after a gap of six long years. The cyclone affected people suffered long due to delay in the implementation process. The reasons were mostly pre-construction delays and delayed implementation of social safeguards requirement. The other lessons learned are i) embankments, water control structures should have an user-friendly design so as to better serve the purpose of irrigation management, ii) social safeguards related to payment for project affected persons (PAPs) needed to be expedited to complete targeted works by the scheduled date, iii) compliance of environmental mitigation measures during implementation as required for environmental management plan (EMP) including health and sanitation and safety of the workers needed to be in place before starting physical works and iv) there is a need to adapt more participatory approach to develop ownership of the community in the post-project operation and maintenance (O&M). Local resource mobilization may be opted for routine maintenance of the embankment and water management structures for the farmers for maintaining sustainability of irrigation water management benefit. Increased agricultural support services related

to irrigation equipment and field school trainings are needed to cover more areas under irrigation and crop diversification.

5. Recommendations

The study concluded that large irrigation benefit to the Polder community was observed as a result of repair of the damaged embankments and water control structures (irrigation structures) after the cyclone SIDR, although started late. The annual incremental cereal productions turned out to be around 10,000 tons due to increased cultivated area coverage and better irrigation management. Local farmers expressed their happiness over the benefit brought by the project. The cyclone SIDR severely damaged 30 such Polders and 29 of these were rehabilitated under the ECCRP program since 2009. Many of the earlier completed works (2012-13) deteriorated over time in the absence of routine maintenance works. Government cannot provide the needed O&M fund due to budget shortage and the best option is the adoption of participatory O&M through mobilization of local resources. Irrigation water management committee should be established in the command area of each water control / irrigation structure and the committee should be entrusted with the responsibility of minor / routine maintenance of dykes and other structures to reduce major maintenance works. Government should take responsibility of major maintenance only such as replacement of a section of dyke and water management structure. Polder repair and rehabilitation works are completed by March 2018 and when fully operational, it is expected that the irrigation area and productions would be largely increased. It is recommended that further study is undertaken after the Polders works are fully operational to understand the full irrigation potential better and to better assess the resulting production benefit.

References

EPWAPDA (1961). Coastal Embankment Project (CEP), June 1961. East Pakistan Water & Power Development Authority (EPWAPDA).

UAO (2017). Field Data Collection Questionnaires: - Upazila Agriculture Office (UAO), Dasmina Patuakhali, Bangladesh, December 2017

THEME – III

Modernising Irrigation Systems for Better Services

Irrigation modernization by enhancing water productivity through water accounting

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Abstract

Water accounting based on satellite data and outputs of global hydrological models which determine surface and ground water flows in irrigated river basins is increasingly recognized as a useful method for getting insights on the performance of irrigated systems. With the advances in the information and communication technologies, the resolution in which these data are available and the cost and effort of analyzing these data are gradually decreasing. This has been offering users the advantage of receiving more frequent, accurate, and spatially discrete assessments of the status of irrigation and its geo-spatial distribution in the field. Even though this approach is rapidly gaining popularity, in part because it allows users to quickly identify when and where problems exist without leaving the office, it still cannot be considered a replacement to the earlier approaches for assessing irrigation performance and identifying solutions for improving irrigation services. Rather, these rapidly developing diagnostic tools should be combined with a robust understanding of the situation in the field. In this paper, we highlight the need and importance of conducting water accounting exercises to determine water availability and use, and opportunities for improving water productivity. We also emphas ize the need for standard procedures of benchmarking irrigation performance, especially the MASSCOTE (Mapping System and Services for Canal Operation Techniques) approach. MASSCOTE was developed by the Food and Agricultural Organization (FAO) and includes the Rapid Appraisal Procedure (RAP) developed by the Irrigation Training and Research Centre (ITRC). We also discuss how the results of these assessments can be effectively combined with water productivity analyses based on satellite images to produce a multi-perspective evaluation of irrigation systems. We explore how this approach can provide accurate assessments of irrigation issues and bottlenecks and help identify the appropriate interventions (e.g. physical) and/or management options for enhancing irrigation services. Additionally, we outline the process of how these tools can be combined to develop irrigation modernization plans that are more comprehensive and realistic. We conclude by highlighting the relatively inferior performance of most irrigation systems in Asia, and the need for mainstreaming the modernization process through effective implementation of methodologies like the one proposed here.

Keywords: *Asia; irrigation modernization; irrigation performance; water accounting; water productivity.*

1. Introduction

Increasing population and trends like rapid urbanization, deforestation, enhancing lifestyles and water quality degradation are increasingly putting more pressure on the water availability in most Asian countries. Added to all this is the effect of climate change which seems to have further worsened the situation.

Agriculture being the largest consumer of water accounts for about 84% of the total water use in Asia. The water requirement ratio is 58% and the pressure on freshwater resources due to irrigation is the highest in the world – about 14% overall (FAO, 2012; David, 2004). In many Asian countries, agricultural growth remains a key component of economic growth and employment. Hence, wise agricultural water management is critical for these countries.

Unfortunately, this topic is not getting due attention in most Asian countries. Many assessments have revealed that water for agriculture in Asia is not being wisely used. The performance of most irrigation systems in Asia is quite poor (Burt, 1997). Hence, it is imperative to improve the irrigation performance through proper irrigation modernization. However, effective irrigation modernization demands thorough understanding of the existing situation which essentially means field level knowledge related to land, water and crop. This process of collection of all these essential data is quite challenging.

Fortunately, in recent times, satellite data and outputs of global hydrological models are increasingly being easily accessible which offer users the advantage of receiving more frequent, accurate, and spatially discrete assessments of the status of irrigation and its geo-spatial distribution in the field. They allow users to quickly identify when and where problems exist without leaving the office.

This paper discusses about the advantageous position offered by these recent advances in the information and communication technologies. However, it also emphasizes on the importance of field level data and points out how these digital data can be integrated with the data from the field to produce insights of irrigation performances.

2. Water Data and Analysis Tools

Water resource managers rely on accurate and accessible data to make informed management decisions. Though water is fundamental to human flourishing, fundamental data needed to properly manage water resources are often lacking over both space and time (Gleick, 1998; Hannah et al., 2011; Shrestha et al., 2012). Remarkably, despite the many advantages of long-term water information, the amount of data (e.g. river flow data) being collected is declining in many parts of the world, especially in Africa, Latin America, Asia, and even North America (Mishra and Coulibaly, 2009; Van de Giesen et al., 2014). The underlying issues leading to weakened monitoring are various; but include a lack of understanding of the importance of long-term water data, and ongoing funding challenges (Pearson, 1998). Despite these challenges, advances in remote sensing, citizen science (Fienen and Lowry, 2012; Sanz et al., 2014) and better data analysis and modelling tools can help bridge these widening data gaps.

2.1 Remote sensing

Remote sensing (RS) is the process of gathering information about an object from a distance. There are several contexts where remote sensing can be applied. In earth system sciences, such as hydrology, remote sensing generally involves observations of the Earth's surface from a distance by either aerial

platform (e.g. planes) or satellites in space. The types of information about the Earth's surface that can be collected from a distance, and the various uses of these data are rapidly expanding each year. Of particular interest to hydrologist are remotely sensed data products for precipitation and evaporation, because these are two of the primary water balance fluxes. More recently, the use of drones (i.e. unmanned aerial vehicles or UAVs) appears to be a promising method of increasing the resolution of remotely sensed data. Higher resolution data can support analyses at the finer spatial and temporal scales.

There are two primary types of electromagnetic radiation (EMR) based remote sensing instruments - passive and active. Passive instruments detect EMR either emitted or reflected by the object of interest, whereas active instruments provide their own EMR and measure the returned EMR signature from the targets of interest. Measurements of visible spectrum EMR from satellites like Landsat are widely used by the general public and researchers alike with free tools like Google Earth. Landsat images can also be used to determine land use, vegetative indices like the Normalized Difference Vegetative Index (NDVI), or to estimate evapotranspiration (ET) with models like the Surface Energy Balance Algorithm for Land (SEBAL) and Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC). More recently, NASA's Soil Moisture Active Passive (SMAP) mission uses radar and radiometer measurements to map soil moisture and freeze/thaw patterns. The Gravity Recovery and Climate Experiment (GRACE) measures changes in the Earth's gravitational field to estimate changes in the various components of water storage on the Earth's surface.

2.2 Citizen science

Citizen science involves including citizens in the scientific process as researchers (Kruger and Shannon, 2000). Citizen science can include community-based monitoring (Whitelaw et al., 2003) and/or community-based management (Keough and Blahna, 2006). Citizen science is on the rise in the USA (Whitelaw et al. ,2003), Canada (Savan et al., 2003), and in many other areas around the world (Nagendra et al., 2005; Sultana and Abeyasekera, 2008). New developments in sensing technology, data processing and analysis, and methods of knowledge communication are opening novel opportunities for citizen science (Buytaert et al., 2014). Recent advances in mobile technologies, and the widespread availability and use of smartphones makes them a perfect tool for citizen science. Global Positioning System (GPS) and high-resolution camera technology embedded in smartphones can be used to collect verifiable records in the field, and cellular networks can be leveraged to transmit collected data to a central repository.

2.3 Analysis and modelling tools

Advances in computing devices combined with global remotely sensed coverages of land use, precipitation, soil moisture, ET) etc. increasingly facilitate the development of global hydrologic models. In turn, these global hydrologic models can provide information on difficult to measure fluxes and can help fill spatial and temporal data gaps in difficult to measure regions. Many of these efforts are publicly funded and provide outputs that are open source and freely available to the scientific and management communities. Additionally, these data are increasingly available at smaller time steps with lower latency, enabling near real time analyses.

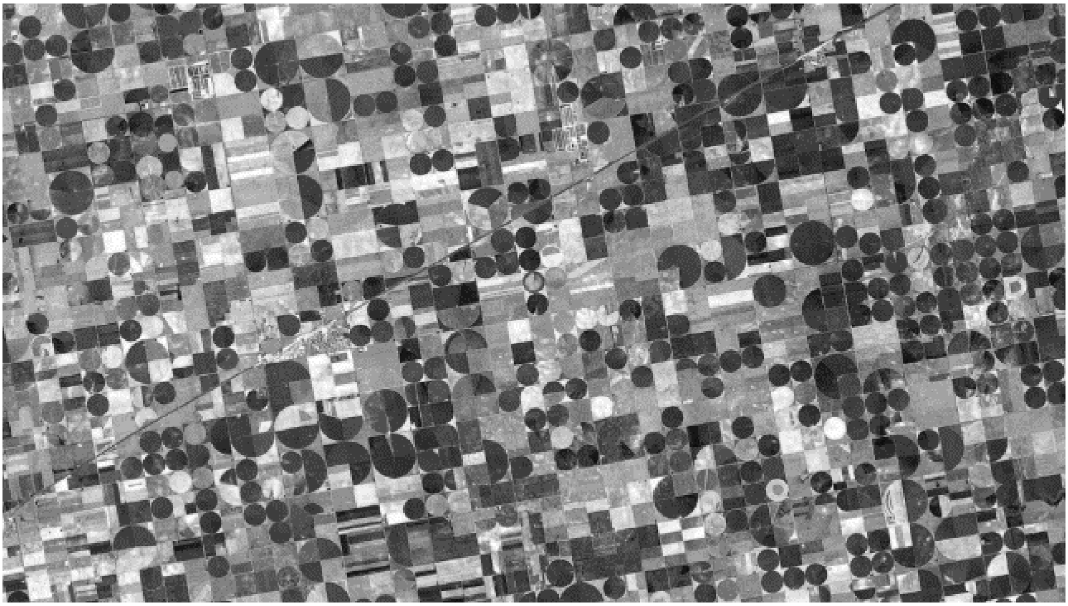


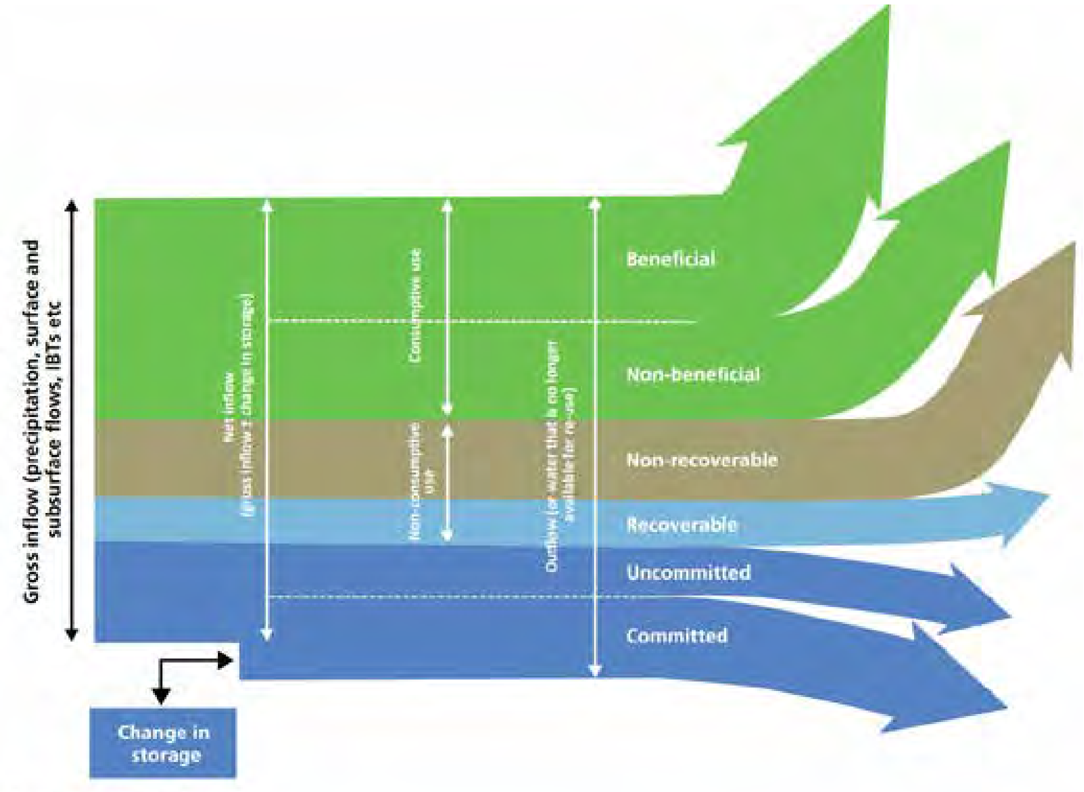
Figure 1:*Analysis of water use in irrigation area through crop-water use models (Source: Nature Geoscience, 2017)*

3. Water Accounting

Water accounting (WA) is the systematic study of the status and trends in water supply, demand, accessibility and use in domains that have been specified. It involves learning new terminology and the theoretical mechanisms of several interrelated hydrological and meteorological processes. WA essentially involves characterizing all inflows, outflows, and changes in storage within a specified spatial domain for a specified period.

Among others, WA offers the following benefits towards understanding and managing river basins:

- WA explicitly differentiates between depletion (Fig. 2; upward pointing arrows) and outflows (downward pointing arrows). Depletions are consumptive uses that render the water no longer available for other uses, whereas outflows leave the domain but are available for downstream uses.
- WA groups depletions and outflows into basic categories that are intuitively meaningful from both operations and management perspectives.
- WA helps to identify closed basins where there are no uncommitted outflows.
- WA can help characterize chronic exploitation of groundwater storage as a necessary inflow to balance outflows. Sustainability requires that long-term changes in storage within a domain should be on average near zero.
- WA can support decisions to maximize water productivity.



Source: Molden et a.l., 2003

***Figure 2**: Basic water accounting diagram (Source: FAO, 2017)*

3.1 Need for water accounting

There is an urgent need for independently gathered water resources-related data sets that can be commonly analyzed and understood by hydrologists, economists, agronomists, environmentalists, social scientists, legal experts, and political scientists. These data should enable evidence-based decision support and policy making. Access to accurate and up-to-date information continues to be a serious constraint for actors in the fields of natural resources management, and this is especially true for water resources. Considerable progress has been made in many countries in processing and storage of basic data; however, data dissemination is often constrained by ownership policies or lack of resources for proper data distribution. Moreover, the integration of data and information from across sectors that depend on secure access to water is a significant challenge. A common framework for modeling, interpretation, and dialog about these data is also lacking in many cases.

A common system of water accounting has for the most part been missing in the emerging debate of global water governance. The concept of water accounting provides a coherent and consistent water resources reporting methodology that includes hydrological processes, distribution of water to various competing sectors, the depletion and outflow of water, and the resulting ecosystem services. Importantly,

water accounting also provides a common set of terminology, that can be used to break through the "water language barrier" that often hinders productive dialog between competing interests.A prerequisite for profiting from the availability of water accounts, is that all reports and linked data sets are public domain, something that is not straightforward in the current world of limited data democracies. Further to data sheets, tables and maps, decision makers need to understand the degree of uncertainty inherent to both the input data and the results of water accounting.

3.2 Improving water productivity

As previously discussed, WA can help make informed decisions aimed at maximizing water productivity. Water productivity can be taken as either the caloric or economic output of an activity per unit of water depletion. In common terms, water productivity is either "crop per drop" or "dollar per drop". As competition over water increases, improving water productivity will be increasingly essential to satisfy the multiple and conflicting water demands from various sectors. Many river basins in the world already experience issues of water scarcity and populations live with an inadequate level of water security. Among other things, water scarcity negatively affects food security, energy production, and the ecological health of basins. It also adversely affects the health and livelihoods of populations. Globally, climate change and the associated increases in climate variability, as well as other global and regional changes such as declining groundwater tables, are expected to make matters even worse. The impacts are expected to be especially acute in countries with mountainous environments and snow-based hydrology.

3.3 Water accounting examples

The following subsections discuss two pertinent water accounting applications.

3.3.1 Nepal

Groundwater constitutes the largest supply of available freshwater and comprises roughly one-third of global freshwater withdrawals (Famiglietti, 2014). India's groundwater production rates have increased ten-fold in the last 50 years, currently making it the nation with highest amount of groundwater production in the world (Margat and vander Gun, 2013). Much of Nepal is characterized by significant rainfall during the roughly four-month long monsoon period ranging from June through September, followed by a relatively dry eight-month period from October through May. During this prolonged dry period, the groundwater system provides critical baseflows to springs and streams essential for human needs, food production, ecological health, and hydropower production. The importance of groundwater contribution to dry season baseflows and human demands is expanded by the lack of surface water storage in Nepal.

In the Kathmandu Valley, groundwater provides a critical source of water for domestic, industrial, agricultural, and environmental uses (Pradhanang et al. 2012). The recent rates of population growth in the valley have far outpaced the ability of the public-private partnership (PPP) Kathmandu Upatyaka Khanepani Limited (KUKL) to design, construct, and maintain adequate water and sanitation infrastructure. Additionally, even where KUKL drinking water service is available, the frequency of availability and water quality is often poor. For example, some parts of the KUKL service area only receive water for an hour or two each week. Starting in earnest in the 1980s, as an alternative to KUKL water service, many companies and private parties have drilled both shallow and deep wells, and now rely on groundwater as their primary water source (Shrestha et al., 2012). Additionally, groundwater has the benefit of always

being accessible, assuming an energy source for abstraction is available, and the well yield is sufficient to meet pumping demands.

It is estimated that groundwater provides roughly 50 percent of the Valley's water supply during the monsoon (Shrestha et al., 2012), and roughly 60 to 70 percent during the subsequent dry period (ICIMOD, 2007). It is a generally accepted qualitative fact, based on the limited amount of groundwater level data available, that the Kathmandu Valley aquifer system is currently in a state of overdraft. Since metering and reporting of groundwater extraction is not required for most groundwater users, quantitative data about the amounts of groundwater extraction are unavailable.

Unsustainable groundwater development can lead to several undesirable results including: chronic lowering of groundwater levels, reductions in groundwater availability, intrusion of saline water, degradation of water quality, land subsidence, and depletions of interconnected surface waters such as springs, lakes, and streams (SGMA, 2014). Many of these are already being observed in the Kathmandu Valley. The reality of mismanaged groundwater on a global scale, the critical nature of groundwater resources as a freshwater supply to Nepal, the extreme dependence of the Kathmandu Valley on groundwater for urban, agricultural, and industrial uses, all serve to underscore the importance of improving our understanding of the water balance in the valley.

SmartPhones4Water (S4W) is a US based non-profit organization that aims to leverage the power of citizen science and mobile technology to enrich lives in the developing world by improving our understanding and management of water. S4W's first pilot project is focused on the Kathmandu Valley (i.e. S4W-Nepal; Davids et al., 2017; Davids et al., 2018), where extreme population growth has led to extensive degradation of water quality and quantity. S4W-Nepal is employing a three-pronged approach of research, education, and employment to try and accomplish its mission statement. With regards to research, the goal is to use citizen science and mobile technology to develop the data necessary to characterize the water quality and quantity problems within the Kathmandu Valley, so fact-based solutions can be developed, and successfully implemented. All S4W field measurements are collected digitally in the field with an Android application called Open Data Kit (ODK) (Anokwa et al., 2009). In order to characterize the nature of groundwater depletions, S4W-Nepal aims to use citizen science-based measurements of precipitation, groundwater storage change, and runoff to further constrain the water balance.

As part of S4W-Nepal, citizen scientists are currently collecting data pertaining to the primary water fluxes and changes in storage including precipitation, streamflow, groundwater level, land use, and water quality. At nine streamflow monitoring locations on all the historically perennial tributaries to the Bagmati (Fig. 3), low-cost staff gauges are installed, and water level data is collected by local residents with smartphones ODK Collect (Anokwa et al., 2009). Within ODK Collect, each water level observation requires the citizen scientist to enter the water level reading, save the current date, time, GPS coordinates, and take a photograph of the observation. The data is automatically transmitted to ODK Aggregate instance running on the Google Cloud. Stage-discharge curves for the selected sites are developed from monthly to bi-monthly observations of discharge with a SonTekFlowTracker Acoustic Doppler Velocimeter (ADV) performed by local BSc and MSc science and engineering students.

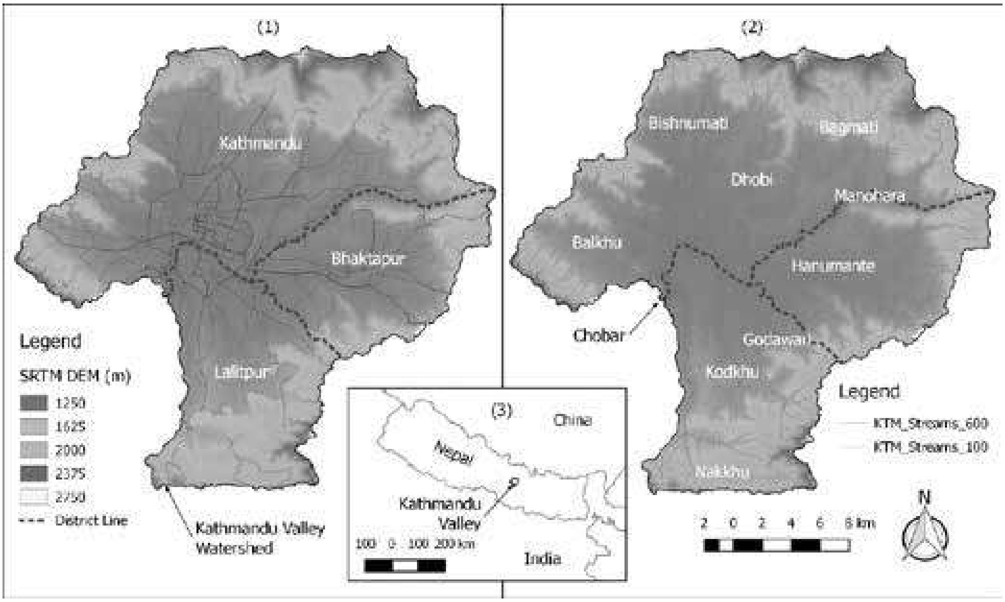


***Figure 3**: Kathmandu Valley (1) and the historically perennial watersheds (2) (Source: Davids et al., 2018)*

Starting with the 2017 monsoon, precipitation is being measured in the Kathmandu Valley at 50 plus locations. Groundwater levels are being measured at 40 locations every month with more extensive monitoring planned for the pre and post monsoon periods.S4W-Nepal provides free water quality testing to help motivate citizen scientists to start and continue collecting groundwater level data. Stream flows of the nine perennial watersheds, in addition to the Bagmati River outflow at Chobar are measured monthly. These data will be combined with data collected by the Government of Nepal and with other remotely sensed products to improve understanding of net groundwater withdrawals in the Kathmandu Valley.

3.3.2 Afghanistan

Ensuring water security remains critical in Afghanistan for future agricultural production and to satisfy the other livelihood needs. Agriculture contributes roughly to a third of the national economy and over two thirds of employment, especially in rural areas. Agricultural growth remains a key component of national growth and employment, and it also provides a foundation for successful structural transformation of the national economy. Given Afghanistan's arid to semi-arid climate, agriculture is dependent to a large extent on the availability of irrigation water. Hence, Afghanistan's economy is essentially water dependent.

As competition over water increases under the combined effects of population and economic growth, improving water productivity will be increasingly essential to satisfy the multiple and conflicting demands from various sectors. Many river basins experience issues of water stress and populations live with an inadequate level of water security. Water stress affects food security, energy production and the ecological status of the basin. It also adversely affects the health and livelihoods of its populations. Afghan river systems are already the most stressed river systems in Asia (with Helmand river at top) and

probably in the world. As in the rest of the world, climate change and the associated increases in climate variability, as well as other global and regional changes such as declining groundwater tables, are expected to exacerbate water issues. Afghanistan is particularly vulnerable given its mountainous environment and snow-based hydrology.

At least three different WA activities are either in progress or have recently been completed. First, based on Afghan government's decision of establishing River Basin Councils (RBCs) following the principles of Integrated Water Resource Management (IWRM), FAO supported the government with the Technical Cooperation Programme (TCP) on "Analysis of Water Availability and Uses in Afghanistan River Basins". The project commenced on 1st August 2012 and was completed on 31st December 2014. The TCP successfully completed its task of analyzing the water resources availability and uses in the five major river basins of the country and disseminating the improved knowledge base and information on land and water resources. The analysis reveals that better management of Afghanistan's water resources can be achieved by dividing the country into 34 management units. These management units are primarily of three types: standard (20), multiple outlet (7) and transboundary (7) management units. The analysis also revealed that the total long-term annual average endowment of water resources within the national territory of Afghanistan is about 201 Billion Cubic Meters and the country is basically a giver in terms of water as the major bulk (98%) of the water endowment is from internal sources and only is very small portion (2%) comes in as inflows. Major share (61%) of the available water is in the form of landscape water and only 39% of it is in the form of exploitable water. Hence, there is 1.5 times more scope for management of water at the field level then in streams. This implies that activities like water conservation, soil moisture management; water harvesting has good scope. Including reuse, about 193 billion cubic meters (BCM) of water in Afghanistan is used for various purposes. Considering the total water endowment and the level of water use in the different river basins, the water availability in the different river basins is: Amu (30.4 BCM), Northern (3.4 BCM), Harirud Murghab (7.2 BCM), Helmand (18.1 BCM) and Kabul (20 BCM), thus, totaling 79.3 BCM for the whole country.

All the findings of the study were well documented in a Synthesis Report. However, it was also admitted that the study had to work with limited and less reliable data and make many assumptions. Hence, in an effort to move towards a new approach, FAO also decided to carry out Water Accounting Plus (WA+) exercise using remote sensing. For this, coordination was established with UNESCO-IHE and WA+ exercise was carried out for Helmand River Basin. This study demonstrates that the approach is well suited for monitoring water accounting components like: biomass, water productivity, evaporation and transpiration. Its main added values being that it requires lower resources in terms of costs and time, when compared to traditional field-based water accounts, particularly in data-poor conditions and security–constrained locations where field surveys are difficult or too expensive to implement. It is an approach based on input data which are objective and replicable over time, thereby supporting sound time-series analysis. It provides spatially explicit information products allowing improved geographic targeting. It directly monitors consumptive water use, avoiding assumptions related to non-consumptive use (such as irrigation efficiency, return flows, etc.). However, it also has some limitations like RS can't measure withdrawals and it needs to be estimated by applying efficiency factors to water consumption. Moreover, although water accounting should pursue stakeholder engagement throughout the process, RS water accounting tends to be performed in isolation due to its technology and knowledge intensive nature. The quality of such studies can be largely improved through better inclusion of ground knowledge at different levels, and processes integrating local with RS information need to be enhanced.

The study showed that incremental ET due to irrigation represents 19.1% of available water resources annually generated in the basin. The study also revealed that agricultural water withdrawals account for about 40% of renewable water resources in this basin which, according to FAO global water scarcity classification (FAO, 2011), characterized Helmand as a severely water scarce basin. It also showed significant variations of cropwater productivity in the basin both spatially and by farming systems. This, in the above-mentioned settings of severe water scarcity, made efficient use of water resources a priority issue for the basin. Rainfed systems have an annual average 75% of soil evaporation on their total ET. Non-beneficial consumption in irrigated systems accounts for 40% of total irrigation ET and most water resources are utilized in non-productive land. This study also provided spatial maps where irrigation water productivity is standardized by crop yield class, and farmer and farmer communities can be detected from the images that are highly efficient with water. However, mapping of rainfall with virtually no real-time rainfall measurements on the ground had serious implication on the assessment of the river flow. The estimation of the rainfall is believed to be on the higher side in certain parts of the basin, which may have resulted in errors in non-utilized outflow. In this context, on one hand, there is a need to expand the exercise carried out for Helmand basin to be expanded to the whole country, while on the other hand, there is also a need to create greater awareness and improve the situation of data availability and reliability.

Lately, FAO has also initiated a capacity building WA training series for Afghan water managers. This national capacity development program on water accounting and auditing principles includes sessions on RS and GIS, numerical modelling, and water productivity. Participants represent the Ministry of Energy and Water (MEW), Ministry of Agriculture, Irrigation, and Livestock (MAIL), and Ministry of Rural Rehabilitation and Development (MRRD). The overall objective of this program is to achieve improved data and information on water resources in Afghanistan while the purpose is to build national capacity in water accounting and auditing methods.

4. Benchmarking Irrigation Performance

Various tools have been developed for benchmarking irrigation performance. Some of them are also linked to irrigation modernization. Mapping System and Services for Canal Operation Techniques (MASSCOTE) was developed by FAO and includes the Rapid Appraisal Procedure (RAP) developed by Irrigation Training and Research Centre (ITRC). MASSCOTE is a methodology developed by FAO based on its own experience on modernization programs in Asia between 1998 and 2008. It aggregates all the pieces into a consistent framework, complementing tools like RAP and benchmarking, to allow a complete sequence of diagnosis of external and internal indicators of performance and practical solutions for an improved management and operation of the system. MASSCOTE organizes project development into a stepwise revolving frame including:

- mapping system characteristics, water context and factors influencing management
- delineating manageable sub-units
- defining strategy for service and operation for each unit
- aggregating and consolidating canal operation strategy at the main system level

MASSCOTE is an iterative process based on 10 successive steps. Some steps need to be re-discussed and refined several times before reaching consistency. The ten steps are presented in Table 1 below.

***Table 1**: MASSCOTE steps*

1. INITIAL ASSESSMENT	
1. RAPID DIAGNOSIS	Initial rapid diagnosis and assessment through RAP or others. Objectives: i. to get an initial sense of what and where the problems are, how they should be prioritized, etc.; ii. to start mobilizing the energy of the actors (managers and users) for modernization; iii. to generate a baseline assessment, against which progress will have to be measured.
2. MAPPING THE SYSTEM CHARACTERISTICS	
2. SYSTEM CAPACITY AND SENSITIVITY MAPPING	a) Assessment of the physical capacity of irrigation structures to perform their function of transport, control, measurement, etc. b) Assessment of sensitivity of irrigation structures (offtakes and regulators) and identification of singular points. c) Mapping the sensitivity.
3. PERTURBATION ANALYSIS	Perturbations analysis: causes, magnitudes, frequency and options for coping with it.
4. MAPPING WATER NETWORKS AND WATER ACCOUNTING	a) Assessment of hierarchical structure and the key features of irrigation and drainage networks, based on which partition of the system into sub-systems will be made. b) Water accounting exercise considering both surface and groundwater and mapping their opportunities and constraints
3. MAPPING THE SERVICE: COST OF OPERATION AND DEMAND PER SUB-COMMAND AREAS	
5. MAPPING SERVICE OPTIONS	Mapping options for services to users: farmers, crops and other users.
6. MAPPING THE COST OF OPERATION	Mapping the cost for current operation techniques and services, disaggregating the elements entering the cost, costing options for various levels of services with current techniques and with improved techniques.
7. MAPPING THE DEMAND FOR CANAL OPERATION	a) Assessing means, opportunities and demand for canal operation. b) A spatial analysis of the entire command area, with preliminary identification of Sub-Command Areas(Management, service, etc).
4. DESIGNING SUB-UNITS FOR SERVICE & OPERATION	
8. PARTITIONING IN MANAGEMENT UNITS	Division of irrigation system and the command area into SUB-UNITS [sub-systems and/or sub-command areas] which are homogeneous, and/or separate from one to the other with a singular point or a borderline.

9. CANAL OPERATION IMPROVEMENTS	Identification of improvement options for each Management Unit for (i) Water control (ii) Water management and (iii) Canal operation (service and cost-effectiveness).
5. AGGREGATING AND CONSOLIDATING	
10. AGGREGATING & CONSOLIDATING MANAGEMENT	a) Aggregation of options at the system level, and consistency check. b) Consolidating and designing an overall cost-effective Information System for supporting operation and Service Oriented Management (SOM).
A PLAN FOR MODERNIZATION And MONITORNING & EVALUATION	a) Modernization strategy and progressive capacity development b) Select/choose/decide/phasing the options for improvements c) Plan for monitoring and evaluation of the project inputs and outcomes.

MASSCOTE exercises is being followed in many Asian countries. In Nepal, it was carried out in Sunsari Morang Irrigation Project (SMIP) and Narayani Irrigation System (NIS) through which quantified performances in terms of water delivery service at each canal level were determined. Through field rating and analysis, major constraints of both these systems were identified.

Capacity development activities and analysis of selected irrigation systems were carried out as part of a series of initiatives by FAO in Asia. MASSCOTE methodologies were applied in many countries in Asia including China, India, Pakistan, Vietnam, Nepal, Sri Lanka, Kyrgyzstan, Tajikistan, Uzbekistan, Thailand and Malaysia. These tools proved useful for evaluating performance of irrigation systems, their multiple uses functions and planning for modernization.

The earlier exercises carried out in Asian countries have indicated relatively poor performance of most irrigation systems and the need to mainstream tools like MASSCOTE in the modernization process of irrigation.

5. Integrated Systems for Irrigation Performance

The present need is to combine these earlier established methods of assessing irrigation performances and with the benefits derived from advances like remote sensing and citizen science for better availability of water related data like precipitation, land use, soil moisture, ET, etc. and the effective use of hydrologic models which provide information on difficult to measure fluxes and can help fill spatial and temporal data gaps in difficult to measure regions. These data are increasingly available at smaller time steps with lower latency, enabling near real time analyses. Some of the models provide assessments of water productivity of command areas of irrigation systems. These integrated approaches provide more accurate assessments of irrigation issues and bottlenecks and help identify the appropriate interventions (e.g. physical) and/or management options for enhancing irrigation services. These tools facilitate not only in preparing comprehensive assessment of the performances of the irrigation systems but also in developing realistic irrigation modernization plans.

6. Conclusion

This paper first discusses about the different geo-spatial data related to land, water and crop that are more easily accessible in recent times which support in the computation of water productivity. It then goes on to explain the advantages offered by these recent developments. It also discusses about the various tools have been developed for the benchmarking irrigation performance like MASSCOTE and RAP. It also emphasizes on the importance of field level data and points out how these digital data can be integrated with the data from the field to produce insights of irrigation performances.

Acknowledgements: The authors would like to thank SmartPhones4Water for providing the necessary data. We also thank all the stakeholders from Nepal and Afghanistan who supported the works of the author and provided their ideas and helpful comments paper. Special thanks are extended to the irrigation managers who shared their views.

References

Anokwa, Y., Hartung, C., Brunette, W., Borriello, G., Lerer, A. (2009). Open source data collection in the developing world. Computer, 42(10), 97-99.

Burt, C.M., Clemmens, A.J., Strelkoff, T.S., Solomon, K.H., Bliesner, R.D., Hardy, L.A., Howell, T.A., Eisenhauer, D.E. (1997). Irrigation performance measures - efficiency and uniformity. Journal of Irrigation and Drainage Engineering, 123(6), 423–442.

David, W. P. (2004). Water Resources and Policy Issues in Asia. Asian Journal of Agriculture and Development, 1(1), 76-97.

Davids, J.C., van de Giesen, N., Rutten, M. (2017). Continuity vs. the Crowd—Tradeoffs Between Continuous and Intermittent Citizen Hydrology Streamflow Observations. Environmental Management, 60(1), 12-29.

Famiglietti, J.S. (2014). The global groundwater crisis. Nature Climate Change, 4(11), 945-948.

Eekelen, van, M., W.G.M. Bastiaanssen, C. Jarmain, B. Jackson, F. Fereira, J. Bosch, P. Dye, P. Van der Zaag, A. Saraiva, E. Bastidas-Obando, R. Dost, W. Luxemburg, (2015). A novel approach for estimating direct and indirect water withdrawals using satellite measurements: a case study from the Incomati Basin, Agriculture, Ecosystems and Environment, 200, 126-142.

FAO (2006). Modernization Strategy of Large Rice based Terai Irrigation Systems of Nepal. Rome: Food and Agricultural Organization (FAO).

FAO (2011). Aquacrop Reference Manual, Chapter 1, Version 3. 1plus.Rome, Jan 2011 (available at: http://www.fao.org/nr/water/docs/AquaCropV31plusChapter1.pdf)

FAO (2012). AQUASTAT. http://www.fao.org/nr/aquastat. Food and Agriculture Organization of the United Nations (FAO). Website accessed on 05/01/2018.

FAO (2017). Food and Agriculture Organization of the United Nations, Water Accounting and Auditing - A Sourcebook, 2017.

Fienen, M.N., Lowry, C.S. (2012). Social.Water—A crowdsourcing tool for environmental data acquisition. Computers & Geosciences, 49, 164-169.

Gleick, P.H. (1998). Water in crisis: paths to sustainable water use. Ecological applications, 8(3), 571-579.

Hannah, D.M., Demuth, S., van Lanen, H.A., Looser, U., Prudhomme, C., Rees, G., Stahl, K., Tallaksen, L.M. (2011). Large-scale river flow archives: importance, current status and future needs. Hydrological Processes, 25(7), 1191-1200.

Keough, H.L., Blahna, D.J. (2006). Achieving integrative, collaborative ecosystem management. Conservation Biology, 20(5), 1373-1382.

Kruger, L.E., Shannon, M.A. (2000). Getting to know ourselves and our places through participation in civic social assessment. Society & Natural Resources, 13(5), 461-478.

Margat, J., Van der Gun, J., (2013). Groundwater around the world: a geographic synopsis. CRC Press.

Mishra, A.K., Coulibaly, P. (2009). Developments in hydrometric network design: A review. Reviews of Geophysics, 47(2), RG2001, doi:10.1029/2007RG000243

Nagendra, H., Karmacharya, M., Karna, B. (2005). Evaluating forest management in Nepal: views across space and

time. Ecology and Society, 10(1), 24.
Pearson, C.P. (1998). Changes to New Zealand's national hydrometric network in the 1990s. Journal of Hydrology (New Zealand), 37 (1), 1-17.
Pradhanang, S.M., Shrestha, S.D., Steenhuis, T.S. (2012). Comprehensive review of groundwater research in the Kathmandu Valley, Nepal.In: (S. Shrestha, D. Pradhananga, VP Panday (Eds.), Kathmandu Valley Groundwater Outlook. pp.6-18.
Savan, B., Morgan, A.J., Gore, C. (2003). Volunteer environmental monitoring and the role of the universities: the case of Citizens' Environment Watch. Environmental management, 31(5), 0561-0568.
Serrano Sanz, F., Holocher-Ertl, T., Kieslinger, B., Garcia, F.S., Silva, C.G. (2014). White Paper on Citizen Science for Europe. URL: https://www. zsi. at/object/pro ject/2340/attach/White_Paper-Final-Print. pdf (visited on 28th May 2015).
Shrestha, S, Pradhananga, D, Pandey, VP (2012) Kathmandu valley groundwater outlook. Kathmandu, Nepal: AIT/SEN/ CREEW/ICRE-UY.
Sultana, P., Abeyasekera, S. (2008). Effectiveness of participatory planning for community management of fisheries in Bangladesh. Journal of environmental management, 86(1), 201-213.
van de Giesen, N., Hut, R., Selker, J. (2014). The Trans-African Hydro-Meteorological Observatory (TAHMO). Wiley Interdisciplinary Reviews: Water, 1(4), 341-348.
Whitelaw, G., Vaughan, H., Craig, B., Atkinson, D. (2003). Establishing the Canadian community monitoring network. Environmental monitoring and assessment, 88(1), 409-418.

Technological transformation in on-farm irrigation management in Punjab, Pakistan – Achievements, challenges and prospects under climate change

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Abstract

Water has become the most important strategic resource in Pakistan. Agriculture sector uses over 93% of the total freshwater supply. Irrigation is the key for agro-based economy of Pakistan. Punjab province is called as the country's breadbasket producing more than 60% of food and fiber requirements for the population of Pakistan. More than 80% of the cropped area of Punjab is irrigated by the Indus Basin Water System served through over 60,000 watercourse commands in Punjab. Despite paramount significance and immense potential, Punjab's irrigated agriculture suffers from low productivity vis-à-vis profitability. Amid various emerging irrigation challenges, inadequate water availability at for crop production and subsequently its inefficient use due to lack of technology in irrigation operations at the farm level remain the main impediments to low productivity from otherwise highly productive agricultural lands. Climate change has further aggravated the situation. During the last five years, a number of climate-smart technology based interventions have been introduced for improving irrigation water management at the farm level. Under one mega, 650 million USD, the World Bank assisted program, mainly three technologies have been introduced including pre-cast concrete parabolic segment (PCPS) for rehabilitation of farm level water conveyance network (watercourses), laser land levelling for enhancing water application efficiency and the most important one is high efficiency irrigation systems (drip and sprinkler) for increasing productivity. Solar systems have been introduced for operating high efficiency irrigation systems under locally funded projects. These irrigation technologies have made a huge impact in improving irrigation management at the farm level with benefits ranging from water saving, increasing irrigation efficiency, enhancing water productivity, curtailing crop production inputs (fertilizer, labour, etc.), ease of irrigation operation, crop diversification resultantly enhancing the net farm returns to a great extent. High Efficiency Irrigation Systems (HEIS) are transforming the irrigation sector, however, they are facing multiple challenges in Punjab. Amid substantial achievements, challenges like new technologies requiring complete paradigm shift in crop cultivation, high capital cost and low installation capacity of the private sector as well as lack of knowledge of farmers to operate such hi-tech systems are the main impediments in accelerated adoption of HEIS technology. Despite challenges, these irrigation technologies have great prospects for transforming the Punjab's irrigated agriculture into a sustainable, technology driven,

diversified and internationally competitive sector under the climate change scenario.

Keywords: *drip irrigation; laser land levelling; pre-cast concrete parabolic segment; Punjab; technological transformation*

1. Introduction

Water is fundamental to socio-economic development of developing countries. In Pakistan, it is the most important input and strategic resource for development of the agriculture sector, which provides employment to 25 million people and is the main earning source for 34% and 74% economically active men and women, respectively (CIAT and World Bank, 2017). Agriculture sector in Pakistan uses over 93% of total freshwater supplies (Afzal and Ahmad, 2009). Farming is mostly irrigated as almost 94% of the cropped area is equipped for irrigation (CIAT and World Bank, 2017) using the surface water supplied through the world's largest contagious Indus Basin Irrigation System that comprises of rivers, dams, barrages, canals, distributaries, minors and watercourses as well as groundwater. Groundwater has got paramount importance due to continuously dwindling surface water supplies as 60% of cropwater requirements are met though groundwater abstractions.

Punjab is the richest agriculture province producing 76% wheat, 72% cotton, 51% rice, 81% maize, 65% sugarcane, 97% citrus, 75% mango and 83% gram of the total production of these crops respectively in the country (PDS, 2015). This agriculture production is totally dependent on irrigation as about 86% (14.33 million hectares, Mha) of Punjab's total cropped area (16.52 Mha) is irrigated. Ninety percent of Punjab's 90% agricultural output comes from irrigated lands (ADP, 2016). Irrigation is the most critical input for crop production.

Despite gigantic significance of irrigation in Punjab, the sector has remained confronted by various challenges including dominant poor irrigation practices causing huge water losses, lack of modern irrigation technology (PASP, 2015), water scarcity, growing water demands at 10% per annum (Mustafa et al., 2013), shortage of energy, and low water productivity (PGS, 2015). According to an estimate of Punjab Agriculture Department (PAD), over 50% of the irrigation water lost during conveyance at the farm level and subsequently its application in the field mainly because of aged irrigation system and lack of modern technologies and methods for efficient use of irrigation supplies (PAD, 2012). The system is supply driven and inflexible with very limited possibilities of demand-based irrigation applications according to crop needs. It is a proven fact that crop productivity is directly related to efficient irrigation application to meet the cropwater requirement (Bakhsh et al., 2008).

Lack of technology for irrigation management at the farm level has got huge importance in Punjab under water scarcity and the climate change scenarios. Climate change has put already resource-stressed country under additional stress (Farooqi et al., 2005). The irrigated agriculture is the most vulnerable sector to climate change and its impacts are predicted to be more adverse on crop yields and irrigation supplies (Piracha and Majeed, 2011). The Punjab Growth Strategy (PGS, 2015) outlines climate change as a major factor responsible for decreasing agricultural productivity, crop failure, inefficient use of inputs, water scarcity, environmental and land degradation.

In view of the above challenges, the Government of Punjab, Pakistan has introduced various modern climate-smart technological solutions for efficient on-farm irrigation management to enhance irrigation efficiency, cope with the water shortages, minimize impacts of climate change and enhance crop and

water productivity. These initiatives have been started with the assistance from the World Bank and from its own resources. These technological transformations include pre-cast concrete parabolic lining for rehabilitation of earthen community watercourses, drip irrigation, laser land levelling, solar powered irrigation systems and tunnel technology.

The objective of this paper is to examine the initiatives regarding water saving and climate-smart technologies and their impacts as well as challenges in adoption of these technologies faced by Punjab farmers using secondary data and available policy, strategy and operational project documents. Explicitly, this paper ascertains (a) key government initiatives and technologies introduced and their adoption; (b) impacts of these technologies; (c) potential and prospects of these technologies; and (d) identification of challenges for upscaling these technologies for sustainability of irrigated agriculture in Punjab.

2. Materials and Methods

Punjab is the land of 36 administrative units, called districts (Fig. 1), having arid to semi-arid climate. The total geographical area of Punjab is 20.63 Mha, out of which 12.74 Mha (or 62%) are cultivated. Punjab is the agricultural and economic heartland of Pakistan producing over 60% of the total agricultural produce (PCCP, 2016) of the country. More than 70% of the total cropped area of the Indus food machine is situated in the Punjab.

Punjab has a unique irrigation landscape in the world with headwork/barrages, main canals, branch canals, distributaries, minors and 60,000 watercourses with command area of over 8.5 Mha. However, over the years, groundwater has emerged as exceedingly important freshwater resource because of inadequate surface water supplies. The groundwater contribution in overall cropwater use is about 60% whereas surface water is contributing only 40% (PID, 2016). Major crops grown in the Punjab are wheat, rice, sugarcane, cotton and maize. Flood irrigation is the most common method practiced by the farmers for irrigating their crops, whose efficiency is not more than 50% (PIPIP, 2012). The crop yields, both per acre and per m^3 of water, are much lower than international benchmarks and even lesser than neighboring countries. For example, the irrigation water productivity for cereal crops is only 0.13 kg/m^3, which is very low compared to India's 0.39 kg/m^3 and China's 0.82 kg/m^3 (PASP, 2015). It is alarming that about 50% the water gets lost during its conveyance, application and use for crop production (PIPIP, 2012).

Figure 1: *Location of Punjab province in Pakistan*

2.1 Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) – World Bank-funded reform program

The Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP), a reformatory initiative, has been launched with the World Bank assistance at a total cost of US$ 423 million by PAD through On-Farm Water Management (OFWM) wing of the department. The overall Project Development Objective (PDO) is to enhance water and crop productivity through upgrading the farm-level irrigation conveyance infrastructure and equipping the farmers with improved climate smart irrigation technologies together with creating an enabling environment for sustained technology transfer at the grassroots level for optimal and efficient management of available water resources. Installation of drip irrigation, provision of laser land levelers to the farmers, and rehabilitation of farm level irrigation infrastructure are its main components. These activities spread all over the Punjab province and so far has made a huge visible impact in terms of water saving, reduction in fertilizer use, productivity enhancement, crop diversification, and employment generation at grassroots level. The World Bank has rated performance of this project as "Highly Satisfactory". Based on tangible and transformatory impact of project interventions, the project has been up-scaled to US$ 650 million.

2.2 Solar-powered irrigation systems

Nature has blessed Pakistan with abundance of renewable energy resources, which have not been harnessed appropriately. Replacing or supplementing the conventional fuels (diesel and electric) for operating high efficiency irrigation systems, especially drip irrigation with solar energy is a workable option as sunlight is available for more than 3000 hrs/yr in Pakistan with about 8 hours of effective daylight period (Saleem et al., 2015). Its seasonal variations are also within acceptable limits. The arid/semi-arid climate of the Punjab, therefore, provides ideal conditions for adoption of solar energy for operating irrigation water pumps. Owing to above advantages vis-à-vis acute energy shortages, Punjab government has launched first ever solar powered drip irrigation system naming it as "Climate Smart Technology Package" for installation on 9,000 hectares (20,000 acres) on farmers' field initially.

3. Results and Discussion

3.1 Drip irrigation technology

Drip irrigation is the most efficient technology that makes highly effective use of the precious and scarcely available crop production inputs, especially water and fertilizer. It enables efficient use of irrigation water, less fertilizer use, increased production and better quality produce (Asif et al., 2016). Bakhsh et al. (2008) have carried out field experiments in Pakistan and concluded that drip irrigation has the potential of increasing water productivity even under deficit irrigation environment. Similarly, as much as 50, 47 and 43 percentages of water saving were reported for cotton, sugarcane and chilies, respectively (Ali, 2010). The developed world has been benefitting from this technology since the 1960s but its propagation in developing countries like Pakistan has been late and had only been limited to research and evaluation studies. Concrete efforts to promote drip technology on farmers' field in Pakistan has been made by the Punjab Government under PIPIP whereby farmers are getting 60% financial assistance for its installation.

3.1.1 Impact of drip irrigation under PIPIP

Drip irrigation technology has made a momentous impact in terms of water saving, fertilizer use reduction and productivity enhancement though the technology is still at its nascent stage in Punjab. So far, drip irrigation systems have been installed in over 9,635 hectares (23,800 acres) at about 900 sites on various crops including orchards (citrus, olive, grapes etc.) vegetables (tomato, cucumber, chilli etc.) and other row crops (maize, sugarcane, cotton etc.).

The comparative performance of drip irrigation system in Punjab against conventional methods such as flood and furrow has been evaluated on variety of crops by various agencies and researchers during last few years. Table 1 is the compilation of results from various research publications (Asif et al., 2016; Bakhsh et al., 2015; OFWM, 2015) and project/strategy documents (PASP 2015; PIPIP, 2012) showing percentage water saving, fertilizer use reduction, and yield increase by drip against traditional methods of irrigation. Water saving ranging from 40-64% accrued from drip irrigation systems as compared to traditional irrigation systems.

Table 1: *Impact of drip irrigation on farmer field*

Crop	Irrigation water saving (%)	Fertilizer use reduction (%)	Yield increase (%)
Capsicum	62	57	30
Cucumber	64	52	32
Green pepper	58	49	27
Tomato	53	66	26
Citrus	50		105

Monitoring and Evaluation (M&E) consultants of the PIPIP has taken 26 sample High Efficiency Irrigation Systems (HEIS) farms and carried out impact evaluation of drip irrigation systems installed for cultivating different crops by the farmers across Punjab and compared results of drip irrigation with the conventional irrigation systems. The M&E consultants presented results in terms of perception of the farmers about benefits and utility of drip irrigation system as compared to traditional irrigation methods. Out of the 26 HEIS farms, about 91% of the farmers were convinced about saving of water accrued from this technology whereas 81% farms were convinced about significant reduction in use of fertilizers (Fig. 2). A glimpse of drip irrigation system installed in Punjab is provided in Fig. 3.

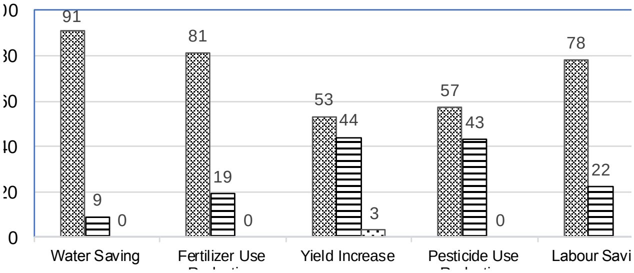

Figure 2: *Farmers perception about drip irrigation system as compared to traditional irrigation methods*

Figure 3: *Glimpses of drip irrigation systems installed in Punjab*

Drip irrigation technology has emerged as a multi-solution technology in many parts of the world, which addresses the issues of farm level water security, sustainable productivity enhancement and climate change adaptation. World Bank (2014) has presented drip irrigation as one of the tools to address water security in the agricultural sector in India. Jha et al. (2016) have evaluated the impact of drip irrigation as compared to furrow irrigation in Nepal and found that water use was 73% less under drip irrigation and concluded that technology can substantially expand smallholder farmers the ability to cultivate crops during dry season as well as increase their resilience to fluctuating water supplies in a changing climate. Asif et al. (2016) has recently evaluated the drip irrigation systems installed by farmers under PIPIP and revealed saving in 49-66% fertilizer use as compared to conventional flood irrigation because fertilizers in drip system were applied only to the plant root zone as per crop requirement and fertilizer loss due to run-off and deep percolation is significantly reduced.

Despite strenuous efforts made by OFWM staff in promotion of drip technology among farmers, it could not take off as planned due to various challenges such as (i) drip technology is new in Punjab; (ii) high initial capital cost of drip equipment (iii) lack of technical knowhow amongst all stakeholders; (iv) inadequate (negligible) capacity of private sector in terms of manpower and inventory to cater even whatever demand is available; and (v) availability of highly subsidized canal water. Bakhsh et al. (2015) analysed that drip irrigation is the most efficient but an expensive technology option, which needs technical knowledge and intensive training for its successful operation. Despite all these issues, drip irrigation has emerged as the multiple solution technology in Punjab's irrigated agriculture, especially in terms of tackling the farm level water scarcity under the changing climate.

3.2 Pre-cast concrete parabolic segment technology for rehabilitation of community watercourses

Pakistan has the largest single contiguous gravity flow irrigation system in the world consisting of reservoirs, barrages, main canals, branch canals, distributaries, minors and watercourses (Fig. 4). Watercourses is the

lowest level of the irrigation network owned by the farming community with command area ranging from about 120-200 hectares (300-500 acres). There are huge water conveyance losses (about 40%) in these century old community watercourses because of their poor maintenance and aging (PIPIP, 2012). Arshad et al. (2008) found average water loss of 66% from unlined watercourse. According to estimates by Agriculture Department about 12,334 million cubic meter (MCM) (or 10 million-acre-feet, MAF) of water has been lost in these watercourses, which is a big loss under the current scenario. The main sources of water losses are seepage, spillage, and side leakage from the watercourses. There are about 60,000 watercourses in Punjab out of which about 47,000 watercourses have been rehabilitated with lining of its maximum 30% part while remaining part is earthen improved. Recently, PAD has made a major policy decision and increased lining percentage limit up to 50% and shifted the technology from brick lining to pre-cast concert parabolic segments. Rehabilitation of community watercourses improves conveyance efficiency and helps to conserve water at the farm level. Numerous evaluation and impact assessment studies have been carried out by various national and international organizations/institutions to document impact of watercourse improvement.

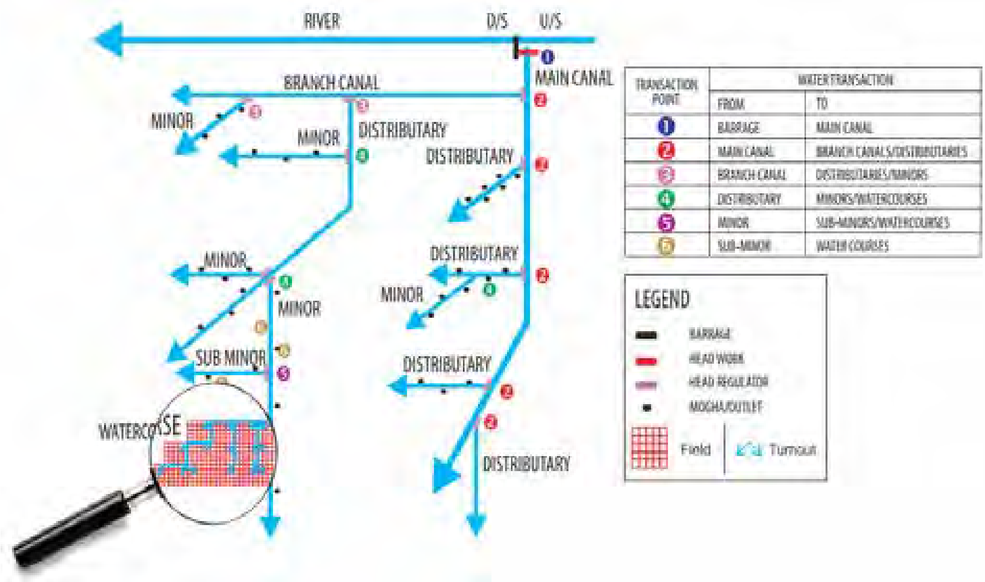

Figure 4: *Typical irrigation network of Punjab (Source: Briscoe and Qamar, 2006)*

A glimpse of traditional and improved water course is shown in Fig. 5. Rehabilitation/ improvement of watercourses consists of complete demolishing of community channel and its rebuilding/re-aligning according to the engineering design with clean compacted soil and parts of reconstructed channel are lined and necessary water control structures are installed to improve conveyance of the canal and tubewell water (PIPIP, 2012). Water Users Association (WUA) has been organized and registered under OFWM and WUA ordinance 1981 for rehabilitation/improvement of these community watercourses. Traditionally, brick lining technology has been used for community watercourse rehabilitation but more recently pre-cast concrete parabolic segments (PCPS) technology has been introduced, which is more durable, quick in installation, and climate resilient.

Figure 5: *Glimpse of conventional and improved watercourses*

The Planning Commission of Pakistan has carried out impact evaluation study in 2012 and found that improvement/ rehabilitation of one watercourse results in saving of about 119 MAF of water per annum. It has been estimated this saved amount of water can help in bringing additional 14 hectares (35 acres) under cultivation in a rice-wheat cropping system. Mangrio et al. (2015) found that water saving of 30% was obtained by lining of watercourse, which could be utilized to cultivate an additional land of 7 hectares (23 acres). Table 2 shows the benefits accrued from watercourse improvement/rehabilitation.

Table 2: *Impact of improved watercourse on farmer field*

Impact factor	Yield increase (%)
Annual water saving (acre feet)	119
Increase in cropping intensity (%)	4
Saving in irrigation time (%)	28
Decrease in conveyance losses (%)	39
Curtailment in saline area (%)	87
ERR (%)	28
Befit cost ratio	2.3

3.3 Laser land levelling

The promotion of precision land levelling was started in Punjab during the 1970s at inception of OFWM program. Laser land levelling was, however, started during 1985 which consists of a laser transmitter, a signal receiver, an electrical control panel, and a solenoid hydraulic system operating valve. The laser transmitter transmits a laser beam, which is intercepted by the signal receiver mounted on a levelling blade attached to the tractor. The control panel mounted on the tractor interprets the signal from the receiver and opens or closes the hydraulic control valve that raises or lowers the levelling blade. The technology has proved to be highly beneficial because it minimizes the cost of operation, ensures better degree of accuracy in much lesser time, saves irrigation water, ascertains uniform seed germination, increases fertilizer use efficiency, and resultantly enhances crop yields (PIPIP, 2012). Naresh et al. (2014) carried out impact evaluation studies and found that farmers could save irrigation water to the extent of 21% and energy by 31% by laser land levelling their fields as compared to traditional land levelling. Abdullaev et al. (2007) found that water productivity in laser levelled field increased by 32% in comparison with non-levelled field of the same sizes. Conventional versus laser levelled fields are shown in Fig. 6.

Figure 6: *Conventional versus laser levelled fields*

This technology is the most effective and highly popular amongst farming communities in Punjab because of its quick returns in terms of water saving and crop productivity enhancement. Under PIPIP, the government has provided 3,000 laser land levellers to the farmers who are acting as service providers in rural areas. M&E consultants of the PIPIP have carried out impact evaluation of laser land levellers and found 30% reduction in irrigation time. Pakistan National Climate Change Policy (2012) envisages laser land levelling as short-term priority actions to minimize climate change impact at the farm level. Wagan et al. (2015) found almost 50% saving of irrigation time as time to irrigation per acre was reduced from 2.26 hrs in unlevelled field to about 1.18 hrs in laser levelled field and also revealed that about 21% of irrigation water was saved by using laser technology, which is huge saving under dwindling water resources and changing climate.

3.4 Solar-coupled high efficiency irrigation system

Solar is the most abundant source of energy available in the world and it is a sustainable solution to counter not only the energy crisis but also the environmental issues and solar powered irrigation pumps makes agriculture possible even in areas, which previously could not be farmed (Kashiv et al., 2016). Solar-coupled drip irrigation system has recently been introduced in Punjab as a climate-smart technology solution to help small farmers to cope with the water scarcity and climate change. It has been planned to install solar systems for operating high efficiency irrigation system for irrigating crops through

site specific designing. It will help to ensure timely availability of irrigation water for crops, particularly at their critical stages through uninterrupted water supply from solar units. The PAD has decided to provide 80% of system cost as subsidy to the farmers and remaining 20% will be borne by farmers. Solar-powered drip irrigation systems have been installed on over 1.215 hectares. A typical layout of solar-coupled high efficiency irrigation (drip system) is shown in Fig. 7.

Mongat et al. (2015) evaluated the impact of solar powered high efficiency on farmer field in Punjab and found such systems are more efficient, save energy, are economical and environmentally safe as compared to diesel operated traditional systems. Application uniformity was measured as 98-99% and distribution uniformity was 99%. The study recommends installation of solar panels for high efficiency irrigation systems and suggested that government should provide subsidy to the local farmers to publicize such systems as best replacement to conserve natural resources as well as the government should take steps to encourage local industry to make solar panels available at its lowest prices. Saleem et al. (2015) also analysed the solar powered high efficiency irrigation systems and found them to be technically feasible and economically viable.

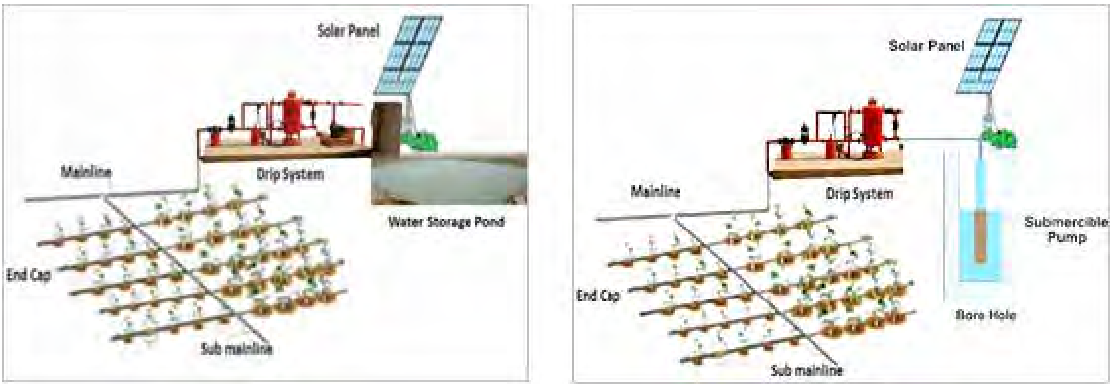

Figure 7: Conceptual layout of solar powered drip irrigation systems

All the above interventions are making significant impacts at the farm level to address irrigation management challenges, water security challenges and offering a sustainable option to tackle with the climate change issue. At the same time, these are highly capital-intensive technologies requiring continuous support of the government and indigenization at the local level.

4. Conclusions

This paper aimed at analysing various climate-smart technological interventions launched for efficient irrigation management, impacts of these technologies, challenges and prospects of these interventions in Punjab, Pakistan. Following conclusions and recommendations are drawn from above analysis.

- Climate-smart technologies like drip irrigation, laser land levelling, pre-cast concrete parabolic lining for community watercourse rehabilitation and solar powered high efficiency irrigation system have made a huge impact in terms of water saving (40-64%), reduction in fertilizer use (30-66%) and enhancing crop productivity (6-105%) besides several concomitant tangibles and intangible benefits.

- High initial cost of these technologies is a major challenge especially to be adopted by the small farmers.
- Acquired benefits of these resource conservation and climate smart technologies suggest its adoption on large areas to mitigate the prevailing water crisis and better irrigation management.
- Government is providing financial assistance for such technologies, which require continuity to help farmers in addressing issues of water security and climate change at the farm level.
- All the stakeholders i.e. government, agriculture industry, farmers private sector companies need to collaborate for mobilizing initial investment, its repayments, and follow-up assistance for successful adoption of these technologies by the farmers for sustainability of irrigated agriculture in Punjab.
- New and on-going irrigation projects envisaging development of commands of small dam, new canals, commands etc. should be given priority to practice these climate smart technologies. It should be made mandatory to install high efficiency irrigation systems, especially drip technology to get water rights under command area development projects.

Acknowledgements: The author is highly grateful to experts of Agriculture Department, Punjab for their valuable comments and suggestions. The paper has also benefited from valuable suggestions of engineers/scientists of Directorate General Agriculture (Water Management) Punjab.

References

Ali, T. M. (2010). Adoptability of Trickle Irrigation System for Small farmers in Punjab. M.Sc. Thesis, Center of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore.

Abdullaev, I., Hassan, M.U., Jumaboev, K. (2007). Water saving and economic impacts of land levelling: the case study of cotton production in Tajikistan. Irrig. Drainage Syst., 21, 251–263.

Afzal, N., Ahmad, S. (2009). Agricultural Input Use Efficiency in Pakistan: Key Issues and Reform Areas. Natural Resources Division, Pakistan Agricultural Research Council, Islamabad, Pakistan.

Annual Development Program (ADP) (2016). Irrigation Sector, Government of the Punjab, Planning and Development Department, Pakistan.

Arshad, M., Zaman, Q., Madani, A. (2008). Lining Impact On Water Losses in Watercourses – A Case Study in Indus Basin, Pakistan. The Canadian Society for Bioengineering, 08-171.

Asif, M., Akram, M., Ali, A. (2016). Multi-locational trials to compare the relative water use and vegetable crops productivity by drip irrigation and conventional furrow irrigation systems in district Toba Tek Singh, Pakistan. Science Letters, 4(1), 60-65.

Bakhsh, A., Hassan, A., Chaudary, M.R. (2008). Virtual Water Reality: Pakistan's Perspective In: Proceeding of Conference on: Agriculture; Challenges, Opportunities and Options under Free Trade Regime held in University Agriculture of Faisalabad on 28-29 May, 2008.

Bakhsh, A., Ashfaq, M., Ali, A., Hussain, M., Rasool, G., Haider, Z., Faraz, R.H. (2015). Economic Evaluation of Different Irrigation Systems for Wheat Production in Rechna Doab, Pakistan. Pak. J. Agri. Sci., 52(3): 821-828.

CIAT and World Bank. (2017). Climate-Smart Agriculture in Pakistan. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); The World Bank. Washington, D.C. 28 p.

Jha, A. K., Malla, R., Sharma, M., Panthi, J., Lakhankar, T., Krakauer, N.Y., Pradhanang, S. M., Dahal, P., Shrestha, M. L. (2016). Impact of Irrigation Method on Water Use Efficiency and Productivity of Fodder Crops in Nepal. Climate, 4 (4), 1-13. doi:10.3390/cli4010004.

Farooqi, A.B., Khan, A.H., Mir, H. (2005). Climate Change Perspective in Pakistan. Pakistan J. of Meteorology, 2(3), 11-21.

Food and Agricultural Organization (FAO) (2012). Water Scarcity: An action framework for agriculture and food security, FAO Water Reports 38, Rome.

Kashiv, A., Bilala, A., Shirazi, N., Dwivedi, A., Joshi, R. (2016). Solar Drip Irrigation System. International Journal of Emerging Technology and Advanced Engineering, 6(4), 160-161.

Mangrio, M. A., Lohano, A. K., Leghari, N., Khatri, K. L., Hyder, M., Shaikh, M. J., Soothar, R. K. (2015). Economic Feasibility of Watercourses Lining in Sindh Pakistan. Sci.Int. (Lahore), 27(2), 1237-1242.

Mongat, A. S., Arshad, M., Bakhsh, A., Shakoor, A., Anjum, L., Hameed, A., Kalsoom, U., Shamim, F., (2015). Design, Installation and Evaluation of Solar Drip Irrigation System at Mini Dam Command Area. Pak. J. Agri. Sci., 52(2), 481-488.

Mustafa, D., Akhter, M., Nasrallah, N. (2013). Understanding Pakistan's Water-Security Nexus, United States Institute of Peace, Washington, DC.

Naresh, R. K., Singh, S. P., Misra, A. K., Tomar, S. S., Kumar, P., Kumar, V., Kumar, S. (2014). Evaluation of the laser leveled land leveling technology on crop yield and water use productivity in Western Uttar Pradesh. African Journal of Agricultural Research, 9(4), 473-478.

On Farm Water Management (OFWM). (2015). PC-I of Optimizing Watercourse Conveyance Efficiency through Enhancing Lining Length, Punjab Agriculture Department, Lahore.

Pakistan National Climate Change Policy (2012). Ministry of Climate Change, Government of Pakistan, Islamabad.

Piracha, A., Majeed, Z. (2011). Water Use in Pakistan's Agricultural Sector: Water Conservation under the Changed Climatic Conditions, Inter. J. of Water Resources and Arid Environments, 1(3), 170-179.

Punjab Agricultural Sectoral Plan (2015). Government of the Punjab, Agriculture Department, Lahore, Pakistan.

Punjab Development Statistics. (2015). Bureau of Statistics, Government of the Punjab, Lahore, Pakistan.

Punjab Growth Strategy (2015). Government of the Punjab, Planning and Development Department, Lahore, Pakistan.

Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) (2012). Project Document, On Farm Water Management, Punjab Agriculture Department, Lahore.

Punjab Irrigation Department (PID) (2016). Punjab's Water Policy Framework (Draft), Government of Punjab, Pakistan.

Saleem, M., Ashraf, M., Fripp, J. (2015). Solar-Powered Pumping Systems for High Efficiency Irrigation: Design Manual for Practitioners, Design Manual for Practitioners. A joint Report published by PARC, PCRWR and ICARDA-Pakistan under USDA project "Watershed Rehabilitation and Irrigation Improvement in Pakistan", pp. 42.

Wagan, S. A., Memon, Q. A., Wagan, T. A., Memon, I. H., Wagan, Z. A. (2015). Economic Analysis of Laser Land Leveling Technology Water Use Efficiency and Crop Productivity of Wheat Crop in Sindh, Pakistan. J. of Environment & Earth Science, 5(15), 21-25.

Operation performance of a modernised irrigation system: A case study of Sitagunj irrigation system in Sunsari-Morang irrigation project, Nepal

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Abstract

Operation performance in an irrigation system is viewed as a process result of comparison and evaluation of the control and management of water (quantity and quality) through a delivery system having (modernized) physical facilities aiming to meet the cropwater requirements in time, quantity and space. Improving operation performance of water delivery through the conveyance system management is as essential as the tertiary system management, apart from on-farm water management by the farmers. In order to improve performance with the limited available water to be served through the delivery system requires accurate control and management of facility that competes with intended supply at respective offtakes serving the user groups in a large-scale irrigation system. This triggers unsteady flow in hydrodynamics of canal network while adjusting the control structure and managing discharge for the user groups served by the main system. Consequently, volume and timing of actual flow would be different from intended flow at the outlets to the users' groups. Further, careful design, implementation and maintenance of physical facilities, among others, perform a vital role in improving the operation performance of the water delivery system.

This study assesses operational performance of the Sitagunj Secondary Canal (S9) System in Sunsari-Morang Irrigation Project (SMIP) of Nepal. Water delivery performance at respective offtakes is measured by adequacy, efficiency, equity and reliability. A study of management performance, structure performance and operation performance at offtakes has been made separately for each designed and actual flow condition. Results showed that in designed condition, all the offtakes to the corresponding watercourse canal receive inequitably deficient water, especially in SS9F canal, due to structural limitations in the design. Further, reliability of water delivery considering management performance coupled with the delivery schedule is least in the downstream section due to incompatible response time between actual supply and intended supply. In actual flow condition, the supply is less than intended over study season and discharge is fluctuating. The adequacy and efficiency of water delivery have small deviation from design case but the spatial and temporal variation are poor than the designed value due to variable supply and structural limitation.

Keywords: *adequacy; efficiency; equity; modernization; reliability*

1. Introduction

Water is such a scarce resource and of such a high value that it merits profound reflection on its future management (Biswas et al., 2009). As a consequence of the rapid increase in human population and changes in diet habit, food consumption is increasing globally and thereby demanding agricultural expansion/intensification (Izquierdo et al., 2011). It is well known that irrigation input at right time and quantity in the framework of agriculture system contributes significant increase in production to feed the growing population.

Most of the large-scale irrigation projects appear to perform below expectation. On account of increasing water demands, accurate control of water flow in the irrigation system is becoming more and more important, but in practice control of water flow in irrigation systems is still rather poor. This implies an inefficient, unreliable and/or inequitable water distribution, which may occur in main canal systems as well as in the minor canal systems (Schuurmans, 1991).

Operation performance in an irrigation system is viewed as a process result of comparison and evaluation of the control and management of water (quantity and quality) through a delivery system having (modernized) physical facilities aiming to meet the cropwater requirements in time, quantity and space. Improving operation performance of water delivery through the conveyance system management is as essential as the tertiary system management, apart from on-farm water management by the farmers (Mishra, 2004). Furthermore, there are many participants involved in an irrigation enterprise, and it cannot be assumed that they all share the same view as to what constitutes a good performance (Abernethy, 1989). In addition, it is impossible to specify the objective of irrigation, and consequently, the optimal water distribution does not exist. For example, an optimal water distribution from an economic viewpoint might not be optimal from a social viewpoint. Therefore, instead of looking to the objectives of irrigation, another narrower approach is followed: the hydraulic performance of the operation of the system is examined rather than the performance of system itself. Hence, objectives of operation system are defined in terms of adequacy, efficiency, reliability and equity. The success of a water delivery system is, therefore, measured by how well it meets the objectives of delivering an adequate, while not excessive, and reliable supply of water in an equitable manner to the users served by the system. Hence, performance measures associated with the evaluation, planning and design of water delivery system in a quantitative manner holds its place.

The present scenario of large irrigation systems in Nepal is that operation and maintenance cost are increasing and the irrigated area is decreasing year by year. One of the reasons is due to unsteady/ low flow of water at source causing unreliable and inadequate supply into irrigation system resulting in poor operation performance directed to discouraging collection of irrigation service fee (ISF) from users. Therefore, improved operation performance of an irrigation system with the available water to be served through the delivery system using accurate flow control and management that competes with intended supply at respective offtakes serving the user groups is important in alleviating stress in field crops growth and sustainability of (dual managed) irrigation system.

Adjusting the control structures and managing discharge for the user groups served by the main system consequently creates unsteady flow in the canal network. Therefore, timing of actual supply discharge would be different from intended/scheduled discharge at the outlet to the user groups. Hence, accurate adjustment of gates as well as timing of actual supply discharge, among other parameters, is a vital contribution to improving operation performance of the water delivery system. Further, careful design, implementation and maintenance of physical facilities including channels, control structures/ offtakes

and role of water users' association (WUA) altogether perform a vital role in improving operation performance of the water delivery system.

2. Water Delivery Performance

A water-delivery system may be viewed as one of the components of an irrigated agriculture system. As such, it provides the water required to achieve farm-level agriculture production policies, such as maximizing net economic and social-welfare benefits (Abernethy, 1986). For planning and management, the objectives of irrigation systems often are viewed in terms of desire to best meet agriculture water requirements (Molden and Gates, 1990). If the management is unsuccessful, it will not be possible for agricultural management to succeed. The objectives of delivering an adequate and reliable supply of water in an equitable and efficient manner (i.e., delivery of water where and when it is wanted for crop production, efficiently and in the right quantities) to users served by the system are the key to merit irrigation-water-delivery system. To evaluate how well an irrigation-water-delivery system is functioning in its present state relative to its objectives, and to make decisions about designing or modernizing a system, requires defining of measures of system performance and prescribing standards for assessing the values of those measures. Performance measures should be functions of state variable that is used to indicate the state of system performance relative to system objectives, should be intuitively easy to interpret, and should be relatively easy to measure or predict. Once performance measures have been estimated for a given state of the system, their values must be assessed, or evaluated (Molden and Gates, 1990). Furthermore, to assess the need for improvement in structural and management components of the delivery system, it is necessary to evaluate the separate contribution of these components to the overall performance of the system. Thus, operational performance of water-delivery systems is comprised of scheduled plan of delivery, hydraulic structures and institutional organizations in charge of managing water as it flows through different hydraulic layers of the system in space and time. The structural components of water-delivery systems include facilities for conveyance, regulation, measurement and distribution of water. The management component is responsible for operation and maintenance of the facilities.

Thus, delivery performance is the product of delivery-schedule performance and operational performance of water-delivery system. Further decomposition of operational performance into two components results as structural performance and management performance of water delivery system. These performance measures/indicators, expressed in dimensionless ratio form, are referred to from publication of Molden and Gate (1990) and presented in Table 1 and Fig. 1.

***Table 1**: Overall delivery performance*

Delivery performance, P_D	$= V_a/V_r$
Schedule performance, P_{SC}	$= V_i/V_r$
Operational performance, P_{SM}	$= V_a/V_i$
Structural performance, P_s	$= V_e/V_i$
Management performance, P_M	$= V_a/V_e$

Hence, $P_D = P_{SC} \times P_{SM} = P_{SC} \times (P_S \times P_M)$ $= V_i/V_r \times V_a/V_i = V_i/V_r \times (V_e/V_i \times V_a/V_e)$

V_r =	Volume of water required in canal/structure based on crop over space and time
V_i =	Volume of intended/scheduled water delivery in canal/structure over space and time
V_a =	Volume of actual water delivery in canal/structure over space and time
V_e =	Volume of water become effective through canal/structure over space and time

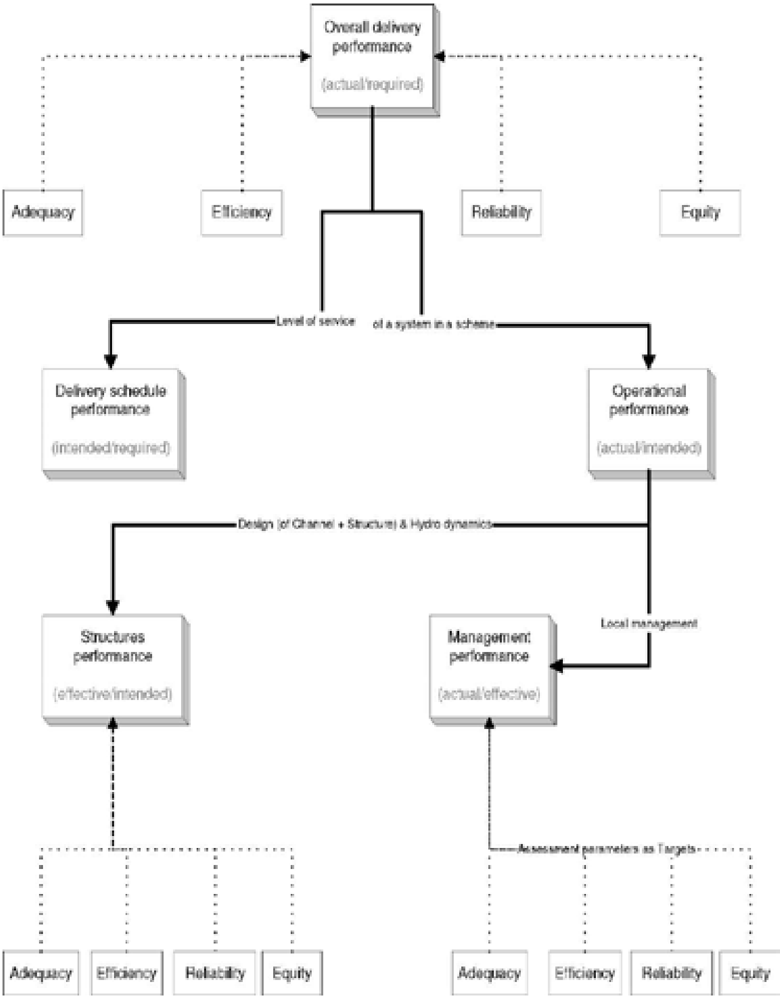


Figure 1: *Performance diagram of system components*

Additionally, parameters of delivery performance and operational performance that relate to water delivery system objectives in matrix form are presented in Table 2

***Table 2**: System objectives performance matrix*

System objective	Delivery performance	Operational performance	
		Structural	Management
Adequacy	$P_A = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_A\right)$	$P_{AS} = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_{AS}\right)$	$P_{AM} = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_{AM}\right)$
Efficiency	$P_F = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_F\right)$	$P_{FS} = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_{FS}\right)$	$P_{FM} = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_{FM}\right)$
Equity	$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_a}{Q_r}\right)$	$P_{ES} = \frac{1}{T}\sum_T CV_R\left(\frac{Q_e}{Q_i}\right)$	$P_{EM} = \frac{1}{T}\sum_T CV_R\left(\frac{Q_a}{Q_e}\right)$
Reliability	$P_R = \frac{1}{R}\sum_R CV_T\left(\frac{Q_a}{Q_r}\right)$	$P_{RS} = \frac{1}{R}\sum_R CV_T\left(\frac{Q_e}{Q_i}\right)$	$P_{RM} = \frac{1}{R}\sum_R CV_T\left(\frac{Q_a}{Q_e}\right)$

Table 2 indicates an average of discrete functions of ratios in comparison of sate variables over a hydraulic level or a region or sub-region, R, served by the delivery system for a time period T. Adequacy is defined in its simplest term as sufficiency and deficiency of supply in space and time. Efficiency is viewed as gainful and wasteful use of water supply in space and time. The Adequacy and Efficiency are reciprocal to each other with ideal value equal to one in fractional term. Further, upper limit of Efficiency is taken as one. Therefore, adequacy and efficiency should be observed and interpreted simultaneously. Equity and reliability are measured through Coefficient of variation (CV) in space and time respectively. Therefore, as the value of CV becomes close to zero, more the uniformity of supply in space and time is envisaged. Furthermore, performance standard prescribed by Molden and Gates (1990) is presented in Table 3.

***Table 3**: Performance standard*

Measure	Performance classes		
	Good	Fair	Poor
P_A	0.90-1.00	0.80-0.89	<0.80
P_F	0.85-1.00	0.70-0.84	<0.70
P_E	0.00-0.10	0.11-0.25	>0.25
P_D	0.00-0.10	0.11-0.20	>0.20

3. Methodology

The idea proposed by Molden and Gate (1990) for performance assessment of water delivery system is used as fundamental principal for this study. A case study has been made on operation performance of the Sitagunj Secondary Canal (S9) System, which is under operation since 1995 in Sunsari-Morang Irrigation Project (SMIP) Stage-II development phase in Nepal. The S9 canal is ninth in an alphanumeric series of secondary canals off-taking at chainage 24+800 of the Chatra Main Canal (CMC) in SMIP. The command area of S9 is 7,985 ha with discharging capacity of 5,600 lps at its head. There are seven cross regulators and thirteen head regulators along 14.34 km length of S9 canal. The command area lies in the eastern Terai (plain) of Nepal, between the latitudes of 26^0 25' 00" N to 26^0 38' 45" N and longitude of 87^0 10' 00" to 87^0 13' 15" E.

The S9 system, experiencing Irrigation Management Transfer (IMT) to WUA under Irrigation and Water Resources Management Project (IWRMP) since 2012, is originally designed to irrigate about 50% of command area, with 95% paddy cropped area, at a time during monsoon season crops. The cropped area in the system during winter wheat season is 50% followed by less than 25% spring paddy cropped area. As per Design Report of 1987 and 1995 the S9 canal is originally designed to experience full supply continuous flow, while canals off-taking from S9 are designed to operate in 1:2 mode forming Group-A and Group-B rotation in time share of 3.5 days each during monsoon season. Therefore, flow through each group of sub-secondary canal is designed to experience either full flow or no flow. Once the flow enters in its turn of respective off-take, its lower hydraulic layers operate through fixed overflow and orifice flow structures. Therefore, with preset scheduled performance (i.e., level of service) at 50% during monsoon and winter crops, an attempt to improving the performance of S9 canal operation is thus become cost-effective.

Three sub-secondary units of canal networks, namely SS9B (1800 ha) at 0+360, SS9F (980 ha) at 7+066 and SS9J (1980 ha) at 14+340, representing head, middle and tail reach of S9 canal, respectively, have been taken up under the performance study for the case of designed as well as actual flow conditions. The SS9B (1281 lps) and SS9F (698 lps) units operate in Group-A turn and SS9J (1411 lps) operates in Group-B turn during S9 flow. To assess water delivery performance, Design and Actual water delivery system in S9 system were reviewed. Hydraulic dimensions of the canal and structures were collected from as-built drawings and the vertical sliding gate openings height of Head Regulators (HRs) and Cross Regulators (CRs) including gauge records for Actual operation from IWRMP unit office of SMIP. Those data were input for mathematical simulation of S9 canal using DUFLOW 1-D hydrodynamic model.

As per Reference Manual DUFLOW (2002), it works with the complete de St. Venant equation for unsteady flow that includes transient flow phenomena as well as backwater and drawdown profiles. DUFLOW is based on the one-dimensional partial differential equations that describe non-stationary flow in open channels. DUFLOW gives regional water manager a quality tool for modelling irrigation systems, drainage systems and natural streams in low lands. DUFLOW offers the support, which is needed for effective planning, design and operation of new and existing water system. Therefore, the application can be typically related to optimizing agriculture production through the water quantity control.

To work with DUFLOW, schematization of S9 canal network under study is done as first step. The schematization consists of number of channels, defined as section that connects nodes, and number of structure is defined between the nodes. The node that defines canal network (i.e., sections and structures) starts from1onwards. Location of structures and sections of canal network is obtained by

specifying its coordinates (measured in clockwise direction from North) at respective nodes.

Hydraulic properties of S9, SS9B, SS9F and SS9J canals and structures were specified in the model. HR and CR gates along S9 were trigger opened to pass designed flow. Initial condition relating to normal flow, and boundary condition relating to depth-discharge and water level were further modelled in those canal networks. Continuous seepage loss along reaches was also modelled in DUFLOW.

Upon model calibration and validation, the resulting output hydrographs of DUFLOW were used in analyzing and evaluating performance against system objectives presented in Table 2 and Fig. 1 for both Designed and Actual flow cases. Sample of output hydrograph is presented in Fig. 2.

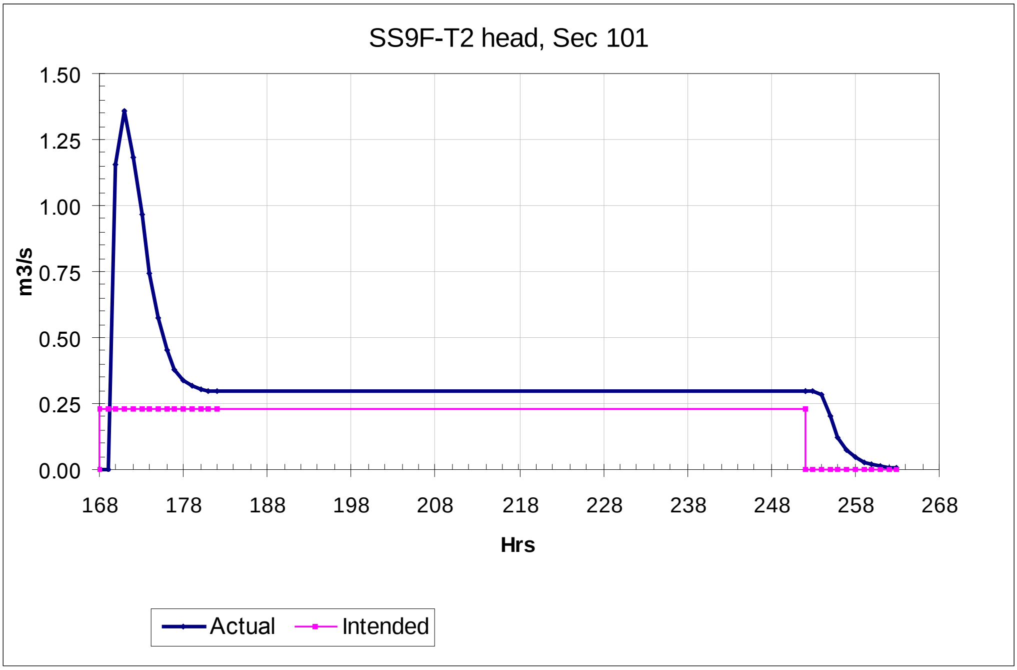


***Figure 2**: Model output discharge in the SS9F-T2 canal head*

Use of the performance measures were made along off-takes in the network of sub-secondary units comprising of Tertiary units and Watercourse unit. Performance simulation was made under full supply flow in Designed condition and Actual flow condition of winter irrigation season for the year 2014, while taking reference of water delivery schedule prepared for S9 system. The water delivery schedule prescribed that group of offtakes along S9 canal would receive 4 continuous days of irrigation at an interval of 22 days. It was assumed that canal shape and size are maintained as per design condition as the original scope rehabilitation program under IWRMP was accomplished in year 2013.

In Design condition, the period of water delivery simulation is taken as 3.5 days for each Group (Group A and Group B) of S9 canal off-takes as originally envisaged in canal water management criteria. The boundary of actual delivery period of water to respective off-take is taken from the beginning of actual supply (i.e., when offtake gate is open in its turn to receive delivery) to the end of intended time of supply. Further, the boundary of effective period of water delivery through structure at an off-take is

taken from the point of time when actually supplied water realises steady state to the point of end time of intended supply into respective off-take. In actual operation condition, daily discharge data set of winter season in 2014 were additionally input to DUFLOW already modelled for design case in order to study performance measures over parameters of adequacy, efficiency, reliability and equity for water delivery system. The period of water delivery under study was taken as 120 days (December, 2013 to May, 2014) for winter season. Intended schedule of water delivery were planned to meet 6 doses with 4 water delivery days per dose at an interval of 22 days for each off-taking canals Group (Group A and Group B) over 120 days by SMIP. Therefore, S9 canal runs for 6 doses of irrigation with 48 days of water delivery. The intended schedule was derived using CROPWAT model and spreadsheet.

Upon data arrangement for winter season canal operation, it has been observed that water delivery in S9 canal of the first dose run for 4 days (Dec 25 to 28); second dose run for 7 days (Dec 31 to Jan 6); third dose run for 7 days (Jan 12 to18); fourth dose run for 4 days (Jan 24 to27); fifth dose run for 13 days (Feb 6 to 18); and sixth dose run for 7 days (Mar 8 to 24). Therefore, S9 canal run for altogether 42 days against 48 planned days. Further, actual operation of S9 canal against intended schedule starts with gap of 1 day for 1st dose; 2 days for 2nd dose; 6 days for 3rd dose; 5 days for 4th dose; 9 days for 5th dose and 1 day for 6th dose. The reason for this variation is due to absence of canal operational plan at CMC led to run CMC on historical experience by WUA and SMIP officials.

The gate settings in the validated model were triggered over time series for all offtakes from S9 canal including S9 offtake from CMC as per actual operation condition duly recorded in gauge book by gate operators under supervision of operation and maintenance engineer of S9 system. The output in the form of discharge under study is tabulated over one-day time step for S9, SS9B, SS9F and SS9J canals for actual water supply.

4. Results and Evaluation

4.1 Response time to steady state

The response time to steady state of the canal network based on model output hydrograph in Design case is presented in Table 4. The response time to steady state at an offtake is found dependent on:

- Time lag of wave through the structures across the canal networks. Overflow structures acted as an information exchanger. So, more number of overflow structures upstream of offtake, less time to initiate change to new steady state, and response time to steady state is less.
- Response time to steady state is significant if there is cross regulation of water level downstream of offtake aiming to meet target water level for intended discharge through offtake. The action of cross regulator creates waves to travel upstream while it transfers information of the waves coming from upstream to downstream. Thus response time increases, as the case is for SS9F canal network in Table 4.
- Higher discharge requires high water depth to fill in given geometry of channel. Thus response time to steady state for intended discharge increases and vice versa.
- Distantly located offtake from supply source has longer time lag for the wave to reach. Thus, response time increases and vice versa.
- Combination of above

***Table 4**: Response time at off-takes*

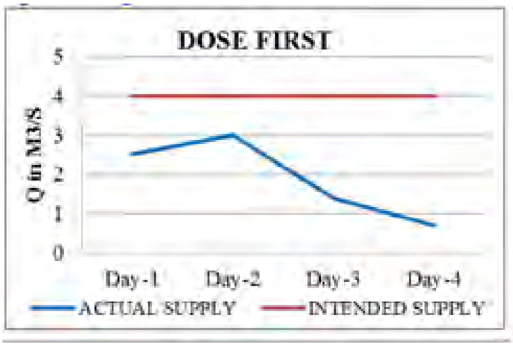
Canal	Location*	Hours	Canal	Location	Hours
SS9B	**360**	1.00	SS9F-R6	2200	4.00
SS9B-T1	20	1.50	SS9F-R8	3534	4.50
SS9B-T2	1126	3.50	SS9F-T1	3890	12.50
SS9B-T3	1900	3.50	SS9F-T2	3890	12.50
SS9B-T4	1900	4.00	SS9J	**14300**	10.00
SS9F	**7066**	5.50	SS9J-T1	459	11.00
SS9F-R1	720	3.00	SS9J-R1	480	1.50
SS9F-R2	868	3.00	SS9J-R3	1109	1.50
SS9F-L3	1125	3.50	SS9J-L2	1124	7.00
SS9F-R4	1900	0.00	SS9J-T2	1666	10.00
			SS9J-T3	1666	9.50

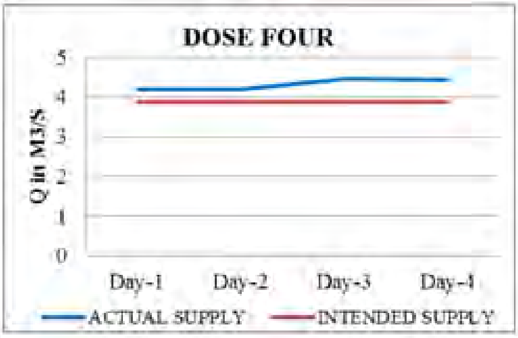
* Location in meter from respective parent canal

It is observed that SS9B canal network takes four-hours response time, whereas SS9F canal requires 12.5 hours and SS9J canal needs 11 hours to achieve steady state. Therefore, actual supply from the parent canal S9 should be ahead of the greatest response time to fully meet the balance of actual supply with intended supply and effective (steady state) supply through the offtakes.

4.2 Actual operation condition in S9 canal

The daily discharge hydrograph at head (chainage: 0+000), middle (at chainage: 7+000) and tail (chainage: 13+700) sections of S9 canal for different doses of water delivery is presented in Fig. 3, Fig. 4 and Fig. 5.





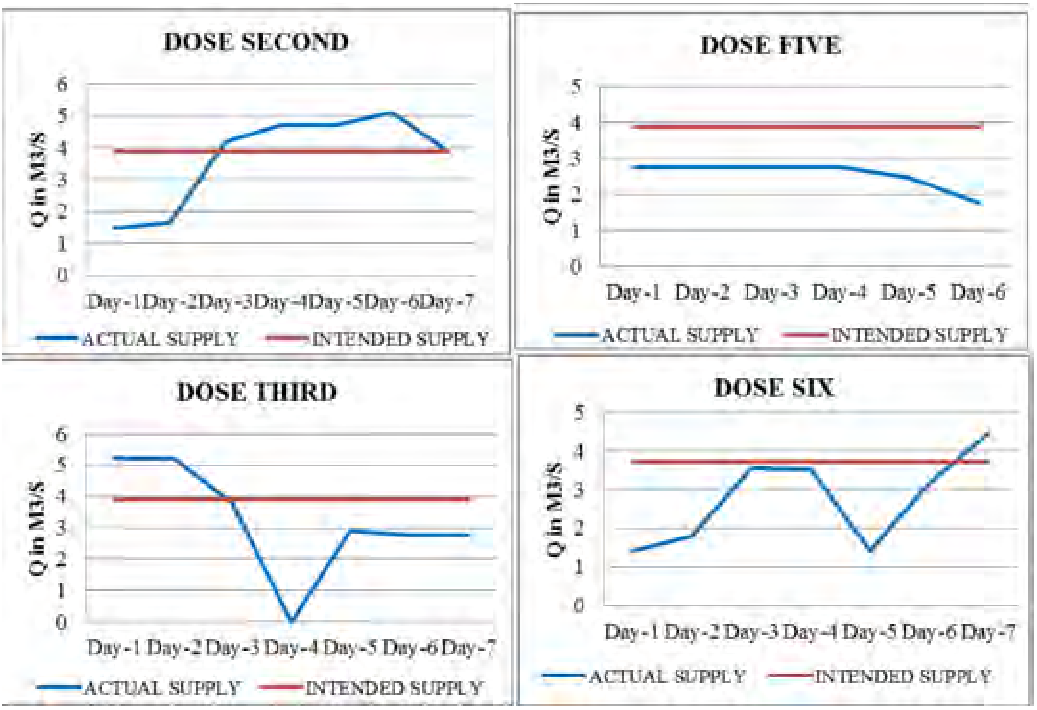
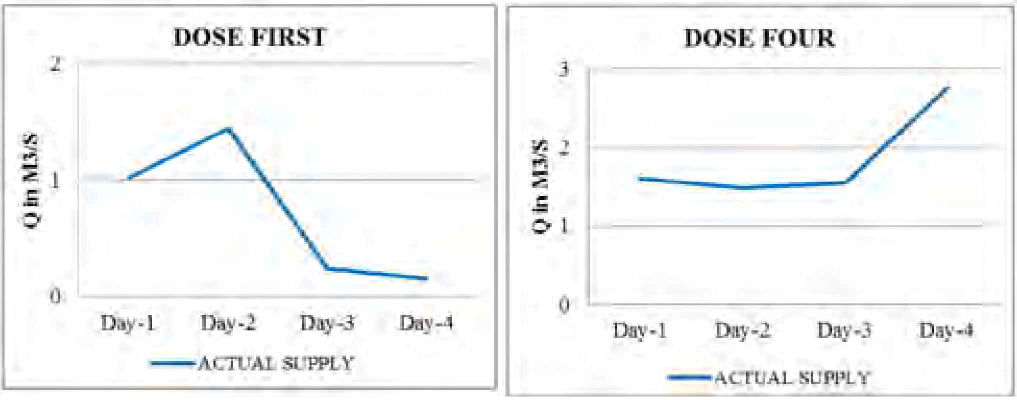


Figure 3: *Daily discharge hydrograph at head section of S9 canal (chainage: 0 + 000 km)*



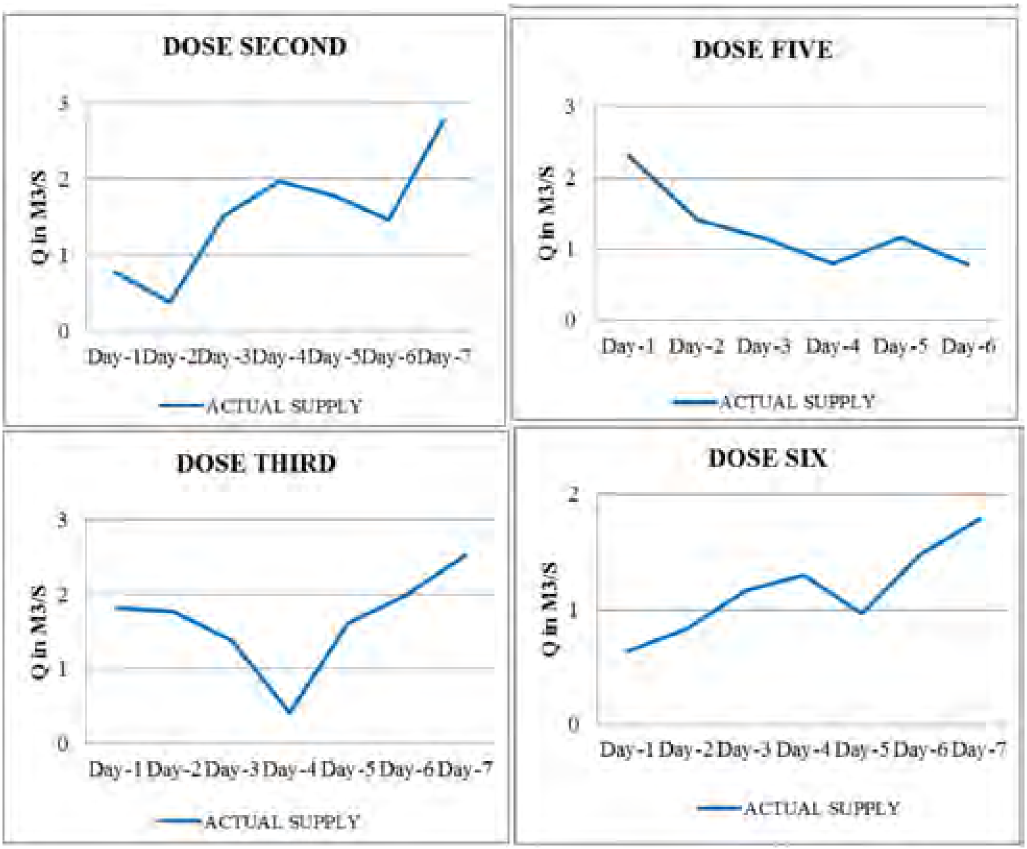


Figure 4: *Daily discharge hydrograph at mid-section of S9 canal (chainage: 7 + 000 km)*

It is observed that winter season actual supply in S9 canal over majority of doses is less than intended scheduled supply coupled with high fluctuation of discharges at head, middle and tail reaches. It can also be observed that flow in S9 canal is grossly unsteady over daily basis that obviates calculation of effective supply discharge through off-taking structures under study. Therefore, contribution of Structure Performance and Management Performance cannot be separated in Actual operation performance of the system under study. However, contribution of structure performance in Designed case would give insight on Management performance in Actual operation case. Further, the model output of different section of S9 canal shows S9 had never run in steady state even a one day during winter season under study, except for small part of head reach which limit the analysis of effect of management and structure performance separately in operational performance.

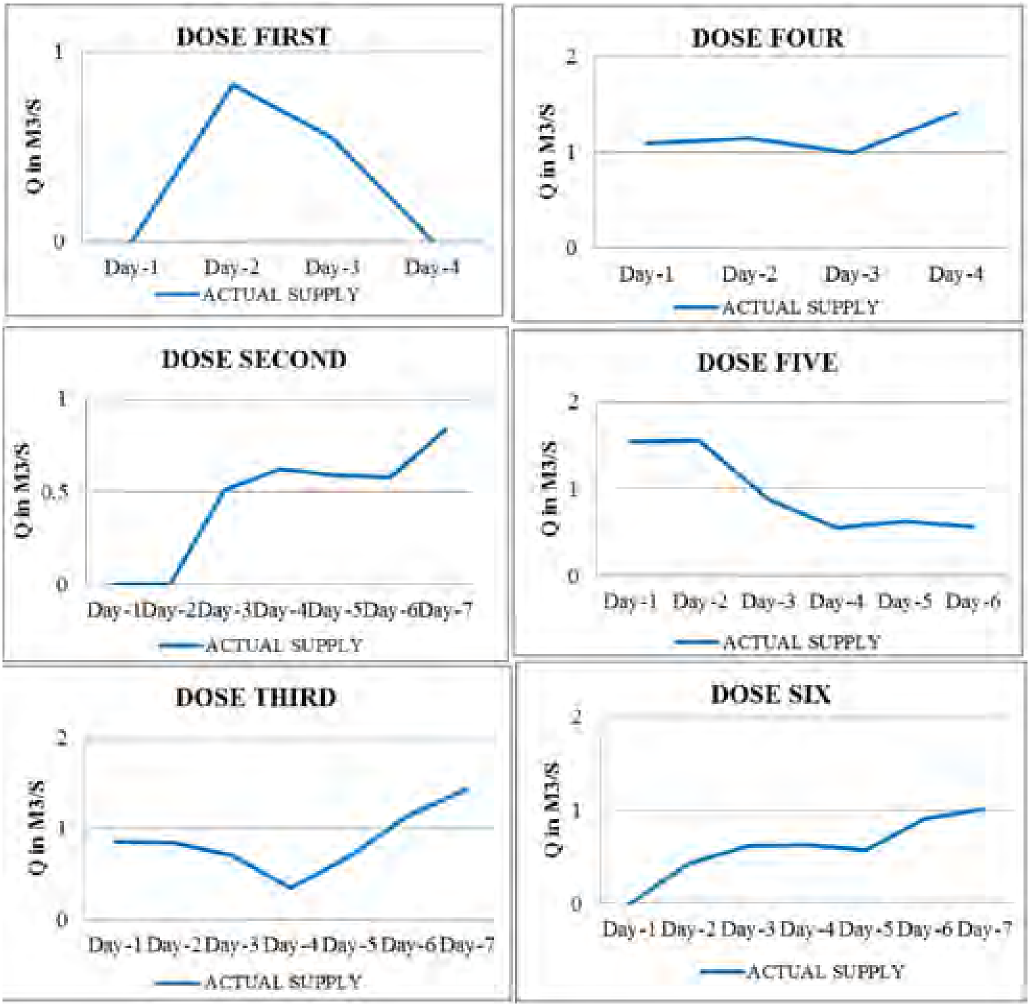


Figure 5: *Daily discharge hydrograph at tail-section of S9 canal (chainage: 13 + 700 km)*

4.3 Operation performance of S9 system in design and actual operation case

The comparison of operation performance using system objectives (Adequacy, Efficiency, Reliability and Equity) in Design and Actual operation case are presented in Fig. 6. It shows that S9 system perform better in Design case than Actual operational case. The operation performance measure of S9 system in meeting objectives in terms of adequacy, efficiency, reliability and equity for Design case are 0.99, 0. 96, 0.01 and 0 .01, whereas for operational case are 0.81, 0.84, 0.39 and 0.68, respectively. The comparative value of adequacy and efficiency of operation performance is less due to unsteady flow as in Figs. 3-5 coupled with less than intended volume of water supply over study period. Further, the coefficient of spatial and temporal variation is poor in Actual operation due to unsteady flow, frequency of supply is concentrated in the month of January 2014 and structural limitations as identified in the Design case.

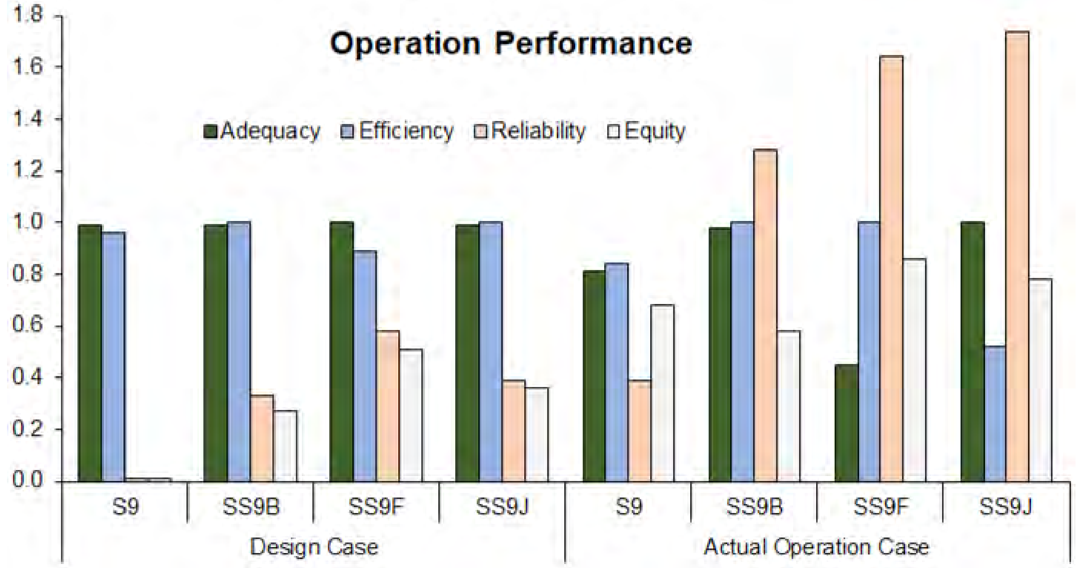


***Figure 6**: Comparison between Design and Actual condition*

In actual operation case, from Fig. 6, the smaller supply than intended reduces the water depth in off-taking canals. Further, no flow or low flow at offtakes with limitation of elevated crest level like SS9F-R4 and SS9F-R1 as derived from Table 5 instigates violation of operation schedule by water users. That is why operational adequacy of SS9F is 45% and S9 is 84%. For higher performance, canal should run with intended supply. The response time of flow from S9 head to its tail is around one day in almost dry canal, which is clearly shown in first through sixth dose of irrigation in Figs 3-5. This causes unreliable and non-equitable supply, the reliability and equity indicator for S9 are 39% and 66% respectively which are significantly high and the situation for SS9B, SS9F and SS9J are also very poor. Therefore, intended schedule should be followed as 4 days' continuous irrigation at 22-day interval. The coefficient of time variation for SS9B, SS9F and SS9J observed as 128%, 164% and 174%, respectively. This numerical value of CV clearly shows that S9 operational reliability for winter season is low. This also represents the actual operation condition of irrigation system in Nepal. The coefficient of spatial inequity in operational performance for respectively S9, SS9B, SS9F and SS9J are 68%, 58%, 86% and 78%. Thus, inequitable distribution in S9 canal system exists. Therefore, during winter season in year 2014 the S9 canal run had inadequate, unreliable and inequitable operational performance characterised by unsteady flow over winter season crop.

4.4 Structural performance of SS9B, SS9F and SS9J canal system in design case

It is observed in Table 5 that adequacy of structural performance in SS9B, SS9F and SS9J canal are respectively 0.95, 0.88 and 0.91. The coefficient of time variability (i.e., reliability) of flow due to response time are 0.27, 0.73 and 0.37 respectively in SS9B, SS9F and SS9J canal system. Therefore, quicker the response time of the system network to steady state lesser the flow variability coupled with higher adequacy of flow through offtakes in canal network.

***Table 5**: Structural performance in Design case*

Performance	Canal	Adequacy	Efficiency	Reliability	Equity
Structure	SS9B	0.95	1	0.27	0.27
	SS9B-T1	0.88	1	0	
	SS9B-T2	0.56	1	0	
	SS9B-T3	0.85	1	0	
	SS9B-T4	1	0.82	0	
Structure	SS9F	0.88	1	0.73	0.72
	SS9F-R1	0.27	1	0.05	
	SS9F-R2	0.4	1	0.03	
	SS9F-L3	0.45	1	0.02	
	SS9F-R4	**0**	**1**	0	
	SS9F-R6	0.43	1	0.14	
	SS9F-R8	0.52	1	0.12	
	SS9F-T1	1	0.9	0	
	SS9F-T2	1	0.85	0	
Structure	SS9J	0.91	1	0.37	0.36
	SS9J-T1	0.88	1	0	
	SS9J-R1	0.35	1	0.02	
	SS9J-R3	0.5	1	0.02	
	SS9J-L2	0.62	1	0.01	
	SS9J-T2	0.93	1	0	
	SS9J-T3	0.95	1	0	

Further, Table 5 also suggests that variable flow adequacy through offtake structures along SS9B, SS9F and SS9J leading to higher coefficient of spatial flow variation as 0.27, 0.72 and 0.36, respectively. The said table also suggests that most of the watercourse canal equipped with fixed orifice flow has adequacy less than 0.5. This instigates limitation of structure performance due to higher crest elevation in place than for intended supply to become effective supply. The designed discharge in such watercourse canal range from 30 lps to 50 lps, while tertiary canal carries discharge of more than two watercourse canals in S9 canal system. The efficiency of structure performance in tertiary canals SS9B-T4, SS9F-T1 and SS9F-T2 is as low as 0.82, 0.9 and 0.85 respectively. This shows that off-taking structures experiencing more effective volume of supply than intended volume of supply, partly due to supply of accumulated flow that would have been effective through upstream offtakes and due to submerged flow through proportional divider structures in place at the head of each tertiary canal off-taking from sub-secondary canal of S9 system in SMIP.

5. Conclusion and Recommendations

Design Case

- Evaluating structure performance in Design case while assuming highest management performance gives insight on behaviour of flow control structures in real world with an opportunity to review design before implementation.
- Use of such 1-D hydrodynamic model, without sacrifice, should be made to improve structure performance of an irrigation system under Design condition in order to offset higher cost of managing and maintaining irrigation system over its life time.
- The organisation prescribing schedule of water delivery preset by operational rule of irrigation system should consider in advance the greatest response time of 12 hours to steady state in scheduled operation of vertical sliding gate of S9 head in order to make performance of structure and management at its highest, as the coefficient of time variation in all sub-secondary canals is high leading to poor reliability of flow.
- Design of all watercourse structures along Sub-secondary canal merits revisit, with significantly high crest design at SS9F-R4 where water level in parent canal is below 0.69 m from the crest of offtake. Hence, sufficient care should be given to the design of physical facilities such that flow through control structures is in line with intended supply resulting in high structure performance.
- At tail location of SS9B canal, performance of proportional divider behaves hydraulically different with free flow in SS9B-T4 and submerged flow in SS9B-T3 for a constant head upstream. Hence, lowering bed level of SS9B-T3 downstream of proportional divider without sacrificing command area ensuring modular flow over the offtake can modify this discrepancy, as there is 0.6 m bed drop at 100 m downstream of SS9B-T3 canal with no offtake structure along this length.
- Unless structures are designed to the best of its performance, management contribution in Actual operation condition is difficult to separate from.

Actual Operation Case

- The S9 canal run had experienced inadequate, unreliable and inequitable operational performance characterised by unsteady flow and violation of delivery schedule over winter season in year 2014. In consequence, operational adequacy of S9 is 84%. Therefore, S9 canal system should run invariably with intended supply as per water delivery schedule to attain higher operation performance.
- S9 operation performance in terms of coefficient of time variation (reliability) and coefficient of space variation (equity) are 39% and 66% respectively, which are considered rather poor. This numerical value clearly shows that S9 operational reliability for winter season is low. Therefore, operating personnel should strictly follow water delivery schedule prepared for crop-based irrigation.
- Actual supply in S9 was lower than intended supply with daily variation of CMC flow occurred in absence of CMC operation plan in SMIP. Therefore, separate effect of management and structure performance in operational performance has become difficult to distinguish.
- No flow or low flow at offtakes with limitation of elevated crest level for SS9F-R4 and SS9F-R1 instigates inevitable violation of operation schedule by water users.
- Use of such 1-D hydrodynamic model supports water manager in understanding and optimising

scheduled base operation performance of an irrigation system through sustainable use of the facility.

- Eventually, using the performance measures with 1-D hydrodynamic model, for example, DUFLOW and cropwater requirements model, say, CROPWAT in isolation takes quality time and energy to a water manager to come to a quick decision as to the adjustment of water allocation in canals according to the availability of water at source and the crop need at farmers' field. Hence, a model that couples water delivery system performance indicators, canal hydrodynamics and cropwater requirements all together in one is required to be adopted to support short term and log term decision-making procedures in water management of sustainable irrigation system.

Acknowledgements: This is a part of an outcome of Irrigation Management Transfer (IMT) consolidation process implemented by World Bank (WB) funded Irrigation and Water Resources Management Project (IWRMP) under Department of Irrigation, Nepal. Authors would like to express gratitude towards IWRMP team, SMIP team and WUA of S9 canal system for necessary support and cooperation.

References

Abernethy, C. L. (1986). Performance measurement in canal water management. ODI/IIMI Irrigation management network paper 86/2d. London: Overseas Development Institute/ International Irrigation Management Institute (IIMI).

Abernethy, C. L., (1989). Indicators of the performance of irrigation water distribution systems. Symposium on Performance Evaluation of Irrigation Systems. 23 November 1989. Colombo: IIMI.

Biswas, A.K., Tortajada, C. (2009). Changing global water management landscape, in AK. Design Report, Nov 1987, Sunsari Morang Irrigation Project, Stage II.

Design Report, Oct 1995, Sunsari Morang Irrigation Project, Stage III.

Design Report, Nov 1987, Sunsari Morang Irrigation Project, Stage II.

Izquierdo, A.E., Grau, H.R., Aide, T.M. (2011). Implications of Rural–Urban Migration for Conservation of the Atlantic Forest and Urban Growth in Misiones, Argentina (1970–2030). AMBIO: A Journal of the Human Environment, 13 (4), 1-12.

Mishra, S. K. (2004). Operation Performance of a Modernised Irrigation Scheme. Unpublished MSc Thesis. Delft, The Netherlands: UNESCO-IHE Institute for Water Education.

Molden, D.J., Timothy, K. G. (1990). Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering, 116(6), 804-823.

Reference Manual Duflow, Stowa/MX. Systems, version 3.5, April 2002.

Schuurmans, W. (1991). A Model to Study the Performance of Controlled Irrigation Canals. The Centre for Operational Water Management, Delft University of Technology, the Netherlands.

Efficient water usage and food security: Nepalese-Indian experiences

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Abstract

We are living at a time, when population is increasing and availability of land for agriculture is decreasing. Therefore, we certainly need irrigation in support of ever-green revolution, the theme of this international conference. One of Nepal's strengths in irrigation sector is her numerous self-sustaining traditional farmer managed irrigation systems (FMISs). However, FMISs is facing several challenges as competing water demand, climatic variability and change, and socioeconomic transformation. The intensity and frequency of the changes have weakened their institutional adaptive capacity, which includes human, financial, natural, social, and physical factors, governance, and learning. Long-term adaptation requires harnessing the synergies and trade-offs between various capacities towards development goals and specific adaptive capacity that strengthens climate-risk management. The good points of Water User Associations (WUA) need be roped in to act as an interface between the farmer and the government system for water supply, usage, distribution charges as well as other legal and administrative issues based upon participatory irrigation management (PIM). The issues for suggesting appropriate technology and crop could also be available on optional basis.

Keywords: *efficient water use; food security; India; Nepal*

1. Introduction – Nepalese Context

Nepal has approximately 2.7 Million ha (Mha) area under agriculture; out of which only 1.3 Mha area is irrigated. Agriculture is very crucial for Nepal as about 33% of the Gross Domestic Product (GDP) comes from agriculture. A large population residing in villages depends upon agriculture. Livelihood is affected due to monsoon and topography. A recent study by climate and development knowledge network highlighted that about 0.8% of agriculture GDP is being lost annually due to climate change. There is a need to improve both productivity and climate resilience in Nepal.

The irrigation system is severally affected by climatic and non-climatic factors having the following impacts.

- Reduce run-off in rivers due to changing rainfall patterns in the catchment
- Increased flood flows due to more intense rainfall in some of the months
- Enhanced water demand because of high temperature & more erratic rainfall
- Changes and crop suitability

The impact of non-climatic factors include change in land usage, resource mining in the river in months having no water, and migration from rural areas with adverse consequences for irrigated agricultural practices. It has a larger impact on groundwater irrigation also.

Out of the above said 1.3 Mha irrigated area, majority of the area is irrigated during monsoon season. Only about 18% of total cultivated land receives year-round cultivation. Irrigation plays an important role in crop production, crop rotation as well as multiple cropping. Paddy, maize and wheat are the main cereal crops cultivated in Nepal but production is variable because of diverse local climate and agro-ecological condition. These are growing under limited irrigation conditions. The small tributaries developed by farmers over a century are drying up because of non-availability of water resulting in further lowering of crop productivity.

Threats posed by climate include drought resulting from decreasing dry season flows and floods due to anticipated high intensity erratic rains. Further increase in temperature would enhance cropwater requirement and will affect crop choice and productivity. It is understood that a week-long dry spell in the month of September becomes critical as flowering and grain formation stage of paddy falls during this month.

The population in different countries in Asia is continuously increasing. The population of Nepal is also likely to be doubled by the year 2050 which would have corresponding impact on food demand. There is a need to revitalize irrigation sector in Nepal by introducing innovative practices. Only the limited part of total land area of Nepal is suitable for agriculture which holds great potentiality for achieving higher productivity, meeting development challenges and promoting role growth and food security besides increasing agriculture productivity, promoting green revolution poverty elevation.

Nepal has different ecological endeavors giving rise to a range of production of crops. However, there is a need to improve infrastructure facilities, transportation, linkages to international market, technical knowhow to get a real value. Variety of fruits are being grown in Nepal because of having three distinct seasons of hot and dry, wet summer, dry and cold. Nepal is rich in biodiversity; wild olive plants are also grown in abundance which can bring better value to the farmer from international trade.

During the last decades, area of vegetable crops has increased from 1.9 lakh ha to 2.7 lakh ha and production increased from 22 to 36 lakh metric ton. However, productivity is much lower than surrounding countries in India and China. In case of fruit, area under fruit during the last decade increased from 0.9 to 2.6 lakh ha and productivity increased from 45.4 to 17.6 lakh metric ton. There has also been a considerable increase in area and production of various cash crops.

Nepal is importing fruits of value NRs. 11,000 million whereas export is merely NRs. 3,000 million. Similarly, vegetable import and export are NRs. 1,250 crores and 20 crores, respectively. This shows the importance of domestic production to reduce burden of imports and foreign exchange. This could be achieved through the use of innovative technologies like micro irrigation with efficient water usage and increased productivity.

2. Micro Irrigation Technologies

2.1 Drip irrigation

Drip irrigation involves technology for irrigating plants at the root zone through emitters fitted on a network of pipes (mains, sub-mains and laterals). The emitting devices could be drippers, micro sprinklers, mini sprinklers, micro jets, misters, fan jets, micro sprayers, foggers and emitting pipes, which are designed to discharge water at prescribed rates. The use of different emitters will depend upon specific requirements, which may vary from crop to crop. Water requirement, age of plant spacing, soil type, water quality and availability are some of the factors which would decide the choice of the emitting system. Sometimes micro tubes are also used as an emitter, through it is inefficient. Fig. 1 provides a glimpse of drip irrigation system.

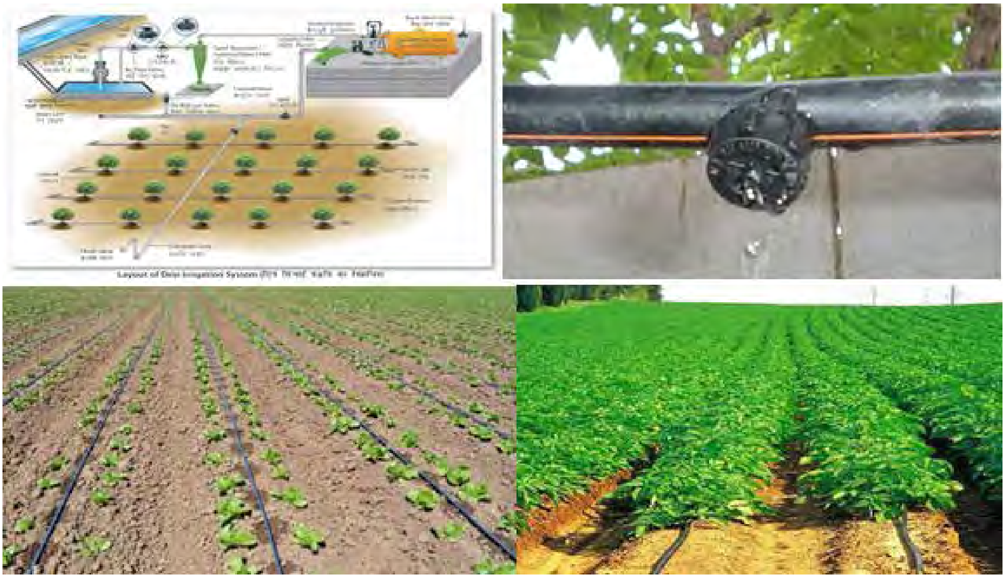

Figure 1:*A glimpse of drip irrigation system*

2.2 Sprinkler irrigation

Under sprinkler irrigation system, water is sprinkled under pressure into the air and plant foliage through a set of nozzles attached to network of aluminum or High Density Poly Ethylene (HDPE) pipes in the form of rainfall. These systems are suitable for irrigating crops where the plant density is very high and adoption of drip irrigation systems may not be economical. Sprinkler irrigation is suitable for horticultural crops like vegetables and seed spices. Conventionally, sprinkler irrigation has been widely in use for irrigating cereals, pulses oil seeds and other field crops.

The sprinkler system sets, unlike drip system, are movable. Hence one sprinkler set could cover more than one ha by shifting from one place to another. There are rainguns also which could cover larger areas. Pivot sprinklers could cover further very large areas. Fig. 2 provides a glimpse of sprinkler irrigation system.

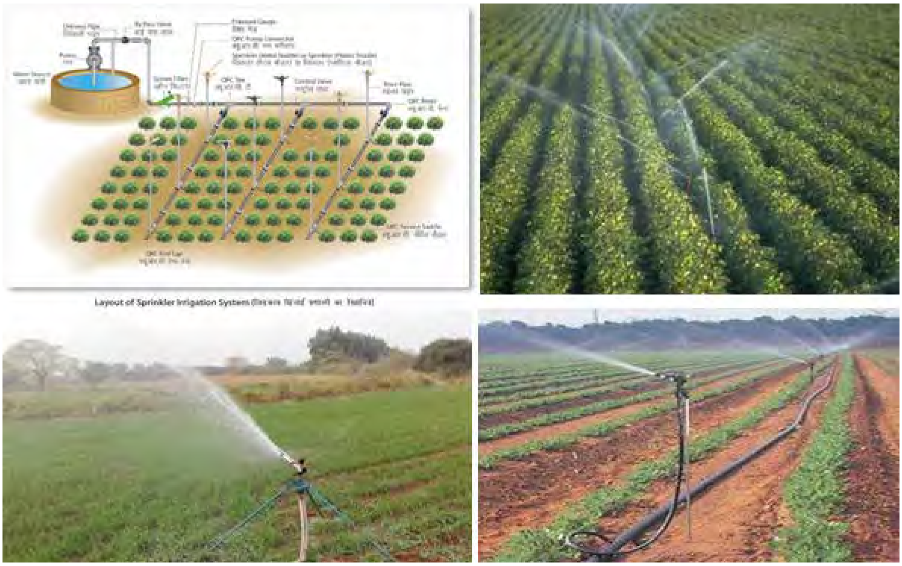

***Figure 2**:A glimpse of sprinkler irrigation system*

2.2.1 Micro sprinkler (up to 3 m radius of throw)

Micro sprinkler (Fig. 3) is mostly used for irrigating leafy vegetables, nurseries, hardening of seedlings and a few vegetables. Apart from providing irrigation, the micro sprinkler also helps in changing the micro climatic conditions near the plant. Micro sprinklers are low radius sprinklers which have a radius of throw up to 3 m. Discharge of micro sprinkler varies from 20 liters-per-hour (lph) to 150 lph. The selection of micro sprinkler depends on the type of crop, soil, etc.

***Figure 3**: Micro sprinkler installed in a field*

2.2.2 Mini sprinkler (more than 3 m up-to m radius of throw)

Mini sprinklers (Fig. 4) are mid-range sprinklers having radius between 3 m to 10 m. The discharge of these sprinklers vary from 150 lph to 600 lph. They are commonly used for close growing crops like groundnut, potato, onion, ginger, short statured fodder crops, etc. Mini sprinklers are also suitable for frost protection.

Micro sprinkler and mini sprinklers are distinct from drip system as the emitting systems are located above the ground with the help of risers duly supported with stakes. The discharge is high and all the standing crops within its radius can be irrigated.

***Figure 4**: Mini sprinkler installed in a field*

2.3 Family drip system (FDS)

Recognizing drip irrigation's ability to help smallholders overcome traditional irrigation challenges, Family Drip System (FDS) is a unique, gravity-based drip irrigation system requiring no electricity or energy source, FDS has revolutionized small-scale family farming.

A comprehensive solution accompanied with capacity-building tools and an optional "training-the-trainer" package, FDS is an affordable, cost-effective system that addresses the specific conditions and needs of small-scale farmers. Here, a small plastic tank is used from where the water is applied on gravity flow basis (Fig. 5). It features the following:

- A comprehensive gravity-based drip irrigation system based on Netafim's low volume drip-irrigation technology
- Maximizes productivity using current and existing resources
- No additional investment in infrastructure

***Figure 5:** Family drip irrigation system (FDS)*

3. Suitability of Micro Irrigation Systems for Nepal

Agriculture in Nepal has been hampered by the lack of irrigated land, by the small size of farms and by inefficient farming methods resulting in low productivity. Given a large altitudinal variation from south to north, landform and soil in Nepal differs from place to place. Considering soil type, landforms, micro-irrigation techniques such as drip irrigation is highly suitable for many areas in Nepal. The advantages of drip irrigation systems are:

- Irrigates the plant and not the soil.
- Delivers water and nutrition by a pipe (small diameter) with "smart holes"- Drippers.
- The water flow rate is low and uniform.
- Every plant gets the same amount of water.
- Saves water, energy, fertilizers & labor.

Most of the land is undulating in Nepal and smaller land holdings per farmer; hence pressure compensated drippers and small size dripper lines (12mm), HDPE pipeline are best for this topography. On other hand, considering investment capacity of the small land holder's, low cost drip irrigation systems like family drip sets are suitable.

The irrigation potential of the country is estimated at 2,177,800 ha. In 2002, the area equipped for irrigation was an estimated 1,168,300 ha, of which 79.5% was irrigated by surface water, 19.2% by groundwater and 1.3% by conjunctive use of surface water and groundwater. In 1992, the area equipped for irrigation accounted for 882,400ha.

Many irrigation systems use surface irrigation through basin and furrow. Very limited number of farmers are using drip/sprinkler irrigation systems. Irrigated areas are often classified as public irrigation systems and farmer-managed irrigation systems (FMIS). In Nepal, informal associations have existed for a long time in almost all FMIS. Water user association (WUAs) received legal status after the promulgation of the 1992 Water Resources Act. The WUA has now become a prerequisite for the transfer of public schemes to users. In 2008, 70% of the country's irrigated area fell under FMIS. In the remaining areas, some systems are being transferred completely to the WUAs for management, whereas some are being jointly managed by the government and WUAs. Farmer – and community-managed systems are found to be more efficiently managed than the government-managed systems. However, the government plays a crucial role in research and development, extension services and other regulatory fiscal and non-fiscal mechanisms. At the same time, essential and emergency assistance form the government to the communities in the rehabilitation and repair of irrigation systems has to be continued to sustain the farmer-managed systems.

The canals are usually unlined and prone to damage which results into a large expenditure of labor every year to restore the system. Modernization of irrigation systems and improved water management practices could lead to a reduction in irrigation water withdrawal. A higher crop intensity in irrigated areas could lead to increased food supply.

Micro irrigation is a technology which saves water by 40-50%. It includes drip irrigation, micro sprinkler, mini sprinkler, overhead sprinkler etc. The water is delivered in desired volume as per the cropwater requirement on daily basis. This helps maintaining adequate ratio of air and water in the soil resulting efficient use of water and achieving higher productivity.

In Nepal, non-governmental organizations (NGOs) like International Development Enterprises (iDE) are

providing low cost drip irrigation systems in water scarces areas of Nepal whereby women vegetable growers have been provided with micro irrigation system. The organization is suppling multiple use water systems which tap and store water and distribute to the small farms. These systems are gravity-fed located at elevation below the water source. The farmers are able to increase crop productivity, enhance water use efficiency, control weed growth and economize labor too.

4. Indian Experiences of Implementation of Micro Irrigation Programmes

India's population stands at 1.27 billion and is estimated to rise at a steady pace to reach 1.6 billion by the year 2050. Even though food grain production has increased significantly over the years, there is a need for the production to increase even further in order to meet the ever-growing demand created with this population increase. Given the fact that land and water are limited resources, this would require an improvement in the productivity of crops. Additionally, agriculture is the one sector where water scarcity has greatest relevance. Agriculture accounts for approximately 70% of the global freshwater withdrawals. According to the Food and Agriculture Organization (FAO), irrigation and livestock in 2010 accounted for 91% of water withdrawals in India, which is well above the global average. India has 18% of the world's population with only 4% of the usable water resources and is expected to face the brunt of looming water scarcity crisis. With the need to increase productivity while saving water, micro-irrigation will play a key role for the future of Indian agriculture. 54% of India faces high and extremely high-water stress. As per United Nations, there is likely to be around 3.4 billion people living in water scarce countries by the year 2025, including India. The average land holding in India is merely 1.18 ha. For food security of 1.6 billion people in 2050, India would require efforts for increased productivity. The only solution is adoption of micro-irrigation, which would not only economize water usage but also help in achieving higher productivity.

Considering this need, India is expanding area under micro-irrigation over the years. Almost 10 Mha area in India has been covered under micro-irrigation, which is only 10% of the total potential area. However, in terms of gross area covered under micro-irrigation, India is the leading country, even leaving behind Australia, USA and Israel. The benefits of micro-irrigation as per Indian experiences are:

- Increase in water efficiency- 50 to 90%.
- Energy consumption savings- 30.5%.
- Fertilizer consumption savings- 28.5%.
- Productivity increase, fruit/crops- 42.4%, vegetable-52.7%.
- Irrigation cost savings- 31.9%.
- New crop production- 30.4% farmers
- Increase in farmers' income- 42%.

5. Lessons Learnt from Indian Experiences for Nepal

Based upon the learning from India in terms of implementation of micro-irrigation programmes, the following strategies could be adopted in Nepal:

- Creating technology awareness through public programs such as workshops, seminars, exhibitions at different level involving various stakeholders.
- Technology demonstration at block level with the help of industry whereby farmers could be invited periodically.

- Financial assistance to beneficiaries for technology adoption to lower the financial burden, which would provide additional production to the farmers and food security to the country as well as reduction in imports.
- Operational research to develop package of practices for various terrain, crops, agro-climatic conditions, etc.
- Standardization of irrigation components.
- User-friendly operational guidelines for planning and implementation of micro-irrigation programmes.
- Special Purpose Vehicle (SPV) for implementation of micro-irrigation programmes in the country.
- Possibility of use of mulch film along with drip irrigation to conserve more water, reduction of weed growth.
- Use of mulch film for dry land farming.

Intermediate reservoir in irrigation laterals for improving system operation making it efficient and women-friendly

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Abstract

Irrigation system in general is found to be low performing in actual operation for various reasons. In Nepal , development of canal network is not complete, leaving water courses to be constructed by farmers in most irrigation systems. However, this is not done and farmers adopt very low efficient field to field irrigation owing to lack of field channels to convey water to prevalent small plot size. Furthermore, water delivered in the night time is much wasted as is not attended mainly by small farmers and women irrigators. Intermediate reservoir in the lateral could serve to store night time irrigation water for allowing irrigation the following day with double discharge and at farmer's convenience. This has become essential now when most rural males are out of village/abroad and women have to take care of irrigation. Farmers are interested to provide land for making reservoirs if financial support is provided for construction and they are allowed to raise aquaculture in the reservoir. It will also allow using modern efficient irrigation methods at farmer's convenience.

Keywords: *intermediate reservoir; irrigation laterals; women-friendly; system performance*

1. General

A growing population and changing food consumption patterns are estimated to require a doubling of food production in the developing countries by 2050. Eighty percent of this increase (Colback and Nagayets, n.d.) would need to come from higher crop yields and greater crop intensity given limited scope for agricultural land expansion. Expanding the use of efficient irrigation and agricultural water management technologies is a key part of the solution to increasing yields in a sustainable manner.

Ensuring availability of water in time creates an enabling environment for farming as it safeguards against possible drought stress. So much has been done to expand irrigation facility. Improvement in irrigation practice and technology has been strived. And it has been observed that efficient irrigation enables farmers to (i) increase the crop yield using less water; (ii) more productively farm larger areas of land by using the same amount of water; or (iii) use the same amount of water to grow higher value crops.

Furthermore, efficient irrigation reduces the amount of fertilizer needed per plant, as nutrients can be dissolved in the irrigation water for uniform application, reduced waste and lower labor input. Therefore, focus by farmers as well as the government has been to expand irrigated area in Nepal.

2. Irrigation Development

In Nepal, farmers have dug many large and small irrigation canals from nearby streams within their reach for providing supplemental irrigation mainly to paddy fields. Such canal system is generally earthen laid at a uniform grade by constructing a side intake canal with temporary diversion to divert rainy season flood. Depending upon the size of the command area, branch, distributaries, tertiary and water courses are also dug to let water reach to each farmer's plot. Farmers' plots are around 3-5 ha. Water is supplied continuously to all canal networks proportionally day and night during the paddy growing rainy season. To distribute water among the outlets, proportionate weirs called "*sancho*" (meaning "key" in Nepalese parlance) are made through which water is regulated to each outlet. In high flow, more water enters while in low flow it is reduced accordingly. This is how the canal system has evolved in both the hills and plains.

The Government of Nepal (GoN) and farmers are developing and expanding irrigation systems continuously. The Department of Irrigation (DoI), under the GoN, constructs more robust systems that include a permanent intake, appurtenant structures, lined as well as earthen canals and river protection works as well. In Nepal, total estimated cultivable land is 3.0 Million ha (Mha) (ADS, 2013), and in that irrigation potential has been created only for less than half, i.e. for about 1.4 Mha (DOI Handbook, 2017/18); the proporation being around two-third from surface irrigation and one-third from groundwater exploitation.

The water distribution pattern is also traditional continuous delivery, from intake distributing water proportionally among branches, distributaries and tertiaries during full flow period and is rotated when the flow reduces considerably following almost as in the Farmer Managed Irrigation System (FMIS).

The DoI is mandated to provide support in the development of main canal, branches and tertiaries leaving construction of water course/field channel (network to convey water below 30 ha command are) to farmers as their part for contribution (Irrigation Policy 2063). A tertiary is built for irrigating a command area of about 30 ha. A couple of outlets are provided along the tertiary to command about 5-6 ha. In each outlet command, there may be a number of plots. In practice, only few farmers construct water courses to individual plots; and hence in most areas, water is applied by flowing from one plot to another by gravity. Easter (1975) has presented the situation of irrigation in this region based upon his observation in eastern India which is comparable to the case of Nepal. He explains canal irrigation is dominant, with water flooding from field to field where farmers have little control over the flow of water. Once the water is in the main channel, the outlets are usually never closed, and so water flows continuously through the fields, and the water distribution is quite uneven. The continuous flow through ungraded terraces with different shapes and sizes of plots generally causes heavy percolation loss of irrigation water. In fact, water may not always reach those at the end of the service area or at the end the canal. The main channels are provided by the government but those channels beyond the outlets are the responsibility of the farmers. If field channels are to be constructed, the farmer must build them. Yet without technical assistance and the agreement of the other farmers served by the same outlet, the individual farmers cannot construct the field channels. Thus, field channels are almost nonexistent in eastern India.

Earlier farmers had large holdings and they were cooperative, so they could manage water among them. But now, land size has much decreased mainly due to division of property (land) among inheritors causing fragmentation over the years. Farmers know that field channel is needed else more water will be lost in conveyance from plot to plot. But the thought of land being lost for constructing field channels dissuades them from construction.

3. Current Situation

Performance evaluation of irrigation systems has revealed that the systems are performing low, with only about 70% of the area actually irrigated in rainy season, 40% in winter and about 10 % in summer (WECS, 2002). Reduced water availability and mismatch of operation from that of design is the major reason. Irrigation system is designed for rotational water distribution among field plots conveying water through water courses to each plot. But water distribution schedule is not developed and implemented and field to field irrigation is practiced from the water delivered through outlets. First come first serve idea is followed, i.e. head reach plots get water first and then the next plot and so on with tail plots receiving water at the last.

Campbell (1995) has analyzed the irrigation practice in South and South East Asia minutely and has pointed out problems in night irrigation and practice of field to field irrigation. He has candidly described the situation as

> "…. canal irrigation is dominant, with water flooding from field to field where farmers have little control over the flow of water. Once the water is in the main channel, the outlets are usually never closed, and so water flows continuously through the fields, and the water distribution is quite uneven. The continuous flow through ungraded terraces with different shapes and sizes of plots generally causes heavy percolation loss of irrigation water. In fact, water may not always reach those at the end of the service area or at the end of the canal. The main channels are provided by the government but those channels beyond the outlets are the responsibility of the farmers. If field channels are to be constructed, the farmer must build them. Yet without technical assistance and the agreement of the other farmers served by the same outlet, the individual farmers cannot construct the field channels. Thus, field channels are almost nonexistent."

More water is also wasted or required due to uneven field levelling and crude water application methods. Furthermore, canal is fed by run-of-the-river system with no storage facility; water is supplied in the canal both day and night. Problem of night irrigation is reported much in the literatures. Water delivered in night is mostly wasted. Most canal irrigation water in South and Southeast Asia and elsewhere continues to flow at night and much is inefficiently used or wasted. Yet what happens to water at night is a neglected subject, a matter for anecdotes more than analysis. Darkness, cold, fear, normal working hours, and desire for sleep deter irrigation staff and farmers from activities at night (Chambers, 1988). In the night time, especially small farmers and women do not go out for water application and water may flow to drain. Thus, those lying at lower reach in outlet command do not get water to their fields. Next day, same farmer claims water until their land is watered. There is no account of how much water is lost and how much is used.

Khan et al. (2004) has explored possibility of reducing night irrigation using hydrodynamic models while Ghuman et al (2009) believe that farmers may gradually abandon night-time irrigation if circumstances permit, and thus simulated scenarios of reducing night irrigation for the Maira branch of the Upper Swat Canal, in Pakistan. It appears night irrigation should be now avoided with suitable alternatives.

4. Possible Options

Various techniques are used to minimize wastage of water at night. One is developing a schedule such that field irrigation will start from dawn only and another one is construction of storages which could be: online storage, intermediate storage, on-farm storage and groundwater storage.

Bievre et al. (2003) have demonstrated significant water savings by reducing nighttime supplies in medium-sized canal networks. Significant water savings were achieved through night-time closure of Shingrai Minor in Pakistan, but this work indicated that good diagnosis is required to identify canals that can be effectively operated.

Amarasinghe et al. (2008) has evaluated benefits of constructing an intermediate storage (*diggi*) or surface water banking as farmers' interventions to mitigate the effects of scarce and unreliable canal water supply in the Indira Gandhi Nahar Pariyojana, Rajasthan, India. The farmers first construct a small pond, called a *diggi*, in their farm to store the canal water supply. Next, they pump the water out from a *diggi* to irrigate the crops, through field channels or micro-irrigation technologies. With increase in control of the water management, farmers meet the cropwater requirement as best as possible. In fact, a *diggi* addresses the reliability issue through a self-enforcement mechanism and corrects the allocative inefficiency of water use. In the end, the society achieves both equity and efficiency. The cost of achieving efficiency is reflected in the cost of *diggi*. Raising fish means that farmers cannot empty there *diggi* for an extended period of time of the year. However, we do not know whether net benefit loss of crop production after retaining water in *diggis* for fisheries is less than the net value of production gains through fisheries. In Rajasthan India around $ 500 (about 20% of total cost) is provided subsidy to construct such *diggis*.

4. A Case Study

A typical outlet command area of Bagmati Irrigation Project in southern Nepal is shown Fig. 1. It shows water should traverse across 5- 6 parcels to reach to the lowest plot. A spreadsheet was developed to estimate time to irrigate each parcel from an outlet and estimate loss that can occur in conveyance from field to field. When water flows from one plot to another passing over light soil with high percolation rate, much water is lost as percolation.

The flow from one field to another is dependent on the discharge delivered through outlets and the percolation rate. In the Bagmati Irrigation Project, the percolation rate is very high around 5 at the upper reach, so much will be wasted when water is reduced.

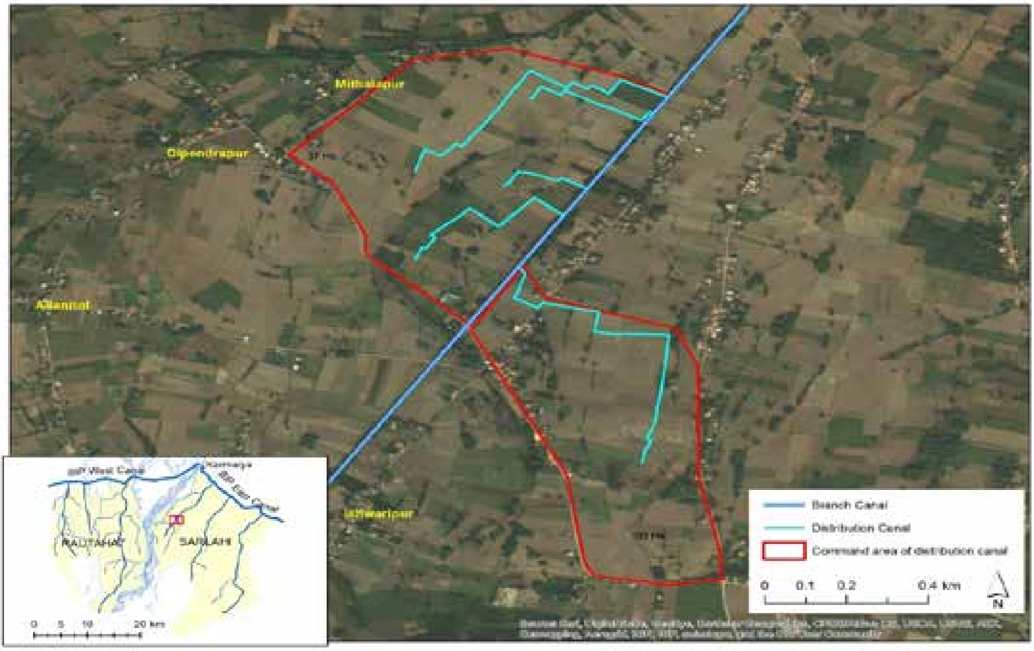

Figure 1:*A Typical tertiary command area*

As mentioned by Campbell (1995), at night, water is divided among a few number of outlets and a small stream is allowed to flow. As no one is there to regulate, much water is wasted. Lack of strict irrigation roaster and low motivation to farming per se due to low profit from agriculture and secondly of the hardship they have to face, farmers do not go to field for irrigation and water flows wastefully sometimes to drain. In turn they complain and ask for water next day and may get it, more water to be wasted. This will continue unless a solution is developed.

5. Promising Solution

Irrigation system in Nepal does not have storage provision, so intermediate tank or on-farm storage seems to be appropriate to remove the drudgery of night irrigation, which is dissuading small landholder youths and women to farming. These tanks will also provide storage facility and safeguard against effects of climate change. Furthermore, new improved irrigation technology and practice has emerged like micro irrigation, alternate wet and dry irrigation for Systematic Rice Intensification (SRI) method of cultivation and water could be conveyed through lay flat plastic tube. A spreadsheet was developed to estimate time to irrigate each parcel from an outlet and to estimate loss that can occur in conveyance from field to field. It shows there is much saving of water (over 20% in high percolation rate soil) in field conveyance. Thus, using storage and piped conveyance water could be applied efficiently. Fishery has good scope and has high profit. Hence farmers have expressed readiness to provide land for constructing storage reservoirs as farm ponds but with the condition that they shall be assured to allow raising fish in those ponds with some minimum water, and the night water supply shall be stored above the mark and that stored water shall be released to irrigate in day time.

Fish cultivation is highly profitable and if the farmers get financial support for constructing intermediate storages like in Rajasthan, providing minimum depth of water for fishery throughout the irrigation period, it is a very attractive option for the farmers who are venturing on their own too. Here need of acquiring land which is costly is avoided and farmers who are seeking funds get financial assistance, a win-win situation is established and irrigation service is also improved.

6. Conclusion

Irrigation development works are mainly focused at main system level overlooking water distribution practice below tertiary outlets. There is no field channel to convey water to each plots and water is transported from one field to another incurring huge percolation loss. And at night, irrigation is left unattended causing wastage of water to the drains. This gap of link between outlets to the field is as if no man's land, serves as a hurdle to adopt modern improved irrigation technology.

An intermediate storage in the form of on-farm ponds that will store night time water for delivering next day can be an attractive option to serve small and women farmers' irrigation drudgery and enable adoption of modern efficient irrigation method.

Reference

Campbell, D. (1995). Design and operation of smallholder irrigation in South Asia, World Bank Technical Paper Number 256 Irrigation And Drainage Series The World Bank Washington, D.C.

Chambers, R. (1988). Managing Canal Irrigation Practical Analysis from South Asia, Oxford & IBH Publishing Co. Pvt. Ltd. Bombay. pp. 133-231.

Colback, R., Nagayets, O. (n.d.). Impact of Efficient Irrigation Technology on Small Farmers, A Brochure of IFC The World Bank Group

De Bie`vre, B., Alvarado, A., Timbe, L., Ce´ lleri, R., Feyen, J. (2003). Night Irrigation Reduction for Water Saving in Medium-Sized Systems. J. Irrig. Drain Eng., 129, 108-116.

DOI (2017-18). Handbook, Department of Irrigation (DoI), the Government of Nepal.

Ghumman, A.R., Khan, Z., Turral, H. (2009). Study of feasibility of night-closure of irrigation canals for water saving. Agricultural Water Management, 96, 457–464.

Khan, M.Z., Ghumman, A.R. (2008). Hydrodynamic Modelling for Water-Saving Strategies in Irrigation Canals Irrigation and Drainage. Irrigation and Drainage, 57(4), 400-410.

Upali, A., Amarasinghe, A.B., Singh, O.P., Ojha, A., Anand, B.K. (2008). Cost and Benefits Of Intermediate Water Storage Structures: Case Study Of Diggies In Rajasthan. In Kumar, M. Dinesh (Ed.). Managing water in the face of growing scarcity, inequity and declining returns: exploring fresh approaches. Proceedings of the 7th Annual Partners Meet, IWMI TATA Water Policy Research Program, ICRISAT, Patancheru, Hyderabad, India, 2-4 April 2008. Vol. 1. Hyderabad, India: International Water Management Institute (IWMI), South Asia Sub Regional Office. pp.51-66.

William, K. (1975). Easter Field Channels' A Key To Better Indian Irrigation. Water Resources Research, 11 (3), 389-392.

Application and evaluation of reservoir operation model with reinforcement learning

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Abstract

Agricultural reservoirs determine the irrigation water supply depending on reservoir operation models which are run according to a climatic condition, cropping system, water requirement, etc. Ordinary reservoir operation models have simulation or optimization approaches. However, these approaches have limits that need artificial effort such as changing constraint under different circumstances. The artificial neural network is the system imitating intelligence, thinking, and a decision of human by learning from the data. It is expected that artificial neural network fills up the limits of ordinary reservoir operation models. This study will develop agricultural reservoir operation model with artificial neural network model, especially by using reinforcement learning and evaluate the model. Reinforcement learning (RL) model decides what to do according to circumstances, which return a reward to RL model. RL model learns from data to get better rewards. Therefore, using RL model in an artificial neural network is expected to make the reservoir operation model to cope with changes of circumstances.

Keywords: *artificial neural network; reinforcement learning; reservoir operation; water supply;*

1. Introduction

Reservoirs are artificial irrigation facilities which store the water stream (river, flowing water). It can be possible to supply water at the location and time of need by efficient management of reservoirs (Jung and Kim, 2007). Especially agricultural reservoirs are major infrastructures for agriculture which have functions for supplying agricultural water and flood control. They supply 60% of the agricultural water in Korea. In recent times, the necessity of developing water resources and significance of efficient management of reservoirs are increasing because of intensified water shortage and diversified demand for agricultural water (Lee at al., 2008). Agricultural reservoirs are commonly managed by empirical judgment and determine irrigation water supply depending on climatic condition, cropping system, infiltration, evapotranspiration, and existing water management methods (Kang et al., 2014).

Reservoir operation models assist decision-making process for efficient management of reservoirs and commonly adopt simulation or optimization approaches. The models simulate the reservoirs in accordance to established operating rules. Simulation models are commonly used because they are simple in structure and versatility in application. Simulation models can answer the questions of decision-maker and reflect reality and flexibly because they don't have a normative assumption. However, simulation models are time-consuming for drawing operating rules and cannot assure the Pareto optimum because simulation models suggest an alternative by trial and error. Optimization models find optimal solution with mathematical models. They consider manifold purposes and suggest the optimal solution among alternatives. However, optimization models cannot reflect reality and flexibility because mathematical models have premises which differ from reality. In addition, the optimal solution from the models may be different from the best solution for decision-maker because of the distinction between models and reality (Kong et al., 2013).

Reinforcement learnings are one of the machine learning methods which have environment and agent for learning. They improve the action of an agent by exchange of information between environment and agent. Reinforcement learnings don't require specific mathematical models such as those in optimization models because agent learns from selecting actions and rewards from the actions (Kim et al., 2005). In reinforcement learning, an agent selects the action (how to do) depending on its state which can figure out from the environment, and then the environment is changed by action of an agent. The agent is rewarded depending on its state. If the state is good, it will get advantages and if the state is bad, it will get penalties. The agent learns to select the actions in direction of high-advantages. In short, an agent in reinforcement learning makes a decision at every time step and it learns to select better actions from the effect of the decision. If reinforcement learnings are applied to reservoir operation models, it can find the optimal solution without specific mathematical models. In this study, we developed the reservoir operation model with reinforcement learning and evaluated its applicability.

2. Materials and Methods

In this study, reservoir operation model is developed with reinforcement learning applying DQN (Deep Q-Learning), one of the reinforcement learning techniques. The environment of reinforcement learning is composed of reservoir water balance model with the "tank" model. The daily submerged depth routing method is used for estimating paddy water requirement and the Penman-Monteith equation is used for calculating paddy evapotranspiration. The reservoir operation model is applied for the Onam-reservoir which is located on Onam-ri, Onam-eup, Namyangju city, Gyeonggi-do, Republic of Korea. The weather data from 1954 to 2016 was collected from Seoul meteorological station. The reinforcement learning model uses annual weather data which is chosen randomly for learning.

2.1 Reinforcement learning

2.1.1 Basic theory of reinforcement learning

Reinforcement learning models are composed of environment and agent and environment models satisfying the Markov property are formatted in the MDP (Markov Decision Process). The Markov property means that the response of environment model at time "t+1" depends on state and behavior at time "t". Table 1 summarizes the components of the MDP.

Table 1: *Components of Markov Decision Process (MDP)*

Components of MDP	Meaning
state(S)	Information of agent from the environment for figuring out its own states
action(A)	All the actions that can be selected by the agent in the current state
reward(R)	Information from the environment: reward that will be given on next state depending on the current action
discount factor(γ)	The factor that converts future values into current values
policy(π)	Probability of choosing a certain action on current state
return(G)	Sum of total reward from explorations of agent in the environment
value function(v)	Sum of all expected rewards from available actions on certain state (expectation of reward)
Q-function(q)	Value function of next state when agent choose the action on current state depending on policy
Equation of MDP	

$$G_t = \Sigma_{k=0}^{\infty} \gamma^k R_{t+k+1}$$

$$v_\pi(s) = E_\pi[R_{t+1} + \gamma v_\pi(S_{t+1}) | S_t = s]$$

$$q_\pi(s,a) = R_s^a + \gamma v_\pi(s')$$

$$q_\pi(s,a) = E_\pi[R_{t+1} + \gamma q_\pi(S_{t+1}, A_{t+1}) | S_t = s, A_t = a]$$

Where

t: time step

v_π: value function for policy π

q_π: Q-function for policy π

R_s^a: reward that will be given when the agent in state s choose action a

s': next state

2.1.2 Deep Q-Learning (DQN)

Q-Learning, one of the reinforcement learning models, is a method to find the optimal behavior function (policy, π) by calculating all possible state spaces. When the state space is wide or changed by updates, there is a disadvantage that it becomes unstable (Moon and Choi, 2016). On the other hand, DQN is incorporating artificial neural network in Q-Learning, which makes it possible to improve stabilities and performance of learning through experience replay (Mnih et al., 2015). The experience replay refers to a method that the agent saves the samples obtained from the environment in replay memory and reinforcement learning model extracts them randomly at the learning time. Through this, agent can learn stably by using various historical data that they have saved. The following is an equation of update process in Q-Learning.

$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha(R_{t+1} + \gamma \max_{a'} Q(S_{t+1}, a') - Q(S_t, A_t))$$

where

$Q(S_t, A_t)$: sum of all expected rewards when choosing action A_t in state S_t

R_{t+1}: reward will be given on next state S_{t+1}, depending on the action selected in state S_t

$\max_{a'} Q(S_{t+1}, a')$: Largest value of Q-function in state S_{t+1}

α: step size to determine update size

γ: discount factor

Fig. 1 is a diagram of learning process of DQN.

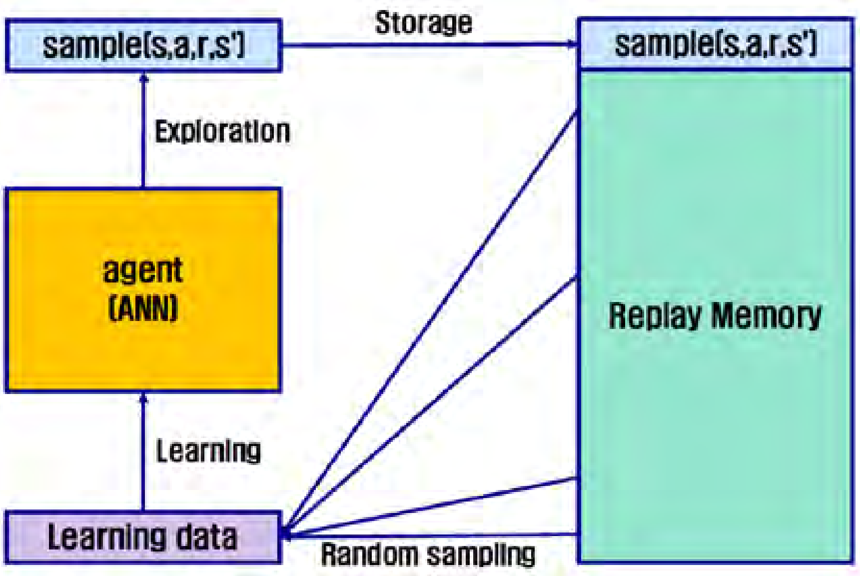

***Figure 1:** Learning process of DQN.*

2.2 Estimating paddy rice water requirement

In this study, paddy rice water requirement was estimated by the paddy water balance model. The Penman-Monteith formula was used to calculate the evapotranspiration of paddy rice in the paddy field and crop coefficient that is suggested by Yoo et al. (2006) was applied.

2.2.1 Paddy water balance model

In this study, the paddy water balance model was constructed by applying the daily submerged depth routing method. The levee height of paddy is determined by existing water management methods. The daily submerged depth routing method tracks the submerged depth of paddy and we can determine paddy rice water requirement through submerged depth, levee height of paddy, etc. The following is the equation of paddy water balance model.

$$PD_t = PD_{t-1} + IR_t + PR_t - (DR_t + ET_t + DP_t)$$

where

PD_t: submerged depth on day t

IR_t: irrigation requirement on day t

PR_t: effective rainfall on day t

DR_t: surface drainage on day t

ET_t: evapotranspiration on day t

DP_t: infiltration on day t

2.2.2 Estimating evapotranspiration of paddy rice

In this study, evapotranspiration of paddy rice is estimated based on Penman-Monteith method and crop coefficient. The reference evapotranspiration can be estimated by Penman-Monteith methods and then we can get crop evapotranspiration by multiplying crop coefficient and reference evapotranspiration. The following is the Penman-Monteith equation and Table 2 is Penman-Monteith crop coefficient of paddy rice(PM) suggested by Yoo et al. (2006).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where

ET_0: reference evapotranspiration

Δ: slope vapor pressure curve

R_n: net radiation at the crop surface

G: soil heat flux density

γ: psychrometric constant

T: air temperature at 2 m height from the ground

u_2: wind speed at 2 m height from the ground

e_s: saturation vapor pressure

e_a: actual vapor pressure

Table 2 : *Crop coefficient of paddy rice in Korea suggested by Yoo et al.(2006)*

Days	10	20	30	40	50	60	70	80	90	100	110	120	Avg.
PM	0.78	0.97	1.07	1.16	1.28	1.45	1.50	1.58	1.46	1.45	1.25	1.01	1.27

*PM: Penman-Monteith crop coefficient of paddy rice

2.3 Reservoir water balance model

In order to construct an environment model, which is the background for an agent to select the actions, a reservoir water balance model is utilized. In this study, the reservoir water balance model is simulated by applying runoff of watershed (reservoir inflow) from the "tank" model, agricultural water supply from paddy rice water requirement, current water level of reservoir and weather condition. The agent figures out the environment through paddy rice water requirement, the current water level of the reservoir and weather condition and then determine an amount of supply. Then the environment changes because of supply of agent and agent get rewards depending on the result. The following is reservoir water balance equation used in this study.

$$S_t = S_{t-1} + I_t + P_t - E_t - AW_t - O_t$$

Where,

S_t: water storage of reservoir on day t

I_t: reservoir inflow on day t

P_t: water surface rainfall on day t

E_t: water surface evaporation on day t

AW_t: agricultural water supply on day t

O_t: spillway release on day t

Acknowledgements: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science and ICT) (No. 2017R1E1A1A01077413)

References

Jung, G., Kim, T. (2007). Comparison of Water Distribution Model through Reservoir and Water System Operation. Water for Future, (41), 38-43.

Kang, M. Oh, S., Kim, J. (2014). Estimation of Amounts of Water Release from Reservoir Considering Cutomary

Irrigation Water Management Practices in Paddy-Field Districts. Journal of the Korean Society of Agricultural Engineers, 56(5), 1-9.

Kim, J. Kang, D., Park, J. (2005). Robot Control via RPO-based Reinforcement Learning Algorithm. In: Proceedings of KFIS Spring Conference. pp. 217-220.

Kong, J. Kim, J., Kim, S. (2013). A Study on the Fundamental Comparison of Simulation and Optimization Approaches for Water Resources Systems Planning and Management. Journal of Korea Water Resources Association, 46(4), 373-387.

Lee, Y. Park, M. Park, K., Kim, S. (2008). Analysis of Hydrologic Behavior Including Agricultural Reservoir Operation Using SWAT Model. Journal of the Korean Association of Geographic Information Studies, 11(1), 20-30.

Mnih, V., Kavukcuoglu, K., Silver, D., Graves, A., Antonoglou, I., Wierstra, D., Riedmiller, M. (2013). Playing Atari with Deep Reinforcement Learning. In: 2013 Neural Information Processing Systems (NIPS) Deep Learning Workshop. pp. 1-9.

Moon, S., Choi, Y. (2016). A Study on Application of Reinforcement Learning Algorithm Using Pixel Data. Journal of Information Technology Services, 15(4), 85-95.

Yoo, S. Choi, J., Jang, M. (2006). Estimation of Paddy Rice Crop Coefficients for FAO Penman-Monteith and Modified Penmen Method. Journal of the Korean Society of Agricultural Engineers, 48(1), 13-23.

Potential of using solar energy for irrigation in hilly region of Nepal

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Abstract

This paper aims to identify areas suitable for using solar water pumps for irrigation in hilly region of Nepal. With more than 300 days of sunshine in a year, Nepal can be considered as a country gifted with abundant solar energy resources. The use of solar energy for pumping water to 'difficult terrains' or 'Tars' could be one of the sustainable solutions that help to increase the food security and reduce poverty. This study identified about 120 thousand hectares of cultivable land, within a buffer distance of 2000 m along the bank of major rivers in the hilly region of Nepal, are suitable for single stage pumping (pumping head between 30 to 200 m). It further estimated that benefits equivalent to about 0.95 USD could be obtained from agricultural products by using unit volume of water for irrigation. The cost involved in lifting a unit volume of water using solar pumps installed along with drip or sprinkler irrigation system varied from 0.6 USD/ m^3 at an elevation of 30 m to 0.79 USD/m^3 at an elevation of 200 m. Providing irrigation facilities on these 120 thousand hectares of suitable areas, about 860 thousand populations in the hilly region are directly benefited and the country can save approximately NRs. 104 billion flowing out annually from the reduction in import of agricultural products from foreign countries.

Keywords: *insolation; irradiance; micro irrigation; photovoltaic; solar pumps; sump well.*

1. Introduction

Food, water and energy are believed to be important basic needs without which human life cannot sustain. Due to the limited resources in earth to satisfy these basic needs, crucial efforts for sustainable development should be taken to pave the pathway that preserves these limited resources for life of future generations in the planet. Eradication of extreme poverty and hunger is one of the Sustainable Development Goals (SDGs) as set by United Nations. Nepal, among many least developed countries, still has majority of population under poverty and suffering from insufficiency of food.

The fluctuation in the monsoon of Nepal, directly effects the gross domestic product (GDP) growth of the country. Parasai and Balkrishna (2010) has also pointed out how crop yield of Nepal has been

reduced by climate change and poor monsoon. The impact of climate change on agriculture and its influence on the GDP can be directly related to the status of irrigation services in Nepal.

According to the ecological regions of Nepal, irrigation systems can also be classified as Mountainous, the Hilly and Terai irrigation systems. Terai region includes about 50% of the total cultivable land of the country and more than 98% of this land is irrigable. The Hilly region occupies 40% of the total cultivable land of which only 34% is irrigable with conventional irrigation systems. Mountainous region has only 10% of the total cultivable land of which only 22 % of land is irrigable.

Almost all of the upland areas in the Hilly region of Nepal called "Tars" are under cultivation. These *"Tar"* land can be irrigated either through gravity flow surface irrigation schemes or through lift irrigation schemes. Naturally, for gravity flow irrigation schemes, length of the canal depends on the elevation differences between *"Tar"* and the river water level. If the length of the canal is large, the construction, operation and maintenance cost can be large compared to lift irrigation schemes.

Hence, in this study, an effort to find the potential sites for installation of solar pumps, design efficient irrigation system and perform the economic analysis of the selected project has been made. This study is supposed to be helpful in connecting food and water through renewable energy and make the irrigation schemes in the Hilly region of Nepal sustainable.

1.1 Photovoltaic powered pump

Use of solar photovoltaic (PV) panels for generating electricity has been increasing rapidly around the globe. The commercial use of PV pumping system in 2007 increased more than 10 times compared to that in 2000 (GTZ, 2007). The key reasons for this significant rise in use are the decrease in price of PV panels (from about $75 in 1977, as shown in Fig. 1, to less than $0.3[1] in 2015), increase in the efficiency of PV panels, and the need for sustainable development of energy systems by minimizing environmental effects. The advancement in technology, reduction in cost of PV panels and solar energy being the most abundant renewable energy on the earth, has positively influenced in the development and deployment of PV powered water pumps. Such PV power-based water pumps can be used for lifting water to irrigate agricultural land and increase the yield of crops. Albeit, low operation and maintenance cost, the initial investment cost of PV powered system is high compared to conventional power systems. Solar energy being clean and renewable, the PV powered pump system has smaller environmental footprint compared to conventional system and therefore, help in sustainable development of irrigation systems. However, design of PV powered pump systems should be done carefully to optimize all the components of the system and thereby reduce the investment and maintenance cost. A proper design of all the components can result in long-term cost saving and make the PV powered pumps more attractive than the conventional pumps in economic terms as well.

1.2 Land suitability analysis and multi-criteria decision making using GIS

Land suitability analysis is a technique to find appropriate parcels of land that satisfy already established criteria, the most (Hopkins, 1977, as cited in Malczewski, 2004, pp 4-5). Food and Agricultural Organization (FAO) defines agricultural land suitability analysis as a measure to identify to what extent the qualities of land match the criteria of a particular form of Landuse. Analysis of agricultural land suitability using solar pumps is a multidisciplinary approach, which requires information from soil science to metrological science, environmental science to water science and management. Kalogirou (2002), Prakash (2003), and

1 based on average sales price of $0.3/W on 29.04.2015 2015 from http://pv.energytrend.com/pricequotes.html accessed on 30.04.2015

Peveen et al. (2007) have used multi-criteria for analysis of agricultural land suitability. Albeit, there can be many criteria associated with each stream of science, not all of them are equally important. Selection of criteria is an important part of suitability analysis. Selection of different sets of criteria will result in different outputs of the analysis. Better degree of output of the analysis is obtained when the criteria are grouped together in the hierarchy of importance. Simplest method that has been widely used for the suitability analysis with multi-criteria approach is ranking and weighting or weighted summation. In this method the weightage on the criteria are assigned with degree of importance. The critics of this method is that it lacks theoretical foundation in assigning the weight to the selected criteria and cannot reflect the view of decision makers clearly (Malczewski, 2004).

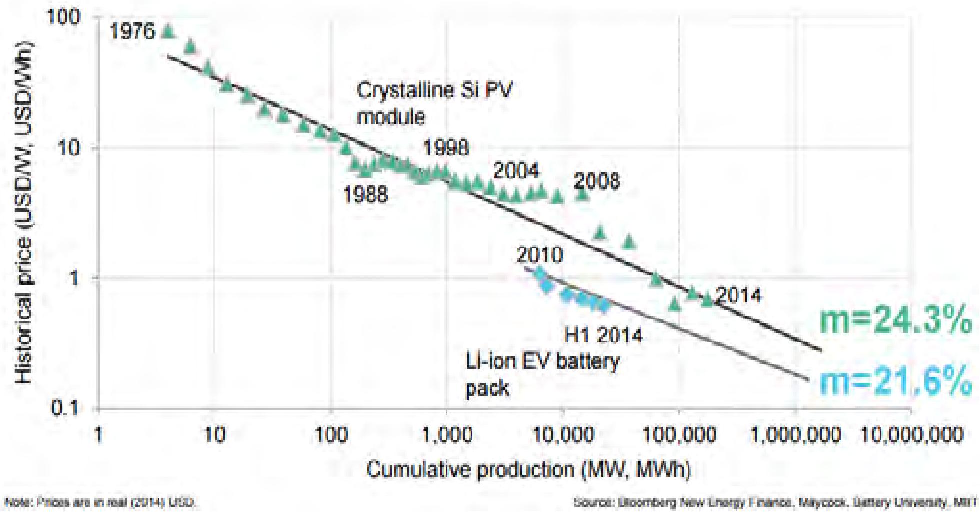

***Figure 1:** Historical price (USD/watt) and cumulative production of silicon PV cells (Source: Bloomberg New Energy Finance, Maycock, Battery University)*

The suitability potential analysis of land for agriculture does not have certain standard to select the criteria therefore; criteria used in similar studies are generally used (Akinci et al., 2013). Such analysis uses large variety and quantity of physiographic data, climatic data and soil characteristics (Wang, 1994).

Until the rapid development of computer systems and Geographical Information System (GIS), MCDM analysis were carried out non-spatially, assuming homogenous spatial characteristics on the area under consideration. Neglecting the importance of spatial variation is not realistic specially when analyzing land suitability (Malczewski, 1999; as cited by Prakash, 2003).

1.3 Potential of solar energy in Nepal

It is essential to know the potential of solar irradiance for designing and sizing of solar PV and solar pumps. The development and deployment of solar energy in Nepal is at an initial stage. Therefore, there are only very few studies and research on the potential of solar energy.

Nepal lies within latitude and longitude varying from 26.35 - 30.35°N and 80-88°E. Shrestha (2006) points out that average sunshine hour per day in Nepal is 6.8, which sums up approximately to 2482 hours in a year with average solar insolation ranging from 3.9 to 5.1 kWh/m^2/day. Solar insolation is the

rate at which energy from the sun reaches to the surface of earth. It is a contracted from of 'incoming solar radiation'. The maximum value of irradiance (power per unit area) on the surface of earth is about 1000 W/m^2. In October 2004, high resolution solar radiation assessment of Nepal was carried out by United Nations Environmental Program (UNEP)[2]. The assessment was done using three years (2000, 2002 and 2003) data of Meteosat (Schillings et al., 2004). Alternative Energy Promotion Center (APEC, 2008) conducted the study of solar potential for Concentrated Solar Power (CSP) and PV systems using UNEP data. The CSP system collects the energy from sun and provides energy in the form of heat. The study shows that the CSP potential of Nepal ranges from of 3.5 to 5.7 kWh/m^2/day. Similarly, PV potential in isolated system[3] ranges from 3.6 to 5.2 kWh/m^2/day. The database of Solar and Wind energy Resource Assessment (SWERA)[4] shows that the Global Horizontal Irradiance (GHI) of Nepal varies from 3.5 to 5.4 kWh/m^2/day.

2. Study Area

This study was focused on the Hilly region of Nepal. The Terai region occupies nearly 23% of the total area of country. Out of which, about 1.3 million hectares (Mha) of land is cultivable and on 0.94 Mha, irrigation services have already been provided[5]. Similarly, Himalaya with altitude ranging from 3000 m and above lies on the northern part of Nepal and touches the border of China. This region also occupies approximately 35% of the area of the country and encompasses many mountains and peaks. The middle region in terms of altitude, ranging from 300 m to 3000 m, is the Hilly region. It occupies maximum area (42%) of the total land of Nepal and most of the cultivable land of the Hilly region still lack irrigation facilities. This study focuses only on the Hilly region as the study area which has about 700 thousand hectares of land which are cultivable but not irrigable through conventional irrigation system as shown in figure below.

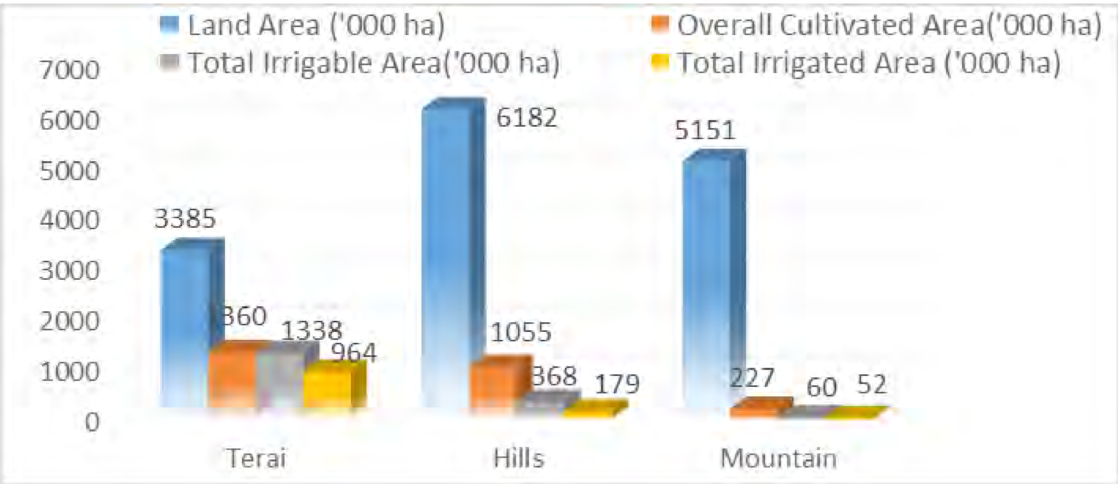

Figure 2: *Cultivable land in different regions of Nepal*

2 http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/SWERA_10km_solar_finalreport_by_DLR.pdf accessed on 10.05.2014

3 Not connected to Grid- in Remote areas of Nepal

4 Prepared by DLR – activities within SWERA, DeutschesZentrumfürLuft- und Raumfahrt, with spatial resolution of 0.1 degree (nominally 10 km).

5 Department of Irrigation, presentation on progress report of fiscal year 2012/2013.

3. Research Methodology

To find suitable potential sites for installation of solar water pumps for irrigation in the Hilly region of Nepal, following methodology was adopted. The detail process of analysis was carried out in ArcGIS as shown in Fig. 3.

- Acquisition and processing of data
- Standardization of the data using selected criteria
- Assigning weight to different raster
- Performing weighted overlay analysis in ArcGIS
- Obtaining the result of the analysis

An ArcGIS model was prepared to input the selected datasets and to analyze these data using the criteria, assumptions and methods as explained above. This model only contains the sequences of steps that has been explained in the methodology and has been used to analyze the areas by varying height (10m to 800m) and the buffer distance from the river (500m, 1000m, 2000m). The obtained result was plotted to get an idea on how the potential area vary with elevation (or altitude).

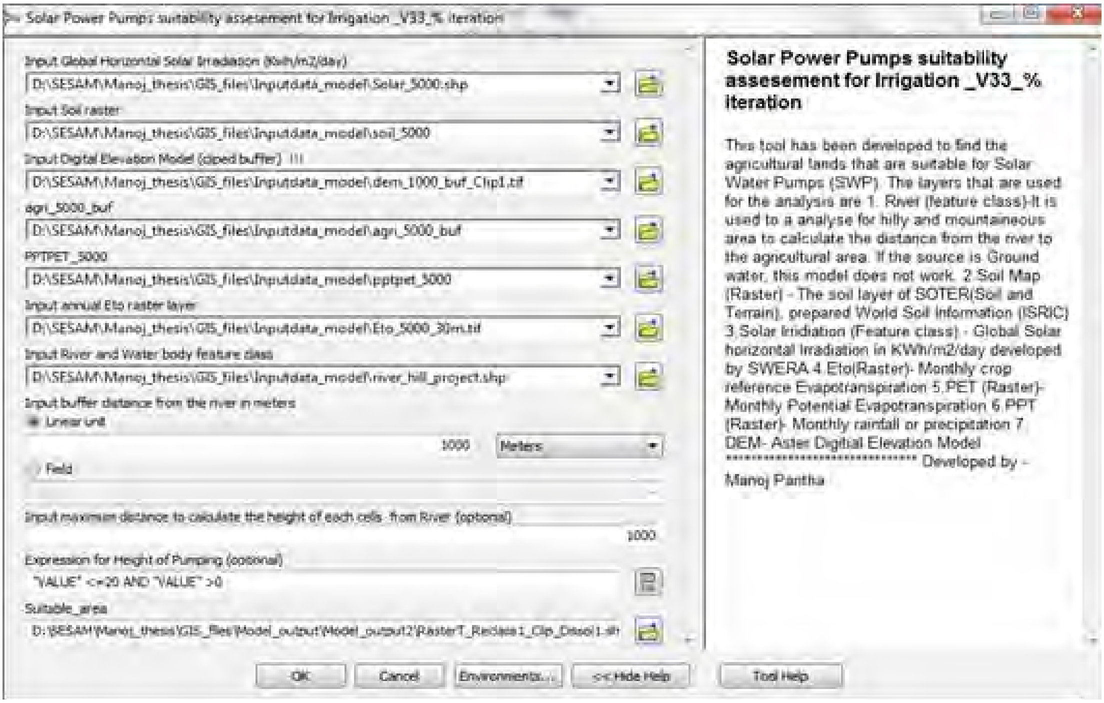

Figure 3: *ArcGIS model for suitability assessment of solar pumps for irrigation*

The dataset used in the analysis is shown in Fig. 4.

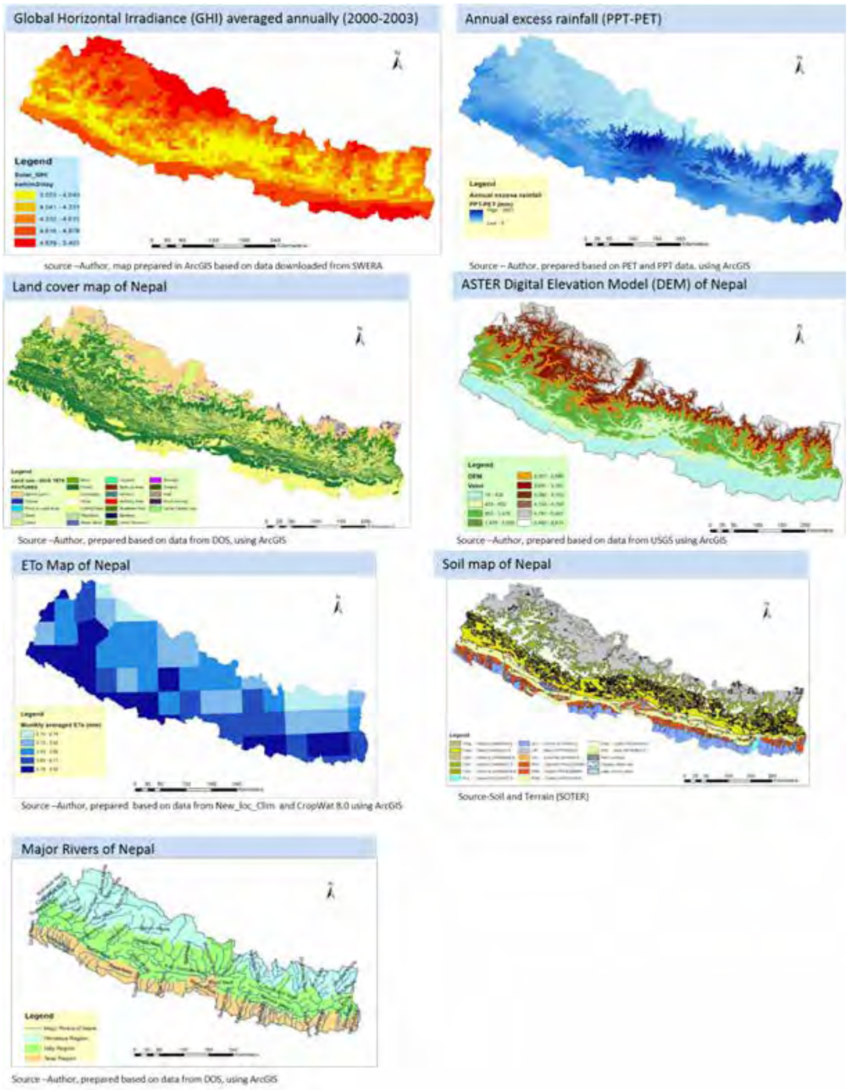

Figure 4: *Dataset used for analysis*

4. Results and Discussion

4.1 Areas suitable for solar pumping

Fig. 5 shows the total potential area at buffer distances – 500, 1000 and 2000 meters from the river at different elevations. The X- axis represents the elevation and the Y- axis represents the areas in thousand Hectare ('000 Ha). From the figure, it can be seen that up to 400 m, potential area increases as the elevation increases and above 400 m, areas remain almost constant.

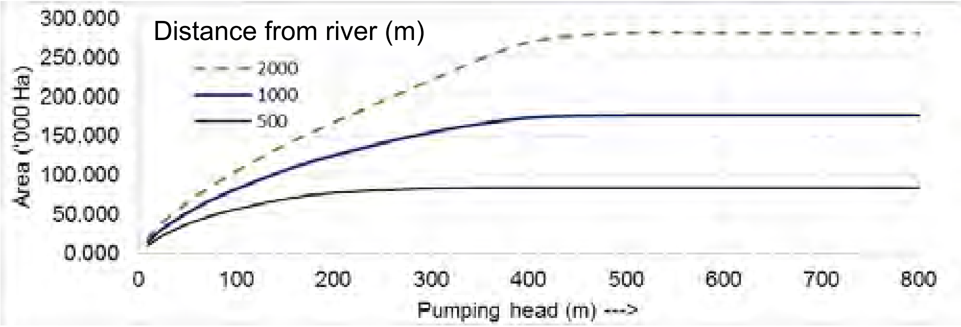

Figure 5: *Potential area at different distance from river*

It has been assumed that for areas with head higher than 30 m when irrigated through conventional gravity irrigation, requires long length canals, which will be costly and incur higher maintenance cost. Therefore, solar pumps can be installed to irrigate the areas above 30 m elevation. Hence, the areas below 30 m is irrigated by conventional irrigation system and only areas above 30 m has been considered for installation of solar pumps. The area between 30 m to 200 m pumping head has been considered as suitable areas for single stage pumping and economic analysis has been performed accordingly using micro irrigation techniques. The map of cultivable areas suitable (between elevations of 30 m to 200 m) for irrigating using solar pumps within a distance of 2000 m from major rivers in the Hilly region of Nepal is shown in Fig. 6 below.

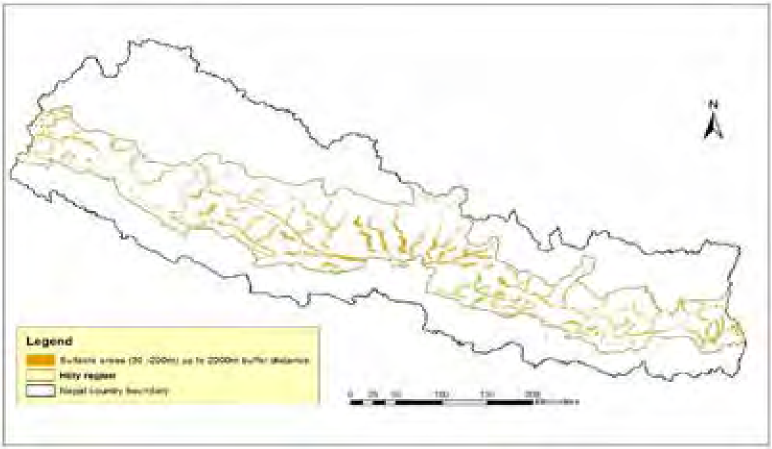

Figure 6: *Suitable site map (between 30 -200 m elevation) within buffer distance of 2000 m in the Hilly region of Nepal*

Table 1 shows the total areas between 30 to 200 m elevation at buffer distance of 500, 100 and 2000 meters. The cumulative area up to 500, 1000 and 2000 meters of distances from river are approximately 50, 89 and 122 thousand Hectares, respectively.

Table 1: *Area between 30 m to 400 m elevation at different buffer distance*

Buffer distance	Area at elevation 30 – 200 m ('000 Ha)	Cumulative area ('000 Ha)
500	50.985	50.985
500 to 1000	37.762	88.747
1000 to 2000	33.454	122.201

The total cultivable area suitable for pumping water in a single stage and percentage of such suitable area compared to total cultivable area of each districts in the Hilly region of Nepal has been shown in Fig. 7. From the analysis, it was found that in Kaski district, more than 24% of the total cultivable area is suitable for installing solar pumps. Similarly, Okhaldhunga district has only about 3.5% of the total cultivable area suitable for installing solar pumps to irrigate farms within a buffer distance of 2000 m and pumping head between 30 m to 200 m.

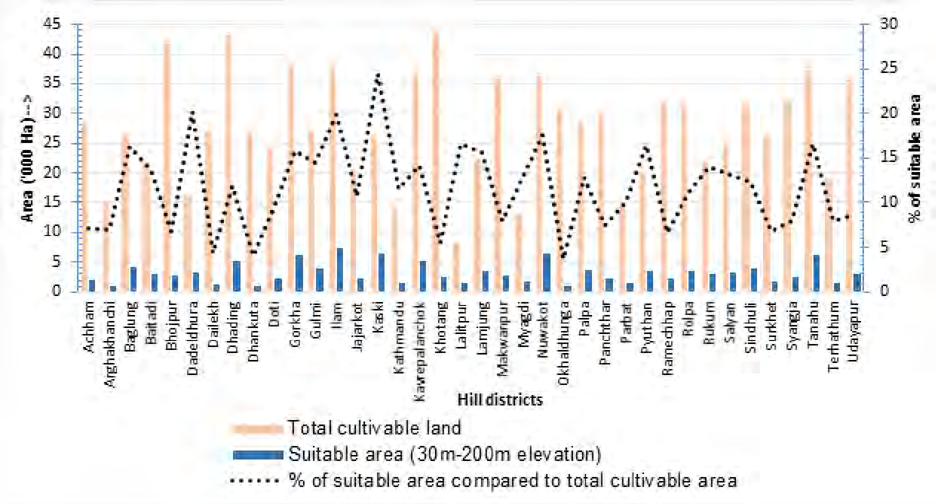

Figure 7: S*uitable area (elevation between 30 and 200 m) for installation of single stage solar pumps for irrigation in the Hilly region of Nepal*

4.2 Water availability for pumping

Even though there are large areas suitable for solar pumping, the key question is whether there is enough water available to pump in those areas. The daily water requirement per hectare of land for irrigation using modern irrigation technique for the proposed cropping pattern is 25 m^3/day. If we assume all the available water is equally distributed to the basin area (for greater assurance of water in cultivation area), only Babai basin (14 m^3/day/ha) has less water available then what is required (25 m^3/day/ha). Fig. 8 shows the total area that is suitable, in different water basins, for providing irrigation services using solar water pumps in the Hilly region of Nepal. To address this issue of water deficit, in Babai basin only 50% (1.48 thousand Ha) of the suitable area has been considered as water available areas.

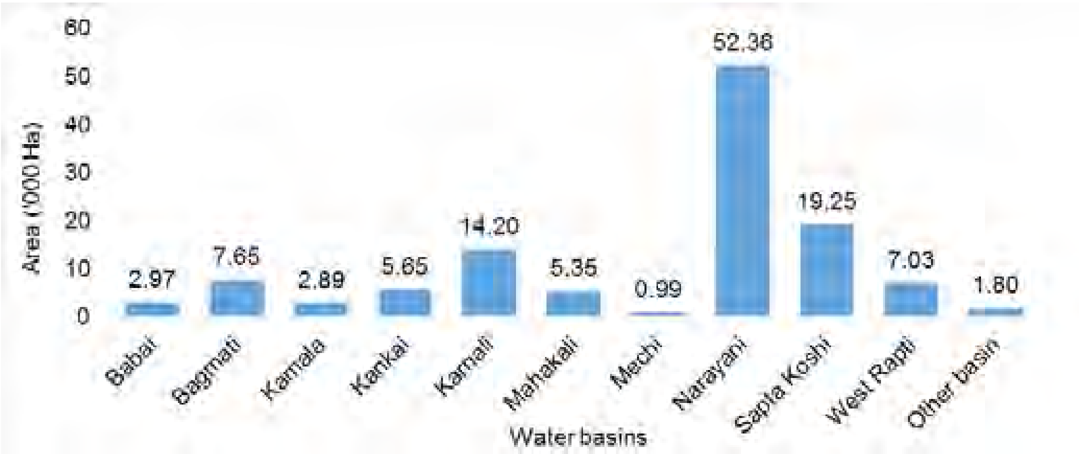

Figure 8: *Suitable area between 30 -200 m pumping head ('000 Ha) of the Hilly region of Nepal, in different water basins*

Water Resources Act (1992) of Nepal has prioritized the use of water for irrigation as second priority after use for domestic and drinking purpose. Hence, from the preliminary analysis of water availability in the water basins of Nepal and the higher priority in the Water Resources Act, it can be said that on 120,000 Ha of suitable area (between 30-200 m) along the banks of major rivers in the Hilly region, water can be made available for irrigation purpose.

4.3 Contribution to food security

Another interesting information useful for many is out of the total suitable areas, whether or not all of them can contribute towards improving food security in the country. In the fiscal year 2012/13, Nepal imported raw and processed agricultural products worth NRs. 99.34 billion[6] which is 30.6% more than that in the fiscal year 2011/12. Food security for Nepal has been one of major challenges to fight against poverty. From a hectare of irrigated land, farmers can earn annually 0.87[7] million (1.26 million with project – 0.39 million without project) compared to unirrigated land.According to the population census of Nepal in 2011, the average household size of Nepal is 4.88 and average agricultural land holding per household is about 0.68 Ha (CBS, 2011, p. 2) .Therefore, by providing irrigation facilities on 120 thousand hectare of unirrigated land along the banks of river in the Hilly region of Nepal, about 860 thousand populations are directly benefited and agricultural products worth NRs. 104 billion can be produced. These areas when provided with irrigation facilities can help Nepal largely to become independent on agricultural products and export when surplus to other countries.

5. Conclusions

The main findings of the study can be concluded with the following points:

- The total potential area (maximum lift of 800 m) for installation of solar pumps along the banks of major rivers in the Hilly region of Nepal up to a buffer distance of 2000 m from the source

6 Published in daily newspaper http://www.ekantipur.com/the-kathmandu-post/2014/05/20/money/nepal-imported-agro-products-worth-rs-99.34-billion-last-fy/263035.html on may 20. Accessed on 09.08.2015

7 From cost benefit analysis form with project and without project, explained in section 5.2.4

(rivers) is estimated as 280 thousand hectares (approximately).

- The benefit (0.95 USD/m^3) obtained from agricultural products by using a unit volume of water is higher than the cost (0.6 USD/m^3 at elevation of 30 m to 0.79 USD/m^3 at 200 m elevation) incurred to pump water using solar pumps.
- Out of 280 thousand hectare of potential area, 120 thousand hectares (area between 30 m to 200 m elevation) of land is found to be suitable (technically, economically, and water availability) for installing single stage solar pumping system
- Providing irrigation facilities to 120 thousand hectares of land suitable for installing solar pumps directly benefits about 860 thousand of the population in the Hilly region of Nepal and saves an annual import of agricultural products equivalent to NRs. 104 billion. This helps for food security within the country and increase the living condition of farmers.

Results from this study can help the stakeholders related to solar pumps and irrigation to plan and to find the suitable areas for installing solar pumps and provide irrigation to rainfed cultivable farms, which allows for cultivating more than two crops per year. Using the result of this study, one can also estimate the cost of installing solar pumps for irrigation in the Hilly region of Nepal.

References

Akıncı, H., Özalp, A. Y., Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. Computers and Electronics in Agriculture, 97, 71-82.

Ali, M. (2010). Fundamentals of Irrigation and On-farm Water Management. s.l.:Springer.

APEC (2008). Solar and Wind Energy Resource, Lalitpur, Nepal: Alternative Energy Promotion Center.

CBS (2011). Summary of Agricultural Census (2011), Kathmandu, Nepal: Center Bureau of Statistics.

GTZ (2007). Resource-conserving Irrigation with Photovoltaic Pumping Systems, Chile, 65760 Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH .

Kalogirou, S. (2002). Expert systems and GIS: an application of land suitability evaluation. Computers, Environment and urban Systems, 26, 89-112.

Kenna, J., Gillett, B. (1985). Solar Water Pumping A Handbook. Southampton Row, London: Intermediate Technology Publications.

Malczewski, J. (2004). GIS-based land-use suitability analysis : A critical overview. Progress in Planning, 62, 3-65.

Parsai, B. K. (2010). National Issue Paper on the Agriculture Sector (Adaptation), s.l.: s.n.

Perveen, M., Nagasawa, R., Uddin, M.. Delowar, H. (2007). Crop-land suitability analysis using a multicriteria evaluation & GIS approach.. USA, University of California, Berkeley, USA..

Prakash, T. (2003). Land Suitability Analysis for Agricultural Crops: A Fuzzy Multicriteria Decision Making Approach, Enschede, The Netherlands: International Institute for Geo-information Science and Earth Observation.

Schillings, C., Meyer, R., Trieb, F. (2004). Solar and Wind Energy; High Resolution Solar Radiation Assessment for Nepal, s.l.: s.n.

Shrestha, J. N. (2006). Application of Building Integrated Photovoltaic Electric System; Its Contribution in Reduction of Load shedding Hours in Nepal. Journal of the Institute of Engineering, Volume ,7, 1-5.

Shrestha, J. N., Jha, A. K., Karki, R. (2014). Traning Manual on Solar PV Pumping System. Khumaltar Lalitpur: Alternative Energy Promotion Center.

Teresa, M. D. (2010). Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems, Portland, Oregon: United States Department of Agriculture.

Wang, F. (1994). The use of artifical neural networks in a geographical information system for agricultural land-suitability assessment. Environment and Planning, 26(2), 265-285.

Application of groundwater irrigation system using solar power generation as a Water-Energy-Food nexus model project

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Abstract

Food security in many developing countries is under threat of water and energy constraints. Water-Energy-Food (WEF) nexus model project could be one of the solutions to address the issue. This kind of project has been implemented by Korea Rural Community Corporation (KRC) in El Porvenir, El Salvador, to build groundwater irrigation system integrated with solar power system funded by Korea. Two models were analyzed and compared in order to find the most favorable and economical one in the consideration of project and operation and maintenance cost. In model-1, water pumped from the groundwater well is stored in water tanks and discharged into irrigation areas using electric power generated by independent solar power generation system and diesel generator. In model-2, solar power system is connected to a nearby national electric grid, and water is pumped directly from the well to irrigation areas using the power from national grid only when necessary. Results showed that the model-2 required lower project and maintenance costs compared to model-1. Increased agricultural production and benefit-cost ratio of model-2 were 152% and 1.57, respectively.

Keywords: *groundwater; irrigation; national grid; solar power; water-energy-food nexus*

1. Introduction

The shortage of water and energy is leading towards food insecurity in many developing countries. To overcome this global problem, Water-Energy-Food (W-E-F) nexus model project is an alternative solution. In most developing countries, agriculture is a determining factor for food security and national economy growth. Groundwater is the main source of water for agriculture production in many countries that have unfavorable geology and topography characteristics for surface water exploitation.

It is generally considered that groundwater irrigation requires electricity to pump water from the wells to the farms. However, in fact in the developing countries, the electricity is supplied from diesel generator or national grid which is much costly compared to the farmers' income. Therefore, an affordable and stable electric supply for groundwater irrigation is a main factor in building sustainable agricultural production.

2. WEF Nexus with Solar Pumping

2.1. Water-Energy-Food nexus

Recently, the renewable energy technology is becoming a universal approach to ensure water and energy security in relation with WEF nexus. Many countries with energy poverty have abundant renewable energy sources like solar or wind. In particular, since the solar photovoltaic (PV) is more advantageous than wind, solar PV application in groundwater irrigation system has become more common. Major four advantages of solar powered pumping are unattended operation, low maintenance cost, simple installation, and long-lasting system.

2.2 Solar-powered pump

Solar power generation technology is the most advanced than any other renewable energy generation options. The advanced technology results in higher efficiency and affordable cost. Therefore, solar-powered pumping system is a cost-effective alternative that can contribute to the improvement of agricultural production and poverty alleviation even in rural areas with no existing electric grid. In consideration of national grid condition, economic feasibility and sustainability of solar-powered pumping system can be improved.

3. Status of El Salvador and Project Area

3.1. Status of El Salvador

El Salvador is a small country in Central America on the Pacific Coastal area with a territory of 21,040 km^2 bordered by Guatemala and Honduras (Fig. 1). It has high precipitation rate of 1,850 mm/year, but only 5% of total farmland is covered by irrigation facilities. The lack of irrigation facilities is resulting in a low agricultural production that leads to high importation rates of rice (80% of annual consumption or about 100,000 ton/year) to meet national rice demand. Consequently, agricultural production during dry season (Nov – Apr) should be necessarily improved.

Figure 1: *Location and administrative details of El Salvador*

3.2. Status of project area

The project area, El Porvenir, is a plain area with fertile volcanic soil located at 700 m above sea level (Fig. 2). Farming practice is generally single cropping between May and October in rainy season, even though some farmers are also trying to cultivate maize and sugarcane in dry season. However, the insufficient surface water resource makes double cropping difficult and unsuccessful.

About 325,000 households or about 82% of the total agricultural households are self-sufficient producers. Therefore, in order to motivate them to be commercial producers, irrigation facilities to provide water for dry season farming is necessary. In addition, the irrigation facilities will encourage agricultural production, food self-support and national food independence.

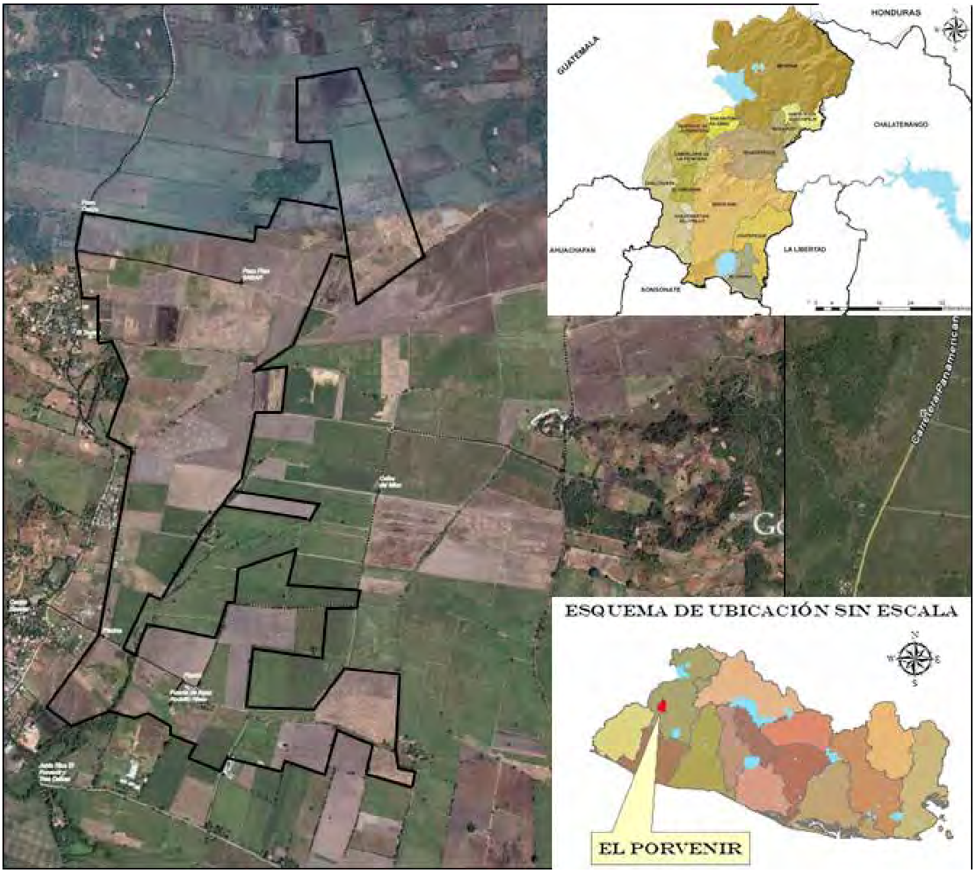

Figure 2: *Location of project area*

In 2007-2008, 537 tons of rice was produced from 89 ha cultivation area in El Porvenir. However, it accounted for 88.6% of total cultivation area and 90.7% of total production in Santa Ana. Sugarcane and vegetables are also commonly cultivated in this area. Details of cultivation area and production in the study area is given in Table 1.

Table 1: *Cultivation area and production in El Porvenir (Source: IV Censo Agropecuario 2007-2008)*

Crops	Cultivation Area (ha)			Production (M/T)		
	Santa Ana	El Porvenir	%	Santa Ana	El Porvenir	%
Maize	24,674	980	4.0	61,576	2,364	3.8
Sorghum	8,758	61	0.7	11,380	71	0.6
Bean	1,4,337	730	5.1	10,735	536	5.0
Rice	100	89	88.6	592	537	90.7
Coffee	31,442	271	0.9			
Vegetable	392	49	12.5	6,245	974	15.6
Sugar	2,880	566	19.6	240,235	48,444	20.2
Fruit	989	55	5.6	6,953	198	2.9

4. Project Implementation

4.1. Project history

Korea Rural Community Corporation (KRC) has implemented W-E-F nexus model project in El Porvenir by building a solar-powered groundwater irrigation system using fund from Korea's Official Development Assistance (ODA) program. A project which analyzed and compared the efficiencies of solar-powered irrigation system that was far and close from national grid has been completed. El Porvenir, an area in 80km to the north-western of San Salvador was selected as the area for pilot project. This project was initiated by Korea International Cooperation Agency (KOICA) in 2012, aiming to improve national food security and quality of rural life by constructing a stable agricultural production system in about 200ha area. A contract for implementing this project from 2013 to 2017 has been signed by KRC and KOICA.

4.2. Project overview

The main components of the project are to construct a 10.8km-long agricultural canal that will supply irrigation water to the 204 hectares of cultivated land by developing seven 100m-deep wells (Q= 3.4☐/min), to build Farmers' Union Offices, conference rooms, and multi-purpose warehouses, and to install electrical facilities.

Figure 3: *Irrigation canal and Well connected to the national grid*

4.3. Solar generation

There are two options in providing electric supply: 1) constructing 4 solar power plants for each well; or 2) constructing one central solar power plant. The big challenge for solar power is an intermittent production because of the limit of time and meteorological condition. The main concerns in solar-powered irrigation system are energy storage and water supply facilities. Occasionally, installation is costlier than generation. However, if national grids exist near project area, third option can be introduced to increase project feasibility. The concept of the third option is to connect the solar power to the electric grid which will provide necessary electricity to the well then, to sell/purchase the electricity to/from electric company. As a consequence, energy storage system and water tank are not required.

4.4. Comparison of solar generation models

In this project, KRC has installed one solar power plant of 250Kw to be connected to electric grid instead of 4 solar power plants of 45Kw, 3 diesel generators of 45Kw and seven water tanks with capacity of 2.8 ton. These two models were compared and analyzed for their economic benefits as shown in Fig. 4.

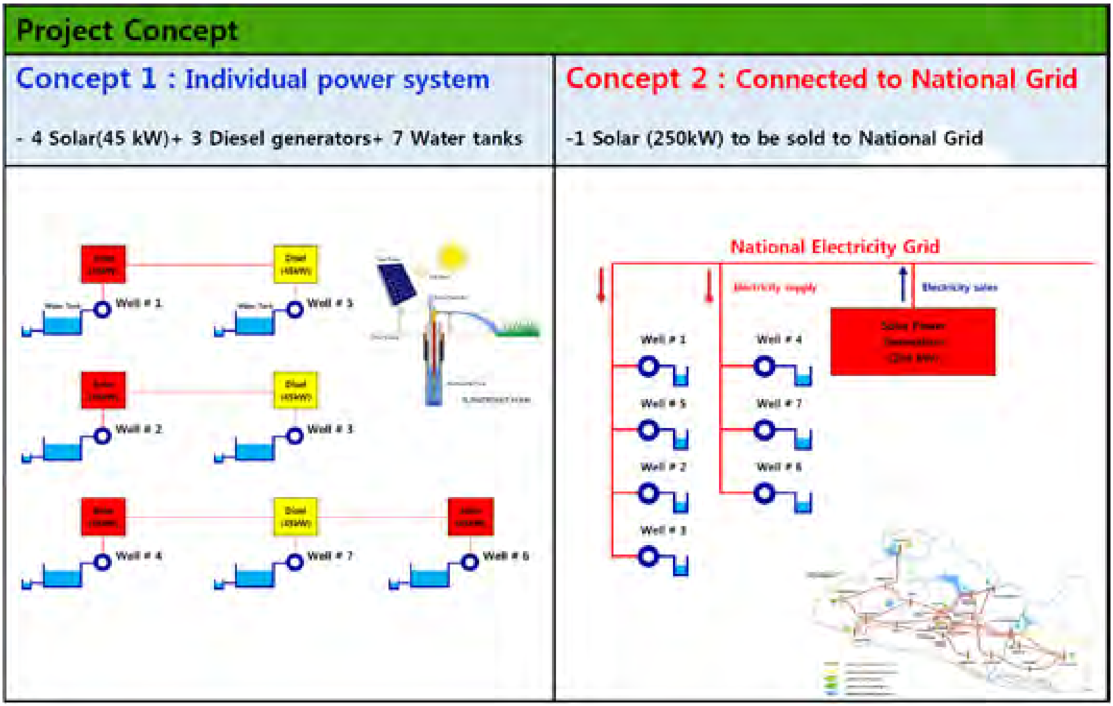

Figure 4: *Comparison of project models*

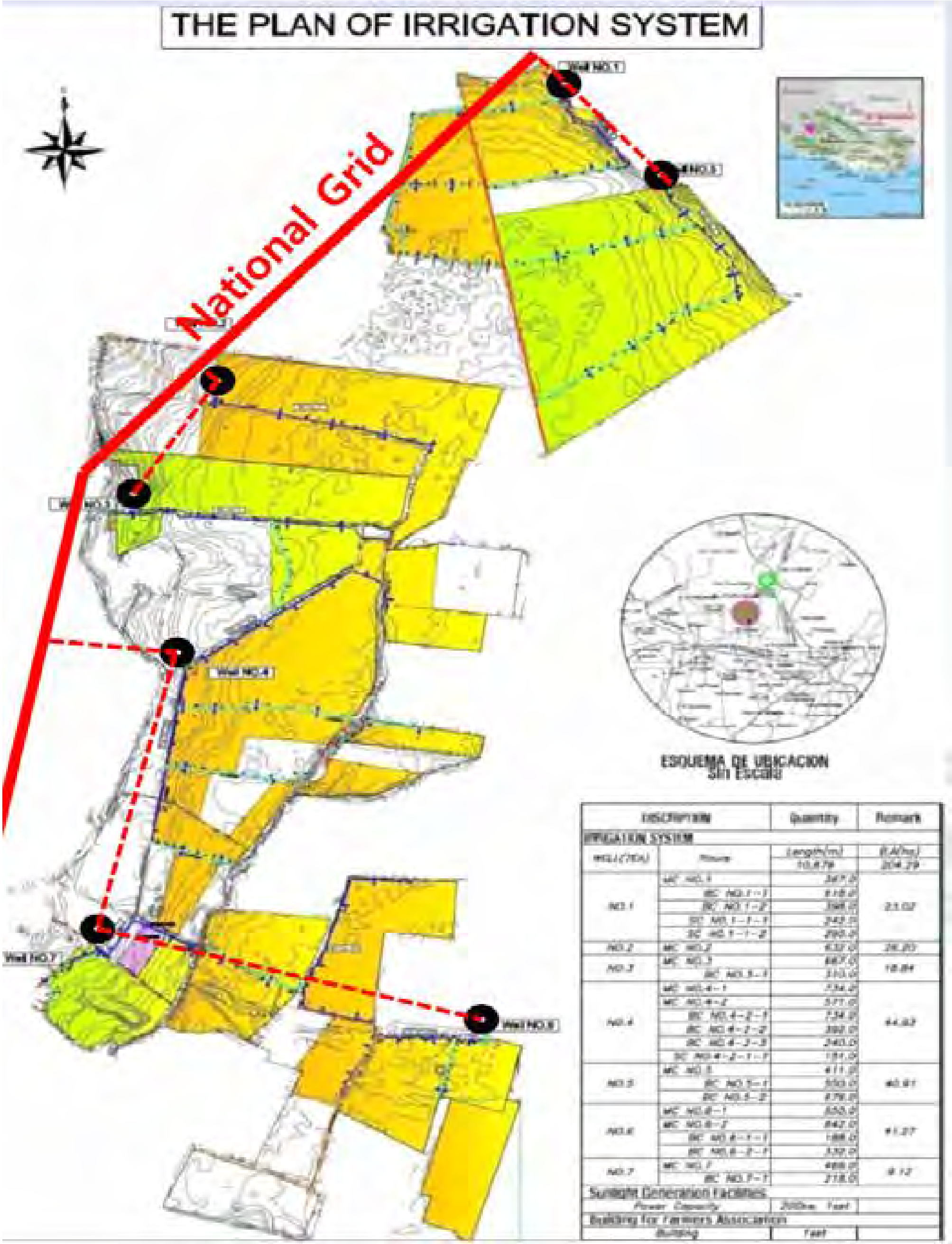

Figure 5: *Plan of irrigation system and national grid*

Model-1 is a type in which water pumped from the groundwater wells is stored in water tanks and supplied to the irrigation areas using electric power produced by independent solar power generation system and diesel generator. Model-2 is a type in which electricity produced by solar power system is connected to a nearby national electric grid, and water is pumped directly from the well to the irrigation area using electric power from the national grid only when necessary. Fig. 5 depicts a plan of irrigation system and national grid. The two models are economically feasible as B/C ratio of the first and the second models are 1.23 and 1.57, respectively (Table 2). Agricultural production increased by 1.5 times after the implementation of the project.

Table 2. *Economic analysis results*

Model 2	Cost (USD)			Increased production ($)	Remarks
	Total	Development	O & M		
Year 1	259,285	245,985	13,400	365,170	First Year
Year 30	2,861,000	2,459,000	402,000	10,955,112	Operating for 30 years
	Present Value of Cost : $1,871,865			Present Value of Benefit: $2,941,515	B/C = 1.57, NPV = $1,069,649

5. Project Outcome

5.1. Increased agricultural production and farmer's income

This project provided the revenue of solar power generation to farmers' union and minimized energy cost for supplying agricultural water by conserving electricity cost. Before project implementation, farmers could only do rice farming in rainy season resulting in low diversity of production and low income. However, the project implementation allowed farmers to farm not only in the rainy season, but also in the dry season which boosted large-scale farming, increased production, income, and crop diversity. Sufficient supply of irrigation water in dry season led to increase in agricultural production by 152% and farmer's income by 195%.

Table 2: *Cultivation area and production in El Porvenir*

Agricultural products	Before			After			Difference				
	Area (ha)	Product (ton)	Income ($)	Area (ha)	Product (ton)	Income ($)	Area (ha)	Product (ton)	%	Income ($)	%
Total	204	2,550	1,868,396	204	3,870	3,651,704	0	1,320	152	1,783,308	195
Rice	142	248	210,552	157	408	346,392	15	160	165	135,840	165

Water melon	50	2117	1,473,432	30	1905	1,325,880	-20	-212	90	-147,552	90
Maize	10	48	8,688	2	14	2,534	-8	-34	29	-6,154	29
Tomato	1	68	85,748	8	818	1,031,498	7	750	1,203	945,750	1,203
Cucum-ber	1	69	89,976	7	725	945,400	6	656	1,051	855,424	1,051

Figure 6: *Solar power generation facilities (Capacity: 250 kW)*

5.2. Project organizations

The farmers' union was composed of beneficiaries for the management of solar generation profit, maintenance of irrigation facilities and agricultural product planning. In order to coordinate and solve the problems among the stakeholders, Project Steering Committee (PSC) composed of officers from Ministry of Agriculture, KOICA El Salvador Office, and Project Manager (PM) was established (Fig. 7).

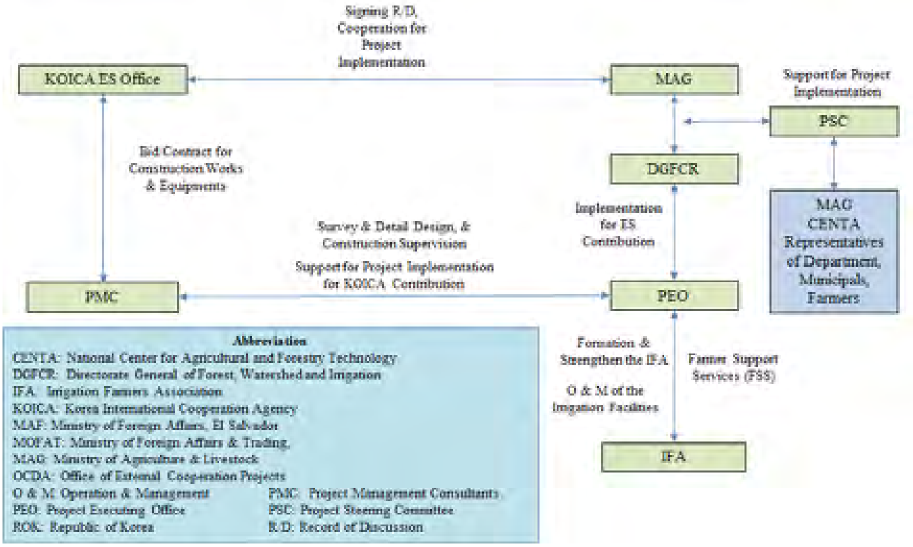

Figure 7: *Project Steering Committee*

The beneficiary farmers made a farmers' union that provided the necessary land for irrigation facilities to Ministry of Agriculture for free and actively engaged in farmer education and training (Fig. 8) for agricultural cultivation and quality improvement.

Figure 8: *Farmers' union training*

6. Conclusions

In many poor countries, agriculture is an important economic sector which usually accounts for 30% of the GDP and employs more than 60% of the total population. An irrigation system with solar power and groundwater can contribute to alleviate rural poverty in the areas with surface water and electricity scarcity. Furthermore, it is important to localize economical, sustainable and stable solar-powered irrigation systems considering the physical and natural environment.

Opportunities and challenges faced by emerging renewable energy-based lift-irrigation systems: A case study of hydro-powered irrigation pumps

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Abstract

About 1.6 billion people in the world live in areas of economic water scarcity, caused by lack of infrastructure to get access to water, despite having physical water resources available. Agriculture, inherently, is one of the most affected sectors, with economic water scarcity forcing farmers to depend on rainfall for agriculture purposes causing reduction in agriculture yield and productivity.

For surface water irrigation, traditionally large-scale infrastructure-based canal systems are used. However, such large-scale systems take extensive capital and time, especially in the context of developing countries. Furthermore, such infrastructures are also being scrutinized for environmental reasons (for dams and efficiency of water use by flood irrigation), and such discussions are further magnified by climate change.

Lifting (or pumping) systems are used as alternatives to such capital-intensive infrastructure. Conventionally, electric and fossil-fuel based pumps (diesel, kerosene, gasoline) are used in such lifting systems. Whereas lack of access to electricity is the main barrier for electric lifting systems, fossil-fuel based pumps are notorious for high operation costs of fuel and frequent maintenance. In addition, such fossil-fuel based pumps are highly polluting, a major concern from the environmental perspective.

As an alternative to these conventional solutions, renewable energy-based lifting systems (solar, wind, hydro) are emerging in the irrigation sector. This paper sheds light on the existing scenario of renewable energy-based pumping solutions, taking the case of hydro-powered pumps. The paper is based on the experience of researching, developing and implementing hydro-powered pumps for irrigation in Nepal and ten other countries across the world.

Hydro-powered pumps are being developed for two distinct scenarios: for creating access to irrigation and for enabling water-efficient pressurized irrigation techniques such as drip systems from irrigation canals. Intermittent availability of solar and wind power, causes low reliability with such irrigation systems, in addition to need for maintenance, especially in rural areas. Hydropower is available 24/7 and can be converted to pumping power with-

out any electronic or electrical components, reducing need for repair and maintenance. Due to this, hydro-powered pumping has been identified as the most cost-effective lifting system.

This paper use cases, experiences and lessons learnt from implementation of the hydro-powered pumps in Nepal and compares similar experiences from other countries. Additionally, the paper analyses and presents comparative strengths and weaknesses of conventional as well as renewable energy-based pumping solutions. Furthermore, the paper also discusses practitioners' perspectives on dilemmas in implementation of renewable energy-based systems across different factors such as crop selection, community versus individual approach, market-based mechanism versus public support mechanism and developing for existing irrigation practices versus emphasizing change in irrigation habits and practices to suit such technologies. Finally, the findings are generalized for all renewable energy-based technologies and the challenges and opportunities during scaling up of these technologies.

Keywords: *energy; hydropower; lift-irrigation; pumping; renewable; technology*

1. Background

About 1.6 billion people in the world face 'economic' water scarcity (FAO, 2016). It means there is physical availability of water, but people cannot access it for productive use for economic reasons. And agriculture accounts for 70% share in the total water withdrawal from the economically available water sources in the world (FAO, 2016). Furthermore, in the developing countries such as Nepal, water withdrawal share in the agriculture sector is even higher, i.e. 98.2% (FAO, 2016). Agriculture, inherently, is one of the most affected sectors, with economic water scarcity forcing farmers to depend on rainfall for agriculture purposes causing reduction in agriculture yield and productivity.

Only about 20% of the total cultivated land in the world is irrigated and areas without proper irrigation have significantly lower yield and productivity compared to the irrigated ones(International Renewable Energy Agency, 2016). With the increasing population, the need for increase in food production is becoming inevitable, for which the share of irrigated land needs to be significantly increased. However, increase in irrigated land requires an enormous increase in the amount of water and energy, which ultimately challenges the energy and water security issues in the world. Thus, it is important to increase access to irrigation in a sustainable manner, without causing significant increase in water and energy usage.

The source of water for irrigation purposes in the agricultural sector is available in two forms, i.e. surface water (for example, rivers, canals, ponds) and ground water. In Nepal, 80% of water for agriculture is withdrawn from surface sources, followed by groundwater (19%) (FAO, 2016).

For surface water irrigation, traditional approach was the use of large-scale infrastructure-based canal systems. However, such large-scale systems take extensive capital and time, especially in the context of developing countries. Furthermore, such infrastructures are also being scrutinized for environmental reasons (for dams and efficiency of water use by flood irrigation), and such discussions are further magnified by climate change.

Lifting (or pumping) systems are used as alternatives to such capital-intensive infrastructure. Conventionally, electric and fossil-fuel based pumps (diesel, kerosene, gasoline) are used in such lifting systems. Whereas lack of access to electricity is the main barrier for electric lifting systems, fossil-fuel based pumps are notorious for high operation costs of fuel and frequent maintenance. In addition, such fossil-fuel based pumps are highly polluting, a major concern from the environmental perspective.

Across 300 million ha (Mha) of irrigated land globally, 62 Terra Watt-hour (TWh) of energy is used annually in pumping irrigation water alone (UNESCO, 2014) (Australian Renewable Energy Agency, 2015), which is equivalent to the total electricity consumption of Singapore in 2014. This shows that, pumping is one of the major energy users in the irrigation sector.

As an alternative to these conventional solutions, renewable energy-based lifting systems (solar, wind, hydro) are emerging in the irrigation sector. Although there are lots of numbers and qualities that explain/validate the applicability and economic viability of the renewable energy-based technologies, they have not quite managed to get a huge breakthrough in the mainstream irrigation sector. Thus, they have a very small fraction of share in the overall mix of the irrigation systems used throughout the agricultural sector.

Whereas electricity production from hydropower has been exploited on a large scale, direct conversion of hydropower to pumping has remained largely unexplored, even though it is proven to be the most cost-effective renewable energy source for pumping water (FAO, 1986). In general, with the term hydro-power, the first thing that comes in our mind is electricity generation. And, when pumping water from the flowing source of water to the fields at certain elevation, people think of using electric pumps for irrigating their fields. However, there is possibility of harnessing the hydropower for direct end use, i.e. pumping, eliminating efficiency losses in electricity generation and transmission, eventually reducing the operating cost of irrigation.

2. Introduction to Hydro-powered Pumps

Hydro-powered pumps utilize the energy of flowing water/stream without any external fuel or electricity to pump water to an elevated region. Hydro-powered pumps directly convert the energy present in flowing water sources to mechanical power for pumping, without conversion to electricity. And since they do not emit any harmful emissions, they do not affect the health of the people using it and are also environment friendly. Fig. 1 depicts different propulsion and pumping techniques of hydro-powered pumping.

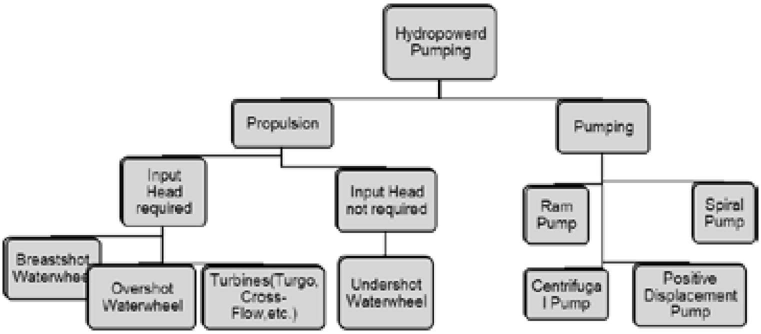

***Figure 1:** Different propulsion and pumping techniques of hydro-powered pumping*

In the irrigation sector, hydro-powered pumps are generally being developed and implemented in different parts of the world for two distinct purposes:

a) Creating access to irrigation
b) Enabling water-efficient pressurized irrigation techniques

2.1 Creating Access to Irrigation

The first purpose is to create access to water for various uses, such as irrigation. Barsha Pump, which is a water-wheel propelled spiral pump, is one such kind of hydro-powered pumpinstalled in various countries like Nepal, Indonesia, Colombia, and Panama for providing water for irrigation, sanitary and in some cases even for drinking water purposes.

2.1.1. Case Study I: Lele (Lalitpur district, Nepal) –*Fig. 2*

Farmer Type: Commercial Farmer

Area Irrigated: 0.5 hectares

Crop: Vegetables (tomato, cauliflower, cucumber, pumpkin)

Irrigation Method used: The water for irrigation is taken from a plastic pond storage located at the highest elevation of the field and distributed to each plot through a pipe network throughout the cultivated area.

Source of Water: Lele river with the available discharge of about 150 liters per second (lps)

Technology Used for Pumping: Hydro-powered Pump having breast-shot water wheel for propulsion and spiral pump for pumping.

Maximum Output Flow Rate: 30,240 liters per day. Water is pumped by the hydro-powered pump to the plastic pond storage.

Pumped Head: 11 meters. Elevation difference from the level of river to the point of plastic pond storage.

Mechanism of Payment: Pay per harvest: In this mechanism the farmer using the service of this pump is provided with the facility of paying for it periodically at the end of every harvest cycle. This removes the barrier for farmers to pay the upfront cost and matches better with the cash-flow cycle of farmers and makes renewable energy-based technologies competitive with fossil-fuel based systems. It also allows the farmers to get rid of the burden of paying a hefty amount upfront for acquiring the renewable energy technologies.

Figure 2: *Breast-shot waterwheel propelled spiral pump in Lele, Nepal*

2.1.2 Case Study II: Rauniyapur (Dang district, Nepal) –Fig. 3

Farmer Type: Semi-Commercial Farmer Group

Area Irrigated: 0.6 hectares

Crop: Vegetables and Fruits (watermelon, cucumber, pumpkin, etc.)

Irrigation Method used: Pumped water is distributed with hose for river-bed farming.

Source of Water: Rapti River with an available discharge above 2000 lps.

Technology Used for Pumping: Hydro-powered Pump having under shot water wheel for propulsion and spiral for pumping.

Maximum Output Flow Rate: 40,000 liters per day.

Pumped Head: The elevation difference from the level of river to the topmost point of overhead plastic tank is 5 meters.

Mechanism of Payment: Subsidy: The price of the technology is subsidized by a Non-Governmental Organization and provided to the marginal farmers doing river-bed farming. The farmer bears labor contribution required during the installation of the technology and a fraction of the total cost of the implementation of the technology.

Figure 3: *Under-shot water-wheel propelled Spiral pump*

2.1.3 Case Study III: Sumba (Indonesia)

Farmer Type: Transition from Subsistence to Commercial Farming after installation of irrigation device

Area Irrigated: 0.3 hectares

Crop: Vegetables (shallots, tomato)

Irrigation Method used: Water pumped to concrete tank or directly coupled to sprinkler

Source of Water: Kalu River with the available discharge of about 300 lps.

Technology Used for Pumping: Hydro-powered pump having under shot water wheel for propulsion and spiral for pumping.

Maximum Output Flow Rate: 30,240 liters per day. Water is pumped by the hydro powered pump to the concrete tank.

Pumped Head: 9 meters. Elevation difference from the level of river to the point of concrete tank is 9 meters.

Mechanism of Payment: Pay-per-harvest Mechanism

2.2 Enabling water efficient pressurized irrigation techniques

The second end use of hydro-powered pumps in irrigation is to enable water-efficient pressurized irrigation techniques, such as drip systems, without the use of external energy (fuel or electricity) for pumping (Fig. 4) and thus eliminating additional irrigation costs thereof. For this use scenario, the hydro-powered pumps are developed to utilize energy from irrigation canals and are used to modernize irrigation in lands which would otherwise have been flood-irrigated from the irrigation canal. Such type of hydro-powered pumps is being demonstrated in Spain for directly coupling the output of the pump to the drip system for water- and energy-efficient usage.

Figure 4: Visualization of hydro-powered pump enabling drip irrigation

2.2.1 Case Study IV: Andujar (Spain) –*Fig. 5*

Farmer Type: Commercial Farmer

Area Irrigated: 1 hectare

Crop: Olive trees

Irrigation method used: Drip irrigation directly coupled to the output of the pump.

Source of water: Secondary canal with flow rate of around 400 lps.

Technology Used for Pumping: Hydro-powered pump having under shot water wheel for propulsion and spiral for pumping.

Maximum Output Flow Rate: 34,560 liters per day.

Pumped Head: Elevation difference about 2 meters. The pressure for drip system at emitters is around 1 bar.

Mechanism of Payment: Upfront payment.

Figure 5: *Hydro-powered pump providing pressurized water to drip-irrigation for olive trees*

2.2.2 Case Study V: Lliria (Spain) (in construction) –Fig. 6

Farmer Type: Commercial Farmer

Area Irrigated: 10 hectares

Crop: Fruit trees (oranges)

Irrigation Method used: Drip irrigation, with 10 hectares of land divided into sectors of 1 hectare each

Source of Water: Canal with flow rate of 1400 lps

Technology Used for Pumping: Hydro powered Pump having hydrostatic pressure water wheel for propulsion and spiral for pumping.

Maximum Output Flow Rate: 400,000 liters per day. Output is directly coupled to drip system

Pumped Head: The elevation difference from the level of river to the point of plastic pond storage is 2 meters.

Mechanism of Payment: Upfront payment, with subsidy from the government

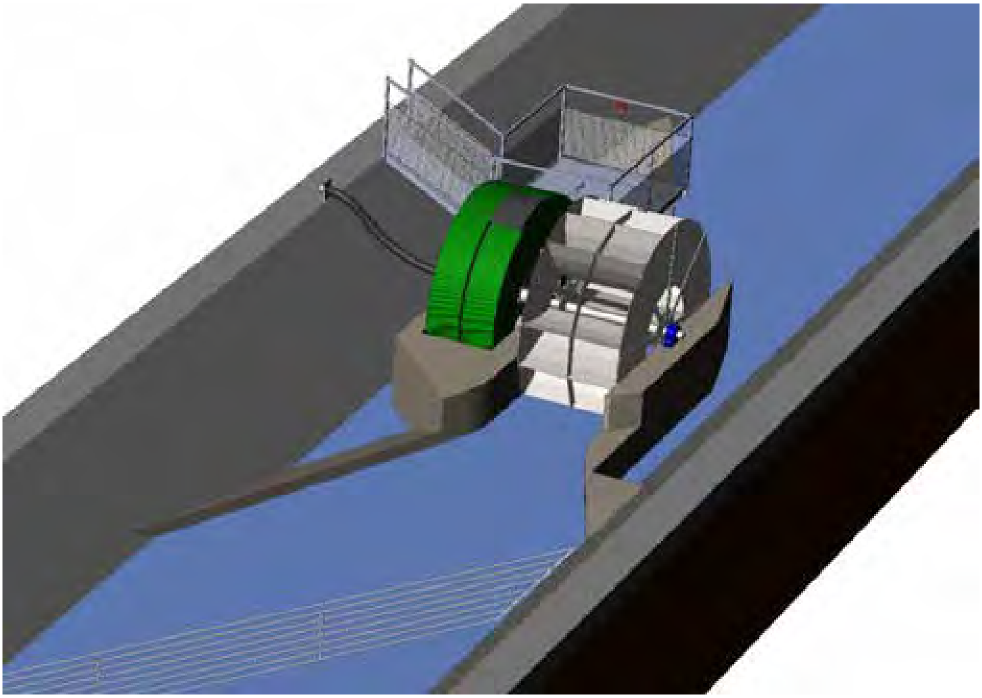

Figure 6: *Visualization of large-scale hydro-powered pump as infrastructure in a canal to deliver pressurized water for drip irrigation*

3. Comparison of Hydro-powered Pumping with Other Pumping Technologies

Most commonly used conventional pumps for agriculture are based on fossil fuel (diesel, gasoline or kerosene). In areas with electricity access, electric pumps are used. Renewable energy-based pumping devices are being developed as an alternative, the most common being solar pumps. In this section different conventional and renewable energy-based systems are analytically compared with each other and with infrastructure-based irrigation system and presented in Table 1.

3.1 Comparative analysis of different lift irrigation systems for 1 hectare

Fig. 7 depicts results of the comparative analysis. Fossil-fuel pumps usually require less upfront costs but are characterised by substantial operating and maintenance cost. Conversely, solar pumps are at least twice as capital intensive compared to hydro-powered pumps to purchase, but require low ongoing operation and maintenance, and have proven to have longer life cycles. Electric pumps have low capital cost and operating, and maintenance cost are lower than fossil-fuel based pumps. However, the investment in infrastructure to get access to (3-phase) electricity to farms is very high, or simply unavailable in rural areas.

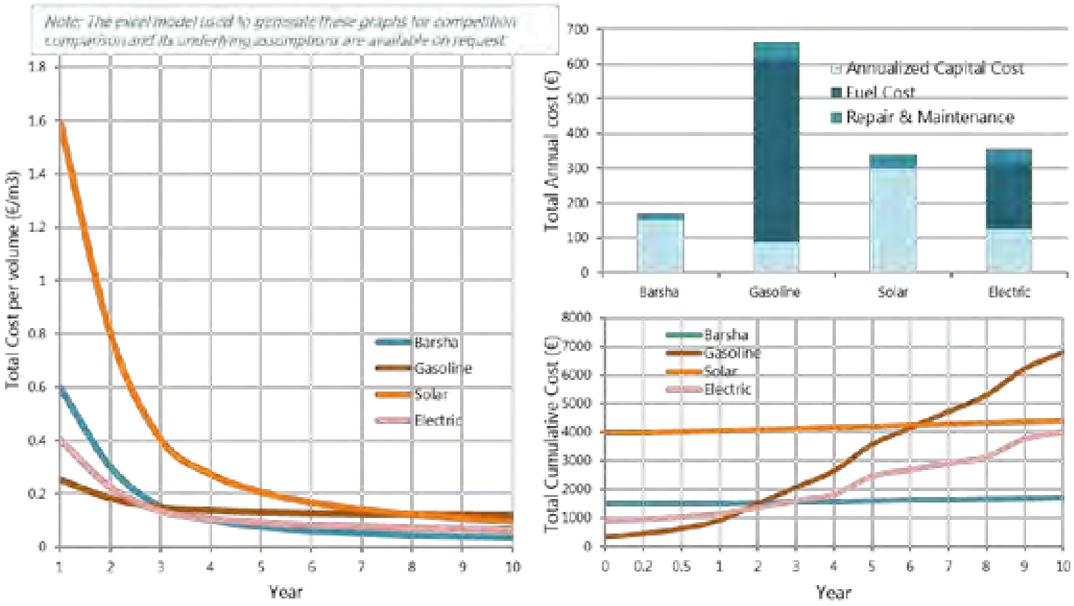

Figure 7: Different graphs comparing various lift-irrigation systems for 1 hectare

Parameters	Irrigation Systems					
	Infrastructure based Irrigation	Lift Irrigation				
		Conventional		Renewable		
	Canal	Electric Pump	Fossil Fuel Pump	Solar Pump	Wind Pump	Hydro-powered Pump
Upfront Cost	-Capital intensive and usually funded by government -Takes couple of years for planning and budget allocation alone and requires few more years for the construction of canals	-Relatively cheap option	Comparatively lower initial cost	Highest upfront cost compared to both conventional and renewable options	Costlier compared to other conventional and hydro-powered pump but a bit cheaper than solar	Relatively high compared to conventional lift irrigation system but cheaper compared to other renewable options
Operating Cost	-Since there is no need of fuel and electricity for the operation, no any direct operating cost is involved	-Extra demand charge is required to be paid in addition to the usage charge in case of 3-phase systems -usage charge per unit (kwh) significantly increases the operating cost of the electric pumping systems	-Cost of fuels for operation is quite high -Costs of transportation of fuel in rural areas	No operating cost	No operating cost	-No requirement of fuel, electricity or solar -Zero operating cost
Maintenance	-Yearly maintenance of the canal after every monsoon is required	-Electric pumps have a complex working principle and involves lots of electrical components -Heating and coil damage are the problems frequently encountered in electric pumps. -Requires skilled manpower for maintenance	-Higher cost involved in maintenance due to presence of valves, pistons, etc. -Change of lubricating oils in a periodic manner also adds to the cost -Skilled personnel required for maintenance. (Solar Electric Light Fund (SELF) , 2008)	-Relatively higher maintenance required compared to other renewable options because of the presence of electrical/ electronic components -Skilled manpower required for maintenance (Solar Electric Light Fund (SELF) , 2008)	-Relatively less maintenance required	- No electrical/electronic components present - No heating problem due to longer hour use -Relatively less maintenance required
Portability	Non-portable	-Portability is an issue because of the grid connections requirement, pump itself is portable	- Can be transferred from one site to another site easily	-Generally, not portable in case of ground water solar pumping system -few micro and nano solar irrigation systems are portable	-Generally, not portable as the wind turbine is fixed	- Can be transferred from one site to another site easily

Feasibility	-Needs to have a river which can be technically/economically diverted for water use -The cultivated field should be in a lower elevation compared to the level of canal	-Needs surface or ground water source with adequate quantity -Location with reliable electricity supply -The elevation difference of cultivated field with the source should be within the head capacity of the pump	- Needs surface or ground water source with adequate quantity -Availability of Petrol/Diesel Pump stations nearby - The elevation difference of cultivated field with the source should be within the head capacity of the pump	-Needs a place with good amount of solar irradiance - Limited delivery head - The elevation difference of cultivated field with the source should be within the head capacity of the pump	-Needs a place where wind speed is at least 8-10 km/hr for operation - The elevation difference of cultivated field with the source should be within the head capacity of the pump	-Needs a flowing source of water i.e. river/canal -If the water source is small, availability of input head also makes the site feasible - The elevation difference of cultivated field with the source should be within the head capacity of the pump
Usability/Suitability	-Suitable for flood irrigation	-Suitable for flood irrigation as well as modernized irrigation -extensively used for both surface and underground water pumping (Shah, Scott, Kishore, & Sharma, 2004)	- Suitable for flood irrigation as well as modernized irrigation -used mainly for surface and ground water pumping (Shah, Scott, Kishore, & Sharma, 2004)	- Mostly suitable for modernized irrigation - Suitable for farming in low lands -can be used for both surface water and underground water pumping (Shah, Scott, Kishore, & Sharma, 2004)	- Mostly Suitable for modernized irrigation - Suitable mostly for underground water pumping (International Renewable Energy Agency, 2015)	- Mostly Suitable for modernized irrigation -Suitable for surface water pumping
Environmental Perspective	-No emission -Dams are necessary for diverting water to the canal -Affects the aquatic biodiversity (Wildi, 2010)	-No emission -No dams required as in canals, so doesn't affect aquatic biodiversity -Environment friendly	-Emission is one of the greatest drawbacks of the technology -Health of the farmers is affected (Solar Electric Light Fund (SELF) , 2008)	-No emission -No dams required as in canals, so doesn't affect aquatic biodiversity -Environment friendly (K.Tiwari & R.Kalamkar, 2017)	-No emission -No dams required as in canals, so doesn't affect aquatic biodiversity -Environment friendly	-No emission -No dams required as in canals, so doesn't affect aquatic biodiversity -Environment friendly
Reliability/Predictability	-If there are large number of households in the community, there is a scheduled time slot for people to irrigate their fields	-Unpredictable power cuts often raise a question of reliability in the developing countries - Repairs need skilled manpower	- High need for repairs - Dependent on fuel supply (e.g- 4 months fuel shortage across Nepal in 2015)	-Performance depends on the intensity of the sunlight -operates only for around 6-7 hours a day (V.S.Korpale, D.H.Kokate, & S.P.Deshmukh, 2016)	-Performance depends on wind, thus not predictable (Campanaa, Lia, & Yanab, 2015)	-Since hydropower is available 24/7, it can deliver water continuously 24/7

4. Implementation of Hydro-powered Pumps in Nepal: Lessons Learnt

In the following section some of the experiences and lessons learnt from the implementation of hydro-powered pumps in Nepal are described briefly:

4.1 Hydro-power and agriculture are both highly variable

Hydropower availability as well as agriculture activities vary widely across different variables:

- Farm size
- Type of rivers: speed, depth, flow rate, availability of input head
- Type of crops
- Vertical head and distance required for pumping
- Type of irrigation system

Given these variables, different variants of hydro-powered pumps are needed to match the requirements for each case, as 'one size does not fit all', a complete portfolio of hydro-powered pumps must be developed to increase the applicability and compete with available solutions. Fig. 8 shows proportion of hydro-powered pumps installed in different water sources.

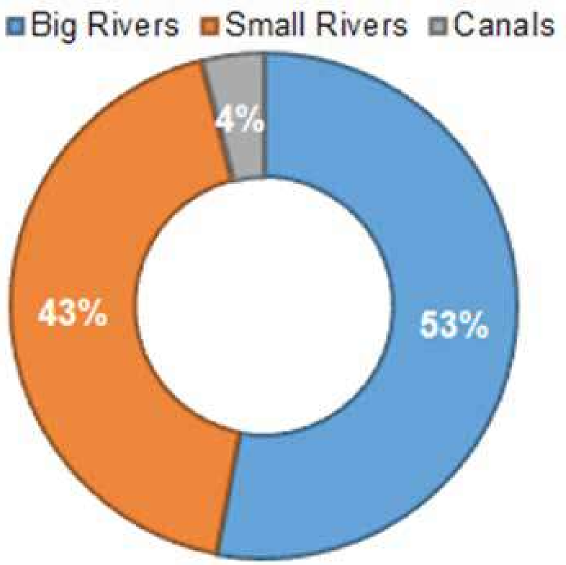

Figure 8: *Proportion of hydro-powered pumps installed in different water sources of Nepal (Source: aQysta)*

4.2 Perfecting an innovation is an iterative process and it takes time

Innovation is an iterative process, with constant iterations conducted to achieve a better product-market fit. In the context of hydro-powered pumps as well, the technology, design and capacity have evolved over time with constant feedback from the users and relevant stakeholders. The Fig. 9 depicts this process in terms of a timeline.

4.3 Bringing an innovation to the market, starting from a developing country

The general convention of technology transfer has been to transfer technologies that have been successfully implemented in developed countries to developing countries and focus on aspects such as cost reduction. In this case the hydro-powered pumps were first introduced to Nepal, at a piloting stage, before being implemented in any developed country, which was out of the general convention, thus difficult to find suitable policies and support structure in the country. The policies of Nepal are biased towards trading of proven technologies and fail to differentiate between technologies that can be

manufactured within the country with technologies that have to be imported. There is no organization or policy dedicated for developing innovations in Nepal, it is almost taken for granted that no new innovations will come from within Nepal, and all technological products will be traded from other countries.

***Figure 9**: Timeline of innovation process of hydro-powered pump (Source: aQysta)*

4.4 Innovations and government are not always compatible

Government is risk averse by nature, with bureaucracy involved in the decision-making process. This makes the diffusion of innovations, that depends on the government for its adoption, difficult. Whereas innovations would like to move fast to enter the market, the government takes an approach of 'wait and see' until the technology and its adoption is fully validated, even though the potential of the technology is clear. The validation process needs resources, which are difficult to secure, especially for the case where the innovation is being developed by a Small and Medium Enterprise (SME).

4.5 Economies of scale

It takes time for renewable energy-based technologies to compete directly with established solutions based on cost, because of economies of scale. The conventional solutions have existed for years, have been iterated and improved over time, and have developed the necessary infrastructure and supply

chain network, whereas all these must be rebuilt for renewable energy technologies. Fig. 10 below depicts how the costs per unit of hydro-powered pumps have exponentially decreased with different versions and can further decrease with new innovations. Thus, it would not be fair to compare innovative technologies vis-à-vis an established conventional technology, only based on cost, also the potential of the new technology must be considered.

Figure 10: *Graph showing decrease of cost of hydro-powered pumps with different versions from 2013 to 2017 (Source: aQysta)*

4.6 Non-governmental organizations as early adopters of innovative technology

In the context of developing countries (International) Non-governmental organization can be promising early adopters of innovative technologies, as they have the financial means and are less bureaucratic than the government. The challenge is that the budget of NGOs are tied to different programs and objectives, and there is little flexibility. Specially, there is not much budget allocated for hardware, which makes it difficult to allocate budget for pumps.

4.7 Demonstration of technology is critical

Demonstration of the technology is crucial and should be conducted as early as possible in the process so that all stakeholders involved have a clear expectation of the pump. Demonstration should not only focus on the technical aspects but also in the agricultural aspect so that the overall impact of

the technology is visible. The technology is judged by stakeholders not merely based on its technical performance but based on the overall visible impact by using the technology.

4.8 Seasonal business

Although the value of irrigation is clear, and the dry season is inevitable after the rainy season, the purchasing decision to invest in irrigation technologies are only made in the dry season, which makes it difficult to forecast the demand and have enough stock of the technology for the dry season.

4.9 Willingness to pay

People expect new technologies for 'free'. The reasons behind this might range from lack of purchasing capacity to the effect of NGOs distributing technologies for free and government subsidizing technologies. This tendency is especially applicable for irrigation technologies which is perceived as a public good, thus people expect the government to subsidize or even provide irrigation technologies for free. Since traditionally irrigation infrastructure is funded by the government, the same is expected also for new irrigation technologies. This poses a challenge for companies to rely on market-based mechanism. Having an innovative technology listed in the government's subsidy programs has its own challenges, as explained above.

4.10 Irrigator's preference to do '*ropain*' (rice plantation)

There was a clear trend that the value of irrigation was considered the highest for rice plantation. Whereas other crops such as vegetables provide higher economic value, the farmers clearly preferred an irrigation technology that would enable them to plant rice (paddy) on time, due to its subsistence value.

5. Differences and Similarities of Implementing Hydro-powered Pumps in Nepal and Spain

In this section some of the primary differences and similarities experienced in deploying hydro-powered pumps in different countries, compared to Nepal, are explained. The similarities and differences co-related well with the level of economic development of the country. Thus, most of the differences are explained with reference to Spain, which is an economically advanced country.

5.1 Differences

5.1.1 Availability of data

Availability of data about cropwater requirements, water requirements across different seasons, irrigation canals capacity and dimensions, flow rate of rivers and their fluctuations across different seasons, market prices of crops, land productivity and earnings from farming are crucial in designing new irrigation technology. Such data are almost non-existent in Nepal. Similar situation was experienced in other countries with similar economic status as Nepal. However, in Spain, all such data are well documented and easily accessible from different databases. Geographic Information System (GIS) databases are available for all irrigation canals, with data of constant monitoring of flow rate. Cropwater requirements could be found in databases and academic papers in the public domain.

5.1.2 Status of irrigation access

Status of irrigation access in a country is proportional, relative to the economic development status of the country. For example, in Spain, the priority has already shifted from access to irrigation to modernization of irrigation to save water with 70% of the irrigated lands already modernized, by being equipped with drip irrigation. Exact data of agriculture modernization in Nepal is not available but the proportion of agricultural lands with modernized irrigation is minimal.

5.1.3 Capacity and land-size

Whereas the average landholding in Nepal is 0.68 hectares (Central Bureau of Statistics, 2011), the average landholding in Spain is 24 hectares (European Commission, 2010). This difference in average landholding implies that the water demand is drastically different from that in Nepal. In terms of lifting head, Nepal demands higher head requirements than other countries where the pumps have been implemented due to the hilly terrain.

5.1.4 Priority of water savings

In Nepal, the priority is still in creating irrigation infrastructure to create access to irrigation. Sustainable and effective water is not yet a priority, either for farmer or at the policy level. However, in Spain, the government has made it mandatory to shift from flood irrigation to pressurized irrigation, to save water. Thus, the focus of hydro-powered pumps in Spain is also to enable pressurized irrigation, without the burden of electricity costs. Such differences in priorities is partly explained by the difference in annual precipitation in the country, as shown in the Fig. 11 below.

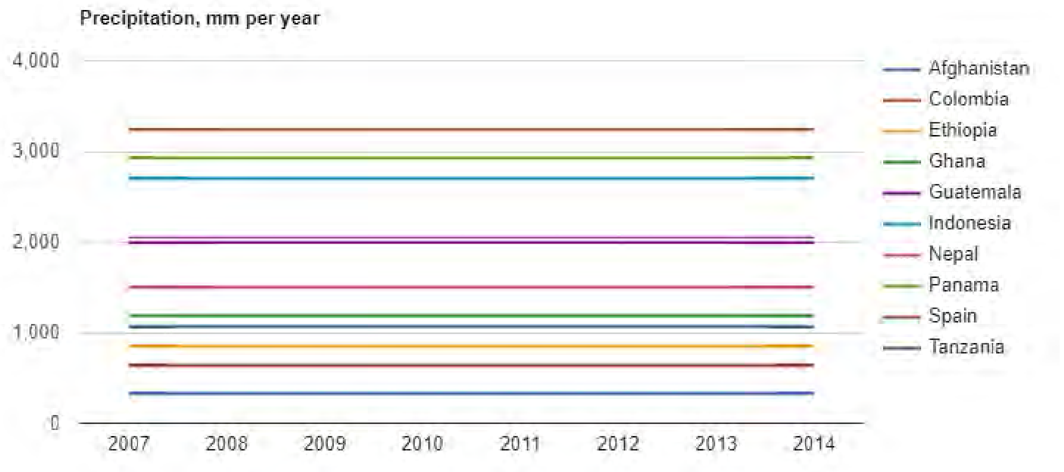

Figure 11: *Annual precipitation of different countries in mm per year (Source: TheGlobalEconomy.com, World Bank)*

5.1.5 Purchasing decision making

In Spain, purchase decision regarding irrigation technology is made in a centralized manner by irrigation communities, and the irrigation community members follow (more or less) the recommended solution. The irrigation community is generally looking for a common solution for the whole community. Irrigation communities are not well organized in Nepal, and purchasing decisions are generally made individually.

5.1.6 Status of commercial farming

Most of the farmers in Nepal farm for subsistence, whereas majority of farmers in Spain farm for commercial purposes. This difference in farming purpose defines a lot of purchasing behaviour and investment decisions made by these farmers and reflect on the economic status of such farmers.

5.1.7 Transparency in policies

Policies for irrigation modernization, including subsidy policies were found to be clear and transparent in case of Spain, with most farmers aware of the existence and nature of such subsidies. Furthermore, such policies were generally found to be long-term without major changes form one fiscal year to the other. In contrast, most of the farmers in Nepal are found unaware of government priorities, policies and subsidy facilities in the irrigation sector, and the duration of such policies are also found to be short-term, with irrational changes in each fiscal year.

5.2 Similarities

Despite of several differences, there are certain factors that were found to be similar in all countries both Spain and Nepal, where the hydro-powered pumps were implemented, thus far.

5.2.1 Farmers are risk-averse

Need for effective demonstration of new technology before adoption is a common factor in all the countries. Farmers are risk averse in nature, and hesitant to invest in new technologies, until fully proven and in most cases where the benefits are visible to their own eyes.

5.2.2 Middlemen take most of the profit, farming is less profitable

Across all the countries that the hydro-powered farmers are implemented, farmers have similar complaints regarding the agriculture value chain, that most of the profit goes to middlemen who take agricultural harvest to the consumers.

5.2.3 Higher upfront cost of renewable energy-based lift-systems – a barrier to scale

It is found common in all the countries that the higher upfront costs required for installation of renewable energy-based systems acts as one of the primary barriers for uptake of such technologies. Even though the technologies make sense in the longer term, farmers are reluctant to make such investments.

5.2.4 Reliant on government subsidies

The common factor that farming is not considered as a desirably profitable business in any of the countries, it implied that most of the farmers are resistant to invest in technology with long pay back periods and rely on subsidies from the government for investment in agriculture technologies. This means that new agriculture and irrigation technologies generally need to approach the government for mass-scaling and cannot do it fully on market-based mechanism.

6. Dilemmas in Scaling Renewable Energy-based Lift-Systems

6.1 Subsistence versus commercial farming

The need for irrigation is clearly bigger in subsistence farming, and the potential impact is also bigger, as in many cases farmers are simply depending upon rainfall. Cropping intensity as well as crop yield can be improved with access to irrigation. In commercial farming, most of the times, there is some irrigation solution under practice, which can be expensive to operate or polluting or having maintenance issues. Whether renewable energy-based systems should clearly prioritize and target either creating new market with subsistence farmers or the replacement market with commercial farmers is not straight forward. The Fig. 12 below shows the classification of different types of farmers where hydro-powered pumps have been installed so far.

6.2 Crop selection

Different crops have different water requirements, economic value and perceived value. In the early phases of new technology, it is difficult to have variants that are suitable for all scenarios. It is not obvious to make the choices, when setting the specifications for lift-irrigation systems. For example, based on economic value, vegetable and fruit crops have higher economic value, thus a lower payback period of irrigation technology, however, from farmers' perceived value, paddy is regarded as a much more important crop, even though it has a relatively lower economic value. Paddy requires significantly more water than vegetable crops, thus designing a system that fits both is a challenge. The Fig. 13 shows the end use of hydro-powered pumps installed to-date in Nepal by aQysta.

6.3 Community versus Individual approach

Should a new irrigation technology target to serve a whole community on a shared basis or should it be targeted towards serving the needs of an individual household, and thus be regarded as a private asset? This is a difficult question that is faced in implementing and designing new irrigation systems, with both community-based systems as well as privately-owned systems having its own pros and cons. Community based systems have the challenges of no ownership, lack of monitoring and maintenance, whereas privately owned systems have the challenges of lack of investment capability. Particularly in the case of irrigation systems, where water needs to be withdrawn from rivers or canals, which are public property, privately owned lift-system faces its challenges to be adopted.

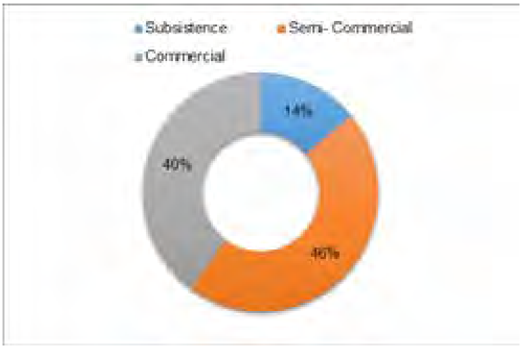

Figure 12: Classification of farmer in the installed hydro-powered pumps in Nepal

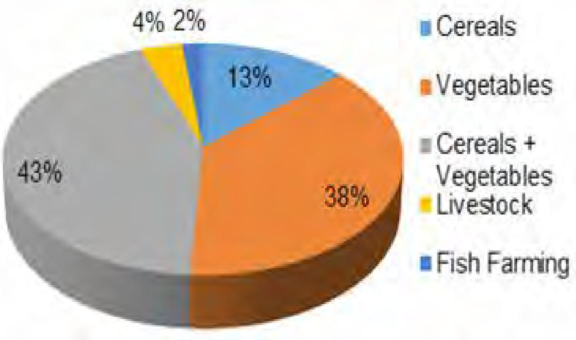

Figure 13: Classification of installations based on end-use of hydro-powered pumps in Nepal

Fig. 14 below shows the number of households per pump, for the pumps that have been installed so far in Nepal, and it further emphasizes the dilemma.

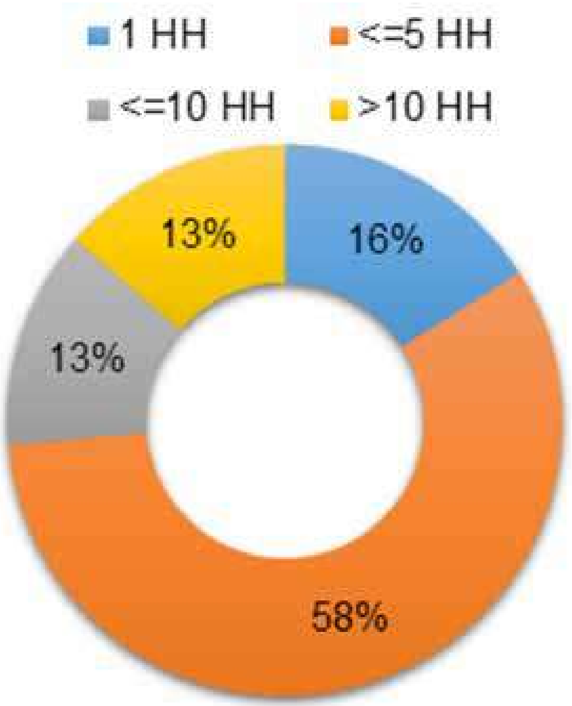

Figure 14: Classification based on number of beneficiary households per hydro-powered pump installed in Nepal

6.4 Market-based mechanism versus public support (subsidy) mechanism

As explained in the previous section, new irrigation technologies face a problem in choosing to scale with completely market-based mechanism or rely totally on public subsidy mechanisms. It is difficult for new technologies to enter government plans and policies, which makes relying on such mechanism for scaling always an uncertainty. On the other hand, as farmers expect irrigation technologies to be subsidized, it is difficult to develop a fully market-based mechanism. As the upfront costs of renewable energy technologies are higher than conventional solutions, even though they will be cheaper over the course of lifetime of the technology, it is logical to approach scaling renewable energy lift technology with financing facilities, however, access to such finance is difficult and the interest rate is usually quite high, creating a barrier for such mechanism.

6.5 Designing for existing irrigation habits versus emphasizing change in habits

The existing irrigation habits of farmers are not always sustainable. Many times, the habits are formed based on the characteristics of the conventional water pumps. Since the conventional pumps deliver a higher flow rate, but do not operate for long hours, farmers flood their lands for a short period of time using these pumps. With hydro-powered pumps, the water is available 24/7 but at a lower flow rate per second, which is better from the plants' perspective but does not match with irrigation habits of farmers. Using drip irrigation or using storage to store water is environmentally beneficial, but it is sometimes difficult to convince the farmers. Thus, the dilemma is whether to emphasize such change in habits or rather design the specifications for existing irrigation habits.

6. Conclusion

From case of hydro-powered pumps, it is apparent that some of the challenges and opportunities can be extrapolated to other cases of renewable energy-based lift irrigation systems. While the developing countries are primarily focusing on increasing access to irrigation, the developed countries who have solved the access part, are prioritizing modernizing irrigation for sustainable use of water resources. Creating access to irrigation as well as for modernizing irrigation, energy is a major factor. For sustainable water and energy usage, it is adamant that there must be a shift from conventional canal infrastructure and fossil-fuel based systems to renewable energy-based systems.

However, renewable energy-based systems face some challenges to be overcome, before they can rapidly scale to replace the conventional systems. All renewable energy-based systems have upfront costs higher than conventional fossil-fuel based systems. This is due to different factors, such as being relatively new technology, additional components and accessories, and mostly due to lack of economies of scale, which the fossil-fuel based systems have already achieved.

As compared to the existing conventional solutions, renewable energy-based systems have the disadvantage of low production volume, requirement to create new supply chain and distribution network, and comparatively lower demand due to lack of awareness of such technologies. Furthermore, the understanding of irrigation technology as a public good, means that farmers expect subsidies from the government to cover at least part of the cost of such technologies. However, the government, in general, is also risk averse in adopting innovative technologies, which increases the challenge to upscale renewable energy-based systems.

In some cases, where favourable government policies are made, renewable energy technologies lobby to frame such policies in favor of a particular renewable energy, rather than making it applicable it for all renewable energy-based systems. This tendency creates a barrier for innovative and potentially more effective renewable energy-based systems to emerge. Combined, these factors have impeded the pace of upscaling the renewable energy-based pumping systems.

As a conclusion, it is critical for the government and actors providing renewable energy-based lift systems to collaborate and co-operate with each other in a public-private partnership, to increase the speed and volume of uptake of such systems. Furthermore, actors within the renewable energy sector must also collaborate with each other and combine efforts to lobby for favourable policies without discrimination between different renewable energy technologies. This will help increase the share of renewable energy-based systems in the overall lift irrigation sector.

References

Australian Renewable Energy Agency. (2015). *Opportunities for Renewable Energy in Australian Water Sector.*

Campanaa, P. E., Lia, H., Yanab, J. (2015). Techno-economic feasibility of the irrigation system for the grassland and farmland conservation in China: Photovoltaic vs. wind power water pumping. *Energy Conversion and Management, 103*, 311-320.

European Commission. (2010). *Eurostat.* Retrieved 2018, from http://ec.europa.eu/eurostat/statisticsexplained/index.php/File:Key_farm_variables,_2010_AgriPB13.png

FAO. (2016). *AQUASTAT.* Retrieved January 2018, from http://www.fao.org/nr/water/aquastat/

International Renewable Energy Agency. (2015). *Renewable Energy in the Water, Energy and Food Nexus.*

International Renewable Energy Agency. (2016). *Solar Pumping for Irrigaiton: Improving Livelihoods and Sustainability.* IRENA.

Tiwari, A.K., Kalamkar, V. R. (2017). Effects of total head and solar radiation on the performance of solar water pumping system. *Renewable Energy*, 118, 919-927.

Renewable Energy Network for the 21st Century. (2015). *Renewables 2015, Global Status Report.*

Shah, T., Scott, C., Kishore, A., Sharma, A. (2004). *Energy-Irrigation Nexus in South Asia: Improving Groundwater Conservation and Power sector viability.* International Water Management Institute.

Solar Electric Light Fund (SELF) (2008). *A cost and reliability comparison between solar and diesel pumps.*

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2014). *The United Nations World Water Development Report.*

Korpale, V.S., Kokate, D.H., Deshmukh, S.P (2016). Performance Assessment of Solar Agricultural Water Pumping System. *Energy Procedia*, 90, 518-524.

Wildi, W. (2010). Environmental hazards of dams and reservoirs. *NEAR Curriculum in Natural Environmental Science.*

World Bank. (2015). *The Global Economy.* Retrieved January 2018, from http://www.theglobaleconomy.com/compare-countries/

Solar powered irrigation pumps as a clean energy solution for Nepal Terai

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Abstract

Nepal's Terai has an estimated renewable dynamic groundwater reserve of 8800 million cubic meters (MCM) of which only 1053 MCM (12%) has been tapped so far for irrigation, industrial and drinking water purposes. In spite of abundant water resources in the plains, farmers are facing water scarcity due to lack of affordable and clean energy to pump water. Lack of access to affordable and reliable irrigation means that farmers often leave a large part of their land fallow. Solar powered irrigation pumps (SPIPs) have been tested widely in the region and has been found to be a technically proven and workable solution for all categories of farmers – men and women. This new technology can prove to be instrumental in addressing food security through increased agricultural production. ICIMOD piloted three SPIPs in Saptari district in August 2015 and they have been operating since then. Cumulatively, three SPIPs have been operated for 2556 hours from August 2015 to December 2017 and irrigated 18.2 ha of land in 2015-16 after SPIP compared to 14.1 ha in 2014-2015. The yearly savings in diesel amounted to about USD 1,000 in 2015-16. Overall, the gross and net irrigated area rose by 29% and 30% respectively in 2015-16. We also noted increase in the cultivation of dry season vegetables and an increase of the number of water users, from 9 to 23.

Keywords: *clean energy; irrigation; Nepal; solar-powered pump; Terai*

1. Introduction

Solar powered irrigation pump (SPIP) is a clean technology that lifts water and provides means of irrigation to farmers. SPIP is considered to be a reliable technology for agriculture water management. SPIP provides a wide range of benefits that align with climate smart agriculture. Climate smart agriculture (CSA) can be defined as an approach for transforming and reorienting agricultural development under the new realities of climate change (Lipper et al., 2014). The Food and Agricultural Organization (FAO) defines it as agriculture that sustainably increases productivity, enhances resilience, reduces greenhouse gases (GHGs) and enhances achievement of food security. SPIP helps in achieving all of these as a clean

solution to irrigation. Firstly, it does not require electricity or diesel for operation which reduces the costs of irrigation. The zero marginal cost for each additional unit of water provides incentives for the farmers to increase their cropping intensity. This has the effect of increasing agricultural production in turn improving the food security status of the farmers. Second, SPIPs reduce GHGs from agriculture production and also reduces local short-lived climate pollutants such as black carbon due to decrease in diesel usage.

SPIP is a proven technology for pumping water (Chandel et al., 2014; Sontake and Kalamkar, 2014). In the context of South Asia, the technology for pumping water is in different stages of implementation. It seems widespread in India and Bangladesh with Pakistan and Nepal following suit. Majority of these pumps utilize groundwater for irrigation. Bangladesh has established a fee for service model in which companies or non-governmental organizations (NGOs) can avail subsidies provided by the government and charge farmers a rate based on their irrigation requirement. India has mainly followed a high subsidy-led models for uptake of SPIP. In Nepal, till recently, there was no provision of subsidy for SPIP except for drinking water, though this has been changed recently with 60% subsidy announced for SPIP. There is a prevalence of NGOs piloting demonstration projects to showcase the technology and test its effectiveness. In Pakistan, a majority of SPIP owners have purchased the systems in full cost as a result of absence of a national level policy provision. In terms of accessibility, the beneficiaries of SPIP tend to be medium to large farmers in both India and Pakistan (Ali et al., 2016; Shah et al., 2013). Contrary to this, Bangladesh leads the way in benefitting small holding farmers by devising an innovative financial model (Hossain et al., 2014).

It is the purpose of the paper to shed light onto the potential of SPIP as a clean energy source for pumping water for irrigation in Nepal Terai by analyzing the groundwater situation and the viability of the technology to be 'climate smart'. More importantly, we examine whether the piloted SPIP systems have benefited the farmers in terms of agricultural yield and irrigated area with the use of some primary data collected from our pilot sites in Saptari, Nepal.

2. Groundwater Situation in Nepal Terai

Groundwater is an essential source of water for irrigation in the Terai region of Nepal. It has become increasingly important in the agriculture sector since the advent of tube well technology in the early 1970's. Since 1980, there have been groundwater irrigation development programs launched by the Government of Nepal that also provided various forms of subsidies. Shallow tube wells have been a mainstay when it comes to many rural development programs through the government. Groundwater irrigation had been placed under a high priority as per the Agricultural Perspective Plan (APP) with a target to irrigate the Terai fields through groundwater in a 20-year period (1995-2015). According to Kansakar (2006), there were close to 800,000 shallow tube wells that have been constructed for fetching drinking water as of 2006. However, a similar growth has not happened in the case of irrigation shallow tube wells despite the 20 years of government subsidy programs from 1980 to 2000 (Kansakar, 2006).

In the year 2000, out of a potential of irrigating 612,000 ha, only 206,000 ha of the Terai landscape was irrigated with groundwater through the use of 60,000 shallow tube wells and 1,050 deep tube wells. Similarly, as of 2006, there was 1,337,000 ha of irrigable agricultural land in the Terai. However, only 1,121,000 ha (84%) was under irrigation. Additionally, out of this land under irrigation, only 206,000 ha (18% of the total irrigated land) was under irrigation by groundwater (Kansakar, 2006). There are groundwater resources enough to irrigate one-half of the agricultural land in Terai. (Kansakar, 2006).

Furthermore, according to the Groundwater Resources Development Board (GWRDB) of Nepal's website (as acquired in June 2017), the Terai region has dynamic groundwater reserves of 8800 Million Cubic Meters (MCM) of which only 1053 MCM is used for drinking, irrigation and industrial purposes. This implies that there is utilization of only about 12% of the dynamic groundwater reserves. In addition to this, groundwater sources have emerged to be the major source of irrigation in Terai. As shown in Fig. 1, percentage of agricultural area irrigated by groundwater source is the highest as per the CBS (2015) – an increase from 18% to 40% of the total land irrigated by groundwater:

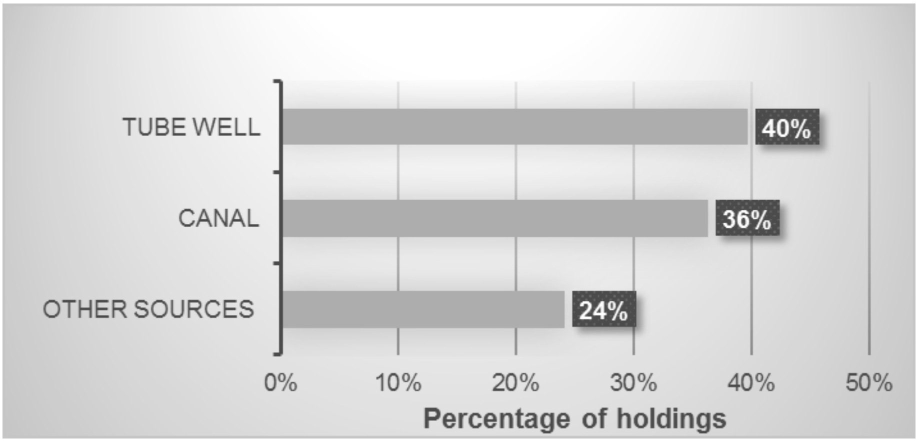

Figure 1: *Percentage of agriculture area irrigated by various sources in Terai (Source: CBS, 2015)*

Despite groundwater being the most important source of irrigation in Terai, a large amount of the resource is still underutilized. Moreover, although the groundwater is the most common means of irrigation, pump ownership is low. On an average, only about 16% of the households in the Terai region own pumps and use it for agricultural purposes. This can be illustrated by Fig. 2:

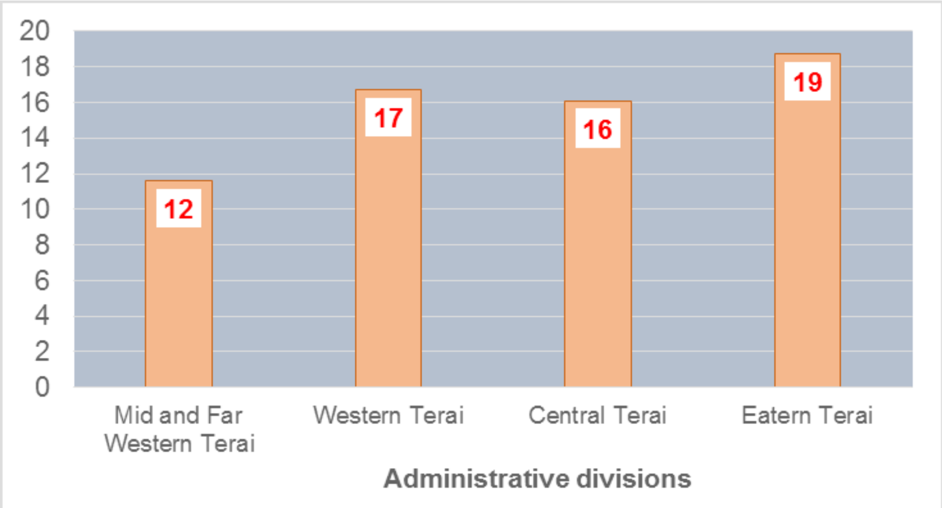

Figure 2: Percentage of agricultural households owning pumps (Source: CBS, 2011)

The high cost of diesel proves a hindrance in operating the most common form of water extraction mechanism i.e. diesel pump. The untapped groundwater reserves and the existence of fewer pumps for irrigation provides an opportunity for a potential entrance of SPIPs that can benefit the farmers in the region. This would be an environment friendly option that would be both sustainable and climate smart when it comes to its operation.

3. SPIP Studies in South Asia

There are only a few experimental studies that have dealt with the impacts of SPIP in the farmers' fields in terms of agricultural yield and energy savings. These studies, in turn, help in providing evidence of the effectiveness of the technology as a climate smart option to sustainably increase agricultural yield and save energy.

We highlight three studies in particular in South Asia that address agricultural impacts of SPIP in experimental or quasi-experimental settings. Two of the studies are based in India and one is based in Pakistan. Kishore et al (2017) and Kishore et al (2014) conducted a post implementation survey of SPIPs in Bihar and Rajasthan respectively. In the Bihar study, the authors analyzed within-farmers' analysis of gains from utilizing SPIP using treatment – control analysis where their treatment group were farmers utilizing SPIP and the control group consisted of farmers whose plots were adjoining to the command area of the pump. Similarly, the Rajasthan implemented before-after methodology to measure the impacts of the technology for SPIP owners. The study done in Pakistan identifies and analyzes factors that influence farmer's adoption of traditional water pump or alternate energy pumps and its impact on the yield of cereal crops using a propensity score matching methodology.

3.1 Agricultural productivity in these studies

It can be seen that all of these studies report an increase in agricultural yield as a result of the implementation of SPIP systems for irrigation (Table 1). As per the data collected during 2012-13, the studies deal with different types of crops and shows an overall favorable increase in yield. The crops in the studies consisted of wheat, paddy and orchard cultivation. The yield increase in each of the studies are reported below with the exception of the study done in Pakistan where the yield increase could not be disentangled between the pumps used (diesel, solar and bio-diesel pumps).

Table 1: *Yield change for SPIP*

Study	Crops	Increase in Yield	% change
Kishore et al (2017)	Paddy and Wheat	Yes	9 to 11% increase in paddy and wheat cultivation respectively
Kishore et al (2014)	Orchard cultivation	Yes	5 to 10%
Ali et al. (2015)	Wheat, rice and maize	Yes	NA

3.2 Energy savings in these studies

In terms of energy costs, cost savings as a result of decrease in diesel use has been regarded as the main impact of SPIP use instead of tradition diesel pumps for irrigation. This, in turn, has improved not only the financial standing of the farmers but also decreased the pollutant released as a result of the operation of diesel pumps.

In cost terms, both studies done in India point to high savings on diesel. On an average, a solar pump owner is expected to save diesel worth USD 762to USD1031 in one crop year depending on the pump replaced and cultivation patterns. The energy savings for each study are listed in Table 2.

Table 2: *Energy savings for SPIP*

Study	Crops	Savings in diesel	USD ha^{-1}
Kishore et al (2017)	Paddy	Yes	52.5
	Wheat	Yes	36.7
Kishore et al (2014)	Orchard cultivation	Yes	N/A

[1]Author's calculations

4. Primary Observations from Pilot Sites

Three SPIP systems were installed in selected pilot sites on August 2015 in the Saptari district (Fig. 3) to make the farmers in the region more familiar with the technology and enable them to assess its performance first-hand in the community. In addition to showcasing the technology to the community, this also provided us with an opportunity to assess the SPIP systems in terms of its use as a sustainable and clean energy solution to replace diesel pumps. In order to do this, we observe indicators like agricultural yield, irrigated area, diesel pump hours used and savings, and compare them before and after the installation of SPIP systems.

The SPIP systems were provided to three different users with varied specifications to test the systems in these environments. Two 1 HP SPIP systems were provided to a woman farmer in Rayapur and a farmer cooperative in Haripur respectively. They were using diesel and electric pump for irrigation. Additionally, a 2 HP SPIP system was provided to a water seller in Hardiya who was also using diesel and electric pump prior to the introduction of SPIP. Apart from the above variations, the SPIP systems were provided to the farmers who would be able to make the most use of it. In this context, the requirement from the pilot sites were:

- Farmer/ farmer cooperative should have a sufficient command area for the system to be showcased.
- Vegetable production should be practiced in the plot during summer. This would ensure full utilization of the system's capacity.

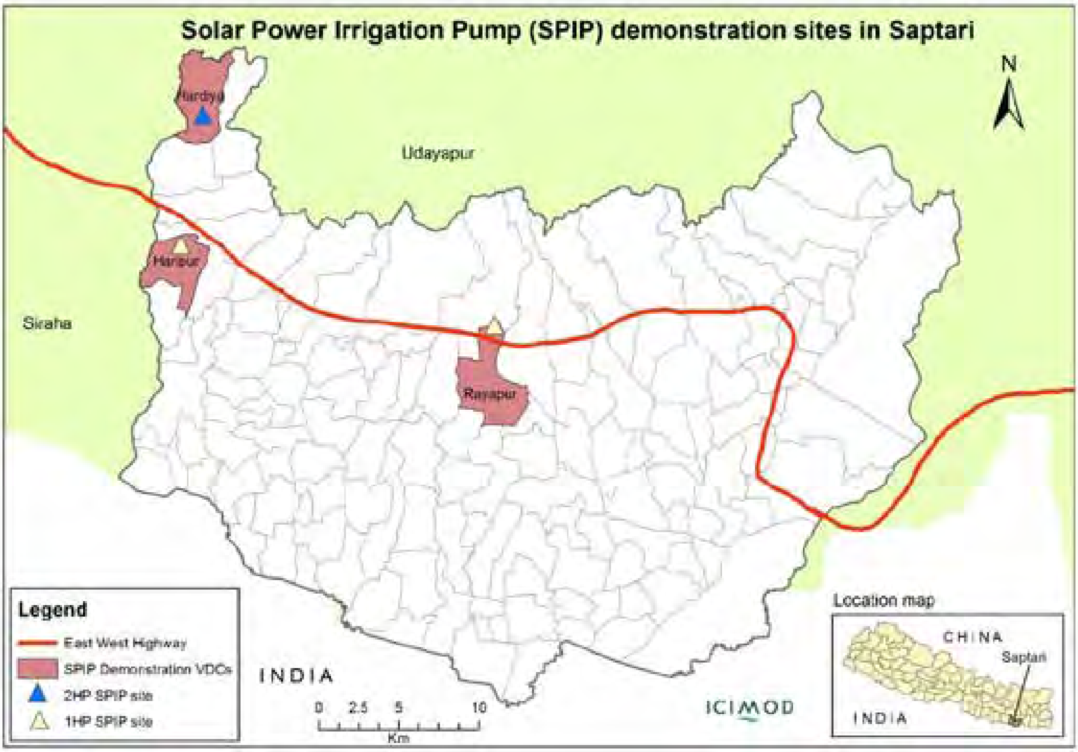

Figure 3: SPIP demonstration sites in Saptari

4.1 Observations from Haripur

The first pump was provided to a farmer co-operative in Haripur Village Development Committee (VDC). In this site, riverbed farming is being practiced. A group of twenty landless farmers were allocated land for cultivating summer vegetables. The group was formed by HELVETAS and Forward Nepal, two NGOs whose role is to provide technical expertise for the farming activities. The group was only a year old and had leased land from six farmers.

These six farmers are members of a farmers' association Nabajagriti Krishak Sahakari Samuha. Before the introduction of SPIP, the farmers rented a diesel pump of 4.5 HP from the association for irrigating the plot. A charge of NRS150 per hour ($1.5 USD approximately) is paid for the cost of renting the pump (inclusive of the cost of diesel). The total area command area for the pump is three and half *Bighas* (2.4 hectares). Table 3 details the cultivation pattern before and after SPIP in Haripur.

Table 3: *Cultivation patterns before and after SPIP in Haripur*

Indicators	Before SPIP (2014-15) (in Hectares)	After SPIP (2015-16) (in Hectares)	After SPIP (2016-17) (in Hectares)
Hours of irrigation (annual)	253	678	428
from diesel	253	22	21
from electric	0	0	0
from SPIP	0	656	407
Area under irrigation (total)	3.04	4.19	4.12
Monsoon (June till October)	0.87	1.72	2.06
Winter (Nov till Feb)	0.84	1.25	2.06
Summer (Mar till May)	1.32	1.22	0
Command area of the WEM	1.79	2.36	2.36
Cropping intensity (%)	170%	180%	170%
Diesel cost savings		NPR 32800(USD328)	NPR 20350(USD 203.5)
Crops grown			
in Monsoon	Paddy	Paddy	Paddy
in Winter	Black Gram and Wheat	Wheat, Mustard, Black Gram and Red Gram	Wheat, Mustard and Masoor Dal
in Summer	Cucumber, Pumpkin, Water Melon, Bottle Gourd and Bitter Gourd	Cucumber, Pumpkin, Water Melon, Bottle Gourd, Bitter Gourd and Chilies	Wheat

Source – Primary data, Authors' calculations; Feb/March 2014 to May/June 2015 is considered an agricultural year.

After the introduction of SPIP, the irrigation costs fell rapidly as the farmers from diesel switched from diesel pumps to SPIP. This was due to the zero marginal cost of pumping. The area under irrigation also increase significantly as a result. Diesel cost savings were realized to be the biggest gain from the switch with Rs 32800 in savings in 2015-16 and Rs 20350 in savings in 2016-17.

In a similar fashion, the yield can be seen increasing for paddy, wheat and bottle gourd after SPIP installations (Fig. 4). However, the yield for the summer vegetables decreased. Discussions with farmers revealed that the seeds provided for most of the summer vegetable crops were of inferior quality resulting in majority of seeds not germinating. For the year (2016-17), we observe that farmers have completely stopped growing vegetables and have switched to rice-wheat cultivation in majority of the command area. This has resulted in a lower cropping intensity and lower hours of pump operation as compared to the first year of installation of the pump. The major reason for this was the unraveling of the cooperative group due to disagreements and lack of longevity among the members.

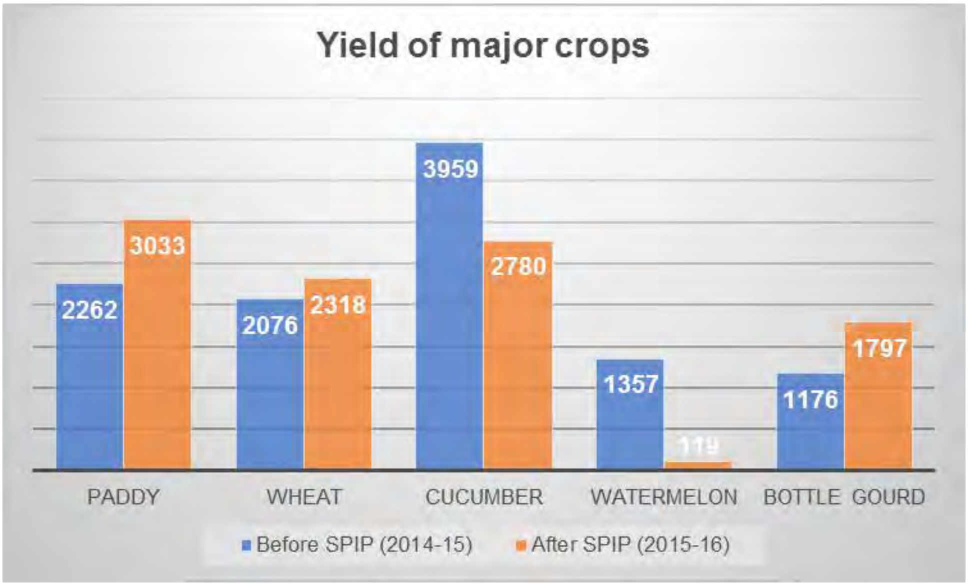

Figure 4*: Yield of major crops in Haripur*

4.2 Observations from Rayapur

The second pump was given to a woman farmer to encourage women farmers to learn more about SPIP and eventually adopt it. Initially, it was a difficult task to locate women farmers owing to the district being the lowest in terms of women ownership of land in Nepal. The recipient for a 1 HP SPIP here was Amrika Devi Yadav, who owns a Bigha (0.67 hectares) of land. In addition to her land, the command area was sufficient to ensure full utilization of the system. The main source of water extraction in this site is a two inch bore well. Both electric (1HP) and diesel pump is used in the site. The pumps belong to a farmers' association of which Amrika is a member. Electric pump for irrigation is the predominant source of water extraction in the site. In 2014/15 about 80% of the irrigation need was met by the electric pump because of its low cost as compared to diesel pumps. Table 4 provides cultivation patterns before and after SPIP in Rayapur.

Table 4: *Cultivation patterns before and after SPIP in Rayapur*

Indicators	Before SPIP (2014-15) (in Hectares)	After SPIP (2015-16) (in Hectares)	After SPIP (2016-17) (in Hectares)
Hours of irrigation (annual)	**978**	**652**	**312**
from diesel	263	168	72
from electric	715	210	114
from SPIP	0	274	126
Area under irrigation (total)	**5**	**5.84**	**5.06**
Monsoon (June till October)	1.45	2	1.96
Winter (Nov till Feb)	3.10	3.55	2.97
Summer (Mar till May)	0.44	0.30	0.13
Command area of the WEM	2.29	2.43	2.44
Cropping intensity (%)	220	240	210
Diesel savings		NPR 13,700(USD 137)	NPR 6300 (USD 63)
Crops grown			
in Monsoon	Paddy	Paddy, Pointed Gourd	Paddy, Pointed Gourd
in Winter	Cauliflower, Wheat, Eggplant, Potato, Chili, Garlic, Coriander, Okra, Green Leafy vegetables, Pointed Gourd	Cauliflower, Wheat, Mustard, Eggplant, Potato, Chili, Garlic, Coriander, Onion Seed, Green Leafy vegetables, Pointed Gourd	Cauliflower, Wheat, Mustard, Radish, Cabbage, Eggplant, Potato, Chili, Brocolli, Garlic, Coriander, Pointed Gourd
in Summer	Pointed Gourd	Pointed Gourd	Pointed Gourd

Irrigation costs decreased after the installation of SPIP system. The cropping intensity and area under irrigation increased. Diesel savings amounted to Rs 13,700 for the year 2015-16 and Rs 6300 respectively. From the data, we see there has been almost no difference in yield before and after SPIP for the primary cereal crops, rice and wheat (Fig. 5). There has been a slight increase in yield for cauliflower and a fall in potato and pointed gourd yield. On the whole there is mixed evidence in this site with regard to impact

on yield for major crops, post-introduction of SPIP. This can be attributed to migration of 2 farmers in search of job opportunities. Lack of labor reduced the cropping intensity.

4.3 Observations from Hardiya

The third pump was given to a farmer who acted as a water seller to the nearby farmers. We were able to identify a water seller, Jiten Yadav, who cultivates approximately 0.64 hectares of land and provides water to nine famers owning a total area of 2.9 hectares. His land is located in Hardiya VDC in Saptari district. Farmers in the command area practice commercial farming. Vegetable farming is a major source of earning. Electricity is yet to reach this site and farmers depend completely on diesel and kerosene pumps for their irrigation needs.

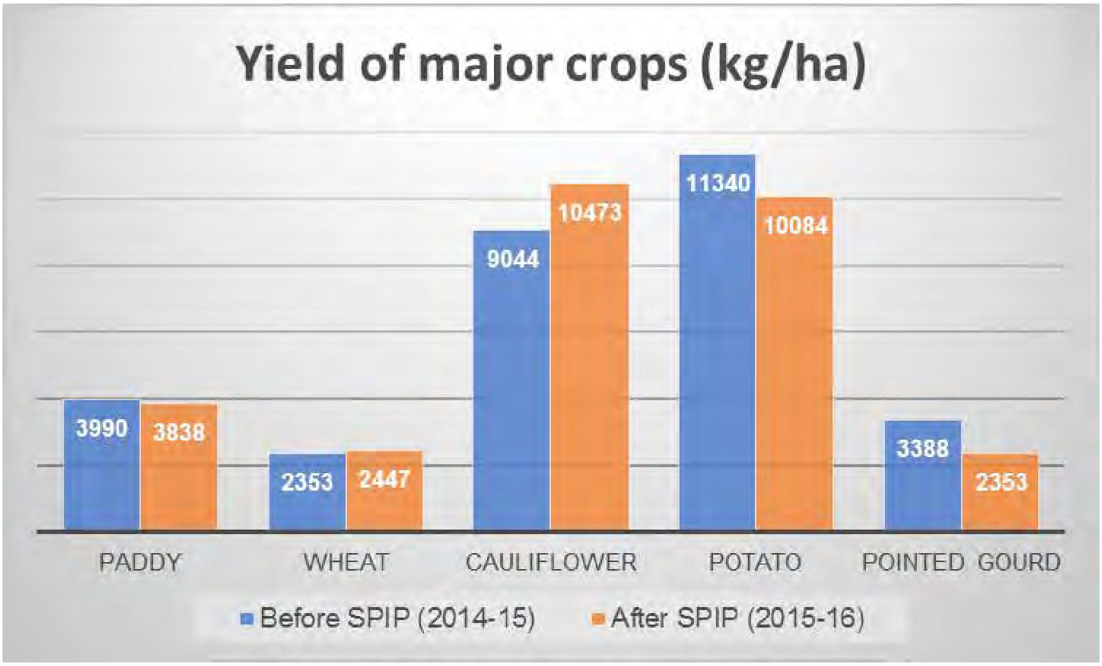

Figure 5: *Yield of major crops in Rayapur*

Prior to the SPIP system, the farmer irrigated the command area with a 5 HP diesel pump and sold water to his customers (other farmers) for a fee of Rs 200 per hour. After the take up of SPIP, he fixed his price at Rs 100 per hour. The lower price of irrigation compared to diesel (Rs 200) meant that more farmers demanded water from the SPIP system. Number of farmers who bought water from him rose from 9 to 23. A majority of the water buyers demanded water during the dry season which lead to the increase in the command area during summer season. Table 5 provides details of cultivation pattern before and after SPIP in Hardiya.

Table 5: *Cultivation patterns before and after SPIP for Hardiya*

Indicators	Before SPIP (2014-15) (in Hectares)	After SPIP (2015-16) (in Hectares)	After SPIP (2016-17) (in Hectares)
Hours of irrigation (annual)	276	473	430
from diesel	276	16	27
from electric	0	0	0
from SPIP	0	457	403
Area under irrigation (total)	**6.01**	**8.08**	**6.08**
Monsoon (June till October)	2.84	3.38	2.4
Winter (Nov till Feb)	3	3.88	2.92
Summer (Mar till May)	0.17	0.79	0.74
Command area of the WEM	2.87	4.26	3.31
Cropping intensity (%)	210	190	180
Diesel cost savings		NPR 45,700 (USD 457)	NPR 40,300 (USD 403)
Crops grown			
in Monsoon	Paddy, Eggplant, Bitter Gourd, Kurli (variant of pointed gourd) , Chilies, Potatoes, Cauliflower	Paddy, Eggplant, Bitter Gourd, Kurli, Chilies, Potatoes, Cauliflower	Paddy, Eggplant, Bitter Gourd, Kurli, Chilies, Potatoes, Cauliflower
in Winter	Wheat, Cauliflower, Cabbage, Onions, Chilies, Potato, Coriander, Cucumber, Bottle Gourd, Radish, Red Gram, Kurli, Pumpkin, Green Leafy Vegetables	Wheat, Cauliflower, Cabbage, Onions, Potato, Eggplant, Chilies, Cucumber, Coriander, Green leafy vegetables, Radish, Red Gram, Millet, Pumpkin, Kurli and Long Bean	Wheat, Cauliflower, Cabbage, Onions, Potato, Eggplant, Chilies, Cucumber, Coriander, Green leafy vegetables, Radish, Red Gram, Pumpkin, Kurli and Long Bean
in Summer	Pumpkin and Onions	Pumpkin, Bottle Gourd, Onion, Eggplant, Horse Gram and Kurli	Pumpkin, Bottle Gourd, Onion, Eggplant, Horse Gram and Kurli

The yield for paddy, wheat and cauliflower has increased after the SPIP take up (Fig. 6). However, other crops like eggplant and coriander had a decrease in yield as a result of a fungus infestation.

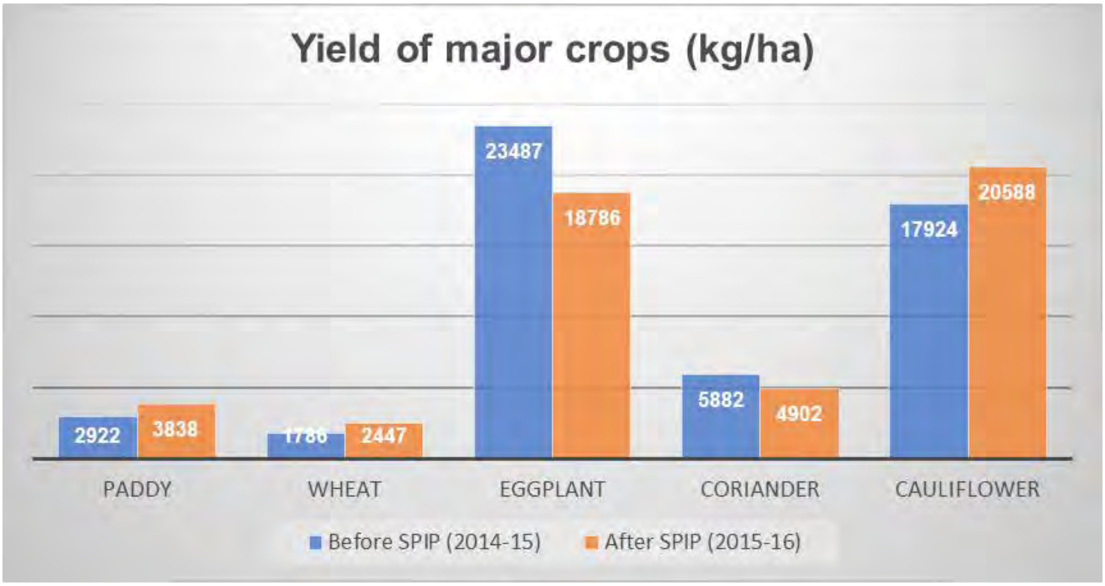

Figure 6: *Yield of major crops in Hardiya*

4.4 Overall observations from all the pilot sites

- In a nutshell, the hours of usage for both diesel and electric pumps declined significantly as a result of the implementation of the SPIP systems (Fig. 7).

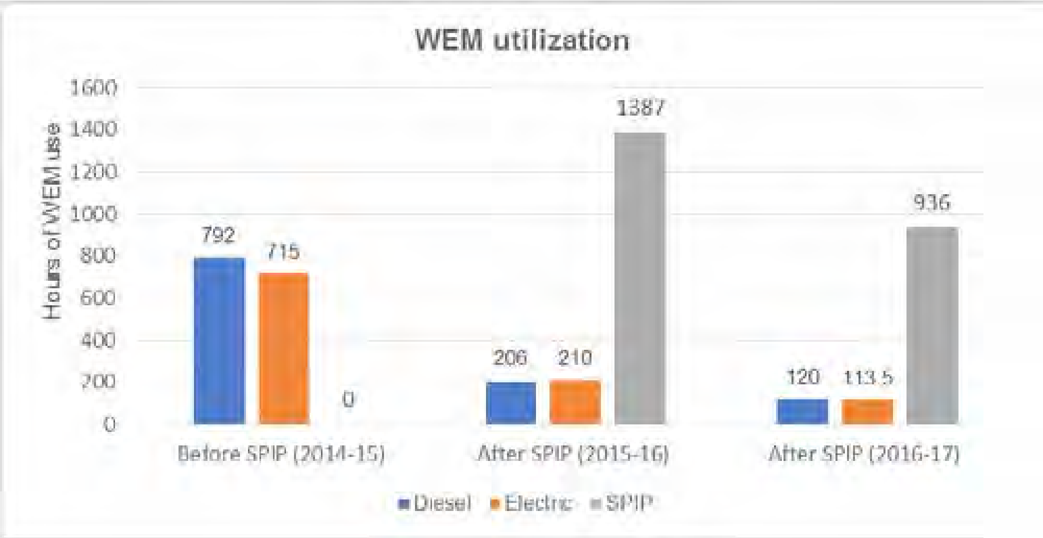

Figure 7: *Hours of operation of various pumps in the demonstration sites*

- Area under irrigation increased post installation of the SPIP (Fig. 8). There has been a decrease in irrigation coverage in summer season for 2016-17 mainly because of lack of summer vegetable cultivation in Haripur site.

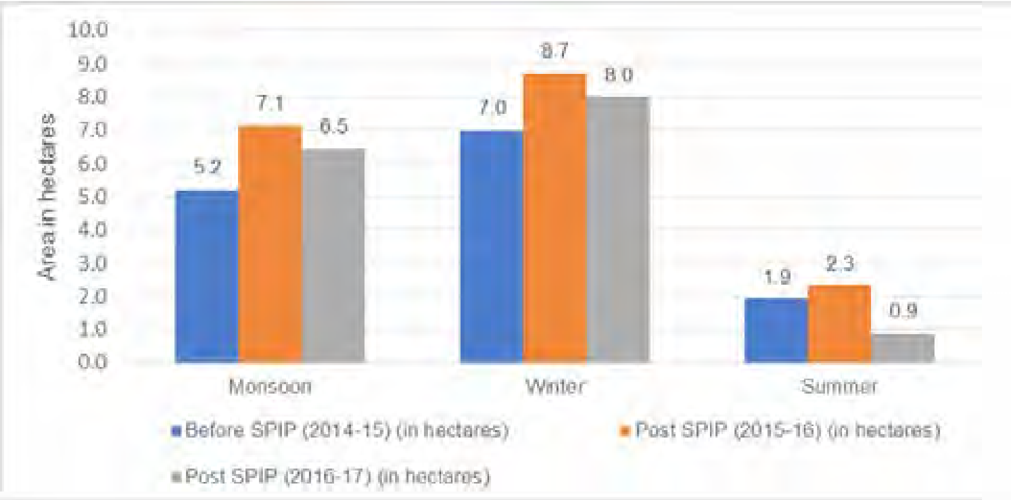

Figure 8: *Area under irrigation (by season)*

- Irrigation coverage has increased after the SPIP system was installed for all the sites (Fig. 9):

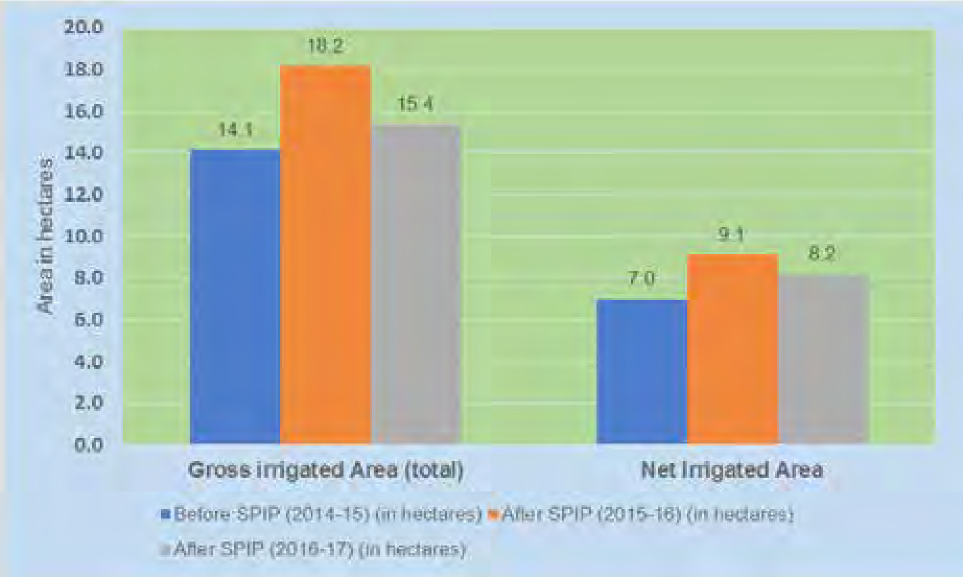

Figure 9: *Irrigation coverage*

5. Conclusion and Way forward

Cumulatively, three SPIPs that were piloted have been operated for 2323 hours from August 2015 to April 2017 and irrigated 18.2 ha of land in 2015-16 compared to 14.1 ha in 2014-2015. The yearly savings in diesel amounted to about USD 1,000 in 2015-16. Overall, the gross and net irrigated area rose by 29% and 30% respectively in 2015-16. We also noted increase in the cultivation of dry season vegetables and an increase of the number of water users, from 9 to 23. This has resulted in yield increases in paddy, wheat and cauliflower in these sites as far as major crops cultivated are concerned. However, different circumstances in these sites resulted in some decreases in yield as well. As a result of different mechanisms of operation in these sites, the yields fluctuated. Overall, it can be concluded that yields for major crops tend to increase if other factors do not interfere as far as production is concerned. Moreover, diesel savings point to a sustainable solution that reduces the marginal costs as well as harmful pollutants.

In a nutshell, SPIP systems have helped in sustainably increasing the agricultural yield of major crops (barring external impacts) as a result of an increase in irrigated area through implementation of a clean pumping solution. In terms of operation, SPIP can be deemed as a viable clean solution for Nepal Terai when it comes to increasing the irrigated area and providing the farmers with a platform to increase their productivity. The only roadblock in achieving this is the high cost of the SPIP systems that are a significant investment compared to traditional diesel pumps. With the advent of solar technology, the costs of solar panels and equipment have significantly come down providing an encouraging future outlook. Though slowly decreasing prices provides encouragement, it is adamant for a subsidy system to be in place to encourage its adoption as the prices are still unaffordable for majority of farmers in Nepal. A subsidy that is similar to the solar energy equipment for pumping drinking water is also needed in the case of irrigation.

References

Ali, D.B., Rahut, B.B. (2016). Factors influencing farmers' adoption of energy-based water pumps and impacts on crop productivity and household income in Pakistan. Renew Sustain Energy Rev, 54 48–57

CBS (2015). Statistical Pocket Book of Nepal 2014. Central Bureau of Statistics (CBS), Kathmandu, Nepal

CBS (2011). Nepal Living Standards Survey 2010-11. Central Bureau of Statistics Kathmandu, Nepal

Chandel S.S., Naik, M.N., Chandel, R. (2014). ***Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies*** *Renew Sustain Energy Rev, 49 (2015), 1084-1099.*

Kansakar, D. R. (2006). Understanding groundwater for proper utilization and management in Nepal. In: Proceedings of IWMI-ITP-NIH International Workshop on Creating Synergy between Groundwater Research and Management in South and Southeast Asia, Roorkee, India, February 8-9, 2005. Pp. 95-104

Kishore, A., Joshi, P.K., Pandey, D. (2017). Harnessing the sun for an evergreen revolution: a study of solar-powered irrigation in Bihar, India. Water International, 47 (3), 291–307.

Kishore, A., Shah, T., Tewari, N.P. (2014). Solar Powered Irrigation Pumos: Farmers' Experience and State Policy in Rajasthan. Economic & Political Weekly, 49 (10), 55–62.

Lipper et al. (2014). Climate Smart Agriculture for Food Security. Nature Climate Change. 4, 1068–1072.

Nepal Groundwater Resources Development Board website, Accessed July 2017, http://www.gwrdb.gov.np/

Shah, T., Verma, S., Durga, N. (2013). Karnataka's smart, new solar pump policy for irrigation. Economic and Political Weekly, 49(48), 10–14.

Sontake, V.C., Kalamkar, V. R. (2016). Solar photovoltaic water pumping system - A comprehensive review. Renewable and Sustainable Energy Reviews, 59 (C), 1038-1067.

Harnessing the hydropower boom: Improving irrigation infrastructure for farmer managed irrigation systems

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Abstract

Nepal has declared, for the third time, a National Energy Crisis Reduction and Energy Development Decade (2016-2026) in February 2016. This declaration means the country is committed to increasing hydroelectric energy generation to meet the current peak demand of 1500 MW. What does this development mean for other sectors such as farmer managed irrigation systems and agricultural livelihoods? With hydropower development expanding in Nepal, there is a need to understand how river water is allocated for multiple needs. To fill this knowledge gap, this study examined 12 run-of-the river (ROR) hydropower projects in the Gandaki Basin to understand how water diversions for ROR hydropower affect water availability for irrigation and agricultural livelihoods. Here, we demonstrate how ROR hydropower projects can be complementary for enhancing irrigation and agricultural livelihoods while simultaneously generating electricity. While many projects can have negative impacts on local water resources, Ridi (2.4 MW) and Mardi (4.6MW) exemplify how privately-owned small hydropower projects can have positive impacts on irrigation and agricultural livelihoods.

These two sites, Ridi and Mardi, are heralded as a success for small-scale farmers and provide valuable insight into river basin management. For example, through early planning along with transparent and trustworthy negotiations, these sites have been able to increase the availability of water resources for farmers while also producing cost-effective hydroelectricity. To support the future development of hydropower that provisions water availability for irrigation and agricultural livelihoods, there is a need to integrate what we have learned from these projects into policy and institutional frameworks so that there can be an irrigation and productivity boom along with the hydropower boom.

Keywords: *Agricultural Livelihoods; Farmer Managed Irrigation Systems (FMIS); Run-of-the-River Hydropower; Water Management*

1. Introduction

The Government of Nepal (GoN) has declared Energy Crisis Reduction and Energy Development Decade (2016-2026). Nepal's quest to mitigate energy crisis has boomed hydropower development in the country. Currently 65 run-of-the-river (ROR) hydropower projects and one reservoir project are under operation with installed capacity of 927 MW in 48 rivers of Nepal (DOED, 2017). Similarly, 151 small and medium privately-owned ROR projects are under construction in 116 rivers of Nepal (DOED, 2017). Furthermore, the GoN has planned to harness 10,000 MW through different privately and state-owned projects by 2026 (IPPAN, 2017). Ultimately, GoN has plan to harness 41,000 MW, which is the economically feasible hydropower potential of Nepal. However, what does this development means for other water consumptive sectors such as irrigation, drinking water, industrial and environment?

Nationally, in the quest of harnessing more energy, water availability for the other sectors are least discussed. Although hydropower does not directly consume water, its generation frequently conflicts with other uses, notably irrigation, because its release schedule does not always correspond to the timing of water use by other activities (Molle et al., 2008). The competition for water is likely to increase in the near future due to socioeconomic development and population growth (McCarl and Parandvash, 1988; Tilmant et al., 2009). Therefore, it is important to look at the tradeoffs of developing hydropower for other sectors. In this paper we look into whether hydropower development complements irrigation facility for the small holder's farmers of projects affected communities. Research in the past such as McCarl and Parandvash (1988), Chatterjee et al. (1998), Tilmant et al. (2009) and Molle et al. (2008) mostly focus on the opportunity cost of diverting water for irrigation rather to power generation. Chatterjee et al. (1998) said that the hydropower-irrigation trade-off has generally concluded that diversions of water from agriculture to hydropower production have the potential to generate welfare gains especially during low water flow. However, this study focuses on how hydropower development complements in improving irrigation system for small holder famer farmers.

2. Materials and Methods

2.1 Study area

The Gandaki River basin, in Western Nepal contains all the elements necessary for investigating how ROR hydropower shapes irrigation facilities for agricultural activities in mountain river basins. Hydropower development is well established in this basin. There are 20 hydropower projects in operation ranging in size (installed capacity) from 1 MW to 100 MW. All 20 projects are ROR type projects. Many ROR projects are either under construction or slated for future development. Agriculture is widespread with many farmer-managed irrigation systems overlapping with both current and projected hydropower development.

2.2 Research design

We choose a representative subset of 20 operational projects (ranging in size from 1 MW to 100MW) in the Gandaki River basin for this study (Table 1). This sub-set included 12 hydropower projects that (a) are spatially distributed in the region, (b) range in size (installed capacity) from "micro" (1- 5 MW), "small" (5-25 MW) and "medium" (25-100 MW), (d) vary regarding governmental or private ownership; and (e) range in length of operation (from over 15 years of operation to less than 1 year) (Table 2).

For each selected ROR project (Table 1), we did a site visit of the headworks and powerhouse and conducted a semi-structured interview with the site manager. We also conducted a semi-structured interview with the hydropower developer (typically located in Kathmandu).

For each selected ROR project (Table 1), we conducted semi-structured interviews with "project-affected" famers and interviewed key informants for farmer-managed irrigation systems (FMIS). Often, this included an interview with the public relations liaison (typically a local community member), a focus group discussion with the formal or informal concerned committee that handles negations between the "project affected" villages and hydropower company, and a least one focus group discussion with local farmers.

Within the subset of representative projects (n=12), we chose two hydropower projects that exemplify the opportunities for improved irrigation facilities with hydropower development. These two sites were Ridi and Mardi Hydropower projects. We returned to each site for a more thorough analysis. At Ridi we conducted a total of seven interviews with farmers along with two interviews with the hydropower project manager, who was previously the community liaison point person, and one with the hydropower developer. At Mardi we conducted a total of nine interviews with local farmers, one with the hydropower staff, one with the hydropower engineer, one with the hydropower developer, and three with the local community leader.

Data from these interviews along with site visits and personal observations form the foundation of our research study.

Table 1: *List of operational run-of-the-river hydropower sites (1-100MW) in Gandaki River Basin of Western Nepal.*

Hydropower Project	River	Installed Capacity (MW)	Location (District)	Promoter	Start of Operation
Andhi Khola*	Andhi Khola	9.4	Syangja	Butwal Power Company	1991
Ankhu Khola-1	Ankhu	8.4	Dhading	Ankhu Jalvidut Co. Pvt. Ltd	2013
Bijayapur-1*	Bijayapur	4.5	Kaski	Bhagawati Hydropower Development Company	2012
Chhandi Khola	Chhandi	2	Lamjung	Chhyandi Hydropower Co. P. Ltd	2015
Daraundi A*	Daraundi	6	Gorkha	Daraundi Kalika Hydro	2017
Khudi Khola	Khudi	4	Lamjung	Khudi hydropower limited	2006
Lower Modi-1*	Modi	10	Parbat	United Modi Hydropower Pvt. Ltd. -	2012
Madhya Marsyangdi*	Marsyangdi	70	Lamjung	Nepal Electricity Authority (NEA)	2008

Mardi Khola*	Mardi	4.8	Kaski	Gandaki Hydropower Development Co. P. Ltd	2010
Marsyangdi*	Marsyangdi	69	Tanahu	Nepal Electricity Authority (NEA)	1989
Modi Khola*	Modi	14.8	Parbat	Nepal Electricity Authority (NEA)	2000
Radhi Small	Radhi	4.4	Lamjung	Radhi Bidyut Co. Ltd	2014
Ridi Khola*	Ridi	2.4	Palpa	Ridi Hydropower Development Co P Ltd	2009
Seti*	Seti	1.5	Kaski	Nepal Electricity Authority (NEA)	1985
Siuri Khola	Siuri	5	Lamjung	Nyadi Group Pvt Ltd	2012
Tatopani	Tatopani	2	Myagdi	Nepal Electricity Authority (NEA)	N/A
Tinau	Tinau	1.024	Palpa	Nepal Electricity Authority (NEA)	~1980s
Upper Hugdi	Hugdi	5	Gulmi	Ruru Jalbidyut Pariyojana Pvt. Ltd	Recently (<2 years)
Upper Madi*	Madi	25	Kaski	Madi Power Pvt Ltd. (Chinese Owned)	Recently (<2 years)
Upper Marsyangdi A*	Marsyangdi	50	Lamjung	Sinohydro-Sagarmatha Power Company Pvt Ltd (Chinese Owned)	Recently (<2 years)

The selected subset of representative study sites (n=12) are marked with an asterisk (*).

Table 2: *Characteristics of operational hydropower sites in Gandaki River Basin of Western Nepal (1-100 MW).*

Run-of-the-River Hydropower Project	Size (Installed Capacity)			Ownership		Length of Operation		
	1-5 MW	6-25 MW	26 - 100 MW	Government Owned	Privately Owned	> 15 years in Operation	5-15 Years in Operation	< 5 Years in Operation
Andhi Khola*		X			X	X		
Bijayapur-1*	X				X			X
Daraundi A*		X			X			X
Lower Modi-1*		X			X			X

Madhya Marsyangdi*			X	X			X	
Mardi Khola*	X				X		X	
Marsyangdi*			X	X		X		
Modi Khola*		X		X		X		
Ridi Khola*	X				X		X	
Seti*	X			X		X		
Upper Madi*		X			X		X	
Upper Marsyang-di A*			X		X			X
Ankhu Khola-1		X			X			X
Chhandi Khola	X				X			X
Khudi Khola	X				X		X	
Radhi Small	X				X			X
Siuri Khola[1]		X			X			X
Tatopani[1]	X			X			X	
Tinau[1]	X			X		X		
Upper Hugdi		X			X			X

The selected subset of representative study sites (n=12) are marked with an asterisk (*).

[1]No irrigation in impacted stretch

3. Results

Ridi and Mardi are both small ROR hydropower projects in Ridi and Mardi rivers, respectively. Ridi is a tributary of Kaligandaki river and Mardi is a tributary of Seti river in the Gandaki basin. Energy produced from these projects is connected to the national grid of Nepal and the developers of these projects have to pay royalty to the GoN as per the Electricity Act of Nepal. Table 3 table shows the basic information

on Ridi and Mardi ROR hydropower projects.

Table 3: *Basic information on Ridi and Mardi run-of-the-river hydropower projects*

Project/Company	Capacity MW	Commercial Operation Date	Energy Production/ Year	Royalty to GON / year (1$=100rupees)
Ridi/Ridi Hydropower Company	2.4	27/10/2009	13.16 million Kwh	1.376 million
Mardi/Gandaki Hydropower Company	4.8	22/01/2010	27.138 million Kwh	2.652 million

(*Source: DOED, 2017*)

3.1 Irrigation system and agricultural livelihoods prior to Ridi hydropower project

Irrigation from Ridi river to the bordering Village Development Committees (VDCs) of Gulmi and Palpa districts was a tedious work for farmers both in the wet and dry periods. There were five irrigation canals: three for Ruru and two for Khya VDC. Famers used to harvest three crops: paddy in the monsoon; wheat in the winter; and maize in the spring. According to the focus group discussions with the farmers from Ruru VDC, who uses three irrigation canals, they said it was very difficult to access water during monsoon. They used to cut seven or eight trees to make the temporary weir to divert water for feeding the first canal (this canal is called *Satmure Kulo)* and another weir downstream to feed two more canals called *Mill Kulo and Tallo Kulo*. Farmers had to voluntarily contribute their labor to build and renovate canals. They always had difficulty in having enough water for paddy cultivation as there was water leakage from the earthen canals and the temporary weir got wiped out several times.

In addition, in the lean period, the water level was too low to flow in the irrigation canal and took too much labor to get water flowing in the irrigation canal. Due to this lack of irrigation water, farmers cultivated wheat in the winter and maize in the spring. In the case of *Mill Kulo*, the canal which fed the water mill, water was flowing throughout the year ensuring a functioning mill. The miller used to maintain the *Mill Kulo* for water mill as this was his business and means of earning. Later, he would charge villagers to have their grains and oil pressed in the water mill. All the five canal committees were responsible for their respective canals for renovations and maintenance. Overall, the irrigation infrastructure was too weak and it was challenging for the farmers to maintain the structure and have enough water for irrigation.

3.1.1 Negotiation process between developer and villagers in Ridi hydropower project

Negotiation between farmers and the developer for using water for irrigation and power, took nearly a year. According to the regulation of Nepal, the hydropower developers should publish notice publicly to inform all the concerned before the construction of hydropower project. Therefore, Ridi hydropower developer published notice in the district office. The ward leader of Ruru village committee brought this news to the villagers. However, villagers thought the hydropower developer should come to their village if they wanted their land and cooperation for the construction. Initially, people did not know about

hydropower projects and its impacts or benefits. Farmers were also worried about the water availability for irrigation and agricultural livelihoods. Later the board members of the company came to the village and visited each and every house and shared about the project, impact and the benefits. From five canals committees, one main canal committee was formed which represented all the canal committees. This main committee and the company had series of dialogues on water availability for irrigation. The dialogue was facilitated by a local leader who is now permanent employee in the Ridi hydropower project. According to a local farme,r who is also in the irrigation canal committee, there were 100 of meetings before and during the construction, and it took one year for complete negotiation.

In addition, a year-long negotiation resulted win–win situation for both the hydropower developer and the farmers. According to the agreement, availability of water for farmers shall be ensured in dry periods. In the one hand, the company shall provide: equity share; improvement of irrigation structure with permanent weir; availability of water for irrigation when needed; contribution for annual maintenance and renovation of irrigation canal; subsidized electricity and new water supply. In the other hand, local people shall not interrupt in smooth construction of the project and cooperate with the developer. While speaking to both the parties, the agreement has been abided faithfully till date.

3.1.2 Improved irrigation system and agricultural livelihood at Ridi

The major output of the agreement is the improved irrigation infrastructure and availability of water for the crops. There are five canals which comes between weir and power house of Ridi Hydropower project. The first three canals irrigate 15 ha in Ruru VDC whereas the remaining two canals irrigate 10 ha in Palpa Municipality. Table 4 shows the interventions from Ridi hydropower project that helped improve irrigation structures. Data is from semi-structured interviews.

Table 4: *Ridi hydropower project interventions to improve irrigation structures*

Canals (*Kulo*)	Length of canal(km)	Canal renovation	Source improvement	Total Cost(Rupees)	Renovation and Maintenance/Year (Rupees)
Satmure	1.5	Masonry works were done where necessary in these canals.	Desilting Basin (new)	15 million	0.3 to 0.5 million
Mill	2.5		New concrete weir in Ridi(new)		n/a
Tallo	2		Ridi raised with gabion wall(renovated)		n/a
Sakhra Kuseni	2		Ridi raised with gabion wall (renovated)		n/a
Sakhra Ridi	1.5		n/a		n/a

Figure 1: *Photo of paddy fields fed from improved irrigation infrastructure within the impacted reach of river at Ridi Hydropower Project*

3.1.3 Satmure Kulo **and desilting basin**

Satmure Kulo used to get water from the Ridi river after farmers built temporary weir in the river. Now, this canal is fed from the desilting basin of Ridi Hydropower project. There are two outlets pipes from the desilting basin each with 12-inch diameter. In the wet season, availability of water is enough for power generation and irrigation. In the dry season (November to March), farmers can go and open the outlets from the desilting basin and can divert the water to *Satmure Kulo* for winter and spring crops.

> *"We are now at peace as we do not have to worry about weir wipe out due to monsoon flood. And in the winter, We need to irrigate our wheat crop once a week which we are getting from desilting basin"… Local Farmer, Satmure Ruru.*

> *"Power generation is disturbed for one week/month during winter as water is diverted for irrigation" ………Plant Manager, Ridi hydropower project*

As it was agreed upon with the farmers, water availability for irrigation is not compromised and the company provides water for irrigation during the dry season (Fig. 1). However, farmers are now beginning to have interest in cash crops such as vegetable farming. The recently established processing unit near the Ridi powerhouse, called Paicho processing unit, is attracting village farmers to grow more food. Paicho processing unit is buying local products such as vegetables, fruits and legumes, and in return providing money or other grocery items. Paicho is producing juice, pickle, dry vegetables and sauce and selling those items in different parts of the country through their outlets. Therefore, the demand of water is expected to increase in the future.

> *"Until now, we are getting enough water and there has not been any conflict over water availability" ………. Local Farmer, Satmure, Ruru.*

3.1.4 Mill Kulo and Tallo Kulo

Downstream from the weir of Ridi hydropower project (approximately 500 m), there is one tributary called Sardiya river. This river, which is perineal reduces the impact from the Ridi hydropower project because this river feeds *Mill* and *Tallo* irrigation canals. Here the company has invested nearly ten million Rupees for constructing a concrete weir which is 7.5 m tall, to raise the river bed to feed in these two canals. The company is responsible to take care of this concrete weir. The company has also invested in upgrading some sections of these earthen canals into concrete canals. According to the agreement, the farmers are responsible for maintenance of these canals, and the company shall contribute in cash or kind for renovation and maintenance. Therefore, irrigation has been much easier for the farmers in Ridi and their agricultural livelihood has also improved with the support from the hydropower project.

3.2 Irrigation system and agricultural livelihoods prior to Mardi hydropower project

Irrigation from Mardi and Saiti (tributary of the Mardi river) was a lot of hard work for the farmers in Macchapucchre VDC. Historically, farmers used water for irrigation from Mardi and Saiti river, which are both now diverted to Mardi hydropower project for power generation. Near the dam site, Mardi river used to irrigate 90 *ropanies* (20 *ropani* = 1 hectare) of farmland. Similarly, Saiti river used to irrigate 125 *ropanies* of farmland. Prior to the dam construction, farmers harvested three crops: paddy in the monsoon, wheat, mustard, or potatoes in the winter, and maize in the spring. According to interviews with farmers from Mardi Bang and Saiti Ghatta, they explained how previously, before the dam, it was very difficult to access water during monsoon. The temporary check dam of local materials would always get wiped out in the monsoon. Farmers had to voluntarily contribute their labor to build the weir before the monsoon and during the monsoon. The canals were earthen, and they needed continuous attention in the monsoon. The road to the nearby city was not fully developed, and access to the market was not easy. In addition, in the dry season, when the water level falls sharply in the Mardi river, farmers in Mardi Bang found it hard to raise the water level to divert in the canal. Overall, irrigation infrastructure was temporary and limited and farmers had difficulty managing the infrastructure.

3.2.1 Negotiation process between developer and villagers

The negotiation process for Mardi hydropower project lasted well over a year due to different interests. In the end, an agreement that was favorable to the community was reached. Prior to the hydropower project, the local communities maintained and operated a 50kW micro hydropower project in the Saiti river. Because the hydropower developer wanted water from this river, which would take the water for the micro hydropower plant, local people originally opposed the project. We found that many local people had no idea of the consequences of diverting water for power generation. They ended up having several internal meetings with the community and also consulted with the district office and donor of micro hydro project for information. The locals had many concerns and were hesitant to take the offered compensation. After a year of meetings and negotiations, they decided that they were ready to give up micro hydro and give water to the Mardi hydropower but under some strict conditions. The negotiated agreement stated that the Mardi hydropower company would provide: 50kW of electricity; Rs 300,000/year as compensation for 25 years; salary for the micro hydro staff; maintenance of the electric connections; regular water release for irrigation; and improve irrigation structures.

Despite this agreement, once the project was under construction the local people were not satisfied with the developer. Local people wanted a road and access to the market. In protest, local people

stopped the construction work of hydropower project until their demands were fulfilled.

> *"The people in the village should be supportive and we need to have one voice. I worked hard enough to have road in this village" ……. Local Leader, Saiti Ghatta, Mardi.*

> *"The demand of the people was skyrocketing and we had to complete this project at any cost. It was a period of Maoist insurgency and the security was a huge problem. Therefore, we fulfilled most of the demands of people" ……. Developer, Mardi Hydropower Project*

Although it was challenging, the series of meetings and negotiations over time, Mardi hydropower developer and local people were able to come to a working agreement and today there is mutual respect.

3.2.2 Improved irrigation system and agricultural livelihood at Mardi

Between the negotiated agreement and the design of the hydropower project, there has generally been improved availability of water for irrigation with less labor for local famers. Mardi hydropower project has supported the improvement of the irrigation infrastructure in Mardi Bang and Saitighatta villages of Machhapuchhre VDC of Kaski district. From the desilting basin, there are three outlets that fed irrigation canals irrigating 125 *ropanies* of farm land of Mardi Bang in the monsoon for paddy crops. There is also a four-inch pipe that supplies water for irrigating 90 *ropanies* of farmland in Saiti Ghatta for paddy and other crops during the monsoon. Local farmers can open and close the valve by themselves to control water flow. Now, the farmers do not have to build temporary check dam in Mardi and Saiti rivers. In addition, the Mardi Hydropower Company has also helped to renovate some sections of earthen canals into concrete canals in Saiti Ghatta, which has reduced the water leakage. Now, the farmers of Saiti Ghatta can have irrigation year-round without much effort.

In addition, agricultural livelihoods have also improved in Saiti Gatta and Mardibang village of Machhapuchhre VDC with improved water availability and hydropower infrastructure. In Saiti Ghatta village, one of the farmers is doing trout fish farming in 12 small ponds. According to the farmer, the earning is good and he is earning more than what he used to earn from foreign employment in the Middle East. Also, he is employing two young boys from the community. He said, more profit can be achieved if done on a bigger scale. Similarly, using water from the tailrace of this Mardi Hydropower project, one group of three investors has invested in trout farming and so far, has been successful (Fig. 2).

> *"Water from the tailrace is best as it is cooler than outside temperature. Trout fish do well in water with the temperature range of 15°C to 22°C, and temperature of tailrace water also has same range. Last year (2016), our profit was 4.6 million Rupees and we have employed six people here" ……….. Investor, Yangdi Rainbow Trout.*

Furthermore, farmers in Mardi Bang and Saiti Ghatta are diversifying their cultivation. In the past, farmers cultivated crops for their subsistence however now, farmers are more interested in cash crops such as vegetables and spices. Now, female farmers in Mardi Bang and Saiti Ghatta are growing vegetables crops as they have better access to nearby city (Pokhara) with the improved road. They can travel to and from Pokhara within half a day to sell their produce. Therefore, overall, Mardi hydropower project has helped the local farmers to improve their irrigation system and agricultural livelihoods.

Figure 2. *Photo of Rainbow trout farm at the Mardi hydropower project tailrace.*

3.3 Ongoing challenges

Despite the successes illustrated from these two projects, there are challenges ahead. Mostly, the challenge is about availability of water during the dry season and when farmers need it for crops. Previously, farmers used to harvest three staple crops and the winter/spring crops such as wheat and mustard, were not water intensive. Now, with more access to markets with improved roads in the hilly region, people are more interested in cash crops such as vegetable farming and fish farming, which are water intensive. This is a challenge for hydropower developers as they need to reach their energy targets in the dry season when energy demand is high and the water level is low. During this time, there seems to be some conflict between hydropower and irrigation over the use of water. For example, in the case of Mardi, there remains some contested disputes, especially as farmers shift from traditional practices to cash crops that require regular water year-round. In the monsoon, farmers of Mardibang get regular supply of water through three outlets from the desilting basin. However, this is closed in the dry period. It was not a problem until recently as farmers cultivated only wheat in the dry period, however now farmers want to produce non-seasonal vegetable farming. For these crops farmers want uninterrupted water and sometimes feel entitled to these water resources.

> *"We want to produce more vegetables as it has market but we do not have water. We feel bad to ask the developer as they also need water in the dry period"… Local Female Farmer, Mardibang*

Moreover, in Ridi hydropower project, there has not been a challenge of water availability just yet. However, this may be an issue in the future. For example, if more people move into these villages and want to irrigate year-round which is likely given the newly established processing unit is ready to take their produce. On another front, we do see that the people at both sites want more electricity and this will also be an ongoing challenge.

4. Conclusions

These two case studies show that hydropower development can complement agricultural livelihoods by improving irrigation infrastructure for small-holder farmers. As the country is gearing up to produce 10,000 MW in ten years (by 2026) and, has a plan to ultimately exploit all the economically feasible potential of 41,000 MW, there is an immense opportunity to improve irrigation infrastructure for farmer managed irrigation systems. Although most hydropower projects interfere with small-holder farmers and their traditional irrigation systems, the impacts do not always have to be negative. Hydropower developers want to generate power by diverting rivers and farmers want improved irrigation infrastructure with uninterrupted water for irrigation. With a genuine participatory negotiation process like in the case of Ridi and Mardi hydropower projects, farmers can benefit through improved irrigation infrastructure and water availability while hydropower developers can also successfully produce energy and profits. Through mutually-beneficial agreements, hydropower development can help farmers reduce time and energy on temporary irrigation structures. Farmers can also improve their agricultural livelihoods with year-round irrigation facility as in Ridi and Saiti even during low flow periods. With improved water security, this allows for farmers to diversify their crops and have more income generation. Therefore, the hydropower boom in Nepal could significantly complement agricultural livelihoods through improving irrigation infrastructure thus improving the life standard of millions of farmers in the hilly region of Nepal.

Acknowledgements: The authors would like to thank the generous time and support from all research participants and those who helped facilitate this fieldwork. We also acknowledge support from ICIMOD as well as the financial support from the U.S. Borlaug Fellows in Global Food Security Program.

References

DOED (2017). 'Operating Projects'. Official website of Department of Electricity Development (DOED). [online] Available at: http://www.doed.gov.np/operating_projects_hydro.php [accessed on 28 December 2017.

Chatterjee, B., Howitt, R.E., Sexton, R.J. (1998). The Optimal Joint Provision of Water for Irrigation and Hydropower. Journal of Environmental Economics and Management, 36 (3),.295-313.

IPPAN (2017). 'Newsletter'. Official website of Independent Power Producer Association. [online] Available at http://www.ippan.org.np/pdf/newsletters/IPPAN%20newsletter_2017_September.pdf [accessed 25 December 2017]

McCarl, B.A., Parandvash G. H. (1988). Irrigation Development versus Hydroelectric Generation: Can Interruptible Irrigation Play a Role? Western Journal of Agricultural Economics. Western Agricultural Economics Association, 13 (2), 267-276.

Molle, F., Jayakody, P., Ariyaratne, R., Somatilake, H.S. (2008). Irrigation versus hydropower: sectoral conflicts in southern Sri Lanka. Water Policy, 10 (1), 37-50.

Tilmant, A., Goor, Q., Pinte, D. (2009). Agricultural-to-hydropower water transfers: sharing water and benefits in hydropower-irrigation system. Hydrol. Earth Syst. Sci, 13, 1091–1101.

A review of agriculture water management technologies in a climate-smart context

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Abstract

In combating the effects of climate change and aid in climate-smart agriculture, the advent of agriculture water management (AWM) techniques, which improve water harvesting and use, have been particularly effective. In essence, efficient management of water for agriculture tends to address climate change by targeting the root of the problem i.e. access to water. AWM techniques are significant as their use help in achieving the climate-smart goals of sustainably increasing agricultural productivity, enhancing resilience through efficient water use, removing greenhouse gases and enhancing food security. The purpose of the paper is to review selected AWM technologies positioned as climate-smart agriculture in South Asia. Using a Delphi process, we shortlisted three technologies for the review: zero-tillage, solar powered irrigation pumps, and micro irrigation. The technologies were then evaluated on their climate-smart aspects. For the purpose of this paper, we discuss the in-depth findings from micro irrigation only. From our analysis, we found that introduction of micro irrigation leads to a rise in productivity, water and energy savings at field level. If we extend the analysis from the field to basin level, we observe that widespread adoption of such technologies may increase water and energy consumption thereby offsetting the initial efficiency gains of climate-smart technologies. Additionally, we found a lack of rigorous impact assessment of these technologies, indicating scope for more internally valid evaluation methodologies.

Keywords: *agricultural water management; climate-smart technologies; conservation agriculture; micro irrigation; zero tillage;*

1. Introduction

Agriculture is vital to South Asia's growth prospects as about 70% of the population live in the rural areas. Most of the rural poor depend primarily on agriculture for their livelihoods (IFAD, 2007). A report that measures the costs of climate change and adaptation in South Asia states that agriculture in the region has improved in recent years with more people being fed. (Ahmed et al., 2014). However, agriculture in the region is extremely susceptible to climate change – mostly in the form of change in intensity of

rainfall events, and the break cycles of monsoon combined with increased risk of critical temperatures being experienced at more frequent intervals. In fact, as reported by International Fund for Agricultural Development (IFAD), temporal and spatial changes in temperature coupled with water stress will have key implications for agriculture, especially adversely impacting crop yields. For instance, models project a 15-30% decline in the productivity of most cereals. Rice, a staple cereal across the region will face a decline of 0.75 tons/ha for a 2-4 degrees increase in temperature associated with climate change. Overall, the report points to crop yield decrease of 30% in the region by mid-21st century with most dramatic negative impacts expected in arid zones and flood affected areas. Further projections also state that irrigation demand for agriculture in arid and semi-arid regions is likely to increase by 10% for temperature increase by 1%. (IFAD, 2007).

Considering the adverse impact of climate change on agriculture, a sustainable approach has been initiated through the advent of climate-smart agriculture (CSA). CSA approach aids in supporting actions required to change and reorient agricultural systems to ensure food security to combat climate change whose three objectives are: sustainably increasing agricultural productivity and incomes; adopting and building resilience to climate change; and mitigating greenhouse emissions (FAO, 2016). A more resilient and productive agriculture requires alterations in the way natural resources are managed (e.g., land, water, soil nutrients, and genetic resources) and greater productivity in the use of these resources and inputs for production.

Improving water access and its management has taken center stage when it comes to agriculture. In combating the effects of climate change and aid in climate-smart agriculture, the advent of agriculture water management (AWM) techniques, which improve water harvesting and use, have been particularly effective. In essence, efficient management of water for agriculture tends to address climate change by targeting the root of the problem, i.e., access to water.

Therefore, the purpose of the paper is to identify and review the AWM technologies that are 'climate-smart'. For identification, we initially prepared a comprehensive list of technologies deemed to be climate-smart. The list was then narrowed down through consultations with experts using a Delphi methodology. Following the methodology, we shortlisted micro-irrigation, solar powered irrigation pumps and zero tillage through this process. One of the technologies: micro irrigation is then evaluated on their 'climate-smart' aspect; in terms of whether the technology (i) enhanced agricultural productivity (ii) improved water savings and productivity and (iii) is energy saving. On an average, we find that there is a rise in yield, water productivity and energy savings associated with this technology for field-level studies. The improvement in water savings from the adoption of the technology could lead to an increase in irrigated area, higher input use and subsequently greater energy consumption. So, an increased adoption of this AWM technology might lead to higher usage of water and energy at basin level.

2. Methodology

2.1 Delphi process

At the outset, we prepared a comprehensive list of AWM technologies for the Delphi process. A modified version of the Delphi process was followed, thereby, enabling a continuously iterated process of discussions until a consensus was determined through a survey process. This was carried out in four rounds, which are as follows:

- Round 1: An open-ended discussion was carried out with key informants (experts) to generate a

preliminary list of climate-smart agriculture water management technologies.

- Round 2: A list of 'climate-smart' technologies was sent to key experts to shorten the list to 10 to establish preliminary priorities among the existing technologies. This process was done through both update meetings as well as email correspondences.
- Round 3: Each Delphi panelist received a short questionnaire administered through Survey monkey. The questionnaire contained questions relating to rating 10 AWM technologies under three criteria namely: water saving, energy saving and agricultural productivity.
- Round 4: The survey results in the form of ratings consensus was disseminated to the panelists. This allowed them to revise or provide feedback on the ratings.

As part of Round 3, the experts were asked to rank the AWM technologies on the criteria of water saving, energy saving and agricultural productivity gains on a Likert scale of 1 (being the lowest) to 6 (being the highest). These scores were then processed to obtain the weighted average scores for each technology. Considering the average scores received for each of the technologies, we listed the top three as follows: Conservation tillage or zero tillage, Solar powered irrigation pumps (SPIP), and micro-irrigation.

2.2 Inclusion/Exclusion criteria

We devised an inclusion/exclusion criterion for shortlisting studies of interest. A high proportion of our experts wanted the review to be for South Asia and we excluded articles for other regions in the world. Since CSA is a relatively new concept (FAO, 2016), we looked at studies post-2000. This makes our review pertinent within the climate change literature. We reviewed studies on the three technologies in South Asia including published studies in journals, unpublished articles and book chapters. A major source for our literature search was the FAO database; Access to Global Online Research in Agriculture (AGORA). We excluded articles that were technical in nature i.e. published for engineering or natural sciences audience. In total we identified 22 studies pertaining to Micro irrigation relevant for the review. A review for micro irrigation follows below:

3. Micro Irrigation

3.1 Background

Micro irrigation comprises of a family of irrigation systems that emit water through small devices. The devices usually deliver water onto the surface of the soil very close to the plant or below the surface of soil directly into the root. (Hla et al., 2003). Predominantly, the use of micro irrigation systems is seen more in arid and semi- arid regions where problems of water scarcity are extensive. In irrigated agriculture, these systems are used mostly for row crops, mulched crops, orchards, gardens, greenhouses and nurseries. Emission devices deliver water in three different modes: drip, bubbler and micro sprinkler. In drip mode, water is emitted in droplets and trickles. In bubbler mode, the water bubbles out from the device. In the case of micro-sprinkler, the water is sprinkled, sprayed or misted. (Hla et al., 2003).

A review of literature related to micro irrigation technologies show that they are promoted or adopted for one or more of the following objectives: 1) as a means of water saving in irrigated agriculture and coping with the water crisis 2) as a strategy to increase income and use it for poverty alleviation among the rural community through increase in yield of crops 3) enhance food and nutritional security in rural households 4) as a means to extend limited available water over a larger cropping area during

water scarce periods (Namara et al., 2005). In the context of our review, we focus on the use of these devices in irrigation emphasizing agricultural water management that is 'climate-smart'. In other words, we analyze the literature on micro irrigation to adjudge if they are yield enhancing, water saving, and energy saving as compared to the traditional methods of irrigation. In addition to assessing this, the review also delves into the differences between the sample farm level observations and experimental plot level observations to look into the extent of saving achieved.

3.2 Agricultural productivity gains from micro irrigation

Yield gains or productivity gains are a direct indicator of an increase in production as a result of provision of efficient conditions for the crops to grow. A lot of the productivity gains achieved can be attributed to the use of an efficient irrigation system. Along these lines, the adoption of drip method of irrigation (DMI), among the micro-irrigation devices, is seen to be the most efficient in terms of economic and productive viability. The higher yield can be seen as a result of three reasons namely: less moisture stress from the adoption of DMI, limiting weed growth by supplying water directly to the root zone, water fertigation means more efficient spread of fertilizers.

The review of literature with emphasis on recent studies (i.e. 2004 onwards) shows to a varying degree of yield gains depending highly on the type of crops grown (Table 1). As a result of adoption of micro-irrigation technologies, the yield gains were observed to be from as low as 4% to as high as 121%. It is important to note the essence of what the percentage increase mean in the case of each crop in consideration. For instance, it was found that the yield gains for horticultural crops and orchards such as banana, grapes, orange, coconut and sugarcane translate to significant rise in value of crop output even if it is just a marginal increase in yield. This can be seen as a result of the high value of these crops. This can be illustrated through an example of two crops: cereals and pomegranate. A 10% rise in yield would result in an incremental gain of 400-500 kg of wheat or INR 3000 – INR 3750 per hectare of irrigated wheat. Similarly, a 10% increase in yield of pomegranate, with minimum yield of 60,000 kg per hectare per year would result in an incremental gain of 6000 kg/ hectare or INR. 90,000 per hectare. (Kumar et al., 2008).

However, a study conducted in Rajasthan, India points out that not all micro-irrigation devices tend to offer favorable results in terms of yield gains. The adopted system of sprinkler system led to no substantial change in yield in this case. A notable decrease in the yield of wheat, marginal decrease in yield in groundnut and cluster bean and just slight increase in yield of bajra has been observed. This yield reduction can be attributed to poor distribution uniformity in watering that have adverse effects on the crop growth (Viswanathan et al., 2016).

Regardless of whether the studies have made use of an experimental plot or sample farmers with actual field situations, most studies have reported yield gains as a result of the micro-irrigation system adoption as compared to traditional method of irrigation.

Table 1: *Yield change for micro irrigation*

Authors	Country	Increase in yield	% change
Narayana-moorthy (2007)	India (Maharastra)	Yes	Productivity gain of 29%, 19% and 23% observed in banana, grapes and sugarcane respectively as a result of the use of DMI over FMI

Malunjkar et al (2015)	India (Maharastra)	Yes	The banana yield gain of 22% and 28% observed in experimental and farmer's field respectively as a result of use of DMI over CMI
Surendran et al (2016)	India (Tamil Nadu)	Yes	Average agricultural yield gain of 17% as per the use of LCDI over FMI
Narayanamoorthy (2004)	India (Maharastra)	Yes	Productivity gain of 23% is observed as a result of the use of DMI over FMI
Kumar et al (2009)	India (Uttarakhand)	No	The yield was not significantly different between gravity fed MIS and check basin irrigation system.
Verma (2004)	India	N/A	
Verma et al (2004b)	India	N/A	
Verma et al (2004a)	India (Madhya Pradesh)	Yes	The average cotton yield increased by around 44% as a result of adoption of Pepsee systems.
Namara et al (2007)	India	Yes	For three crops involved in the study (banana, groundnut, cotton), the use of micro-irrigation technologies generally resulted in significant yield improvement over traditional irrigation practices.
Qin et al (2016)	China (Gansu Province)	Yes	The biomass under drip irrigation was higher than under border irrigation averagely by 42% in 2014 and 26% in 2015 for maize. The maize gained more water and nutrition leading to higher yield using less time.
Narayanamoorthy (2005)	India (Tamil Nadu)	Yes	The sample farmer reported productivity gains in the region of 55% for sugarcane as compared to FMI.
Randev (2015)	India (Himachal Pradesh)	Yes	The observations from the respondents' responses also point out that yield of apple has enhanced by 35% due to adoption of drip irrigation system.
Von Westarp et al (2004)	Nepal (Panchkhal Horticulture Farm)	Yes	There is an observed yield gain of about 12% as a result of using low cost drip irrigation system over hand watering (in the case of providing only 50% of the water requirement for the crop)
Kumar et al (2008)	India	Yes	The review of literature shows that drip irrigation increases yield from 5% to as high as 50%
Sakthivadivel et al (2004)	India	Yes	The use of drip irrigation enabled the farmers to prepone the cotton sowing by about 30-40 days which means that they can harness the benefits of pre-monsoon cotton and then prepone the wheat crop. This translates into higher yield for wheat.

Vishwanathan et al (Narayanamoorthy) (2016)	India (Maharastra)	Yes	A 114% gain in yield (productivity) is observed in cotton for DMI over FMI. The yield gains for other crops have been covered in a similar study by the author.
Vishwanathan et al (2016)	India (Gujarat)	Yes	The increase in the yield of crops have been reported to be quite significant ranging from as high as 121% for fennel during kharif to 80% in groundnut during summer; to 56% for castor during kharif to 32% in wheat during rabi season.
Vishwanathan et al (Dinesh Kumar) (2016)	India (Rajasthan)	Yes	In case of groundnut and cluster bean, yield has decreased marginally whereas for bajra it had increased marginally. Overall, there is no general trend in yield. One limitation could be that these observations have been done for monsoon and winter seasons only.
Vishwanathan et al (D. Suresh Kumar) (2016)	India (Tamil Nadu)	Yes	Yield increase is observed in banana, coconut, grapes and turmeric in the region of 4%, 15%, 16% and 22% respectively.
Vishwanathan et al (Chandra Sekhar Bahinipati et al) (2016)	India (Gujarat)	Yes	Similarly, 83% of respondents perceived that adoption MIS resulted in yield increase.
Chandran et al. (2016)	India (Kerala)	Yes	Yield increase is observed in coconut, arecanut and nutmeg in the region of 19%, 13% and 47% respectively.
Kumar et al. (2004)	India (Gujrat)	Yes	The extent of alfalfa yield enhancement through drip system ranged from 7.4% to 10.8%

3.3 Water saving and productivity from micro irrigation

The water saving potential of the micro-irrigation technologies can be acquired in two ways. The concept can be explained as 'dry' water saving and 'wet' water saving. Dry water saving refers to reducing the water consumption for a particular crop. On the other hand, wet water saving is achieved when yield of a crop is enhanced without changing the amount of water consumed. (Kumar et al., 2008).

The review of literature consisting of recent studies (i.e. 2004 onwards) show water saving in the range of 25% to 80%. A handful of studies discuss improvement in water use efficiency (WUE) when dealing with water saving achieved. It is essential to understand that the real water saving impacts of these systems at the field level highly depends on enhancement in WUE. (Kumar et al., 2008). However, most of the studies reviewed base their results primarily on 'dry' water saving (applied water) rather than the 'wet' water saving. Hence, it is key to look into these distinctions while reviewing the extent of savings presented.

The fluctuations in the extent of water saving is primarily due to different types of crops involved in each of these studies. Apart from the context of different crops in each of these studies, it is also useful to

note that comparison of micro-irrigation systems with the traditional method of irrigation systems could be the varying factor. The condition of traditional method of irrigation systems used for comparison would be crucial. Comparing a poorly managed irrigation system with micro-irrigation system would mean much higher and significant water savings as opposed to other well-managed ones. (Kumar et al., 2008).

In terms of water saving at the holistic level in the context of both experimental plots and sample farmer-owned plots, micro-irrigation systems contribute highly towards net water savings (Table 2). This comes in the form of substantial reduction in losses due to deep percolation, evaporation, and inefficient field conveyance and distribution system. (Namara et al., 2007).

Table 2: *Water savings for micro irrigation*

Authors	Country	Saving	% Change
Narayanamoorthy (2007)	India (Maharastra)	Yes	Water saving of 44%, 37% and 29% observed in sugarcane, grapes and banana respectively as a result of the use of DMI over FMI
Malunjkar et al (2015)	India (Maharastra)	Yes	Water saving of 35% and 29% in experimental and farmer's field respectively due to the use of DMI over CMI
Surendran et al (2016)	India (Tamil Nadu)	Yes	Water saving of 45% observed in sugarcane as a result of LCDI over FMI
Narayanamoorthy (2004)	India (Maharastra)	Yes	Water saving of about 44% per hectare as a result of DMI over FMI
Kumar et al (2009)	India (Uttarakhand)	Yes	Water saving of 41% and 33% observed in garden pea and french bean respectively as a result of using gravity fed MIS
Verma (2004)	India	Yes	A review states that most studies point to farm level savings in water which might actually only be notional savings.
Verma et al (2004b)	India	Yes	From what has been observed a Maikaal, adoption of micro irrigation technologies does lead to improved water efficiency at the individual farm level. However, unless the technologies are adopted on a large scale, the impact would not be significant at the basin level.
Verma et al (2004a)	India (Madhya Pradesh)	Yes	There is a notional saving of 50% in terms of water used.
Namara et al (2007)	India	Yes	The study highlights the fact that water application can be reduced by 50-100% through use of drip method of irrigation.
Qin et al (2016)	China (Gansu Province)	Yes	Water saving as a result of shorter growth days as compared to border irrigation. The growth days were shortened by nearly half month in two years.

Narayanamoorthy (2005)	India (Tamil Nadu)	Yes	Adopting the drip method of irrigation from each acre of sugarcane can save over 58% of water.
Randev (2015)	India (Himachal Pradesh)	Yes	Water saving of 25% has been observed by the drip irrigation system users surveyed in Himachal Pradesh. (130 respondents from Shimla District)
Von Westarp et al (2004)	Nepal (Panchkhal Horticulture Farm)	Yes	Water saving, in terms of scarce water allocation is seen to be efficient as compared to conventional method of irrigation.
Kumar et al (2008)	India	Yes	The review of literature shows that drip irrigation leads to substantial saving in applied water over conventional method of irrigation.
Sakthivadivel et al (2004)	India	Yes	Water saving of 80% is observed as a result of the use of drip irrigation systems over the furrow system of irrigation.
Vishwanathan et al (Narayanamoorthy) (2016)	India (Maharastra)	Yes	Water saving for sugarcane, grapes and banana are similar to another study published on the same. Water saving in cotton is observed to be 45% (in terms of saving in applied water)
Vishwanathan et al (2016)	India (Gujarat)	Yes	Overall water saving of 30% is observed under the micro irrigation system. The water saving is 64% during summer when water scarcity is felt the maximum.
Vishwanathan et al (Dinesh Kumar) (2016)	India (Rajasthan)	Yes	Water saving observed to be 39% as a result of adoption of sprinkler irrigation. Every hectare of sprinkler irrigated area saves water to the tune of 816m^3
Vishwanathan et al (D.Suresh Kumar) (2016)	India (Tamil Nadu)	Yes	The value of water saving is worked out to be Rs 1,49,393 per hectare in over-exploited regions while it is Rs 76,943 per hectare in semi-critical region.
Vishwanathan et al (Chandra Sekhar Bahinipati et al) (2016)	India (Gujarat)	Yes	Out of 355 farmers interviewed randomly, over 88% of respondents perceived and responded that MIS saved water.
Chandran et al. (2016)	India (Kerala)	Yes	No savings in water is specifically mentioned. However, DMI is used to cope with water scarcity.
Kumar et al. (2004)	India (Gujrat)	Yes	The extent of water saving through drip system ranged from 7.2% to 43%

3.4 Energy savings from micro irrigation

Energy savings as a result of adoption of micro irrigation systems relate mostly to reduction in working hours of the pump sets as a direct result of reduction in water consumption. In the context of this review, energy savings have been mostly characterized as electricity savings in line with bulk of the observations in the reviewed studies.

The review of literature consisting of recent studies (i.e. 2004 onwards) show that the electricity savings from the adoption of micro-irrigation systems fall in the range of 25% to 77%. The wide variation in savings can be observed as a result of different field conditions and unit of observations in the studies reviewed. For instance, in hard rock areas like Maharashtra, Madhya Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh, farmers cannot pump as much water and usually have to discontinue pumping after 2-3 hours of pump use and use it sparingly. Adoption of MI systems in this case might translate to more efficient use of the pump by reducing the rate at which the water is pumped. (Kumar et al., 2008). Hence, the degree of savings as a result of adoption of micro-irrigation systems depend on the condition of the field areas in consideration. Similarly, the variation in savings can also occur as a result of different unit of observations used. For example, a sample farmer from Tamil Nadu reported savings of 1260 kwh (58%) for each acre of sugarcane cultivation. An observation of sugarcane farmers in Maharashtra shows savings of 1059 kwh (44.43%) per hectare in sugarcane cultivation. The reported savings can have fluctuations due to use of different unit of observations like acre and hectare in the above case. Overall, it can be observed that due to more efficient use of the pumps for irrigation, significant energy costs (electricity costs) can be saved as a result for both experimental as well as sample farmer fields.

Table 3: *Energy savings for micro irrigation*

Authors	Country	Saving?	Energy Saving (Electricity)
Narayanamoorthy (2007)	India (Maharastra)	Yes	Electricity saving of 44%, 37% and 29% observed in sugarcane, grapes and banana respectively as a result of the use of DMI over FMI
Malunjkar et al (2015)	India (Maharastra)	Yes	Electricity saving of 38% and 33% in experimental and farmer's field respectively due to the use of DMI over CMI
Surendran et al (2016)	India (Tamil Nadu)	Yes	Average electricity saving of 25% as per the use of LCDI over FMI
Narayanamoorthy (2004)	India (Maharastra)	Yes	Electricity saving of 44% observed as a result of the use of DMI over FMI
Kumar et al (2009)	India (Uttarakhand)	N/A	
Verma (2004)	India	N/A	
Verma et al (2004b)	India	N/A	

Verma et al (2004a)	India (Madhya Pradesh)	Yes	Adoption of Pepsee systems is seen to decrease the total hours of pumping leading to energy savings. However, the pepsee systems has led to greater pumping of water in some cases as it has helped farmers to undertake a summer crop of cotton which was not possible earlier.
Namara et al (2007)	India	N/A	
Qin et al (2016)	China (Gansu Province)	N/A	
Narayanamoorthy (2005)	India (Tamil Nadu)	Yes	Estimated saving of around 58% of electricity can be saved from each acre of sugarcane cultivation by adopting drip method.
Randev (2015)	India (Himachal Pradesh)	N/A	
Von Westarp et al (2004)	Nepal (Panchkhal Horticulture Farm)	N/A	
Kumar et al (2008)	India	N/A	
Sakthivadivel et al (2004)	India	Yes	The total number of hours of pumping required for the whole season is significantly less for drip irrigation as compared to furrow irrigation. This saving in electricity can be used to grow much more and irrigate additional areas of land.
Vishwanathan et al (Narayanamoorthy) (2016)	India (Maharastra)	Yes	Gains of 45% in Electricity consumption is observed for cotton for DMI over FMI
Vishwanathan et al (2016)	India (Gujarat)	N/A	
Vishwanathan et al (Dinesh Kumar) (2016)	India (Rajasthan)	N/A	
Vishwanathan et al (D. Suresh Kumar) (2016)	India (Tamil Nadu)	Yes	The per hectare electricity saving in the over-exploited region is observed to be 73%. Similarly, in semi-critical region, the electricity saving was observed to be 77% per hectare.
Vishwanathan et al (Chandra Sekhar Bahinipati et al) (2016)	India (Gujarat)	Yes	Out of 355 farmers interviewed randomly, 63% of the respondents perceived and responded that MIS saved energy.

Chandran et al. (2016)	India (Kerala)	N/A	
Kumar et al. (2004)	India (Gujrat)	Yes	Energy saving ranged from 31 K.W. hr per year to 232 K.W. hr per year as per observations from 4 plots.

4. Conclusions and Way Forward

On an average, adoption of micro irrigation tends to benefit the adopters in all three 'climate-smart' categories, i.e. yield enhancement, water savings and energy savings that fall in line with the climate-smart agriculture. The yield gains, water savings and energy savings seem to increase in the field level. However, the water and energy consumptions will rise if we consider basin level adoption as there would be a tendency for the farmers to pump/use more water as they look to expand their irrigated area. Findings suggest that regions where the land have been left fallow or unirrigated due to shortage of water, adoption of AWM technologies leads to expansion of the command area (Kumar et al., 2008; Kishore et al., 2014; Ahmad et al., 2013). This translates into an increase in yield due to rise in cultivated area but could lead to further depletion in regions suffering from groundwater scarcity. Hence, it is imperative to acknowledge that the water saving capabilities of this AWM technology could, in turn, end up increasing water consumption thereby also leading to rise in energy consumption.

Our review finds that there were no studies conducted with farm level surveys or otherwise that used Randomized Controlled Trial (RCT) methodology. The treatment and control groups for studies tend to be purposively sampled and not randomized which could result in a bias in reporting. Therefore, a RCT methodology should be pursued in the future research. Furthermore, as a limitation, majority of the studies come from plains of South Asia with very few studies looking into the benefit of climate smart agriculture in hill regions.

References

Ahmed, M., Suphachalasai, S. (2014). Assessing the Costs of Climate Change and Adaptation in South Asia. Regional Economics of Climate Change in South Asia – Adaptation and Impact Assessment (RECCSA II). Asian Development Bank.

Chandran, K.M., Surendran, U. (2016). Study on factors influencing the adoption of drip irrigation by farmers in humid tropical Kerala, India. International Journal of Plant Production, 10(3), 347-364.

Dinesh, V.M., Narayanamoorthy, K.A. (n.d.). Micro Irrigation Systems in India. http://doi.org/10.1007/978-981-10-0348-6

FAO (2016). Climate Smart Agriculture. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/climate-smart-agriculture/en/.

Hla, A. K., Scherer, T.F. (2003). Introduction to Micro-irrigation, NDSU Extension Service, North Dakota State University.

IFAD (2007). Climate Change Impacts – South Asia. The Global Mechanism – United Nations Convention to combat desertification. The International Fund for Agricultural Development (IFAD).

Kumar, M. D., Shah, T., Bhatt, M., Kapadia, M. (2004). Dripping Water to a Water Guzzler: Techno Economic Evaluation of Drip Irrigation of Alfalfa in North Gujarat, India, pp. 1–8.

Kumar, M. D., Turral, H., Sharma, B., Amarasingh, U., & Singh, O. P. (2008). Water Saving and Yield Enhancing Micro Irrigation Technologies in India: When and where can they become best bet technologies? (September 2015).

Kumar, M., Kumar, N., Singh, K. P., Kumar, P., Srinivas, K., Srivastva, a. K. (2009). Integrating water harvesting and gravity-fed micro-irrigation system for efficient water management in terraced land for growing vegetables. Biosystems

Engineering, 102(1),106–113.

Malunjkar, V.S., Deshmukh, S.K. (2015). Energy Efficiency Assessment of Micro Irrigation. *Scientific Journal: Agricultural Engineering, XL (1), 95-102).*

Namara, R. E., Upadhyay, B., Nagar, R. K. (2005). *Research Report 93: Adoption and Impacts of Microirrigation Technologies Empirical Results from Selected Localities of Maharashtra and Gujarat States of India. Water Management.* http://doi.org/http://dx.doi.org/10.3910/2009.094

Namara, R. E., Nagar, R. K., Upadhyay, B. (2007). Economics, adoption determinants, and impacts of micro-irrigation technologies: Empirical results from India. *Irrigation Science, 25(3), 283–297.*

Narayanamoorthy, A. (2004). Impact assessment of drip irrigation in India: the case of sugarcane. *Development Policy Review, 22(4), 443–462.*

Narayanamoorthy, A. (2005). Economics of drip irrigation in sugarcane cultivation: Case study of a farmer from Tamil Nadu. *Indian Journal of Agricultural Economics, 60*(2), 235–248.

Narayanamoorthy, A. (2007). Micro-irrigation and electricity consumption linkages in Indian Agriculture: A field based study. *International Conference on Linkages Between Energy and Water Management for Agriculture in Developing Countries* (pp. 29-30), Hyderabad, India.

Qin, S., Li, S., Kang, S., Du, T., Tong, L., Ding, R. (2016). Can the drip irrigation under film mulch reduce crop evapotranspiration and save water under the sufficient irrigation condition? *Agricultural Water Management, 177*, 128–137.

Randev, A. K. (2015). Analysis of crops' productivity potential and drip irrigation system in India – Policy implications. *26th Euro Mediterranean Regional Conference and Workshops*, October 12-15 2015, pp. 1–5.

Sakthivadivel, R., Bhamoriya, V. (2004). The Case of Micro- Irrigation: Does it really save water? Evidence from Maikaal (Nimar Valley) Cotton Growers. *IWMI-TATA Water Policy Program: Annual Partners' Meet 2004.*

Surendran, U., Jayakumar, M., Marimuthu, S. (2016). Low cost drip irrigation: Impact on sugarcane yield, water and energy saving in semiarid tropical agro ecosystem in India. *Science of The Total Environment*, 573, 1430-1440

Verma, S. (2004). Promoting Micro Irrigation in India: A Review of Evidence and Recent Developments. *IWMI-TATA Water Policy Program: Annual Partners' Meet 2004.*

Verma, S., Tsephal, S., Jose, T. (2004a). Promoting Micro Irrigation in India: Lessons from Maikaal. *IWMI-TATA Water Policy Program: Annual Partners' Meet 2004.*

Verma, S., Tsephal, S., Jose, T. (2004b). Pepsee systems: Grassroots innovation under groundwater stress. *Water Policy*, 6(4), 303–318.

Viswanathan, P.K., Kumar, M.D., Narayanamoorthy, A. (2016). Micro Irrigation Systems in India: Emergence, Status and Impacts. *India Studies in Business and Economics.* Springer Science+ Business Media, Singapore.

Von Westarp, S., Chieng, S., Schreier, H. (2004). A comparison between low-cost drip irrigation, conventional drip irrigation, and hand watering in Nepal. *Agricultural Water Management*, 64(2), 143–160.

Irrigation management under changing climate scenario for evergreen revolution - Asian economic perspective

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Abstract

Total utility concept of water signifies huge importance of water as it adds utility to bio and a-bio objects. Any water resource development project must be based upon socio- economic parameters in the light of changing climatic scenario. The relative scarcity of water amongst burgeoning population in Asian countries need to be analysed in economic terms through scientific methods for strengthening water resource infrastructure for irrigation on sustainable basis. Truly remarked 'Stand with your back to water, you find impact of poverty on environment'. In Asian countries, in general, India in specific, it has become a dire need to analyse water management issues at different intervals of time specifically in the field of agriculture as about 80% of water has been found to be used in agriculture sector as a source of irrigation and dependence of majority of population is on agriculture sector for its livelihood. Commonality of socio-economic issues among various Asian countries related to availability of irrigation in agriculture has long been observed. This paper has been developed with following objectives - (i) to find out the existing status of socio economic parameters among clientele groups; (ii) to study growth trends in irrigation and modernised irrigation systems; and (iii) to analyse gaps affecting irrigation availability for making scientific suggestions for improvement. Results have shown that irrigation has been playing a pivotal role globally in affecting crops' productivity. A significant contribution of research and development efforts in managing water resource in India specifically has been vivid due to positive trends in growth of irrigated area accompanied by growth in water saving technologies (acgr = 4.1%). The crops' productivity has been found to be only 2-3 times higher on irrigated farms as compared to rainfed farms as compared to 6-8 times on most productive farms of the world. As crops' productivity has been found to be a resultant effect of total factor productivity of all the resources used by a farmer, therefore, a need has been observed to undertake an overview of all the synergistic efforts made in India specifically in developing irrigation. As socio-economic parameters affect cumulatively crops' productivity, most importantly, holding size, population status, literacy, availability of other inputs and other factors related to outer environment of farming, therefore, government development efforts in developing irrigation in different countries of Asia in the light of socio-economic parameters with emphasis on crops' productivity has been discussed in this paper. Declining trend of per capita holding (1.20 Ha in 2004 and 1.00

Ha in 2016) along with declining per capita availability of water in India (acgr= -19.20%) logically have been showing almost the similar trends as in other Asian countries with an increase in population and those have mainly been found to be the basic causes of lower crops' productivity on Asian farms. Making available water for irrigation through irrigation development projects under changing climatic conditions and modernizing already existing irrigation infrastructures must have been in consonance with the socio-economic parameters/ multidisciplinary issues for larger interest of farming community for this approach only can lead to enhancement of weighted irrigation development indices (presently < 0.50). A balanced economic approach based on scientific methods has been considered to be the only approach for evergreen revolution in agriculture through availability of water for irrigation on sustainable basis.

Keywords: *crops' productivity; economic planning; socio-economic; total utility.*

1. Introduction

Population pressure in Asian countries has been rising over a period of time resulting into fragmented land holdings. It has become a serious concern from policy withstand for reasons of food security. Amongst all the inputs including land, used in growing food crops, 'water' has been playing a critical role in affecting crops' productivity levels, therefore, 'water' in the form of irrigation needs pivotal concern for securing food availability to the growing population.

Total utility concept of water signifies huge importance of water as it adds utility to bio and a-bio objects. Any water resource development project must be based upon socio-economic parameters in the light of changing climatic scenario. The relative scarcity of water amongst burgeoning population in Asian countries need to be analysed in economic terms through scientific methods for strengthening water resource infrastructure for irrigation on sustainable basis. In Asian countries, in general, India in specific, it has become a dire need to analyse water management issues at different intervals of time specifically in the field of agriculture as about 80% of water is used in agriculture sector as a source of irrigation and dependence of majority of population is on agriculture sector for its livelihood. Commonality of socio economic issues among various Asian countries related to availability of irrigation in agriculture has long been observed. This paper has following specific objectives;

- To find out the existing status of socio-economic parameters among clientele groups;
- To study growth trends in irrigation and modernised irrigation systems; and
- To analyse gaps affecting irrigation availability for making scientific suggestions for improvement

2. Methodology

Asian countries in general and south Asian in particular comprises of sub-Himalayan countries dominated by the Indian Plate rising above sea level. This region has commonality amongst socio-economic parameters. More so, dietary habits almost based on common agricultural commodities have led this study to focus on South Asian countries.

South Asia covers about 5.1 million km^2, which is 11.51% of the Asian continent or 3.4% of the world's land surface area. The population of South Asia has been reported to be 1,749 billion; about one-fourth of the world's population making it the most populous and the most densely populated geographical region in the world. The South Asia region accounts for about 39.5% of Asia's population. India has been

reported to comprise of about 70% of South Asian population. Hence south Asian countries comprising of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka have been included in this study with major reference with respect to India by adopting purposive sampling.

This paper has been based upon different research studies undertaken by the author in command areas of different watersheds in the state of Himachal Pradesh, located in North-West Himalayan region of India. The research studies related to land utilisation, water resource availability, conservation measures and utilisation in different watersheds, seasonal and perennial crops' productivities along with other environmental parameters in the light of climate change have been based upon primary data. The secondary data pertaining to area under irrigation, net sown area and crops' productivities have been collected for a period 2004-2005 to 2016-2017 to see the growth trends by adopting functional approach through the function: $Y = a X^b$ and annual compound growth rates have been worked out by ACGR = (b-1) X 100.

Irrigational development index indicates cumulative impact of efforts rendered by the concerned agencies to develop irrigation potential on the total output of irrigation projects/programs. Flow diagram has also been used for conservation and utilization of water through balancing

$$\sum_{i=1}^{n} \text{Demand} = \sum_{i=1}^{n} \text{Supply} \qquad (1)$$

The cost effectiveness of water resource projects has been validated by working out parameters by using law of equi-marginal utility:

$$\frac{MUw_1}{P_1} = \frac{MUw_2}{P_2} = \frac{MUw_3}{P_3} \text{------------} \frac{MUw_n}{P_n} \qquad (2)$$

Inputs implication to the policy issues has been based on multiple responses, scientific recommendations and development oriented existing water resource projects/programs.

A triangular approach involving users, i.e. farmers of the state, scientific recommendations and policy issues have been inter related by adopting utility based economic tools and flow relation among environmental parameters.

3. Result and Discussion

The results and discussion have been arranged as per objectives of the study:

3.1 Existing status of socio-economic parameters in South Asian countries

Water availability and its' use have inherent relationship with socio-economic parameters. Hence to have a compact approach to multi-disciplinary issues of water resource, it has been considered better to have a schematic view of the central parameters/issues related to majority of agrarian economies for water resource development, including irrigation. Socio-economic parameters having direct impact on economic planning in the country are shown in Table 1. It has been found that major growth rates of basic population-related parameters like average annual growth rate of population has been varying between 1 to 2% in all the South Asian countries. Similarly, dependency ratio and unemployment rate have been found to be varying between 47 to 65 and 2.5 to 5.9%, respectively. It has led to population below poverty line between 21.9 to 31.5% except Bhutan and Sri Lanka, where it ranges between 6.7 to 12.0%. These ranges of important population indicators have led to Gini index for all the selected South Asian countries to vary between about 30 to 39% indicating more than one-third of the total population of respective selected countries having inequality with respect to economic indicators and

need serious concern in framing development policies/programs. Most importantly, it has been clear that annual growth rate in agriculture is very low, below 4.4%, in all the selected countries. Gross domestic product (GDP) growth rate of the respective countries range between 4 to 7.9% in all the countries except Nepal, where it is just 2.3%.

Striking lower growth rates of agriculture, in spite of being countries having major population engaged in agriculture, interacting with other socio- economic parameters like higher inflation rates (between 2.9 to 9.9%) may be attributed to lower productivities of agricultural crops grown in these countries.

Table 1: *Socio economic parameters of South Asian countries (Source : www.adb.org)*

SN	Country	Average Annual Growth rate (%)	Population density No/ km2	Dependency ratio (%)	Gini index (%)	Population below poverty line (%)	Unemployment rate (%)
		(1)	(2)	(3)	(4)	(5)	(6)
1.	Afganistan	2.0	45	87	-	36.0	-
2.	Bangladesh	1.3	1083	52	32.1	31.5	4.3
3.	Bhutan	1.6	20	47	38.8	12.0	2.5
4.	India	1.3	395	52	35.2	21.9	4.9
5.	Maldives	3.5	1609	47	-	15.0	
6.	NEPAL	1.4	192	62	32.8	25.2	3.0
7.	Pakistan	2.0	245	65	30.7	29.5	5.9
8.	Sri Lanka	1.0	323	51	39.2	6.7	4.7

SN	Country	Mortality rate due to unsafe water, sanitation and hygiene (%)	Growth rate per capita income (%)	Forest Area to total area (%)	Per capita GNI	Annual value added growth rate agri (%)	Annual growth rate GDP (%)/ Inflation rate
		(7)	(8)	(9)	(10)	(11)	(12)/(13)
1.	Afganistan	-	-	2.1	680	1.6	3.3
2.	Bangladesh	6.0	1.4	11.0	1190	2.8	7.1/5.9
7.9(2015)							
3.	Bhutan	7.1	6.5	72.3	2380	4.0	6.4/3.3
4.	India	27.4	3.7	23.8	1590	4.4	7.1/4.7
5.	Maldives			3.3	5750	-	3.7/4.0
6.	NEPAL	12.9	4.1	25.4	730	1.3	0.8/9.9
7.	Pakistan	20.7	2.5	1.9	1440	-0.2	4.7/2.9
8.	Sri Lanka	3.3	1.7	33.0	3800	-4.2	4.4/4.0

3.1.1 Crops' productivity issues

Among different inputs used in agriculture, irrigation is playing the most important role in influencing crops' productivities. Empirical evidences have shown that surface and assured or protective irrigation has encouraged farmers to invest more in farming technology and inputs leading to productivity enhancement and increased farm incomes. The results have indicated irrigated farms yielding 2.43 times higher production than rain fed farms (Randev, 2015). The results have also indicated that only about 9% of the micro irrigation potential has been covered in the country, therefore, dire need has been observed to increase irrigated area and adoption of water saving technologies in the country.

India is a dominating country among other South Asian countries with respect to contribution of different food and fruit crops. Its' position with respect to many socio-economic parameters has been found to be moderate as some of the countries stand a little better and a few show lower growth rates, most importantly its' GDP has been showing maximum growth rate 7.9% in 2015 and 7.1% in 2016 with moderate average inflation rate of 4.7%. As India stands amongst top ranked countries in the world in producing fruits and vegetables; yet scientific judging from productivity angle has shown **that** productivities of major crops in India are lower by factors varying from about 3 to 6 than the world's most productive farms (Table 2).

Table 2*: Productivity of important agricultural crops in India, Himanchal Pradesh (HP) vs World's most productive farms.*

SN	Crop/s/commodities	Productivity in India/ H.P. (t/ha)	World's most productive farms
1.	Rice	3.3 / 1.74	10.8 (Australia)
2.	Wheat	2.8 / 1.45	8.9 (Netherlands)
3.	Mangoes	6.3	40.6 (Cape Verde)
4.	Sugar Cane	66	125 (Peru)
5.	Banana	37.8	59.3 (Indonesia)
6.	Cotton	1.6	4.6 (Isreal)
7.	Potatoes	19.9 / 12.35	44.3 (USA)
8.	Fresh Vegetables	13.4 / 21.33	76.8 (USA)
9.	Tomatoes	19.3	524.9 (Belgium)
10.	Okra	7.6	23.9 (Isreal)
11.	Beans	1.1	5.5 (Nicargua)

This inference of impact of water/irrigation on crops' productivities have led to explain important water related issues of the South Asian countries in general and Indian farmers in particular in the light of related national water policy of India.

3.1.2 Land holding in India

There is rising number of marginal and small-holding farmers. Land and water have been the basic natural resource on which crops' productivity has its sole dependence. The average size of farms in India has become smaller with the passage of time due to division of land allowed as per share of each child (Table 3). It has been found that the current holding size has declined by about 6.82% and worked out to decrease by 65.85% during the last one and a half decade (1.23 Ha in India against 1.00 Ha in study area–Himachal Pradesh). Consequently, the holding size has reduced to the minimum by the next one and a half decade and this has been considered to be a serious set-back to the basic natural resource – land responsible for economies of scale in agriculture.

Table 3: *Average size of land holding in India*

S.N	Particulars	Years(1970-71)	2000-2001	2015-16	2020	2030
1.	Average size of holding (Ha)	2.30	1.32	1.23	0.68	0.32

Figure 1: *Major river basins - Indus and Ganges*

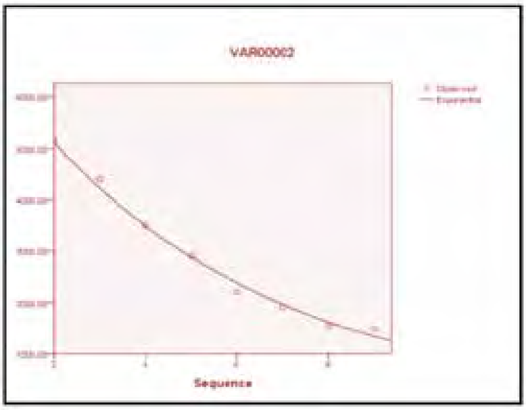

Figure 2*: Per capita water availability trend (1951-2016)*

Water use efficiency in agriculture has also been reported to be 38%, as against 45% in Malaysia and Morocco and 50 to 60% in Israel, Japan, China and Taiwan. Hence, this paper highlights the economic reasons responsible for declining trend in per capita water availability in the country, to be used in planning water resource as well as irrigation.

3.1.4 Other socio-economic issues

The lower endowment to farmers of these three issues accompanied by other socio-economic parameters like public expenditure in the light of public policies and performance of other private organizations have kept all other input use efficiencies in agriculture at lower levels. The pivotal element of all the inputs, i.e. water, has been considered to be of utmost importance in agriculture which needs a

thorough scanning of each part of a 'water tree' (Fig. 3) to find lacunae in performance of water projects in general and irrigation in particular.

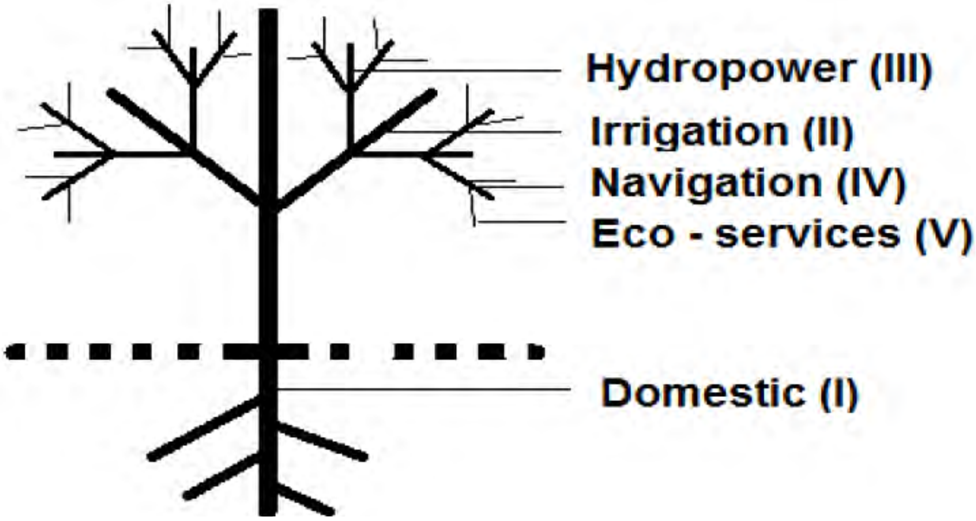

***Figure 3**: Water tree based on multiple uses of water*

3.1.5 Water storage issue

The per capita water storage capacity in India is very low (209 m^3), as compared to 5,686 m^3 in Russia, 3,223 m^3 in Australia, 416 m^3 in China and 2,192 m^3 in USA (Hegde, 2016). The annual extraction of groundwater has also been found too high at some places in the country, though it is lower than national average in Himachal Pradesh. Groundwater potential in the state has been explored up to 30% only, hence about 70% groundwater potential in the state is yet to be explored.

3.1.6 Other environmental issues

Contamination of surface and ground water has direct relationship with health. Non channelization of water has led to many negative impacts of water like land degradation, floods and huge losses to property which account for huge monetary losses to the central and state governments.

3.2 Growth trends in irrigation and modernized irrigation system (micro irrigation system)

Total cultivated area (184.38 Mha) is about 56.09% of the total geographical area (328.73 Mha) of India. Irrigation in India has been explored for ultimate use through major and minor canals from Indian rivers, groundwater, tanks and other rainwater harvesting structures for agricultural activities. Gross irrigated area is about 37.54% (70.64 Mha) of the gross cropped area and about 62% area is rainfed. Gross irrigated area has increased at a compound growth rate of 1.3% during 2005-06 to 2015-16 (Fig.4). Projects at

macro level for irrigation have been put to many uses like electricity generation, transportation, drinking water, flood control and eco-tourism.

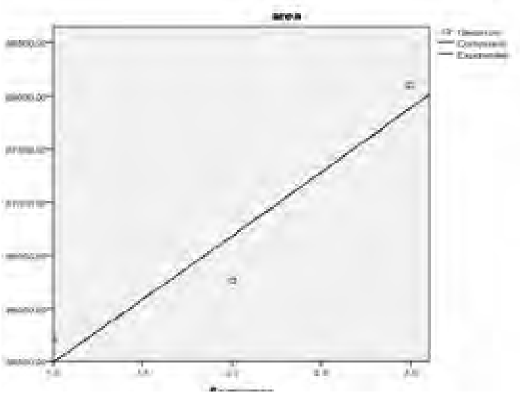

Figure 4: *Total irrigated area in India ('000 ha)*

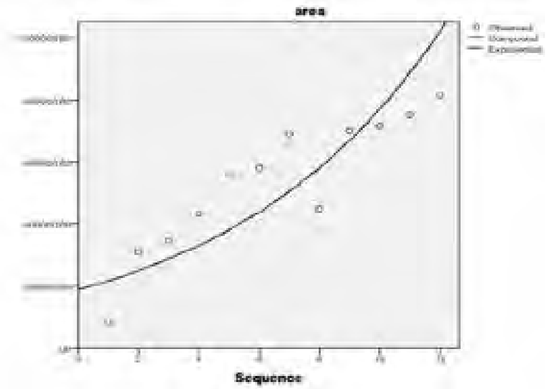

Figure 5: *Area under micro irrigation system (MIS) (ha)*

At micro levels, micro irrigation has been simultaneously taken to provide irrigation water to agricultural crops. There has been a significant growth in micro irrigation in the country (ACGR = 14.1%) (Fig. 5), which has brought significant changes in productivity of different fruits and vegetables along with savings in water. The physical production of pomegranate, mango and radish have been reported to increase by about 3.01 to 3.17 times and water savings in fruits like banana, grapes, pomegranate, guavas, caster apples, mosambi, ground nuts, sugar cane and tomato have been worked out to be 20 to 50%. Although net and gross area sown have decreased at ACGR = 0.02 and 1.5%, respectively (Fig 6 and Fig. 7), yet irrigated area and micro irrigation increase has led to increase in productivity of crops. The weighted irrigation development index has been found to be 0.46 under the existing scenario of available land and water resource use in India.

The Government's programs related to irrigation have given high priority to water security in the current plan. Emphasis has been given to finish long pending projects and expedite efforts further under "Pradhan Mantri Krishi Sinchayee Yojana" so as to make water available **on each farm** at the soonest possible period of time. Budgetary allocations have been made to cover linking of rivers, preventing recurrence of floods and drought by ensuring optimal use of water available. Rainwater has been planned to be harnessed through Jal Sanchay and Jal Sinchan for nurturing water conservation and groundwater recharge. Micro irrigation has been popularized with a missionary zeal in the country to ensure "More Crop per Drop". Feasible expenditure during the first phase of this Yojna in India has been increased from 6,990 crores to 16,210 crores, i.e., from $107.54 million to $ 249.38 million (by about 2.32 times)

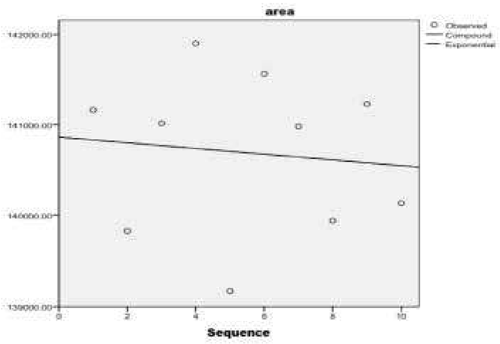

__Figure 6:__ Net sown area (ha)

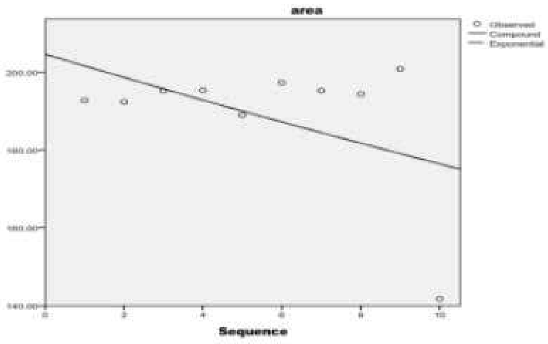

__Figure 7:__ Gross sown area (Mha)

3.3 Gaps affecting irrigation availability as per national water policy

Albeit growth trends are positive yet a wide gap has been observed between demand for and supply of irrigation to agricultural farms. Huge potential of water in South Asian countries in general and India in particular in and around Himalayan region has been found to be possible provided existing gaps are solved in the light of existing national water policies of respective governments.

3.3.1 Interaction between national water policy and socio-economic parameters

In order to have a balance between water availability and its utilisation and enhance weighted irrigation development index (IDIw=0.45), a review of major features, amongst others, of the national water policy of the Government of India (GoI) has revealed **- (i)** Water to be treated as an economic good that has been signifying the use of economic variables in water resource management **(ii)** Water allocation priorities include drinking water, irrigation, hydropower, navigation, industrial and other uses that has also been signifying multiple use of water through utility approach **(iii)** to give importance to impact of projects on human settlements and environment that again signifies economic impact assessment **(iv)** Resource planning that has been emphasizing economic planning and recycling for providing maximum availability and **(v)** Rationalization of the water rates for surface water and ground water that has been leading to pricing criteria amongst others. These major features have direct relationship with economic planning of water that has been lacking into at least at implementation level of water resource development projects in general and irrigation in particular are required at every stage of project even after completion for economic evaluation study.

Taking these into consideration, the following set of models comprising macro and micro level planning in case of water resource projects are considered opined to achieve ultimate goals of water resource development projects and overcome hazards due to droughts and floods in different seasons. At planning level, irrigation has been considered as a part of total water use amongst multiple uses of water as per priorities set according to national water policy.

3.3.2 Macro level planning

"Macro" here denotes national and state level planning of water resource for multiple uses to ensure highest total utility. This has been achieved by applying demand and supply model of water resource use at first at the respective macro level.

(a) Perennial source: Following schematic points for perennial sources of water have been evolved in the light of above mentioned water related issues:

Supply side -

- **Identification of watersheds** or water sources at macro level **(Isma)**
- **Jurisdiction of watersheds** at macro level **(Jsma)**
- **Total supply of water** at macro level **(Tsma)**

Demand side -

- **Identification of demand** for water at macro level **(Idma)**
- **Jurisdiction of demand** central areas at macro level **(Jdma)**
- **Total demand for water** at macro level **(Tdma)**

Thus, supply demand based macro model of water resource/irrigation development has been presented in Fig. 8.

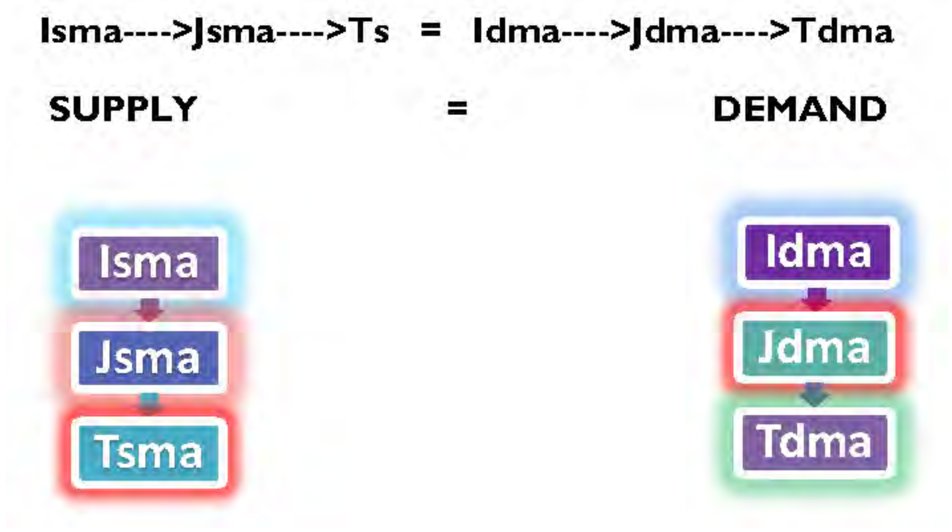

***Figure 8:** Macro level planning*

Depending upon Tsma and Tdma, the primary, secondary and tertiary distribution channels may be developed in the command areas, specifying central points as per requirements of water in the jurisdiction of each central point. However, engineering designs of water channels depend upon how many water related activities can be taken in the command area like transportation, eco-tourism, etc.

In case Ts< Td, need of exploration of groundwater if not over-exploited in that area, otherwise alternative means can be explored.

Depending upon mapping of primary, secondary and tertiary water channels already constructed roads/ bridges can be renovated and new can be constructed in the light of natural flow of water. The capital formation has been considered dependent on water channelization.

(b) Seasonal sources: Seasonal sources can be channelized by adopting vegetative and engineering measures through other locally available schemes supplementing the main channels. The economic planning through demand supply modelling as given above must be followed.

3.3.3 Micro level planning

It should be considered along secondary and tertiary channels for both perennial and seasonal sources, by adopting same procedure of macro planning model i.e. working out total supply and demand too at micro levels (Tsmi and Tdmi). This can be achieved through micro level water development programs of respective departments under watershed approach by exploring traditional means of water conservation and distribution like ponds, *bowaries* (natural springs), etc., constructing small water supplying channels (*kuhls* in hills), groundwater exploration by adopting suitable technologies, water harvesting structures and water lifting programs, etc.

Thus, supply-demand based **micro model of water** resource/irrigation development has been presented as shown in Fig. 9:

Ismi---->Jsmi---->Tsmi = Idmi---->Jdmi---->Tdmi

SUPPLY = DEMAND

Figure 9: *Micro level planning*

3.3.4 Sustainable model for water resource development/irrigation

Balancing of Ts and Td for water at macro or micro levels supported by Psycho-Socio-Techno-Economic parameters (Randev, 2005) has assisted in evolving a sustainable model for water resource projects in general and irrigation in particular, as shown in Fig. 10.

Figure 10: *Sustainable model for water resource projects/irrigation projects*

Socio-economic parameters show that majority of population in agrarian economies depends upon agriculture, therefore, majority of population can be scientifically benefited on sustainable basis if supply-demand models are used in macro and micro level planning of water resources/irrigation by multi-disciplinary experts. The role of Applied Economist specifically has been found missing throughout the gestation period of the projects which need to be considered on priority basis at every stage of the project.

3.3.5 Advantages of sustainable model

As per main features of national water policy of the GoI, major advantages in the light of economic planning will lead to timely water availability to the farmers leading to enhanced crop' productivity and simultaneously minimizing other environmental negative impacts of un-channelized water resource like floods, loss of lives and property etc. Positive impacts have been found including increase in yields leading to increase in income levels accompanied by returns on account of other positive uses of water like eco-tourism. Overall impact of economic planning in water resource development projects has been explained through trade off among economic efficiency, social welfare and environmental degradation – GHI portion of Fig. 10, that has been indicating – 'Total investment on water resource projects has been found to bring incremental benefits with respect to increase in economic efficiency (from D to G) of all the techno-economic parameters along with an increase in social welfare (from E to H) simultaneously lowering down environmental degradation (F to I) to the maximum level, if and only if, economic planning has been adopted at every stage of the project.' Social welfare has been observed to be found through enhanced weighted irrigation development index – the most important indicator for ever green revolution in any nation based on agricultural economy.

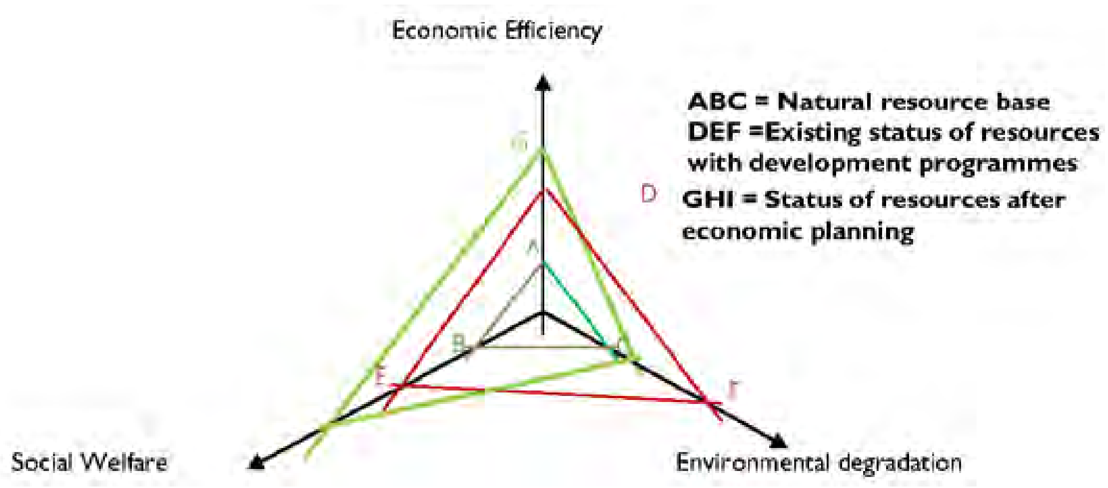

Figure 10: Trade off showing impact of economic planning

4. Summary and Conclusion

This paper addresses the **(i)** Marginal holding size of approximately 1 Ha having meagre irrigation water being the basic cause of lower productivities; **(ii)** Identifies socio economic parameters having strong interred-linkages with water resource like drinking and irrigation etc. as per national water policy; **(iii)** Breaking the vicious cycle of lower incomes by adopting economic planning through supply demand modelling at macro and micro levels in water resource projects/irrigation including the groundwater available and use; **(iv)** Reinforce the concept of economic planning on river basins basis (macro) as well as at every stage of the project (micro level). All individual developmental projects and proposals should be multi- purpose as per national water policy, formulated by the States and considered within the framework of such an overall plan for a basin or sub-basin, so that the best possible combination of potions can be made, thus integrated and coordinated development of surface water and groundwater and their conjunctive use has been found as the most important aspect of economic planning; **(v)** Defining consistent role of applied economists during the gestation and after gestation period of the project**; (vi)** Developing a supply demand based sustainable model showing physical benefits in the form of lowering down environmental degradation simultaneously increasing social welfare with the same or lower economic cost; **(vii)** Third party economic analyses and evaluations have not been found in line with requirements of the national water policy. Without applied economic principles at every stage of the project, sustainable use of water can only be a 'hoax' without yielding any positive results towards social welfare.

Thus, in view of the vital importance of water for human and animal life, for maintaining ecological balance and for economic and development activities of all kinds and considering its increasing scarcity not only in India but all other South Asian/Asian/any other country in the world, planning and management of this resource and its optimal, economical and equitable use has become a matter of utmost urgency. The success of respective national water policy will depend entirely on the development and maintenance of a national consensus and commitments to its underlying economic principles and objectives – to be considered in to through multi-disciplinary experts with emphasis to economic planning at macro

and micro levels: that only can enhance weighted irrigation development index – the most important indicator for evergreen revolution in any nation based on agricultural economy.

References

Anonymous (2007). Water Resources. INDIA (2007). Publication Division. Ministry of Information and Broadcasting, Government of India. pp.861.

Anonymous (2015). Agriculture. Statistical Year Book of Himachal Pradesh. Directorate of Economics and Statistics. Shimla – H.pp.67-77.

Anonymous (2016). Agriculture in India. En.wikipedia.org/Agriculture-in-India.

Anonymous (2016). Irrigation. Economic Review. Himachal Pradesh. Department of Economics and Statistics. Shimla-H.P.pp.41-68.

Anonymous (2017). 50 Years ADB 2017 Basic Statistics, Economic Research and Regional Co-operation, Deptt Development Economics and indicators Division. April 2017 www.adb.org.

Hegde, N.G. (2016). Water Scarcity And Security in India. www.baif.org.in/doc./Water_Resource_Mngt/Water scarcity.

Randev, A.K. (2005). Impact of irrigation on Productivity and Sustainability of Agro landscapes in Himachal Pradesh-India. Paper Published in ***CD-ROM (ISBN 81-85068-96-8)*** *on theme Use of Water Land for Food Security and Environmental Sustainability and sub theme Improving Water and Land Management for increasing efficiency in Irrigated Agriculture 52.2 P. 2.03. by ICID 48, Nayaya Marg, Chankayapuri, New Delhi 110021 – India.*

Randev, A. K. (2007). Socio-economic interactions among multiple uses of water in Himachal Pradesh-India. 4th international conference on 'The Role of Irrigation and Drainage in a Sustainable future'. USCID. CD ROM. pp.981-993.

Randev, A.K. (2014). Impact Mitigation Strategy on Climate Change, Water Supply and Fruit Productivity in India. PD 22nd international congress on Irrigation and Drainage, Gwangju, Korea. Q.58 R.1.15.

Water requirement of different horticultural crops under drip irrigation system in Tamagarda - Erani inter basin

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Abstract

About 70% of the population, living in mountainous regions of Uttarakhand State in India, mostly depend on agriculture for their livelihood, but various climatic, geographical and socio-economic constraints have led to a dismal low agricultural productivity in the region. Frequent and long dry spells retard the growth, size and yield of important fruit crops like apple, plum, peach, apricot etc. Drip irrigation is one of the irrigation methods which is most efficient and water conserving. In the aspect of hilly region of Uttarakhand, drip irrigation system is very useful. Keeping the above in view, the present study was taken up to assess water requirement of different horticultural crops, under drip irrigation system, in Tamagarda - Erani inter basin, located in Champawat district, Uttarakahand state, India. Total monthly irrigation water requirement of all the horticultural plants, planted in the study area, was maximum (i.e. 175,689 liters) in May, whereas, the minimum (i.e., 14,760 liters) in December. The total annual water requirement of all 425 plants of citrus, 200 plants of pomegranate, 45 plants of walnut, 84 plants of peach, 110 plants of apricot, 30 plants of plum, and 130 plants of kiwi was estimated as 344505, 24798, 56174, 102403, 109190, 41293 and 154435 liters, respectively. The available tube well and water harvesting structures are capable to meet this requirement of water for irrigation of planted horticultural crops in the study area.

1. Introduction

The population of India is increasing at an annual rate of 1.7 crores and by the year 2050 may cross 150 crores. India will be requiring about 1,2010,000 lakh m^3 of water in year 2050 to cater needs of population for food, drinking water, domestic and industrial requirements due to which there is a great need to conserve this natural resource. Management of land and water resources in rainfed areas is required for optimum development of these resources and to meet basic minimum needs of the people in a sustained manner. Uttarakhand state of India is largely rainfed, irrigation facilities are minimal, land holdings are small and fragmented, with a predominance of wastelands. Out of the total reported area of the state, only 14.02% is under cultivation. The cropping intensity is 160.6%. The landholdings are small and scattered. The average land holding is around 0.68 ha (that too is divided into many patches) in the

hills and 1.77 ha in the plains. Agriculture is largely (about 90%) rainfed, and the farmers generally face severe soil-moisture stress at germination stage and large dry-spells during the subsequent growing period of winter (*rabi* season) and pre-monsoon crops.

Major part of the Uttarakhand receives good annual rainfall, its intensity and distribution is quite erratic and causes severe drought spells to hamper the growth of timely sown winter crops, and subsequent planting of crops due to lack of soil moisture. This situation forces the farmers to risk their winter (*rabi*) crops at germination and ripening stages of growth. Frequent and long dry spells retard the growth, size and yield of important fruit crops like apple, plum, peach, apricot etc. If proper irrigation facilities are assured, vegetable crop production has a great potential to the economic standard of hill farmers. Off-seasonal vegetables (pea, potato, cauliflower, cabbage etc.) can be produced on a large scale and can be sold at high prices in plain areas. Drip irrigation is one of the irrigation methods which is most efficient and water conserving. In drip irrigation technique, water is directly applied to the root zone of crop in small quantities using a low pressure delivery system with a network of pipes with small emitters (or drippers) built in to them. This method helps in retaining soil moisture at consistent levels as against flood irrigation method where there is a huge variation in soil moisture levels. Keeping the above in view, the present study was taken to assess water requirement of various horticultural crops, under drip irrigation system for the planning of land and water resources management in the Tamagarda - Erani inter basin of Uttarakhand.

2. Materials and Methods

The location of study area is shown in Fig. 1. It is part of the Champawat district in the eastern Kumaun division of Uttarakhand state in India. It is bounded on the north by Pithoragarh district, on the east by Nepal, on the south by Udham Singh Nagar district, on the west by Nainital district and on the north-west by Almora district. The study area is situated at 80˚10'E longitude, 29˚ 60' N latitude and at an altitude ranging from 1600 to 1800 meter above mean sea level. The soil of the study area is mostly sandy-loam with pH value ranging from 6.5 to 7.0.

Figure 1: *Index map of the study area*

The climate of the region is subtropical and humid with three distinct seasons i.e. summer, monsoon and winter. The rainy season starts from middle of June and continue up to the end of September. It is followed by winter season, which starts from the end of October and goes up to February. The winter rains are generally experienced in late December to early January, which brings down the temperature. December and January are the coldest months of the area. The average annual rainfall is about 1152 mm. The maximum and minimum humidity range are from 98 to 66 % and 67 to 25%, respectively. The mean maximum and minimum temperature are 28.20 °C and -1.20 °C, respectively.

3. Data Collection and Analysis

The daily rainfall dataset of 25 years (1991-2015) and weather data of 5 years (2009 -2013) for Champawat district collected from district headquarters, was used for the estimation of effective rainfall, reference evapo-transpiration, crop coefficient, cropwater requirement and irrigation water requirement under drip irrigation of different horticultural crops, planted in the study area (Table 1). The reference evapotranspiration (ET_0) was estimated using the equation, developed by Smith *et al.* (1992), known as FAO Penman-Monteith equation.

Table 1: *Various horticultural crops planted in Tamgarda- Erani inter basin.*

Name of crop	Suitable soil type	Climate	Planting month	Harvesting month	Number of plants
Apricot	Well drained loams	Hot and cold	November - December	December - February	425
Citrus	Well drained, sandy loam to deep loamy or alluvial soils	Hot and dry climate	February - March	July - August	200
Kiwi	Deep silt loam clay loam	Cold	February - March	July - August	130
Peach	Sandy loam and clay loam soils	Cold	February - March	July - August	84
Plum	Clay, Loam, Sandy Loam	Cold	February - March	July - August	30
Pomegranate	Sandy loam and clay loam soils	Cold	February - March	July - August	200
Walnut	Sandy loam and clay loam soils	Cold	February - March	July - August	45

Water requirement of horticultural crops, under drip irrigation, was estimated using following relationship:

$$WR_{drip} = ETc * Kr * Sp * Sr$$

where WR_{drip} = Water requirement under drip irrigation (l/day/plant); ET_c = crop evapo-transpiration (mm/day); K_r = (G_c + 0.10) reduction factor; G_c = average ground coverage; S_p = plant to plant spacing (m); and S_r = row to row spacing (m).

4. Results and Discussions

4.1 Soil characteristics

The surface (0-15 cm depth) and subsurface (15 - 30 cm depth) soil samples were taken from 14 locations at different elevations in the range of 1672 - 1714 m above mean sea level in the study area. These samples were analyzed for their physical and chemical properties. The particle size analysis of soil samples was conducted using Boyoucos hydrometer method, as per procedure given by Black (1965). Textural classification of surface soils of the study area is shown in Table 2. It shows that, sand fraction was in the range of 43.33% to 62.56% with mean value of 57.44% for the soil depth ranging from 0 -15 cm, and 49.33% to 67.33% with the mean value of 60.25% for soil depth ranging from 15 - 30 cm. It indicates that sub-surface soil contained more sand content than surface soils. The silt fraction was in the range of 21.06% to 37.00% with the mean value of 26.41% for surface soils and 24.11% to 34.48% with the mean value of 28.94% for the sub-surface soils. It showed that silt fraction in the soils collected from top layer (0 - 15 cm) had slightly higher silt content as compared to the sub surface layer (15 - 30 cm). The clay fraction in soils was found in the range of 8.48% to 24.34% with the mean value of 13.62 for the surface soils, and 6.48% to 17.79% with the mean value of 18.42% for the subsurface soils. The textural analysis showed that soil of the most of the study area was sandy loam except at two places where it was loam.

Table 2: *Textural classification of surface soils.*

Sample no.	Elevation (m)	Sand (%)	Silt (%)	Clay (%)	Soil texture
1	1672	59.71	25.81	14.48	Sandy loam
2	1681	62.56	28.69	8.74	Sandy loam
3	1686	47.33	34.22	18.45	Loam
4	1696	59.22	24.11	16.67	Sandy loam
5	1684	59.33	28.35	12.32	Sandy loam
6	1707	57.04	34.48	8.48	Sandy loam
7	1695	61.04	28.48	10.48	Sandy loam
8	1715	49.77	37.33	12.90	Sandy loam
9	1714	65.72	25.80	8.48	Sandy loam
10	1714	43.33	32.33	24.34	Loam
11	1715	61.04	22.29	16.67	Sandy loam
12	1705	55.55	27.72	16.73	Sandy loam
13	1708	63.12	27.80	9.08	Sandy loam
14	1700	59.36	27.80	12.84	Sandy loam

4.2 Rainfall analysis

The monsoon in Uttarakhand generally takes place during the month of June to last week of September. Average weekly rainfall analysis showed that Champawat district received maximum average weekly rainfall (71.23 mm) in 29th Standard Metrological Week (SMW) contributing to 6.78% of average rainfall

of the district, whereas, minimum average weekly rainfall was about 0.029 mm recorded during 47th SMW amounting to 0.0027 % of average annual rainfall (Fig. 2). The average monthly rainfall was the maximum (270.92 mm) during July month and the minimum average monthly rainfall was found in the month of November (2.78 mm). The annual rainfall values for the study period was erratic in nature with the minimum value of 574.30 mm during the year 1998 and the maximum value of 1951.32 mm during the year 2007. The mean value of annual rainfall for Champawat, during 24 years of analysis, was found to be 1052.87 mm.

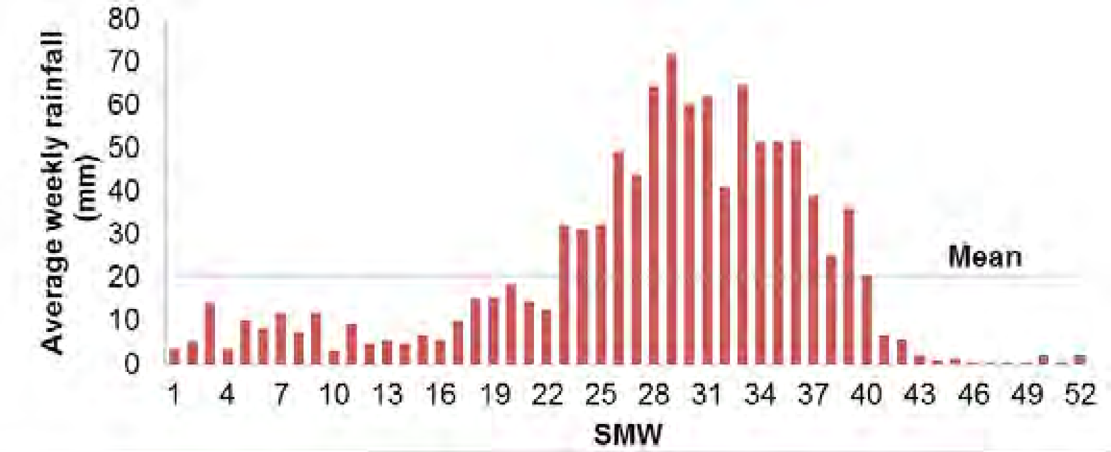

Figure 2: *Variation in average weekly rainfall*

4.3 Reference evapo-transpiration (ETo)

The reference evapo-transpiration (ETo) for the years 2009 - 2013 on monthly basis was estimated using 'CROPWAT' software. The maximum reference evapo-transpiration was found during May, and its value varied from 4.92 to 5.58 mm/day with the mean value of 5.29 mm/day for this month. The minimum ETo value was found during the month of January. Average monthly ETo was found minimum 1.42 and maximum 5.29 mm/day during the month of January and May, respectively.

4.4 Crop evapo-transpiration (ETc) for different horticultural crops

The crop evapo-transpiration of various fruit crops was estimated using the crop coefficient (k_c) values for different stages (Table 3) and reference crop evapo-transpiration data

Table 3: *Crop coefficient (K_c) values for various horticultural crops at different stages.*

SN.	Name of crop	Initial stage (Kc_{ini})	Mid stage (Kc_{mid})	End stage (Kc_{end})
1	Apricot	0.70	0.65	0.70
2	Citrus	0.45	0.80	0.80
3	Kiwi	0.50	1.10	0.65

4	Peach	0.45	0.90	0.70
5	Pear	0.45	0.90	0.90
6	Plum	0.45	0.90	0.70
7	Pomegranate	0.45	0.90	0.80
8	Walnut	0.45	0.90	0.70

The crop evapo-transpiration of Citrus varied from 0.70 to 2.50 mm/day (Table 4) with the maximum in the month of May, and the minimum values in the month of December. For the Pomegranate its value varies from 0.15 to 3.90 mm/day with the minimum the month of December and the maximum in the month of June. In case of deciduous crops (Walnut, Peach, Apricot, Plum and Kiwi) the maximum ETc value was found to be during the month of May and the minimum ETc value was found to be during the month of November.

Table 4: *Monthly reference evapo-transpiration during the years 2009 to 2013.*

Year	Monthly ETo (mm/day)											
	Jan.	Feb.	Mar.	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	1.83	2.07	3.34	3.79	4.92	5.00	3.58	3.4	3.22	2.76	1.75	1.37
2010	1.71	2.16	3.58	4.40	5.58	5.50	4.84	4.56	4.10	2.95	1.87	1.57
2011	1.77	2.32	3.73	4.41	5.02	4.43	3.57	3.47	3.25	2.82	1.63	1.44
2012	1.36	2.14	3.33	3.73	5.52	5.30	3.70	3.41	3.36	2.76	1.75	1.55
2013	1.62	1.88	3.28	4.07	5.44	4.13	3.42	3.34	3.53	2.47	1.90	1.54
Average	1.65	2.11	3.45	4.08	5.29	4.87	3.82	3.63	3.49	2.75	1.78	1.49

4.5 Irrigation water requirement of different horticultural crops under drip irrigation system

For the estimation of water requirement of various horticultural crops of study area under drip irrigation the canopy area, wetting percentage area and canopy factor were determined (Table 5). The irrigation water requirement for deciduous fruit crops (walnut, peach, apricot plum and kiwi), at different stages, is shown in Table 6. The water requirement for different deciduous fruit crops in the initial stage (1 - 20 March), varied from 1.86 to 2.57 lpd/plant. The developing stage starts from 21st March to 31st March. during this period the water requirement for deciduous fruit crops was found to be minimum (2.09 lpd/plant) for kiwi, whereas, the maximum water requirement (3.28 lpd/plant) was found for peach. At the end of developing stage minimum water requirement (3.79 lpd/plant) was found for apricot and maximum water requirement (5.44 lpd/plant) was for walnut. The mid stage varies from 1st April to 11th August.

Table 5: *Measurement of plant height and canopy area of different horticultural crops, planted in the study area.*

Name of plant	Average length of canopy (m)	Average width of canopy (m)	Average height of plant (m)	Average canopy area (sq m)	Average ground coverage (G_c)	Reduction factor (Kr)
Citrus	0.56	0.62	0.51	0.28	0.02	0.12
Pomegranate	0.79	0.79	0.76	0.49	0.04	0.14
Walnut	0.58	0.51	0.61	0.23	0.02	0.12
Peach	0.79	0.75	0.95	0.54	0.05	0.15
Plum	0.66	0.64	1.28	0.33	0.03	0.13
Kiwi	0.43	0.43	0.40	0.14	0.01	0.11
Apricot	0.45	0.43	0.85	0.16	0.01	0.12

Table 6: *Crop coefficient (K_c) values and estimated crop evapotranspiration (mm/day) for newly planted (5-month old) deciduous horticultural crops.*

Month	Walnut		Peach and Apricot		Plum and Kiwi	
	K_c	Etc (mm/day)	K_c	ETc (mm/day)	K_c	ETc (mm/day)
March	0.50 - 1.10	1.73 - 3.80	0.55 - 0.84	1.90 -2.90	0.40 - 1.02	1.38 - 3.52
April	1.10	4.49	0.90	3.67	1.05	4.28
May	1.10	5.82	0.90	4.76	1.05	5.55
June	1.10	5.36	0.90	4.38	1.05	5.11
July	1.10	4.20	0.90	3.44	1.05	4.01
August	1.10 - 0.91	3.99 -3.35	0.90 - 0.81	3.27 - 2.94	1.05	3.81
September	0.91 - 0.71	3.29-2.48	0.80 - 0.69	2.91 -2.41	1.05	3.66
October	0.70 - 0.17	1.92-0.31	0.68 - 0.17	2.39 -0.31	1.05-0.32	3.66 - 0.50
November	0.15 - 0.02	0.27-0.04	0.15 -0.02	0.27 -0.04	0.28 - 0.70	0.50 - 0.06

For the mid stage, estimated water requirement for deciduous fruit crops was found the maximum during the month of May (8.67 lpd/plant) for plum, whereas, the minimum water requirement was estimated as 4.39 lpd/plant during the month of August for apricot fruit crop. The late season stage is

observed during the period of 12th August to 11th September. The water requirement at the end of late season varied in the range of 4.37 To 5.95 lpd/plant. The maximum water requirement of 503.18 Liter/plant was found in entire period for plum, whereas, minimum water requirement of 361.83 liter/plant was found for apricot. The irrigation water requirement under drip irrigation system for evergreen horticultural crops such as citrus and pomegranate is shown in Table 7. The water requirement for the citrus plant was estimated to be the minimum (1.04 lpd/plant) during the December month, whereas, the maximum water requirement (3.78 lpd/plant) was estimated during the month of May. In case of pomegranate the maximum water requirement (6.65 lpd/plant) was found during the month of June, whereas, the minimum water requirement (0.25 lpd/plant) was found during the month of December.

Table 7: *Crop coefficient (K_c) values and estimated crop evapotranspiration (mm/day) for evergreen horticultural crops (9 Months old).*

Month	Citrus		Pomegranate	
	K_c	Etc (mm/day)	K_c	Etc (mm/day)
January	0.51	0.84	0.20	0.33
February	0.55	1.16	0.40	0.84
March	0.50	1.73	0.50	1.73
April	0.50	2.04	0.60	2.45
May	0.48	2.56	0.70	3.70
June	0.47	2.27	0.80	3.90
July	0.45	1.72	0.80	3.06
August	0.45	1.63	0.80	2.90
September	0.45	1.57	0.80	2.79
October	0.45	1.24	0.80	2.20
November	0.45	0.80	0.10	0.18
December	0.47	0.70	0.10	0.15

4.6 Monthly irrigation water requirement of horticultural crops of the study area under drip irrigation system

The monthly irrigation water requirement for different horticultural crops planted in the study area under drip irrigation system is shown in Tables 8 and 9. The total annual water requirement of all 425 plants of citrus, 200 plants of pomegranate, 45 plants of walnut, 84 plants of peach, 110 plants of apricot, 30 plants of plum, and 130 plants of kiwi was found to be 344505, 24798, 56174, 102403, 109190, 41293

and 154435 liters, respectively. These tables show that the total monthly irrigation water requirement of all the horticultural plants, planted in the study area, was the maximum, i.e 175689 liters in the month of May, whereas, the minimum value was found to be 14760 liters in the month of December.

Table 8: *Monthly irrigation water requirement of total plants in liters per month for evergreen fruit crops under drip irrigation system.*

Month	Monthly irrigation water requirement of total plants (liters/month)		
	Citrus	Pomegranate	Total
January	15938	3360	19298
February	21930	8640	30570
March	32513	17640	50153
April	38505	25080	63585
May	48195	37920	86115
June	42840	39900	82740
July	32385	31320	63705
August	30855	29760	60615
September	29580	28560	58140
October	23333	22500	45833
November	15173	1800	16973
December	13260	1500	14760
Total (liter)	344507	247980	592487

Table 9: *Monthly irrigation water requirement of total plants in liters per month for deciduous horti-cultural crops under drip irrigation systems.*

Month	Monthly irrigation water requirement of total plants in (liters / month)					
	Walnut	Peach	Apricot	Plum	Kiwi	Total
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	2284	4020	4285	1376	5148	17113
April	8694	15422	16467	6012	22503	69098
May	11273	20009	21318	7803	29172	89574
June	10368	18421	19635	7182	26871	82477
July	8141	14440	15411	5634	21060	64685
August	7436	135834	14483	5527	20649	61678

September	5418	10965	11684	5283	19770	53121
October	2508	5429	5787	2470	9238	25432
November	52	113	121	6	24	317
December	0	0	0	0	0	0
Total (liter)	56174	102403	109191	41293	154435	463495

5. Conclusion

For the proper management and planning of water resources in the study area, soil characteristics, availability of rain water, evapotranspiration, cropwater requirement and irrigation water requirement of various horticultural crops under drip irrigation, were studied. The maximum water requirement, during a complete one-year period, was found for plum i.e. 503.2 liter/plant, whereas, the minimum water requirement of 361.8 liter/plant was found for apricot. The total annual irrigation water requirement, with drip irrigation system, for 425 citrus plants, 200 pomegranate plants, 45 walnut plants, 84 peach plants, 110 apricot plants, 30 plum plants and 130 kiwi plants was found to be 344505, 24798, 56174, 102403, 109190, 41293 and 154435 liters, respectively. The available tube well and water harvesting structures are capable to meet this requirement of water for irrigation of planted horticultural crops in the study area.

References

Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998). Crop evapo-transpiration: Guidelines for computing cropwater requirements. Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 300p.

Barman, D.; Kundu, D.K.; Ghorai, A.K., Mitra, S. (2014). Determination of evapo-transpiration and Crop Coefficient of Tossa Jute (Corchorusolitorius). Journal of Agriculture Physics, 14 (1). 67-72.

Balanco, F., Folegatti, M. (2003). Evapotranspiration and crop coefficient of cucumber in greenhouse. Rev. Bras. Eng. Agric. Ambient, 7, 285-291.

Casanova, M.; Messing, I.; Joel, A., Canete, A. M. (2008). Methods to estimate lettuce evapotranspiration in green house conditions in the central zone of Chile. Chilean Journal of Agricultural Research, 69(1), 60-70.

Chiew, F. H. S.; Kamaldasa, N. N., Malono, H. M, Memohon, T.A. (1995). Penman-Monteith, FAO 24: Reference crop evapotranspiration and class A pan data in Australia. Agriculture Water Management, 28,.9-21.

Gomez, H.V.; Farias, S. O., Argote, M. (2007). Evaluation of water requirements for a greenhouse tomato crop using the Priestley-Taylor method. Chilean Journal of Agricultural Research, 69(1), 3-11.

Hussein, A. S. A., Eldraw, A. K. (1989). Evapo-transpiration in Sudan Gezira Irrigation Scheme. Journal of Irrigation and Drainage Engineering, ASCE, 115(6), 1018-1033.

Klocke, N. L.; Martin, D. L; Martin, D.L: Todd, R. W., Dehaan, D. L., Polymenopoulos (1990). Evaporation measurements and predicting from soil under crop canopies. Transaction of the ASAE, 13 (5), 1590-1596.

Klosowski, E. S., Lunardi, D. M. C. (2002). Red pepper (Capsicum annum L.) crop coefficient determination, cultivated in green house conditions. Energiana Agriculture, 17(4), 33-42.

Mohammad, F. S.; Alamoud, A. I., Mahmoud S. H. (2015). Water requirements and water use of mango orrchards in Jazan region, Saudi Arabia. The Journal of Animal and Plant Science, 25(4), 1008-1015.

Sprinkler irrigation management in loam soil

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Abstract

Water stress is a major yield-reducing factor in agriculture. The sprinkler irrigation systems are often regarded as a hydraulics problem. The average rate of water application is usually fixed at some level below the basic infiltration rate of the soil to avoid surface water runoff. However, water starts to accumulate on the soil surface when the water application rate exceeds the infiltration rate for a sufficiently long period. Surface runoff occurs when sufficient water accumulates on the soil surface to overflow shallow depressions and flow over or past surface. A good pasture management is the production of economically optimum forage yield and quality without compromising the environment. This field experiments aims to determine irrigation time for traveling irrigation device Bauer Rainstar T-61, and the required water supply rate without puddles and runoffs formation to loamy soil. Results showed that irrigation rate without soil erosion for 5–10 cm high plants is 12.8–15.8 mm at the vegetation beginning, and 19.2–23.4 mm at the vegetation end; for plants 10–20 cm high is 30.0 mm at the beginning of vegetation and 30.0 mm at the vegetation end. The watering time for the water runoff process varies from 64-150 minutes.

Keywords: *Bauer Rainstar T-6; erosion; loam soil; sprinkler irrigation*

1. Introduction

Irrigated land area has expanded rapidly over the last years. In 1961, irrigation occupied 141 million hectares (Mha) globally, increasing to 287 Mha in 2015, and is forecasted to cover 318 Mha by 2050. Irrigation water withdrawal was 2620 km^3 in 2005, and will increase to 2906 km^3 in 2050 (Bruinsma, 2009). Irrigation is the most important water use sector accounting for about 70% of the global freshwater withdrawals and 90% of consumptive water uses (Siebert *et al*., 2010). Water use efficiency is an important performance indicator of sustainable production, widely used overseas (Martin *et al*., 2006). Irrigated agriculture causes various direct or indirect problems, including leaching of nutrient and pesticides, soil salinization, overexploitation of aquifers (leading to ground subsidence and sea-water intrusion), modification of natural flow regimes and damages to water dependent ecosystems (Doll and Siebert, 2002; Stigter *et al*., 2006). Sprinkler systems are used on 50% of the irrigated cropland and

have a water use efficiency of 75% (Locascio, 2005). During a sprinkler irrigation event, some water is lost due to wind drift and evaporation. After the irrigation event, plant-intercepted water is lost due to evaporation. The water lost causes microclimatic changes, which could result in positive or negative plant physiological changes. Sprinkler irrigation during daytime strongly modifies the microclimate where plants grow during the irrigation time and for a short period after the irrigation event is finished (Cavero *et. al*., 2009). As pressure on water resources increases, pasture species that express traits for improved water-use efficiency while maintaining desirable agronomic and production characteristics are needed (White and Snow, 2012). Potential water savings by new irrigation technology and improved irrigation management may be offset by increases in irrigated areas and appropriate measures are necessary to limit water use to sustainable levels (Wriedt *et al*., 2009). The goal of effective management of irrigation water is to enhance economic returns with limited use of water and/or energy. Regulated deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Pandey et al., 2000).

2. Object and Methods

Field experiments were conducted at the experimental field Horki district, Belarus (54°31′ N, 30°93′ E). The loamy soil characteristic in a layer 0–100 cm are: density - 1.62 g cm^{-3}, the density of solids - 2.65 g cm^{-3}, the lowest moisture content - 22.3% by weight of dry soil, the max slope 0.005. The vegetation cover is represented by herbage height from 5 to 20 cm. Traveling gun sprinkler Bauer Rainstar T-61 was used for irrigation. Irrigation was carried out for three soil moisture conditions (60–70% of the field moisture susceptibility (MS), 70–80% MS and 80–90% MS):

1. Soil friable after pre-seeding processing;
2. Soil dense, steam;
3. A vegetative cover in height 5 - 10 cm, in the vegetation beginning;
4. A vegetative cover in height 5 - 10 cm, in the end of vegetation;
5. A vegetative cover in height 10 - 20 cm, in the vegetation beginning;
6. A vegetative cover in height 10 - 20 cm, in the end of vegetation.

Before the start of the experiment on the soil surface were established credentials mortise frame. Accounting rules irrigation was performed using rain gauges. The moments of the time then in the surface were form puddles of 2-3 cm diameter was the beginning of the surface runoff. Irrigation rate is 30 mm, pressure 4-5 bar, watering duration 150 min. The rotation speed around the machine axis of the machine gun equals 0.7 circle/min. Droplet size of rain determined using filter paper in multiple 3 replications. Soil moisture was determined at 10 cm and 20 cm depth. All irrigation was carried out in calm weather.

Data processing by a method of mathematical statistics (Bishof, 1977) has shown that intensity of overhead irrigation from time can be described:

$$i_{adm} = \frac{A}{t^B} + i_s \quad , \qquad (1)$$

where *A* and *B* are the empirical parameters defined by practical consideration depending on soil-relief and other factors, influencing admissible intensity of overhead irrigation; *t* is time of watering before formation surface runoff, min; i_s is the established speed absorption at overhead irrigation, mm/min.

At overhead irrigation by one of the most important agro-technical requirements observance of a condition (Zhaliazko, 1987) is:

$$i_{adm} \geq i_{icp}, \qquad (2)$$

where i_{icp} – average intensity of the car, mm/minute

Irrigation defined intensity under the formula (Lihatsevich, 2010):

$$i_{icp} = \frac{h}{t}, \qquad (3)$$

where h – layer of watering, mm; t – duration of watering, min.

3. Results

Results of the field research for the three considered soil moisture for all 6 variants are presented in Fig.1 and Table 1.

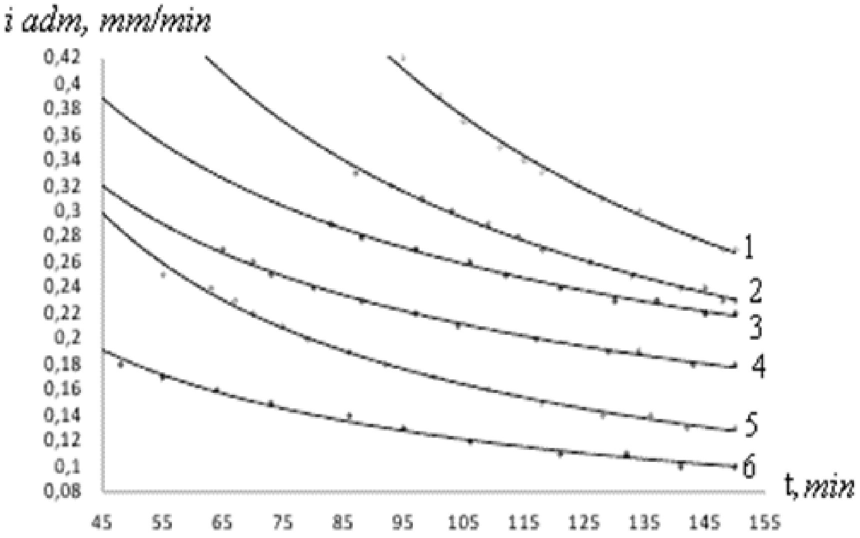

Figure 1: *Change of admissible intensity at faltering overhead irrigation*

The analysis of the results shows that for the condensed surface of soil, admissible intensity of overhead irrigation is several times less than for friable soil.

The irrigation intensity without formation surface runoff water depends on the top soil moisture content, vegetative height and the period of vegetation process. The maximum admissible intensity of faltering overhead irrigation equals 0.42 mm/min at 10-20 cm height of a vegetative cover in the vegetation beginning when the soil is less condensed. The minimum value of 0.08 mm/min is observed on the 0.80-0.90% MS condensed soil Duration of overhead irrigation before formation puddles varies from 43 min (1 variant) to 150 min (6 variant).

Table 1: *Results of admissible intensity of faltering overhead irrigation*

Variant	Admissible intensity, mm/min	Duration of overhead irrigation to a drain, min	Equation parameters		i_s, mm/min	Correlation
			A	B		
1.	0.25 - 0.11	50 - 150	3.17 - 4.36	0.64 - 0.70	0.13 - 0.11	0.99
2.	0.18 - 0.08	43 - 150	1.27 - 1.48	0.53 - 0.54	0.1 - 0.08	0.99
3.	0.29 - 0.20	75 - 150	1.92 - 2.42	0.45 - 0.48	0.22 - 0.2	0.99
4.	0.27 - 0.16	60 - 150	1.98 - 2.14	0.49 - 0.52	0.18 - 0.16	0.99
5.	0.42 - 0.24	90 - 150	12.26 - 29.63	0.79 - 0.94	0.23 - 0.2	0.99
6.	0.33 - 0.20	85 - 150	4.84 - 9.22	0.62 - 0.77	0.27 - 0.24	0.99

Mobile traveling sprinkler Bauer Rainstar T-61 equipped with device SR-140 average intensity was 0.2 mm/min, irrigation norm 0.3 mm for one circle.

Considering the results and learnings from the past experiences, erosion-safe values of irrigation norms and time of overhead irrigation providing watering without formation of puddles and surface runoff have been defined as shown in Table 2.

Table 2: *Settlement admissible erosion-safe irrigation norms and time intervals*

Variant	Soil moisture, % MS	Time of watering before formation of surface runoff, Min	Irrigation norm before formation surface runoff, mm
1.	60-70	79	15.8
	70-80	70	14.0
	80-90	64	12.8
2.	60-70	Watering is recommended under condition of carrying out of agromeliorative actions raising absorbing ability of soil	
	70-80		
	80-90		
3.	60-70	Surface runoff was not observed	
	70-80		
	80-90	144	28.8
4.	60-70	117	23.4
	70-80	105	21.0
	80-90	96	19.2
5.	60-70	Surface runoff was not observed	
	70-80		
	80-90		

6.	60-70	Surface runoff was not observed	
	70-80		
	80-90	150	30.0

Carrying out of watering with rainfall intensity not exceeding received values of admissible intensity, serves as the basic criterion of the prevention of a drain and water dump for limits of an irrigated site. Values of admissible irrigation norm and overhead irrigation time considerably differ by experience variants.

The admissible irrigation norm at overhead irrigation traveling gun sprinkler Rainstar T-61 was found:

a. for friable soil – 12.8 - 15.8 mm;

b. for dense soil – watering is not recommended;

c. for herbage 5 - 10 cm height – 28.8 mm in the beginning of the period of vegetation and 19.2 – 23.4 mm in the end of the period of vegetation;

d. for herbage 10 - 20 cm height – 30.0 mm in the beginning and in the end of the period of vegetation. Time of watering before surface runoff formation was from 64 min to 150 min.

4. Summary

At overhead irrigation of various agricultural crops, first, it is necessary to select such irrigation techniques, and identify average intensity of rain that would not exceed admissible intensity for concrete soil-relief and economic conditions. In case of no possibility of selection of the corresponding equipment, it is possible to provide various agro-technical and agro-meliorative actions for increasing absorbing ability of soils. It is possible to carry out loosening of such soils; there are devices available on the watered area such as various wells, faltering furrows, micro estuaries that enter the soil of the corresponding polymers which raises the absorbing ability of the soils. Application of these systems of processing raises the structure of the soil and cultivation of the agricultural crops keeping and raising structuresoils. This action allows raising admissible intensity of overhead irrigation approximately in one and a half time, and it is more rational to use natural deposits (Zhaliazko, 1987; Lihatsevich, 2010).

References

Bishof, E.A. (1977). Methodical of instructions on static processing of experimental data in land improvement and soil science / E.A.Bishof, G.S.Kalmykov. Leningrad, 6, pp 270.

Bruinsma, J. (2009). The resource outlook to 2050. In Expert meeting on how to feed the world in. Vol. 2050, pp. 1-33.

Cavero, J., Medina, E.T., Puig, M., Martínez–Cob, A. (2009). Sprinkler irrigation changes maize canopy microclimate and cropwater status, transpiration, and temperature. Agronomy Journal, 101 (4), 854–864.

Doll, P., Siebert, S. (2002). Global modeling of irrigation water requirements. Water Resources Research, 38 (4), 8.1–8.10.

Lihatsevich, A.P. (2010). Agricultural of land improvement: studies. "Land improvement and a water management" / A.P.Lihatsevich, M.G.Golchenko, G.I.Mihajlov. Minsk, p. 464.

Locascio, S.J. (2005). Management of irrigation for vegetables: Past, present, and future. Hort Technology, 15 (3), 482–485.

Martin, R.J., Thomas, S.M., Stevens, D.R., Zyskowski, R.F., Moot, D.J., Fraser, T. J. (2006). Improving water use efficiency on irrigated dairy farms in Canterbury. In Proceedings of the Conference-New Zealand grassland association, 68, 155–160.

Pandey, R.K., Maranville, J.W., Admou, A. (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian

environment. I. Grain yield and yield components. Agric. Water Manage., 46 (1), 1–13.

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., Portmann, F. T. (2010). Groundwater use for irrigation – a global inventory, Hydrol. Earth Syst. Sci., 14, 1863-1880, https://doi.org/10.5194/hess-14-1863-2010.

Stigter, T.Y., Carvalho Dill, A.M.M., Ribeiro, L., Reis, E. (2006). Impact of the shift from groundwater to surface water irrigation on aquifer dynamics and hydrochemistry in a semi–arid region in the south of Portugal. Agricultural Water Management, 85, 121–132.

White, T.A., Snow, V. O. (2012). A modelling analysis to identify plant traits for enhanced water–use efficiency of pasture. Crop and Pasture Science, 63, 63–76.

Wriedt, G., Van der Velde, M., Aloe, A., Bouraoui, F. (2009). Estimating irrigation water requirements in Europe. Journal of Hydrology, 373 (3), 527–544.

Zhaliazko, V.I. (1987). Dozhdevanie of long-term grasses drains of pig-breeding complexes: Dis. Cand. Tech.Sci.: 06.01.02, p. 138.

Practices of irrigation and drainage management in terms of sustainability : A case study of Chapagun (Ghyampedada), Godavari Municipality, Lalitpur district of Nepal

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Abstract

Irrigation and drainage management are associated with agriculture, which is the backbone for development of Nepal. Sustainable Development Goals (SDGs) has given high importance to agriculture especially on irrigation and drainage management. Sustainable irrigation and drainage management requires allocating between competing irrigation sector demands, and balancing the economic and social resources to support irrigation and drainage. Irrigation and drainage management are crucial in agriculture due to climate change, migration, land management, and disasters. The purpose of this study is to find the answer of the following two questions: What are the existing practices of irrigation and drainage management in Chapagun (Ghyampedada), Godavari municipality, Lalitpur district of Nepal? Whether the irrigation and drainage management practices are sustainable? In-depth interview, field observation and desk review was performed to gather information. A traditional canal system using irrigation was found, from where two canal systems were chosen for the study based on its size, length, age and the number of users. Still these canal systems are operating and they are in a dangerous situation. Thus, the study suggests four ways to make sustainable irrigation and drainage management system: Firstly, there have to stop intervening agencies like brick factory needs to be closed, land plotting group and deforestation practices need to be stopped. Secondly, need of modification and change in existing canal system through operation and maintenance of infrastructure is required. Thirdly, upgrading the technology in irrigation, drainage management and alternative use of drainage is needed. Lastly, user association needs to be formed to manage the system, advocate for resources and their rights.

Keywords: drainage; irrigation; management; sustainability; sustainable development

1. Context

Agriculture is the primary livelihood of Nepal. The country's future economy is connected with the agriculture sectors whereas; irrigation is the key dimension of agriculture. The Sustainable Development Goals (SDG) number eight focuses on promoting sustained, inclusive and sustainable economic growth-:

full and productive employment and decent work for all through growth of agriculture and others (UN, 2015). Thus, effective irrigation and drainage management system is required for effective agriculture production. The research is based on the information generated through qualitative research with a case study approach. In this study I have used in-depth interview, field observation and desk review to gather information and interpreted them. Godavari municipality, Lalitpur district, Chapagun (Ghyampedada) was my research site and three farmers of the community were the main research participants where, one farmer is female and the other two farmers are males. Besides, one farmer represents the Janajati and other two represent from Dalits. Among the three informants, two are living there from past two generations and one has been living there for more than sixty years. This place was chosen because my field visit in August 2017 gave an impression that people are doing best in planting rice in the community as seen in the Fig.1 and Fig. 2.

Figure 1: *Planting rice*

Figure 2: *Planting rice and its geography*

The research area is located 12 km south from Kathmandu. The farmers irrigate from Karmanasa River, the river having specific identity in Nepal- which flows from south to north; but normally the Nepalese rivers flow from the north to south direction. Maximum agriculture areas in Kathmandu, Lalitpur and Bhaktapur districts are urbanizing and reducing the cropping land even though Ghyampedada communities are still depending upon agriculture. In addition, after four months I visited to observe the irrigation system: how they were using the canal, people's participation for conservation, and management of the canal. Furthermore, I also reviewed different policy and practices on this system. The productivity of agriculture still accounts for one-third of gross domestic product (GDP), but contribution of agricultural section in total GDP has been declining over the year (NARC, 2010). Sources of water and its management is one of the very important dimensions of agriculture. The purpose of the study is to identify the existing practices of irrigation and drainage management and explore whether the irrigation and drainage practices in terms of sustainable aspect are applicable. There are various ways to measure the sustainability of the activities but, in this study, I used three perspectives of sustainability aspect, i.e. economic sustainability, social sustainability and environment sustainability. Here, economic sustainability is connected with the productivity of the agriculture. To measure economic sustainability, I have used seasonal calendar to gather information. For social and environmental sustainability, I have used field observation and interview techniques where I focused on conversation of water resources, soil protection, land management, people's participation and involvement, planning the use of cannel, use of technology, government and non-government support.

2. Practices of Irrigation and Drainage Management

Currently, irrigation covers more than 270 million ha (Mha) and is responsible for 40% of crop output where it uses about 70% of waters withdrawn from global river systems; 17% rainfed crops covers and contribute output (Schultz & Wrachien, 2002). Drainage of rainfed crops covers about 130 Mha and contributes to about 15% of crop output. In about 60 Mha of the irrigated lands, there is a drainage system as well (Smedema, 1995). Irrigation and development in Nepal has a long history. Nepal has a cultivated area of 2642000 ha (18% of its land area) of which two-thirds (1766000 ha) is potentially irrigable (Poudel and Sharma, 2012). DOI (2015) stated that 56.56% of the area in Nepal is covered by surface irrigation system, 14.47% by farmers' canal system and 28.57% by groundwater irrigation system. Numerous small and Raj Kulo (canals) from the government sector first appeared in and around Kathmandu valley in the seventeenth and eighteenth centuries. We can believe irrigation system started when agriculture practices had been started. There are different practices of irrigation system in Nepal because of the geographical condition (terai, hill and mountain). Depending on the local conditions different types of water management with different levels of service will be appropriate (Schultz, 2012). Therefore, we can see different practices of irrigation and drainage system in Nepal and globally.

There are many small irrigation systems scattered all over the country and still able to continue for more than hundred years. Nepal is practicing different types of irrigation systems. We can relate and connect them with the development, time period and geography. Still Nepal has been practicing the traditional farming irrigation systems. Normally, we can see the Farmer Managed Irrigation System (FMIS) which includes traditional irrigation system as well, Agency Managed Irrigation System (AMIS), Jointly Managed Irrigation System (JMIS) which runs by mutual cooperation and understanding between government and users and finally, Private Irrigation System (PIS) which is mostly operated and managed by large farmers. Nepal government and other agencies are increasing their roles for development of irrigation practices in Nepal. Effective irrigation management systems help to improve water distribution and efficiency, strengthening water user associations (WUAs) including gender and disadvantaged group empowerment for long-term sustainability and improving operation and management (O&M) with a view to livelihood improvement and poverty reduction (ADB, 2009). Government of Nepal has invested sustainable financial resources in the part of developing irrigation infrastructure; however, their performance was unsatisfactory as per the investment (Paudel and Sharma, 2012). Nepal government, especially, Department of Irrigation (DOI) and Department of Agriculture (DOA) are key stakeholders for development of agriculture in Nepal. Both departments of government bodies are connected with improvement of livelihood of people.

Ghyampedada (Chapagun, Godavari municipality, Lalitpur) has many irrigation canals where almost canals are owned and managed by individual farmers and communities. Among them two canals are big and very long and around 70 farmers use them. So, in this study, these two canals were taken as key part of the study. Based on conversation, I found that one canal is called Mathilo Kulo (upper canal) (Fig. 3) and its length is around 4km which was built 200 years ago. Another canal is called Tallo Kulo (lower canal) (Fig. 4) and its length is around 3km and it was made 100 years ago. The canals were made by farmers and protected by themselves. Water source for both the canals is Karmanasa River. The farmers said "*these canals have not changed since when I was small child* ". One participant said the canals were made during her/his grandfather's period and they are still using the same canals. They said, all people participated for the maintenance and protection of canals. At the time of planting rice, they prepare schedule to use of canal turn wise. Also, if anyone doesn't participate in the process of maintenance they charge a day's labour cost and use it for lunch. They work with all the communities

in a planned and coordinated manner. While talking to the other three farmers, I observed a very similar condition.

Figure 3*: Mathilo kulo (Upper Canal)*

Figure 4*: Tallo kulo (Lower Canal)*

Normally, the farmers in the area produce rice, potato and wheat. They don't buy rice because they have sufficient production and they also sale. In addition, they shared that the quantity of rice production is decreasing every year which is impacting on their earning level. However, there is no specific trend in the production of potato and wheat. They also shared that due to the decreased water level in the river, the crops lacked sufficient irrigation. In addition, a lack of appropriate and sufficient fertilizer is degrading the quality of soil that later is resulting decrease in rice production. In previous years, they had sufficient natural fertilizer but now they don't have such kind of fertilizer so, they have to depend on market fertilizer but again lack of access is impacting on production of rice. Further, the consumer of river is increasing and now, the water is being supplied for household use that caused reduction of water level in the river. Both canals are very old and leaking more so, which is creating problem in sufficient supply of water.

Furthermore, decrease in water level is impacting on irrigation and on the other hand leaked water is creating small landslide, which has become difficult to manage. Neither the government nor the non-government agencies have been involving to protection, repair and maintenance of canal. The story of participants shows that they are having the difficulty of sustainable management of canals. Furthermore, participants shared that the bricks factories are flourishing there and which is looking to use their fertile land for the purpose. Many farmers have given their own field to brick factory in the rent for few months. The brick factory (Fig. 5) is also using the canals. Farmer said the brick factory convinced them to use in the condition of repair and maintenance of canals, but it only using the canals and interrupting the farmers to use. Farmers are also facing conflict with the brick factory because the factory tries to use whole canal.

***Figure 5**: Brick factory*

***Figure 6**: Use of canvas to protect soil*

The farmers are also concerned about the small landslide and protection of soil quality. They shared they are having the practices to make small canals near the farm. Moreover, they are also having controlling mechanism of water pressure in the canal. None of the farmers are using modern technologies for irrigation management.

From the field observation, I found more possibilities of sustainable irrigation and drainage management in research area. I saw only traditional canal system is in practice. I also found people are using temporary water pressure controlling mechanism system. Besides, there is expanding houses and plotting land. I saw the nearby brick factory is using the clay of farm, which directly impact the productivity of land. Further, I saw more possibilities of expansion of commercial agriculture in the field.

Further to manage drainage, people are highly aware about on drainage management. Mostly, they accumulate required water in the farm. If they are having excess water in the farm, it automatically transfers to the another farm. Similarly, they have made small canal to supply the access water which directly goes into the river. There is another practice to share the access water from one farm to another farm coordinating with the owner of farm. Farmers also focus on need, while irrigating they communicate with another person who have turn to irrigate and after completion of irrigation transfer it to another person's field. If the farmers don't use canal, bricks factory uses it. But it is going to be challenging due to monopolize by the factory.

***Figure 7:** Dam of below Canal*

In addition, people have no practice of alternative use of water resources. People are concerning to protect soil quality of farm. While they supply water from one farm to another farm they are using plastic, canvas (Fig. 6) and

cotton clothes to protect the slope of field. There is also temporary management of dam of canal (Fig. 7) as making sustainable dam requires a lot of resources.

Five months ago while visiting in the same community, I saw different situation than the present because of time period. Chapagun is not far from Kathmandu and many fertile land are plotting, but still the people are struggling for agro farming. Every year they produce lots of rice, and their life is depended on the farm. But they have been using same canal for many years. Also, they started using new technology in agriculture but for irrigation they are using traditional methodology. The farming in this area is in critical stage because of expansion of plotting land, brick factory, increases of deforestation, reducing level of water in the river and traditional method of irrigation system.

3. Sustainability of the Irrigation System

Sustainable development can be viewed as a process of change in which exploitation of resources, the direction of investments, the orientation of technological innovation and adaptation, along with institutional changes, are all in harmony and enhance both the current and future potential, to meet growing human needs and aspirations (WCED, 1987). The study narrows the perspective of sustainability based on three aspects, i.e. economics, environment and society. From the study, it shows high cost in irrigation system management because of high involvement of human resources. Potato, wheat and rice are mostly produce in Chapagun community, but the production of potato and wheat are still same and the production of rice is comparatively decreasing. Todkari (2012) stated that irrigation is basic determinants of agriculture because its inadequacies are the most powerful constraints on increase of agriculture production. There is positive relationship between productivity and irrigation system. If the farming gets effective irrigation system, the production will be high. The production is not only determined by irrigation but irrigation management is one of the major determinants of agriculture.

In social aspect, they have good engagement and participation for protection and maintenance of canal. Farmers using canal making time schedule, but reducing level of water in the river, leaking water and small landslide are challenging part of the irrigation system in this area. Further, lack of modern technology in irrigation system is major issue in the community. Although, the place is near from Kathmandu, still people are using traditional canal. Rapid deforestation, plotting land and influence by brick factory are the major challenging factors of the community. In addition, farmers are highly concerned about the protection of soil and maintenance of canal and sources of water.

The infrastructure is most irrigated and drained areas needs to be renewed or even replaced and thus, redesigned and rebuild, in order to achieve sustainable production. A study by Shivakoti and Shrestha (2004) stated that farmer skills, experience and knowledge have enabled them balance water use, conserve natural resources and indigenous technology. Still in Chapagun people are doing agriculture based on their local resources and indigenous knowledge. Sustainable irrigation water management should simultaneously achieve two objectives: sustaining agriculture for food security and preserving the associated natural environment (Cai et al., 2001). Further, the study argued that infrastructure managements and changes in crop patterns will be necessary to sustain the irrigated agriculture and the associated environment in the region. Due to modernization and development in new technology, we have to adopt new technology which helps to minimize the cost and increase the productivity.

The purpose of sustainable water/irrigation resource management is to sustain both the water supply capability and the environment, now and in the future. If we think about our future, we have to focus on modification and use of new technology in irrigation system. Furthermore, sustainability in irrigation is

indicated by water supply system reliability, reversibility and vulnerability, environment system integration, equity in water sharing and economic acceptability.

To maintain and improve economic acceptability, the area requires more investment both to enhance water supply capacity and to increase water use efficiency. A study by Trivedi and Singh (2008) argued that higher quality and reliability of irrigation would result in better yields. Irrigation management can be categorized as activities related to water use, activities related to physical system or control structure activities and organizational activities (Pradhan, 1989). Further, water use activities relate to the application of water of agriculture activities. Moreover, acquisition, allocation, distribution and drainage consideration are involved irrigation management. Similarly, organizational activities are related towards decision making, resource mobilization, communication and conflict management etc.

Russo, Alfredi and Fisher (2014) stated that sustainable water management in irrigation requires allocating between competing water sector demand and balancing the financial and social resources to support necessary water systems. Sustainable management of irrigation is to improve food reduction, reduce poverty and balance the environment. The primary objective of sustainable water management in developing and developed areas is different. Mostly, developing area concerns about the food security, expansion of irrigated area and supplemental irrigation and cropwater productivity. On the other hand, developed area concerns about cropwater productivity, environmental production and resource conservation.

Regarding drainage management, farmers are aware of managing and protecting the soil quality. Also, they are focusing to reuse the excess water, and if not used, the water is released into the rivers as return flow. The access water is also used by brick factory, this is the positive fact, but factory is negatively influencing the farmer. There are many challenges on irrigation and drainage management in Chapagun. Especially, infrastructure costs, subsidies promotion irresponsible, low water use efficiency, over allocation of water resources, mostly following traditional methodology which leads to high cost of production. But there are lots of possibilities to cope with the challenges through optimizing water productivity, enable strong canal systems, provide government subsidies for maintenance canal, use of new technology in irrigation, supply resources to manage new equipment for drainage management and also need to develop water allocation and irrigation management system.

Wrachien (2001) stated that latest technology, strong institutional and financial resources, research thrust and human resource and networking are required for upgrading the existing irrigation system. Latest technology is a major factor to increase the productivity and reduce the cost of production. If we adopt a new technology in irrigation, it helps in time management of farmers, drainage management, to control landslide and develop effective irrigation system. Further it requires more research in irrigation management because still Nepalese farmesr are doing agriculture through traditional methodology without access of new technology and support or lack of investment. We have good indigenous knowledge and practices but we have to upgrade and update with time.

From above discussion we can –say that the Chapagun farmers are farming a in sustainable way and the irrigation system is sustainable but in a traditional way that is resulting to high cost and low productivity. Farmers are aware of the protection of land slope, soil quality, water sources, and equal involvement of community people to maintain and protect the canals. I also heard about the production of rice is reducing and increasing influence of brick factory, use of clay in the brick factory, expansion of the plotting field, higher leakage of canal, reducing the level of water in the river, small landslides recurring every year, lack of sufficient water for irrigation, are the danger symptoms of unsustainable practices of

irrigation. I also found that government intervention is required to control influences of brick factory and stop the plotting of land. Further, the government should invest to make sustainable intakes, canals and provide subsidies to adopt new technology to manage irrigation and drainage. Government and their agencies should provide sufficient fertilizers to the farmers as per their requirement.

4. Conclusion

Effective operation, good management and well-executed maintenance of irrigation and drainage system are the basic dimensions of irrigation and drainage management. Irrigation and drainage are human interventions in which, generally, the farmer, a service provider or agency or private organization and the government are the key actors to make the system effective. The government is responsible for the designation of policy, legislation and national water agency is responsible for maintenance and distribution systems and farmers are responsible for field systems. To upgrade the technology and irrigation methodology in irrigation management, the government and national agencies have higher responsibility than farmers; farmers are responsible for effective utilization and protection of the system. Still the Chapagun community farmers are using traditional irrigation and drainage management system due to lack of awareness and support for modernization. Modernization in irrigation and drainage system helps to support agricultural production to a sustainable level. Modernization in agriculture is complex, only the farmer themselves can't do but also need equal cooperation and coordination between the government, national agencies and the farmers. Irrigation water use efficiency is crucial in satisfying the food demand of the present and future generations. Lining of canals, preventing leakage in distribution systems and new equipment of water control and regulation can contribute significantly to the productive use of water. Systematic irrigation and drainage helps to maximize water application. In Chapagaun, the government and their agencies are required to intervene for sustainable agriculture. Firstly, they have to stop intervening agencies like brick factories, land plotting groups and deforestation practices. Secondly, there is a need of modification and changes in existing canal system through operation and maintenance of infrastructure. Thirdly, it is required to upgrade the existing irrigation and drainage management system to a modern one Last but not the least, it is required to form a user’s association to manage the system, advocate for resources and their rights.

Acknowledgements: Firstly, I would like to thank the conference committee for accepting may abstract and providing me the opportunity to present my research paper in the 8TH Asian Regional Conference (8ARC). Secondly, I am thankful to the participants and community people for their support and valuable information. Furthermore, I would like to thank Mr. Parbat Dhungana, Assistant Professor, Kathmandu University and my friends Rabin Gainju and Manuka Adhikari for their guidance and support.

References

ADB. (2009). Country partnership strategy: Nepal, 2010-2012. Manila:Asian Development Bank.

Cai, X., Mckinney, D. C., & Rosegrant, M.W. (2001). Sustainability Analysis for Irrigation Water Management: Concepts, Methodology and Application to the Aral Sea region. International Food Policy Research Institute. Washington, D.C, United State of America.

DOI. (2015). Sinchai barshik pustika (Annual irrigation book). Lalitpur: Department of Irrigation, Government of Nepal.

Kairav. T., & Singh, O. P. (2008). Impact of quality and reliability of irrigation on field and farm level water productivity of crops. Research in Agriculture & Applied Economics, 1, 141-155.

NARC. (2010). NARC's strategic vision for agricultural research (2011-2030). Lalitpur: Nepal Agriculture Research Council.

Poudal, K. P., & Sharma, S. (2012). *Small irrigation system in Nepal.* Lalitpur: Ministry of Agriculture Development: Government of Nepal.

Pradhan, P. (1989). *Patterns of irrigation organization in Nepal:A comparative study of 21 farmer-managed irrigation system.* Colombo, Sri Lanak: International Irrigation Management Institute.

Ruso, T., Alfredo, K., & Fisher, J. (2014). Sustainable water management in urban, agricultural, and natural systems. *Water, 6*, 3934-3956.

Schultz, B. (2012). Land and water development. *Finding a balance between implementation, management and sustainability.* The Netherlands: UNESCO- IHE.

Schultz, B., & Wrachien, D. D. (2002). Irrigation and drainage systems research and development in the 21st century. *President Honorarie of the International Commission on Irrigation and Drainage (ICID), International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE).* Netherland.

Sivakoti, G. P., & Shrestha, S. G. (2004). Farmer managed irrigation system of Nepal: Balancing water uses and environmental conservation for sustainable livelihood. *Himalayan Journal of Sociology & Anthropology, 1*, 64-74.

Smedema, L. K. (1995). The global state of drainage development. *IPTRID Network Magazine, 6*. Grid.

Todkari, G. U. (2012). Impact of irrigation on agriculture productivity in Solapur district of Maharashtra state. *International Journal of Agricultutre Science, 4*(1), 165-167.

WCED (1987). *Our common future.* The Brundtland Report. Oxford University Press, London, Great Britain.

Wrachien, D.D. (2001). Irrigation and drainage: Trends and challenges for the 21st century. *Proceedings of the 19th European Regional Conference on Sustainable Use of Land and Water.* June, Brno, Czech Republic.

UN. (2015). *Transforming our world: the 2030 agenda for sustainable development.* New York: United Nation.

Cultivable area recovered by using bamboo bandalling structures

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Abstract

An experimental pilot investigation is conducted in the mobile river bed at the laboratory of River Research Institute, Faridpur, Bangladesh. The laboratory set-up with the bamboo bandalling structures is developed to recover cultivable land in the erosion-prone area. In this case, the bamboo bandalling structures are constructed to address the water flow in the river. The low-cost bamboo bandalling structures are placed at the laboratory river bank at an angle with water flow direction. It was observed that water flow diverted towards the main river due to bamboo bandals resulting maximum velocity accumulated at the centre of the river whereas comparatively less velocity appeared near the river bank where bandals are placed resulting sediment deposition. The sedimentation near the river bank as well as river bed erosion at the main channel of the river gives an indication that the bandalling structures can be used successfully for river bank erosion protection with recovering cultivable area.

Keywords: *bamboo bandal; deposition; erosion; river bank; sediment*

1. Introduction

River bank erosion is the single most common problem at rivers flowing through alluvial plains, which is usually at lowland area. The erosion causes a lot of damage. That can be seen from existence of meandering symptom at the river. The erosion will result the loss of land, or property and endanger people who live near the river. The existing bank erosion control structures are usually expensive, massive and not compatible with the environment and aesthetic. This structure is made from cement concrete block, etc. They badly influence the vegetation growth and habitat for species that are living around water; it does not match with the spirit of eco-hydraulics. Because those are costly, the erosion control is only conducted to protect important places or populous and costly urban areas, which has enough worth to be protected with above construction. In rural areas where land/property values are relatively lower, the river bank cannot be protected by aforementioned structures primarily because that is not feasible if compared to the cost of structure.

In South East Asia, Bangladesh is a land of rivers in which the Jamuna is a braided river whose braiding index varies spatially as well as with time. In general, the braiding index and the overall width are large at the upstream part than further downstream, probably due to the effects of higher slope and grain sizes. The overall width of the river exhibits an increasing trend and there is tendency of shifting westwards, especially at the upstream part of the river within Bangladesh. The widening can be attributed to an advancing alluvial fan or to the not yet completed adaptation process after the shift to its new course according to FAP-24 (1994). The shifting rate of the first-order channel of the Jamuna River is 75 m to 150 m/yr. The second-order channels change continuously, large channels being abandoned and new ones developing in a few years only (Klassen and Masselink, 1992). A bank erosion rate of the second-order channels of 250 m to 300 m/yr is common and in extreme cases, it can be more than 800 m/yr (Klassen et al, 1993). There are some attempts taken to address the river bank erosion protection issues (Rahman et al, 2009). The river systems of Bangladesh are shown in Fig. 1 in which a large agricultural land is engulfed by the river systems.

Figure 1: *River systems of Bangladesh*

It is mentioned here that the Bamboo Bandalling is one of the low-cost structures are shown in Table 1, in which the comparative statements of implementation costs for the different river erosion protection structures are provided.

Table 1: *Comparison among implementation cost of different river bank protection structures (Source: Rahman et al., 2009)*

Structure type	River name	Agency	Cost US$/m	Effectiveness
Guide Bank	Jamuna Bridge	Foreign	33,000	Effective
Hard point	Sirajganj (Jamuna)	Foreign	21,000	Effective
Solid spur	Kalitola (Jamuna)	Foreign	12,500	Effective
Revetment (Geobags)	Jamuna	Foreign	2000-3000	On going
Revetment	Jamuna	BWDB	3800-4000	70-80 %
RCC spur	Jamuna/ Ganges	BWDB	950	60-70 %
RCC spur	Teesta	BWDB	350	100 %
Bandalling structures	Jamuna	RRI	70	effective

Although the land is usually owned by impecunious farmers and become the single place drape its life, it is to disturb sense of justice. Because of the above conditions, River Research Institute, Faridpur, Ministry of Water Resources, Bangladesh has developed bamboo bandalling structure as a low-cost river bank protection. It is easy to construct using natural and local materials, in harmony with the environment. Bank erosion and channel shifting of the untrained alluvial rivers of Bangladesh are big problems to the socio-economic and environmental sector of the country. During the 1960's, a number of earthen embankments were constructed along the major rivers for the protection of rural people and agricultural lands from flooding. Since then the embankments were retired several times due to river bank erosion and bank protection are often required during the monsoon and post-monsoon season. Conventionally, groynes and revetments are applied as a method of bank protection. Very recently the concept of hard points (strong revetment type structure) at the most vulnerable locations along the Jamuna river are considered, while in between hard points, spurs or permeable groynes are recommended (Klaassen, 2002). By applying the spurs or groyne type conventional structures, the river bank erosion can be protected for a short-term, whereas, for a long-term stable channel or regime channel constructed in a way to be locally adaptive and environment-friendly manner need to be developed. The possibility of using bandals for long-term channel stabilization is examined using field data and laboratory investigation (Rahman et al., 2003). The responses of large scale alluvial rivers against sudden changes created by conventional structures are not suitable for the overall stabilization of river courses. Therefore, it is important to have alternative long-term solutions for river stabilization that will create minimum disturbance to river courses.

2. Working Principle of Bandals

The working principles of bandals for the control of water and sediment flow are shown schematically in Fig. 2, where sediments are transported as bed load and suspended load. Within the lower half of the flow depth, major portion of the sediment flow is concentrated, whereas, within the upper half water

discharge is more. Bandals are commonly applied to improve or maintain the flow depths for navigation during low water periods in alluvial rivers of the Indian sub-continent. The essential characteristics of bandals are that they are positioned at an angle with main current and there is an opening below it while the upper portion is blocked. As an empirical rule, the blockage of the flow section should be about 50% in order to maintain the flow acceleration. The surface current is being forced to the upstream face creating significant pressure difference between the upstream and downstream side of bandal. The flow near the bed is directed perpendicular to the bandal resulting near bed sediment transport along the same direction. Therefore, much sediment is supplied to the one side of channel and relatively much water is transported to the other side. The reduced flow passing through the opening of bandals is not sufficient to transport all the sediment coming towards this direction, resulting sedimentation over there. On the other side, more water flows with little sediment, resulting bed erosion of the channel on that side.

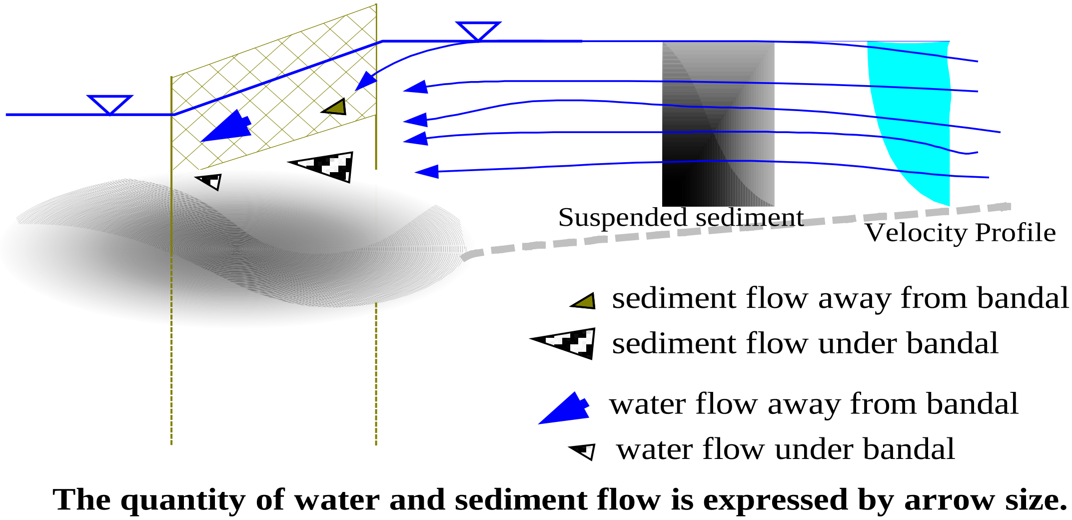


Figure 2: *The self-explanatory working principles of the bamboo bandalling structures for the river bank erosion protection as well as the navigational channel development*

3. Data Collection and Analysis

There is an experimental laboratory river channel at River Research Institute, Faridpur, Bangladesh (Fig. 3, Fig. 4), from which required bathymetric and hydraulic data is collected for this study. The dimensions of the laboratory river channel in terms of length, width and depth are 22m, 2.2 m and 1.50 m, respectively.

Figure 3. *River channel with water supply system at River Research Institute*

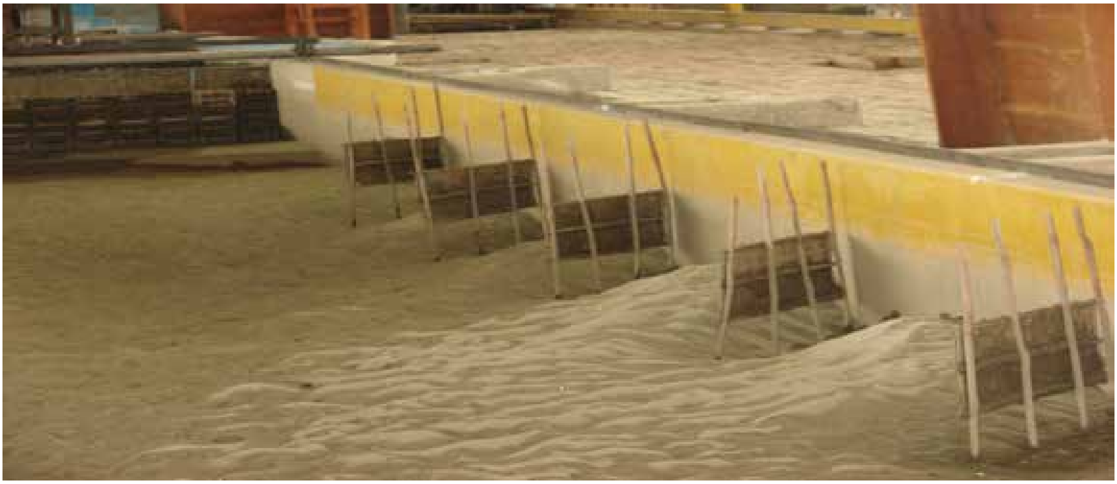
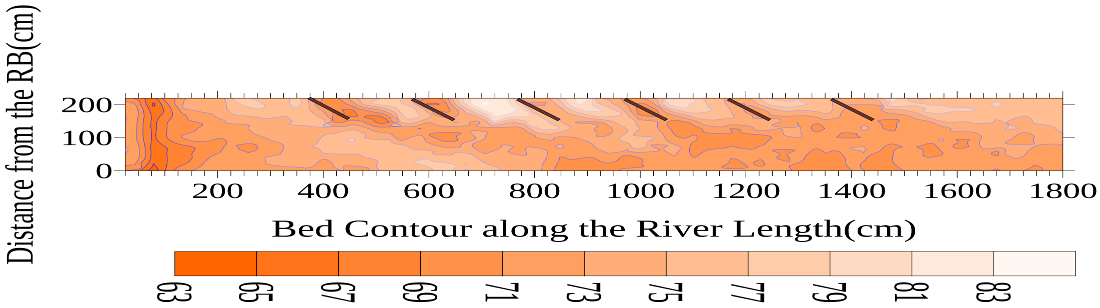


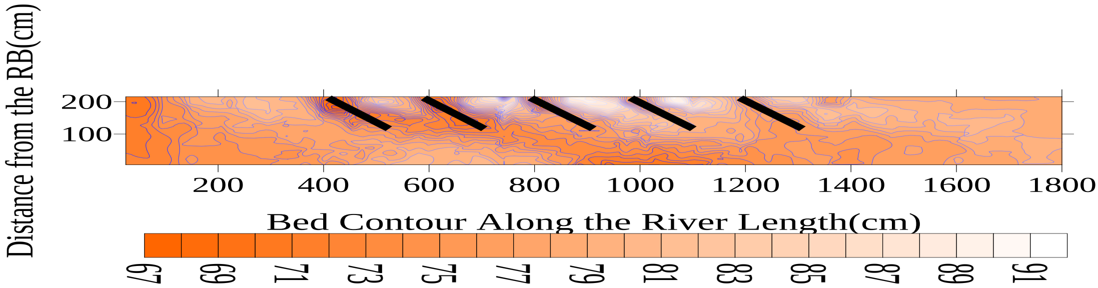
Figure 4: *Laboratory river channel where a series of bandals are placed near the river bank*

3.1. Bed level contour map

The low cost spur like bandalling structures are placed at one side in the laboratory river channel from upstream to downstream at 30 degree angles with the water flow direction. The bed level contour map for the 30-degree angle with the flow direction is shown below in Fig. 5.



(a): Bed contour diagram of the river channel with lower slope

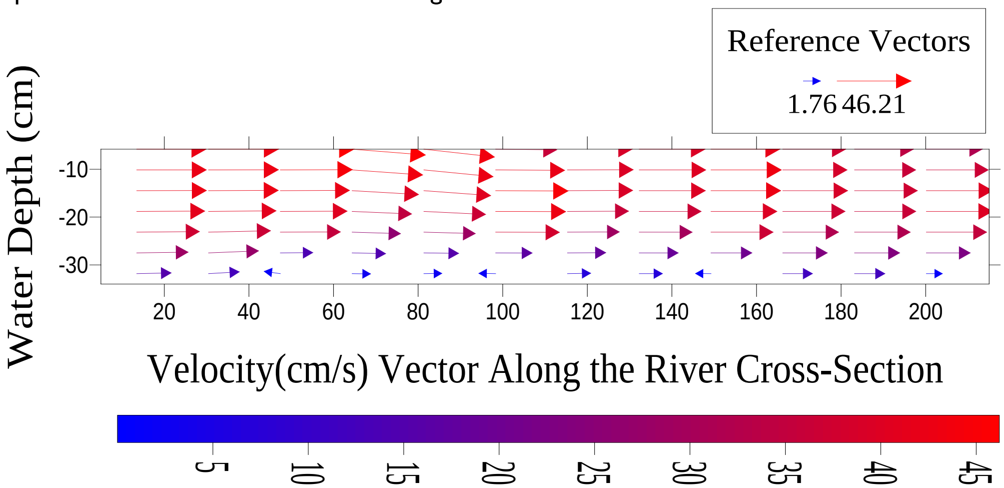


(b): Bed contour diagram of the river channel with higher slope

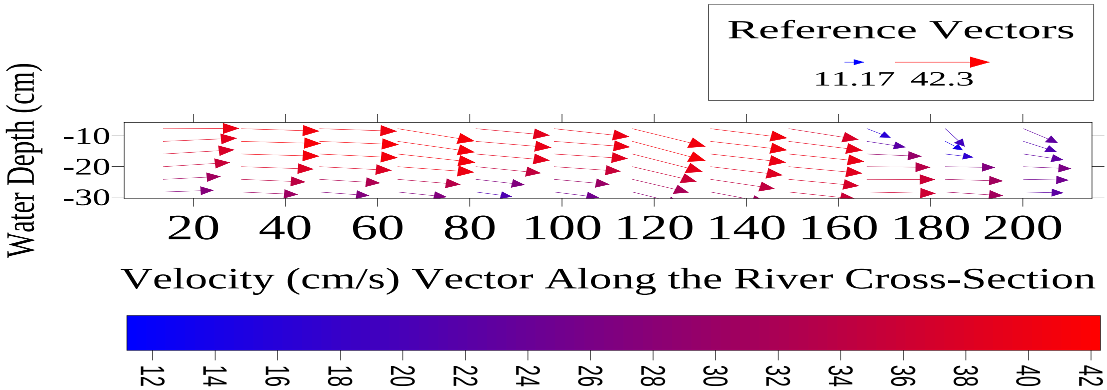
Figure 5: *Bed level contour map for the different angle of flow*

3.2. Velocity distributions

Velocity distribution with contour diagram as well as velocity vector diagram due to effect of bandals in the experimental river channel is shown in Fig. 6.



(a) Velocity vector at the upstream of the bandals

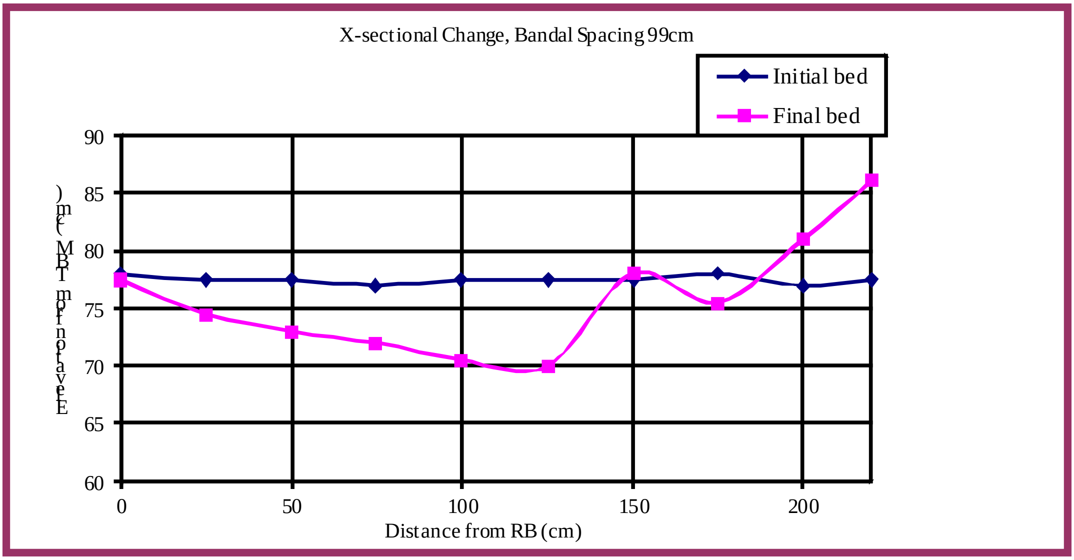


(b) Velocity vector at the downstream in between the bandals

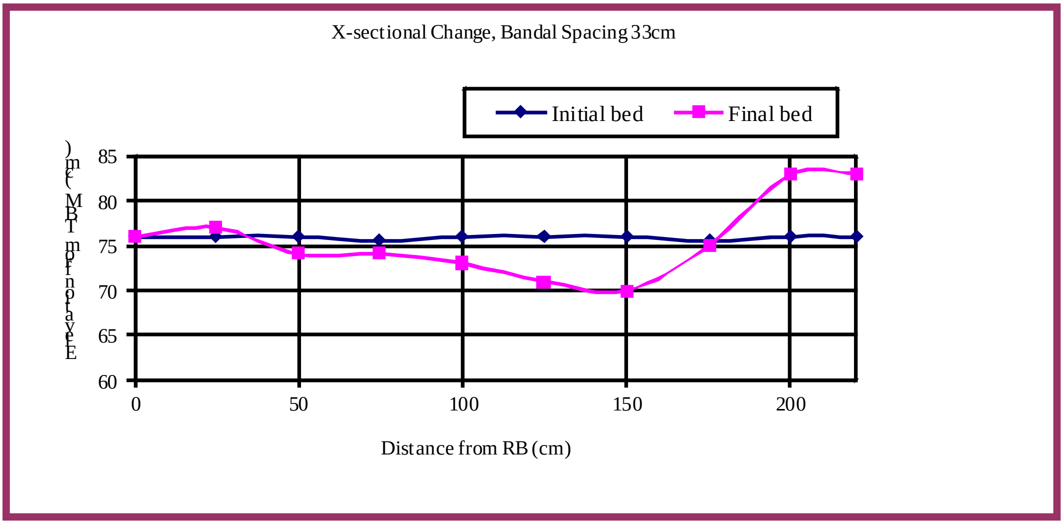
***Figure 6:** Velocity vector diagram of the river channel at different location*

3.3. Erosion-deposition pattern

Bed level reading is taken before and after the test run. The test run conducted with the discharge 200 l/s and water surface slope was provided 8.00 cm/km. The bed level plot along the river channel cross-section is shown below in Fig. 7.



a) Erosion-Deposition pattern along the cross-section



(b) Erosion-Deposition pattern along the cross-section

Figure 7: *Erosion-Deposition pattern along the cross-sections in the river channel*

4. Results and Discussions

It is seen from the Fig. 4 that there is siltation in the river channel near the bank. It is seen also from the Fig. 5 that the velocity near the river bank is lower than that at the main channel. It can further be confirmed from the river cross-sectional plot that there is sedimentation near the river channel as shown in Fig. 6. It is concluded from the Figs. 4, 5 and 6 that there is siltation near the river bank whereas there is a deep pool away from the river bank. So it can be confirmed that the bamboo bandalling structures are working as a river bank erosion protection structures.

5. Conclusion

Bandals are capable of protecting river banks by flow diversion towards the main channel leading to deep navigational channel formation in the main river. On the other hand, flow velocities are reduced near the bank lines that ensure bank protection by the deposition of sediment. If the bandal structure functions optimistically, the river can get sufficient time for its adjustment and new main channel and bank line development.

Acknowledgement: The author is grateful to the River Research Institute, Faridpur, Government of Bangladesh for the financial assistance to conduct this study.

References

FAP-24 (1994). Morphological Studies Phase-1, Delft Hydraulics, Danish Hydraulic Institute, Flood Action Plan (FAP) - 24, Study Report 3, Prepared for FPCO, Govt. of Bangladesh

Klassen, G.J., Douben, K.J., Waal, M.V.D. (2002): Novel approaches in River Engineering.

Klaassen, G.J., Douben, K., van der Waal, M., (2002). Novel approaches in River Engineering, River Flow-2002, pp.

27-43.

Klassen, G.J., Masselink, G.(1992). Planform changes of a braided river with fine sand as bed and bed and bank material. Proceedings of the Fifth International symposium on river Sedimentation, 6-10 April Karlsruhe, pp.459-471.

Klaassen, G.J. Mosselman, E., Brühl, H. (1993). On the prediction of plan form changes in braided sandbed rivers. In: Advances in Hydro Science and – Engineering (Ed. S.S.Y. Wang), Publ. University of Mississippi, University, Mississippi. pp.134-146.

Rahman, M. L., Basak, B.C., Osman, M.S. (2009). Use of Bandal Structures for Scouring River Bed to enhance River Bank Erosion Protection. Proceedings of the National Speciality Conference on River Hydraulics, Maharishi Markandeshhwar University, Mullana and Indian Society for Hydraulics, Ambala, Mullana, Haryana, India, pp-47-50.

Rahman, M.L., Basak, B.C., Osman, M.S. (2009). Velocity Distribution around the Low Cost Structures named Bandalling for River Bank Erosion Protection. Proceedings of the River, Coastal, and Estuarine Morpholdynamics (RCEM 2009), Universidad Nacional Del

Rahman, M.M., Nakagawa, H., Ishigaki, T., Khaleduzzaman, A.T.M (2003). Channel Stabilization using bandalling, Annuals of Disaster Prevention Research Institute, Kyoto University, 46, 613-18

A study of quality control on time series of water level in agricultural reservoir

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Abstract

The number of agricultural reservoirs in South Korea is about 17,500. Integrated Water Management (IWM) System is run by Korean Rural Community (KRC) to manage 3,377 reservoirs and the real-time water level is recorded in the system. Ultrasonic gauge and pressure gauge are used to measure the water level of reservoirs. Raw data are saved in logger and sent to the main system. There are a lot of outlier in the raw data, but adequate quality control process is not applied to the raw data. The anomaly can have a large impact on data. Unreliable data cannot be used in any studies. In USGS and EPA there exists settled quality control process for water level. In this study, ordinary and new quality control (QC) process was applied to the raw data. The result was compared and each QC process was evaluated.

Keywords: *agricultural reservoir; outlier; quality control; water level.*

1. Introduction

Data collection is a basic process for analysis of environmental resources. In agriculture, water is the most important resource for crop cultivation. Therefore, different types of water-related data are being measured for effective water use including precipitation, water level, discharge, groundwater, etc. In Korea, Total Operation Management System (TOMS) is run by Korean Rural Community (KRC) to manage agricultural reservoirs. Water level data of reservoirs and open channels are saved in TOMS database. The raw data are operated with brief quality control process. Since it is not authorized, the quality control process conducted currently is, however, not enough to publish a set of data. Environmental data is needed to be checked with approved quality assessment process because it can cause a misunderstanding of nature. USGS and EPA suggest official data quality assessment program assure data quality. In this study, general outlier detection method and EPA suggested method are applied to the same raw water level data of reservoirs. Both methods are compared statistically and graphically.

2. Methodology

2.1 General outlier detection

Outliers are extreme values that deviate from other observations on data, they may indicate a variability in a measurement, experimental errors or a novelty. In other words, an outlier is an observation that diverges from an overall pattern on a sample (Santoyo, 2017). There are some most popular methods for outlier detection such as z-score analysis, probabilistic and statistical modeling, linear regression models, proximity-based models. In this study, Z-Score analysis and moving average are applied to the dataset.

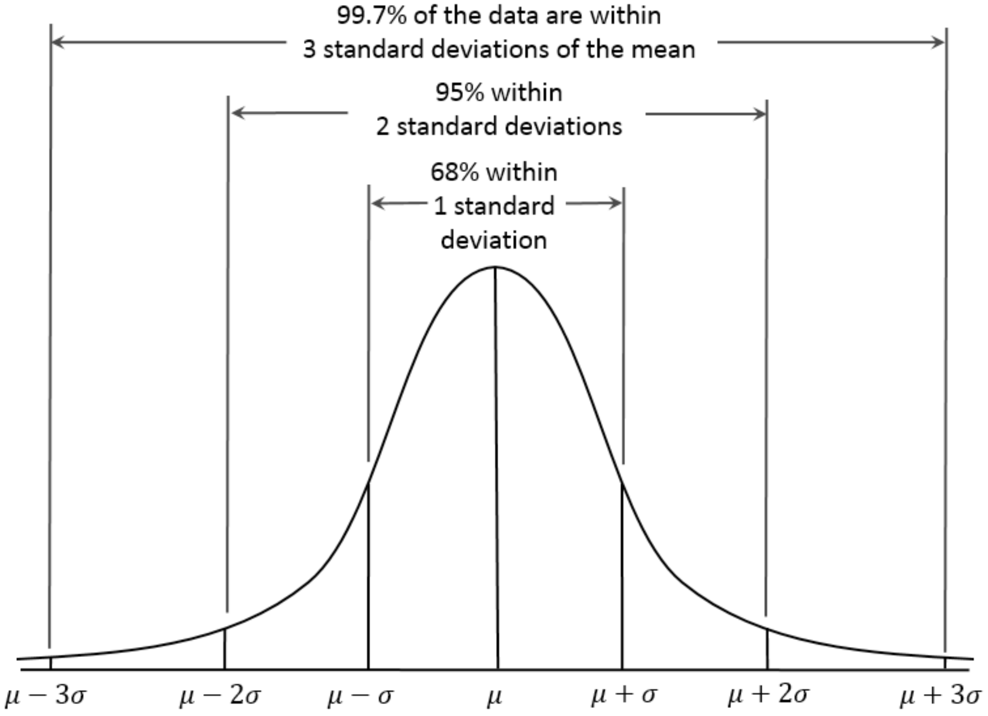

Figure 1 : *Probability for sigma in normal distribution*

2.1.1 3-sigma rule of thumb

The z-score or standard score of an observation is a metric that indicates how many standard deviations a data point is from the sample's mean, assuming a Gaussian distribution. The 3-sigma rule of thumb expresses a conventional heuristic that nearly all values are taken to lie within three standard deviations of the mean. Some good 'thumb rule' thresholds can be 2.5, 3, 3.5 or more standard deviations.

2.1.2 Moving average

Moving average is a calculation to analyze data points by creating series of averages of different subsets of the full data set. Moving average is commonly used with time series data to smooth out short-term fluctuations and highlight longer-term trends or cycles. In this study, moving average was used as an outlier elimination method by smoothing the line.

2.2 EPA decision tree

EPA suggested decision tree for selecting the specific method (EPA, 2006). Reservoir level data is one-sampled time series data and distribution cannot be assumed to a single distribution. Therefore, an instantaneous decision should be made to fit the data distribution. EPA decision tree proposes several kinds of condition for parameters and distribution so that user can select an exact methodology for own dataset. The figure below shows decision tree for selecting the specific method. In this study, reservoir level data is one-sampled data and each reservoir data has a different distribution. Therefore, Walsh's test was selected as a proper method for reservoir water level data (EPA, 2000).

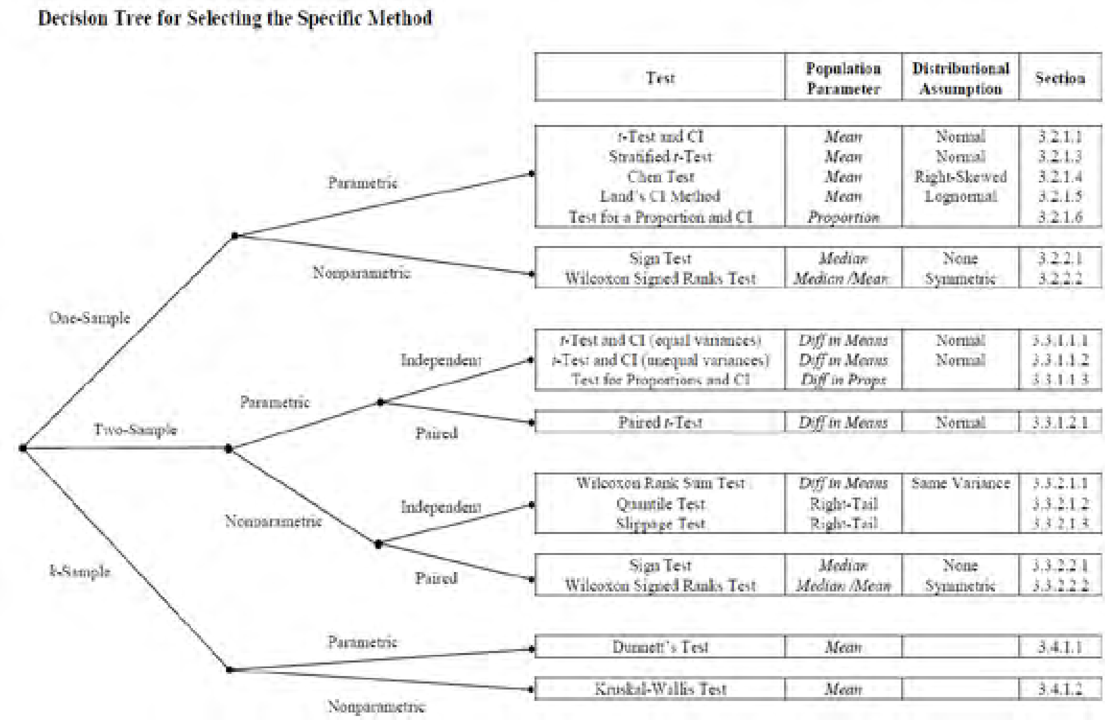

Figure 2: *EPA decision tree*

3. Results and Discussions

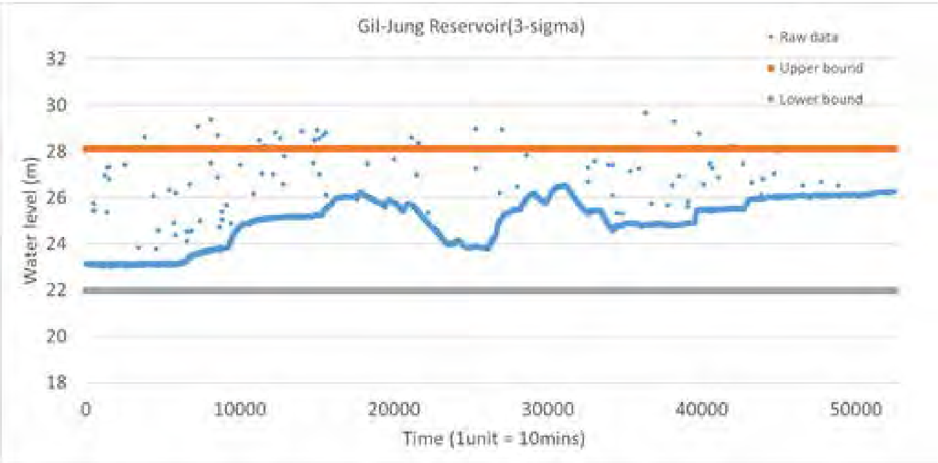

Figure 3: *Application of 3-sigma rule of thumb*

In this study, a quality control method, the 3-sigma rule of thumb and moving average has used The application of general outlier detection method and EPA suggested method is in Figs. 3, 4, and 5. Fig. 3 showed the upper bound and lower bound of Gil-Jung reservoir time series data. The upper and lower bound were 28.12m and 21.96m and they had equal value of positive 3-sigma and negative 3-sigma value respectively. The outliers in raw data are partially excluded but the upper bound exceeded the full level and lower bound was smaller than the dead level of the reservoir. Fig. 4 shows the smoothed results of raw data. In this case, the sample number for a window was 15. Some additive outliers were smoothed but others in early stage showed imperfect linearization. If the sample has an extreme additive outlier, moving average method will not work properly.

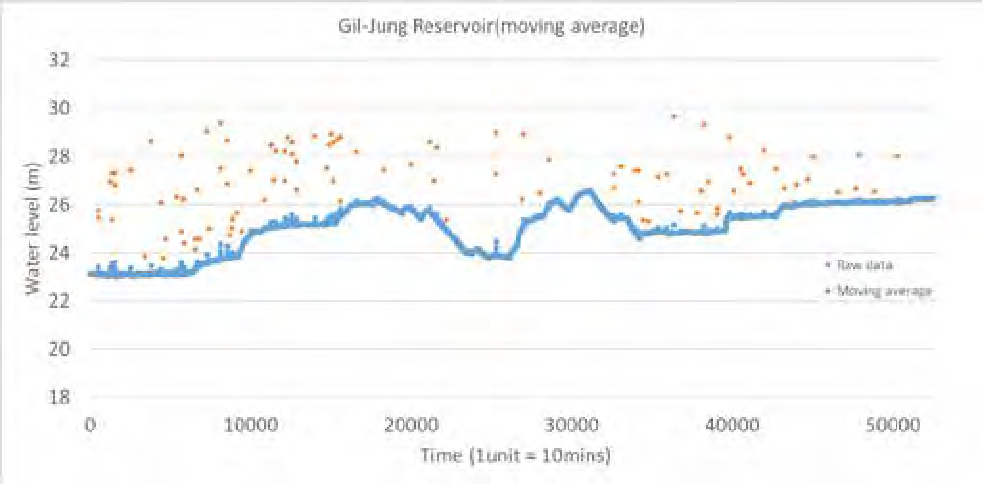

Figure 4: *Application of moving average*

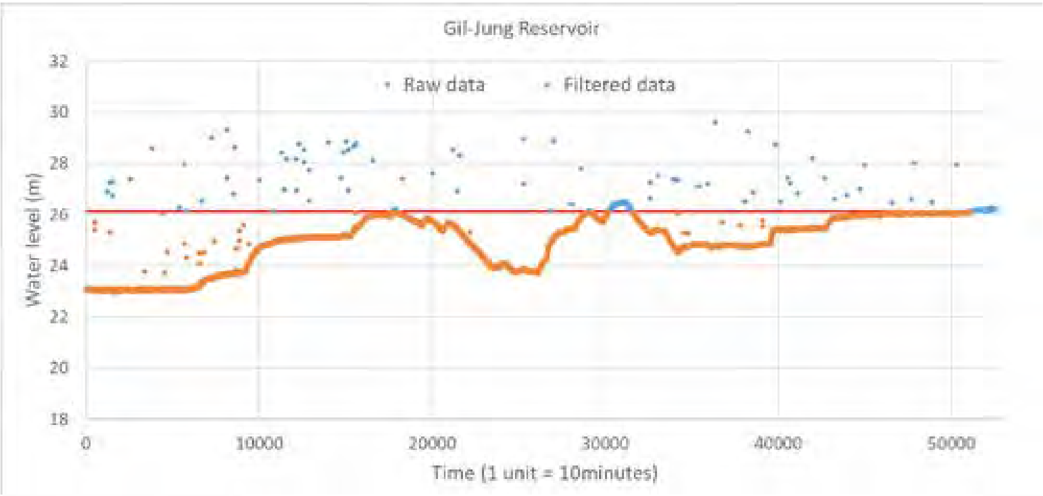

Figure 5: *Application of Walsh's test*

Fig. 5 shows the result of the application of Walsh's test. The upper threshold was 26.12m and it excluded not only outliers but effective points. Therefore, it turned out to be an inappropriate method. The quality control process should be applied to not reservoir level data, but reservoir level fluctuation data.

4. Conclusion

Data quality is the basic component which must be guaranteed for Integrated Water Management because most of the systems is run based on data. Quality control processes such as 3-sigma, moving average and Walsh's test were conducted to reservoir level data, but most of the methods turned out to be inappropriate. Therefore, it would be recommended that reservoir level fluctuation data should be handled instead of reservoir level data. In the future study, 2-step outlier detection method will be applied to reservoir level fluctuation data. In some cases, the suggested method seems to work successfully, but in other cases, additive outlier and innovative outlier remained after the outlier detection process.

Acknowledgements: This work was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries (IPET) through Advanced Production Technology Development Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA) (316022).

References

EPA, (2000). Guidance for Data Quality Assessment. [online] Washington, DC: U.S. Environmental Protection Agency, pp.4-32. Available at: https://www.epa.gov/quality [Accessed 5 Apr. 2017]

EPA, (2006). Data Quality Assessment: Statistical Methods for Practitioners. [online] Washington, DC: U.S. Environmental Protection Agency, p.47. Available at: https://www.epa.gov/quality [Accessed 5 Apr. 2017].

Santoyo, S. (2017). A Brief Overview of Outlier Detection Techniques. [online] Available at https://towardsdatascience.com/a-brief-overview-of-outlier-detection-techniques-1e0b2c19e561/ [Accessed 12 Sep. 2017].

Challenges of sediment removal on Sunsari Morang Irrigation Project, Nepal

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Abstract

Following the Kosi Project Agreement in 1954, the Government of India (GOI) financed and constructed the Chatra canal system to irrigate 58,000 ha in Sunsari and Morang districts in Nepal. This was to compensate Nepal for the construction of Kosi Barrage on the border with India some 42 km downstream of the gorge at Chatra. The canal network of the Sunsari Morang Irrigation Project (SMIP) was handed over to GON (Government of Nepal) in 1975 but the distribution system terminated at turnouts serving 100 – 200 ha blocks and no minor canals were built below this level. SMIP is a run-of-river scheme wherein water is abstracted directly from the Kosi River via headwork. Unfortunately, the backwater from the Kosi barrage is too far downstream to influence water levels and river flows at the headwork which means that the intake to SMIP is run-of-river and subject to variations in river water levels.

From the outset, SMIP was plagued by sedimentation problems that have had an adverse effect on service delivery and limited agricultural production. In summer months, during the wet season, water is easy to abstract from the Kosi river, but sediment laden. In winter months, during the dry season, water is difficult to abstract due to low river levels but sediment-free. A serious problem that exacerbates sediment loads in the Kosi river is the widespread deforestation within the river's catchment where local people have cut down trees and other vegetation for firewood. In addition, rainfall has intensified as a result of climate change, greatly increasing erosion from deforested and other exposed areas throughout the catchment. The management of sediments is critical to the sustainability of SMIP and making sure that investment in modernization of SMIP contributes to the sustainable development goals (SDGs).

Over the decades, various measures have been implemented to remove sediment from SMIP including the use of dragline and bulldozers to remove larger boulders and cobbles away from the headwork and downstream of the headwork, the construction of a settling basin that was also cleared with mechanical equipment. Even with these measures, significant volumes of sediment, particularly sand, had to be removed manually from the canal network. When the silt load exceeds 3000 ppm at the headwork, the main canal is closed but this can be tolerated only for a limited period in the wet season. An estimated 370,000

m^3 of silt has to be trapped and removed. In a high flood year this volume increases to about 500,000 m^3.

In this paper, the experience is described of supervising both local and international contractors on the rehabilitation of irrigation structures including the installation of vortex tubes for sediment removal on the Chatra main canal. At the time in the mid-1980's, vortex tubes were new to Nepal. The performance of the vortex tubes is assessed. The paper concludes by reviewing subsequent efforts to reduce sediments within SMIP.

Keywords: *canal flows; maintenance; modernization; sediment removal.*

1. Introduction

Excessive sediments in surface water supplies present major challenges for many run-of-river irrigation schemes. On the supply side, global warming and climate change exacerbate sediment loads as rainfall becomes more intense and vegetative cover is removed from catchments. On the demand side, water delivery is reduced due to sediment deposition in canal networks raising canal bed levels, reducing canal capacities and compromising the quality of soils being irrigated. In addition, management of sediments can overwhelm maintenance budgets to the detriment of other maintenance needs of canal networks.

Over centuries different techniques such as settling basins or diversion weirs have been applied to remove sediments from irrigation water but the scale of the problem in some schemes results in standard techniques being overwhelmed by the volume of sediments that need to be removed. Modernizing irrigation networks to improve service delivery can make significant contributions to achieving the Sustainable Development Goals (SDG's) but modernization without addressing sediment problems diminishes the scope for improving service delivery and will not assist farmers to increase production and move out of poverty.

The Sunsari Morang Irrigation Scheme (SMIP) in Nepal is one such scheme where sediment has caused major problems with scheme performance and sediment removal presents a major challenge. Sunsari Morang is located adjacent to the India/Nepal border as the Kosi River emerges from the foothills of the Himalayas onto the Gangetic plains of India (Fig.1).

Figure 1: *Location of Sunsari Morang Project, Nepal.*

In this paper, the experience of introducing and constructing a novel sediment removal measure to SMIP is described and the performance of the measure evaluated. Subsequent sediment removal activities on SMIP are also reviewed.

2. Study Area

2.1 The Koshi River

The source of water for SMIP is the Kosi River, one of the major rivers emerging from the Himalayas and Nepal onto the Gangetic plain in India. The Koshi (In Nepali, *kosī nadī*) drains the northern slopes of Himalayas in Tibet and the southern slopes in Nepal (Fig. 1). The river is 720 km (450 miles) long and drains an area of about 74,500 km^2 (28,800 miles^2) in Tibet, Nepal and Bihar.

The river transports sediment down the steep gradients and narrow gorges in the mountains and foothills where bed slopes are10 m/km or more. As the river leaves the foothills and emerges onto the Gangetic plains south of the Chatra Gorge, bed slopes flatten to below 1 m/km or even less. The result is that sediments are deposited on an immense alluvial fan that has grown to an area of about 15,000 km^2. This fan extends some 180 km from its apex where it leaves the foothills, across the international border into Bihar state in India.

The average flow of the Koshi River is 2,166 m^3/s (76,500 ft^3/sec). During floods, flows increase to as much as 12 times the average. The largest recorded flood was 25,854 m^3/s on 5th October 1968 with a return period of 1 in 33 years (Bromwich, 1995).

The river has numerous interlacing channels that shift laterally over the fan from time to time. Its unstable nature has been attributed to the heavy sediment loads it carries during the monsoon season. Extensive soil erosion from denuded hillsides and landslides in its upper catchment has produced a silt yield of about 21 tones/ha/year, one of the highest in the world (Carson, 1984). During the last three hundred years the alignment of the Koshi River south of Chatra has changed significantly as shown in Fig. 2.

Figure 2: *Changes in the alignment of the Koshi River.*

There are two types of floods in the Koshi:

- Monsoon floods occur every year as mountains and monsoon rains inundate foothills to the north. Between 1947 and 1978, annual flood peaks ranged from 5420m^3 /s to 25 854 m^3/s. The return period for the maximum peak flood was1 in 33 years. The Koshi barrage was designed for a peak flood of 27,014 m^3/s.
- Glacial Lake Outburst Floods (GLOF) with climate change and global warming, glaciers; in the Himalayas are melting and retreating, which produce lakes insecurely dammed by ice or moraines. These dams are at risk of breaking, causing a GLOF with flows as great as 10,000 m^3/s. There was a major GLOF in June 1980 resulting in erosion of East Bank of the River Koshi. Spur (groins) were constructed to protect the CMC during future floods (Fig. 3). The Dig Tsho GLOF occurred on 4 August 1985, causing devastation upstream.

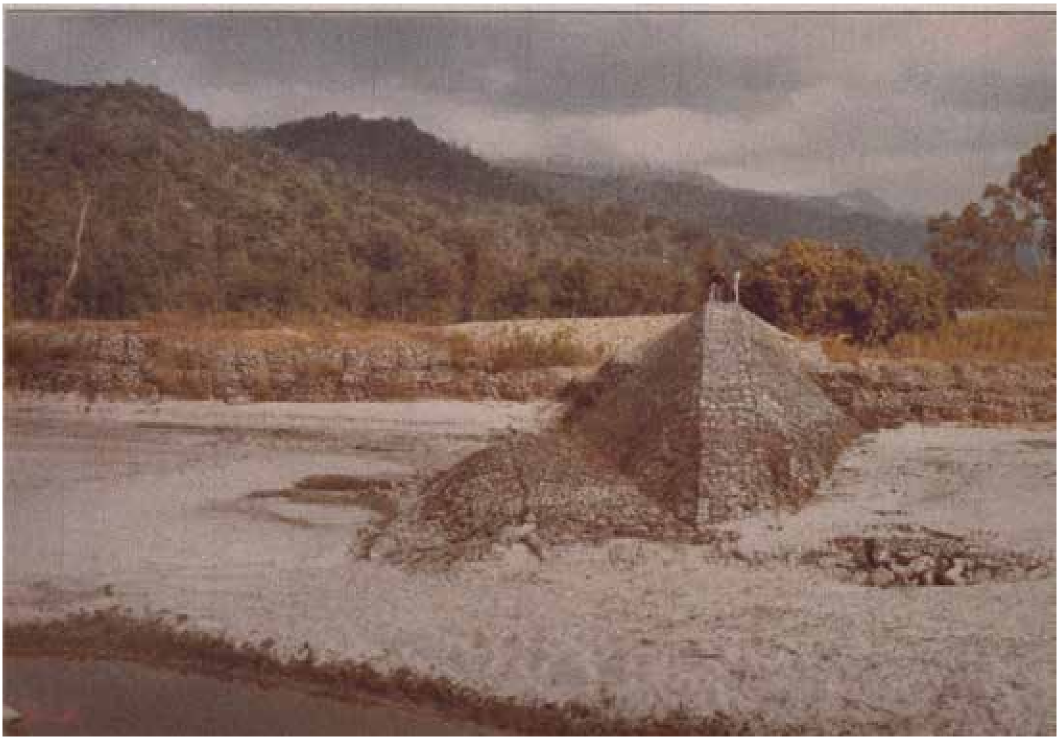

Figure 3: *Spurs constructed to protect the west bank of the Chatra main canal from Koshi River*

2.2 The Sunsari Morang Project

After the disastrous floods of 1954 in a large part of the Kosi River basin, the Kosi Project was formulated as part of the GOI National Flood Control Policy in 1954 and was designed to control floods through a series of barrage and dams, embankments and river training works. The Koshi Project south of Chatra had two interlinked stages:

- A barrage to anchor the river that had migrated about 120 km (75 mi) westward in the last 250 years (Fig. 2) laying waste to a huge tract in north Bihar and to provide irrigation and power benefits to Nepal and India.
- Construction of embankments both below and above the barrage to hold the river within the defined channel.

On 25 April 1954, Nepal and India signed the Koshi Agreement. The SMIP was formulated and developed by GOI as part of the agreement.

The Chatra Main Canal (CMC) that delivers water to SMIP takes off the Koshi River at headwork located just downstream of Chatra Gorge as the Koshi River opens onto the wide Gangetic plain. The headwork is located about 42 km upstream of the Koshi Barrage and the Indian border. SMIP was designed as an unlined manually operated system to irrigate a gross area of 66,000 ha in Nepal. After Nepal took over the project in 1976, SMIP Stage I was renovated with IDA assistance (GON/IDA, 1976). The layout of the SMIP is shown in Fig. 4.

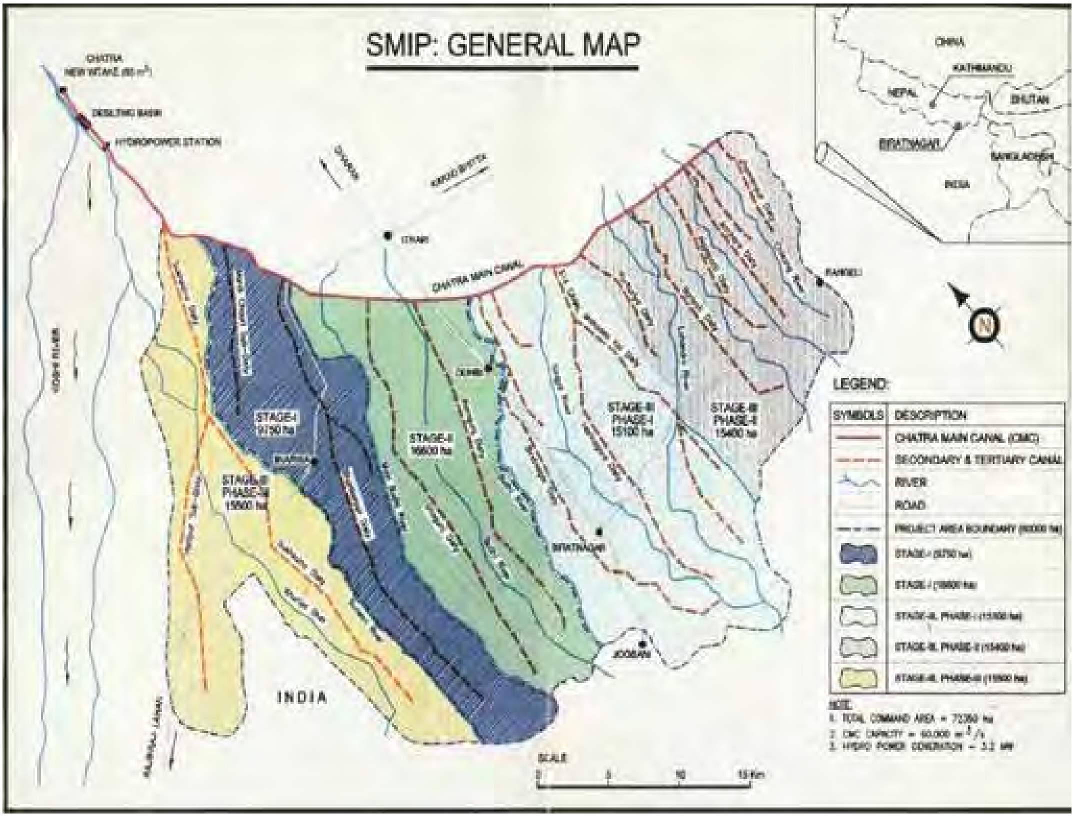

Figure 4: Layout of the Sunsari Morang Irrigation Project (SMIP).

The CMC carries diverted river water eastward across the regional drainage pattern with shallow bed slopes and inadequate cross drainage structures. CMC is 52 km in length with a design flow of 45.3 m^3/s

a (1,600 cusecs) at its head. The design duty is 0.67 l/s/ha and dates from a time when coverage and water spreading for protection for crop failure was more important than meeting cropwater requirements. Branch canals offtake from the CMC to distribute water throughout SMIP (Fig. 5).

The bed slopes in the CMC are flatter than Lacey indicates which implies that during design, sediment was not considered or a smaller silt factor was used (Paudel, 2010). No sediment excluders or sediment traps were provided resulting in all sediment was deposited in the canals to reduce their capacity or on the fields to reduce soil quality. In addition, inadequate O&M budgets allowed only partial removal of deposited sediments each year (Hydraulics Researchm, 1988).

The flow on the Koshi river is always far in excess of this requirement, mean flows ranging' from about 350 m^3/sec during March to 4,760 m /s during August. However, the river water carries a heavy sediment load during the monsoon season, with the mean monthly sediment loads ranging from 2.30 to 3.75 g/l during July through September.

The climate of SMIP is subtropical with daily maximum temperatures ranging from about 9° C during the cool months (November to February) to about 34°C in the hottest months (March to October). The mean annual rainfall is about 1729 mm with a range of 1403 mm to 2110 mm recorded for the period 1976-1985. June to September are the wettest months with about 80% of the total rainfall.

The main crop grown is paddy and is planted on about 92% of the cultivated land. Early Rice (*Bhadai*)/ Millet (May-Aug) Main Rice (*Aghani*)/followed by wheat (Sep-Dec). Paddy yields are low (about 2 tonnes/ ha) which in part is a result of unreliable water supplies caused by sedimentation in the CMC and branch canals reducing flows.

Figure 5: *Shankapur branch canal*

In the 1980's, public irrigation in Nepal was the responsibility of the Ministry of Water Resources through its Department of Irrigation, Hydrology and Meteorology. The department then passed different stages working under different ministries and finally ended up as Department of Irrigation (DOI) in 1987 The DOI is currently under the Ministry of Irrigation (MoI). The department has a mandate to plan, develop, maintain, operate, manage and monitor different modes of environmentally sustainable and socially acceptable irrigation and drainage systems, from small to larger scale surface systems and from individual to community groundwater schemes. Its ultimate aim is to provide year-round irrigation facilities and increase the irrigable area of the country to higher limits. In addition, the DoI also carries out river training activities to protect the floodways, floodplains and agricultural lands in the form of river bank protection such that the loss of properties caused by flooding is reduced

The lead author was employed by an international firm of consultants to supervise local and international contractor on the rehabilitation of SMIP Stage 1 between 1979 and 1986 – (shown in blue on Fig. 4). The irrigated area of Stage I is 9685 ha (23 244 acres).

3. Sediments and Sediment Removal

From the outset, the SMIP was plagued by sedimentation. Sediments create a chronic maintenance problem and sediments completely smother parts of the distribution system and farmers' land. More critically, the high sediment load in the Koshi River causes formation of sand bars that periodically close the entrance to the intake canal thus depriving SMIP of water.

During the summer monsoon (May to October), river water is abundant but sediment laden. In contrast during winter (November to April), water is relatively sediment free but in short-supply. Unfortunately, the CMC is too far upstream from Koshi barrage to benefit from its backwater.

The distribution of sediment along the CMC is shown in Fig. 6 (Hydraulics Research, 1986).

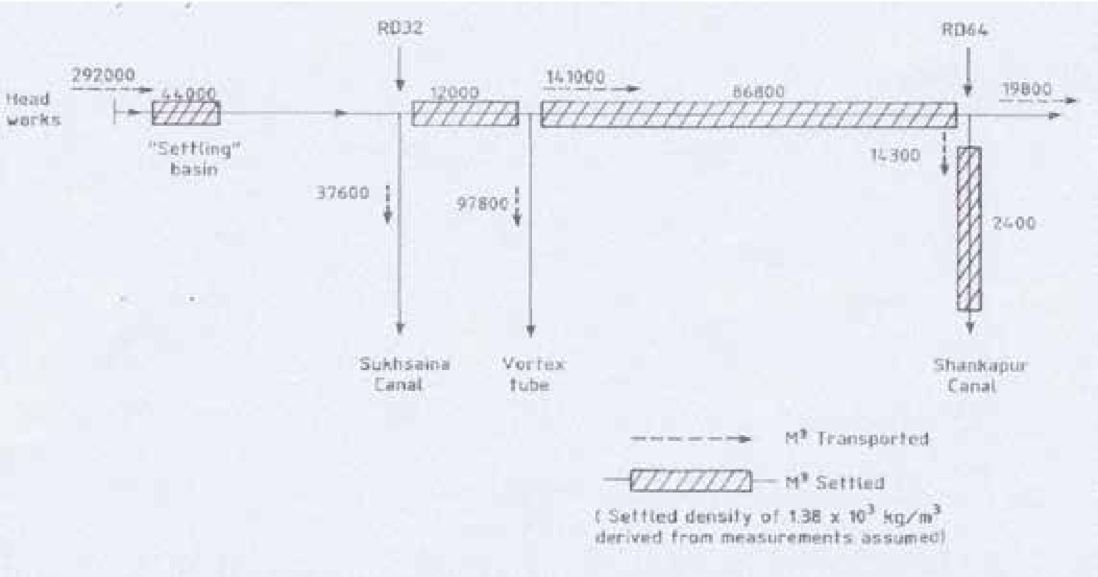

Figure 6: *Distributions of sediments load along Chatra main canal.*

Downstream of the CMC headwork, there is a settling basin for the removal of gravel and boulders by mechanical plant and dredgers. Coarser material is excluded from the intake by river dredging and gate operation. Under the SMIP Headwork Project, the intake was moved 1300 m upstream to increase the capacity of de-silting basin and larger capacity dredgers were provided.

The annual sediment load of river water entering the CMC varies from 370,000 to 500,000 m^3. About 292,000 m^3 of fine sand (63 – 600 microns) are deposited in the CMC and removed by manual labor. Manual labor productivity is 4.07 m^3/laborer/day (Bromwich, 1995) (Fig. 7).

Operationally, CMC is closed when the sediment concentration is more than 3000 ppm. In comparison, the Ganges Canal at Haridwar, some 900 km further West of CMC, the canal is shut down when sediment concentrations exceed 5000 ppm (Bromwich, 2007).

Figure 7: *Manual removal of sediments from Chatra main canal*

3.1 Vortex tubes for sediment removal

A vortex tube is a structure designed to remove sediment from the bed of canals. The soffit of a vortex tube is constructed across the channel bed and the top of the tube is open to allow water and sediments to enter inside the tube. The flow moves through the tube in a spiral motion (hence the name "vortex" tube) towards an open end that allows free discharge of entrapped flow plus sediments. Key criteria in the design of vortex tubes are: the difference in head between the canal and the vortex tube outlet; the diameter of the tube to ensure that the tube does not block with sediment; and water is near-uniformly abstracted along the length of the tube (Atkinson, 1994). Vortex tubes, when properly set and dimensioned, have proved to be very effective for the removal of sand and gravel in bed loads (Atkinson, 1994).

In SMIP, a vortex tube sediment removal structure was constructed at +12.08 km. The structure comprised of three parallel 0.9 m diameter tubes, staggered across the apron and perpendicular to the CMC (Fig. 8). Effluent from the tubes was deposited into nearby drainage channel where bed gradients were sufficient to carry the sediments downstream.

Figure 8: *View of vortex tube structure showing 3 intake slots in apron*

Operation started in September 1984 and field measurements showed that 48.6 % of the sediments were removed at a cost of 9.4 % of the water loss [HRS, 1986). Sediments removed from the CMC by the vortex tubes were mainly fine medium and coarse sand. The composition of the sediment removed is shown in Fig. 9 (Bromwich, 1995). Cobbles and coarse gravels were generally excluded upstream of the main canal intake or downstream in the head reach of the main canal.

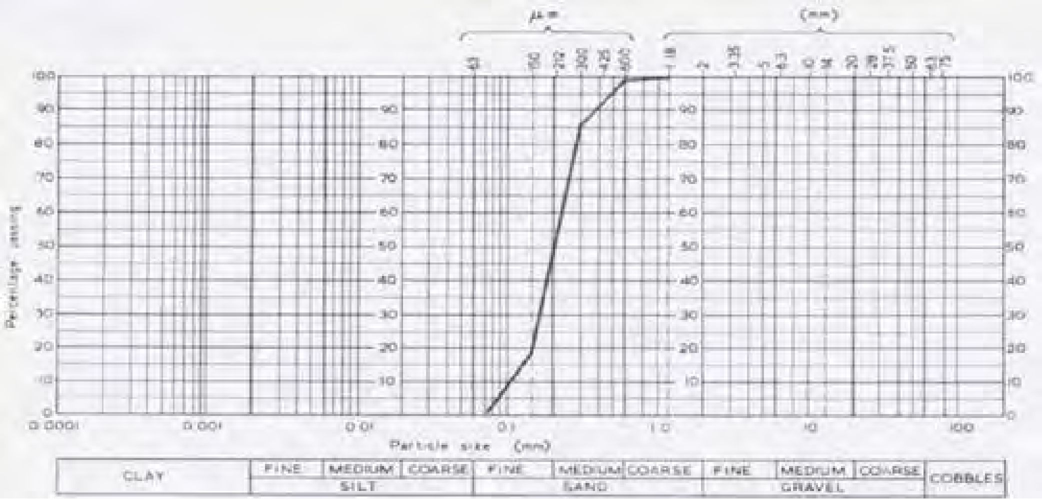

Figure 9: *Grading curve of sediment discharged from vortex tube.*

3.2 Subsequent activities to resolve excessive sediments in SMIP

Based on the monitoring results from the vortex tubes, it was estimated that a second vortex tube structure could remove almost twice the volume of silt as a single vortex tube but with additional water loss (Hydraulics Research, 1986). The GON did not accept further development of vortex tubes mainly due to the loss of water from the CMC where water was already in short-supply, even though water losses due to accumulated sediment in the canal were high and service levels could not be achieved. The vortex tube sediment removal measures were not effective due to operational problems (Khanal, 2003).

After further discussions between GON and IDA, the main funding agency, agreement was reached for the supplementary Headwork Project that comprised of moving the intake structure 1300 m upstream, construction of a de-silting basin, provision of dredgers for desilting and construction of a micro-hydro unit in the main canal to provide power for the dredgers (Fig. 10). Following approval, the Headwork Project was constructed in 1993-96 and successfully implemented. The increase capacity at the New Headwork increased from the design flow of 45. 3 m^3/s. to 60 m^3/s. Reportedly the 'siltation problem was resolved' but no data are provided to support the claim. However, a number of factors were identified that may jeopardize the project management including weak management, high staff turnover and inadequate budgets for O&M (World Bank, 1998)

Figure 10: *Head reach of the Chatra main canal*

By 2003, excessive sediment in SMIP was still causing problems and minimum water delivery to farmers could not be assured (Facon, 2003). Interestingly, Facon (2003) characterized SMIP by:

- Seasonally variable water supplies that may reduce 50—70% in the winter and spring;
- Lack of accurate flow control into secondary and tertiary canals associated with severe water level fluctuations;
- Rotation schedules that are not rigorously enforced;

- Institutionally weak water user associations with responsibility for substantial portions of the project but that have only minimal budgets;
- Severe inequity (tail end problems); and
- Phased implementation of rehabilitation efforts, which has resulted in a mixture of different water control strategies and hardware.

SMIP was originally designed as supply-based system without an assured water diversion provision at the head. After the improvements of the headwork during the rehabilitation, the water diversion from the river has improved but still it is not assured. Hence, the concept of the design to convert it into a demand-based scheme is a difficult proposition to meet. With the present water diversion and delivery infrastructure, the overall objective of the irrigation scheme would have to distribute the available water equitably to the crops in the entire command area keeping in mind that crop stress is unavoidable, even during the wet season. The water delivery plan and cropping schedule are so rigid that there exists very less possibility of changes. That is the reason why with each stage of modernization the cropping schedule is revised. Farmers by default assume that the scheme is a protective one only and there will be water stress if there is no rainfall as expected (Paudel, 2010). Paudel (2010) summarized the findings on the design and management of Secondary Canal S9 as:

- Sediment transport aspect is considered in the secondary canal only (using Lacey's equations). In sub-secondary and tertiary canals, sediment transport aspects have not been considered at all;
- The infrastructure provided in the distribution network (below sub-secondary canal) works properly only for the full supply discharge. For the irrigation scheme with such an un-assured water diversion provision, the system is difficult to operate as designed;
- Sediment transport is a major problem for sub-secondary and tertiary canals. The rate of sediment deposition is different from canal to canal and from reach to reach with in the same canal. Hence, in the system, some farmers have to invest more for sediment removal than the others. This has made the system operation more difficult;
- Water operation plans are not being followed. A canal carrying sediment cannot be operated and maintained unless proper water delivery modes (from sediment transport and water requirement aspects) are established and followed strictly.

During the past 30 years throughout the Koshi catchment, a number of development projects have been successful in reducing poverty and decreasing the sediment entering the river. For example, community forestry has given local people ownership of large areas of forest with the result that many new trees have been planted providing vegetative cover to exposed soils (Gyawal et al., 2017). However, given the size of the Koshi catchment it will take decades if not longer for re-forestation to impact sediment loads in the Koshi river.

4. Conclusions

- Continuing need to manage sediment loads to improve the efficiency of water deliveries and increase yields
- Vortex tubes are effective in removing sediment, mainly sands, but at the cost of taking about 10% of water from downstream users;

- There is a shortage of data to determine the impact of the desilting basin and changes in headwork operation and current sediment loads in the CMC.
- Removal of excess sediments has been passed onto water users association (WUA), which have limited budgets to deal with the problems.
- The CMC was designed without adequate consideration being given to sediment load. The branch and tertiary canals were designed with no consideration of sediment transport.
- Without addressing sediment problems SMIP will continue to underperform.
- The management of sediments is critical to the sustainability of SMIP and making sure that investment in modernisation of SMIP contributes to SDG's.

Acknowledgments: The authors acknowledge the contributions of the Department of Irrigation, Nepal and Hydraulics Research, Wallingford, United Kingdom in preparation of this paper.

References

Atkinson, E. (1994). Vortex -Tube Sediment Extractors I: Trapping Efficiency. ASCE Journal of Hydraulics, 120 (10), 1110-1125.

Bromwich, B. (1995). The Implementation of Stage 1 of The Sunsari Morang Irrigation Project, Nepal. Unpublished Master Degree Thesis, University of Dublin.

Bromwich, B. (2007). A Sustainability Review of 150 years of irrigation in India with particular reference to Uttar Pradesh. MPhil Thesis, University of Cambridge.

Carson, B. (1984). Erosion and Sedimentation Process in the Nepalese Himalaya. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Chancellor, F., Lawrence, P., Atkinson, E. (1996). A Method of Evaluating the Economic Benefits of Sediment Control in Irrigation Schemes. Report OD/TN 81. HR Wallingford Group, United Kingdom

Facon, T. (2003) Technical Completion Report, Training Workshop on Irrigation Modernization, Management Improvement and Benchmarking. SMIP, Nepal Irrigation Sector Project, On-Farm Water Management Proram DOI/DOA/FAO, Baratnagar Nepal. Irrigation Training and Research Center (ITRC), Calpoly Polytechnic State University (CALPOLY), San Luis Obispo, California, USA.

Gupta, K.F. (2006). Water Crisis in India. Atlantic Publishers and Distributors (P). Delhi, India. pp 222-223.

Gyawal, D, Thompson, M., Verweij, M. (2017). Aid, Technology and Development – The Lessons from Nepal. Earthscan from Routledge. London and New York.

Hydraulics Research (1986). Sedimentation in the Chatra Canal, Nepal. Report OD 86. Prepared in collaboration with SMIP. Wallingford, United Kingdom.

Nayak, J. (1996). Sediment management of the Kosi River basin in Nepal. In: Walling, D. E. and B. W. Webb (Eds.) Erosion and Sediment Yield: Global and Regional Perspectives. Proceedings of the Exeter Symposium July 1996. IAHS Publishing no. 236. Pp. 583–586.

Paudel, K.P. (2010) Role of Sediment in the Design and Management of the Sunsari Morang Irrigation Scheme, Nepal. Doctoral Thesis. Wageningen University and UNESCO-IHE Institute of Water Education, the Netherlands. CRC Press/Balkena, Leiden, the Netherlands

World Bank (1992). Proposed Credit for Sunsari Morang Headworks Project

World Bank (1996). Implementation Completion Report for Sunsari Morang Irrigation Project Stage 2

World Bank (1998). Performance Audit Report: Sunsari Morang II and other projects. Operations Evaluation Department. Washington, USA.

THEME – IV

Enabling Water Users Institutions for Sustainability of Irrigation Systems

Japanese model of participatory irrigation management and its implications

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Abstract

To achieve irrigation project goals, governments need to achieve desired operation and maintenance objectives. However, past attempts at water management by governments, especially in small-scale Asian farming systems, have shown that this is not possible without the cooperation of farmers. Even after recognizing the need to include farmers in water management, few governments have succeeded in such participatory irrigation management (PIM). One of the main reasons for this may be the lack of methodology on how to persuade the farmers that benefit to cooperate with the government goals, understanding that this is a point of farmer conflict, especially among regions.

In Japan, as in most countries, central and local governments implement construction/ rehabilitation of irrigation projects. A special feature of Japanese projects is that the completed facilities are wholly transferred to the beneficiaries, including major structures such as diversion dams in source rivers and main canals. An autonomous irrigation association of farmers (Land Improvement District, LID) is established specifically for each project which manages the facilities by collecting membership fees to cover operation and maintenance costs. During water shortages, available water is equitably allocated among farmers, thus minimizing drought damage.

This successful PIM approach in Japan has been developed by a national policy to promote farmer cooperation by recognizing common conflicts and includes the following factors: 1) beneficiary farmers are involved in irrigation projects from the start, because it is the government's policy to approve only those irrigation projects for which an application has been made with the consensus of farmers on project management; 2) the farmers must shoulder a certain percentage of the total project cost, including that for main facilities; 3) the government provides a high ratio of subsidy to overcome difficulties created by different willingness to pay among farmers; 4) the Land Improvement Act (1949) provides a democratic framework and procedures for LID management; and 5) LIDs are inspected by the government every 3 years. The implications of this Japanese model are:

- *Governments should focus on the end goal of achieving stable and high crop yields, and thus, intervene in water management by LID in an indirect manner.*

- *Famers have regional conflicts at the level of every canal. Such conflicts may work as incentives for farmers to cooperate in order to better compete with other groups. Farmer cooperation will be encouraged under the conditions of direct farmer negotiation with disclosed information.*
- *Governments allow farmers to discuss and decide water management issues, and to monitor the results themselves with guidance to enhance farmers' self- governing abilities.*
- *Through this policy, governments can achieve their goals with minimum cost.*
- *The Japanese model might be transferable to other countries with modifications because of its common principles.*

Keywords: *consensus; farmer cooperation; government goal; Japanese model; PIM; regional conflict.*

1. Introduction

Irrigation projects in developing countries are not always successful, especially in terms of operation and maintenance. Because of the importance of irrigation in modern agriculture, improvement of irrigation management is a worldwide concern. In the 1990s the importance of participatory irrigation management (PIM) was widely recognized, and many attempts were made to promote it. With a few exceptions, however, there are not many reports of successful cases (Vermilion, 1997). One of the main reasons for these failures may be the underdevelopment of methodology to promote farmer cooperation, which may derive from a naive optimism that irrigation management will naturally improve once water is transferred to the hands of farmers, who are more serious about it than government officers. Ostrom (1992) presented a thorough discussion of institutions for sustainable irrigation management by irrigation users. However, it should be noted that governments also have the power to introduce new ideas as a policy to change the system within which farmers act. Successfully implementing PIM requires a clearly established methodology, and further discussion is needed similar to that in the 1990s (Gautum, 1997) with a modern focus.

One major discussion focus may be that farmers are not as interested in contributing to a government's goal as they are in increasing their individual benefit. Therefore, we need to develop a methodology for creating conditions under which beneficiaries are willing to cooperate towards the government's goal. Regional conflicts between farmers over water distribution are especially difficult to solve. This paper aims to clarify how the Japanese government has been developing farmer cooperation, and thus successfully achieving their goals in irrigation projects.

As in most countries, central and local governments implement the construction of irrigation facilities (including rehabilitation) in Japan. A special feature of these Japanese projects, however, is that farmers that benefit are deeply involved in the projects from the initial stages, and the completed facilities are wholly transferred to the farmers for management. Japanese farmers have been successfully managing these projects by establishing irrigation associations (Land Improvement Districts, LID), which collect membership fees from farmers to cover all operation and maintenance costs. Some exceptional cases may be seen in newly constructed large-scale projects that are jointly managed by government and LIDs. Japan Water Agency projects are typical examples of such cases (Kono et al., 2012).

2. Background of Japanese Irrigation Management

Japan is a long, narrow island country that stretches north to south. Its four main islands are located between north latitudes of 31 and 45 degrees. It has a total area of 37.8 million ha (Mha), of which mountainous forest occupies almost two-thirds. In 2017, there was 4.44 Mha of agricultural land, with land for paddy production (suiden, land socially recognized for rice production, not a paddy field) accounting for 2.42 Mha. The rest of the agricultural land was allocated for upland crops, orchards, and pastures (MAFF, 2017).

Japan has four distinct seasons (spring, summer, autumn, and winter) over the main islands. In most of the land, due to low temperatures from late autumn to early spring, only one rice crop can be grown during the period from May to October. In Tokyo, for example, average monthly temperatures range from 18.2°C in October to 27.1°C in August. For the rest of the year, the temperature is below 15°C (5.8–13.0°C), which is the lower limit for rice plants. Therefore, farmers generally prefer to prepare for paddy cultivation (paddling and transplanting) from late April to early June to obtain good and stable yields according to hydrological conditions in each region.

The 18th century witnessed a major extension of rice fields in Japan. Throughout the country's history, almost all paddy fields have been irrigated; this means that under natural conditions, stable rice cultivation is difficult in Japan without a stable water source for irrigation. Rainfall in Japan (1980 – 2015) averages about 1720 mm/y, of which almost two-thirds occurs during the irrigation (monsoon) season. However, erratic rainfalls cause dry spells for almost a month with a return period of once in every 10 years (MILT, 2017). In this regard, irrigation in Japan is a must for stable paddy production.

Since rice has been Japan's most productive and stable crop, successive governments have tried to develop paddy fields as much as possible, wherever irrigation water was available. Eventually, all the low flow during periods of drought in major rivers in Japan was allocated to rice irrigation (in the 18th century). Therefore, droughts in the country inevitably led to serious water shortages and farmer conflicts, sometimes resulting in physical fighting among farmers and farmer groups (Shinzawa, 1955; 1962).

These facts suggest that Japanese irrigation management is not at all blessed with a good environment; it is instead marked by fatal droughts and high competition for irrigation water. Yet, it has been developed despite the strong need for irrigation water and demanding farmers.

A registered landownership system was initiated in 19th-century Japan. Before World War II, peasant tenants cultivated 44% of farmland, with owner-farmers cultivating the rest (56%) (O-uchi, 1978). In the period from 1945–1946, the Japanese government instituted land reform that transformed most of the peasant farmers into landowners. Thus, 91% of farmland was in the hands of owner-farmers by 1950.

Based on the land reform, the Land Improvement Act (LIA) was enacted in 1949, under which both land consolidation associations and irrigation associations that had been organized by landowners alone were reformed and renamed "Land Improvement Districts" (LID). An LID was to be established for each irrigation project, and autonomously managed according to the guidelines in the LIA. LID members included owner-farmers and tenant farmers. Land reform provided a simplified condition for water management in terms of membership. However, we should note that the participation of farmers in irrigation management has remained constant since the 17th century.

3. Irrigation Project Formation System of Japan

3.1 Farmer involvement in irrigation projects

The Japanese government has a rigid policy of only initiating irrigation projects for which they have received a written application from concerned farmers. This policy is based on the LIA. Fig. 1 illustrates the whole (simplified) procedure for an irrigation project from initiation to application and, finally, implementation.

The idea for a project to develop or improve an irrigation system may originate from farmers, local leaders or government engineers. Either way, farm leaders and irrigation engineers of the related prefecture must first meet and develop a basic plan, which should include all important matters such as physical, budget, and management plans. It is understood that the farmers will shoulder the responsibility for the principle management of the facility after construction. Thus, it is expected that the LID will be referenced in the management plan as the entity responsible for water management.

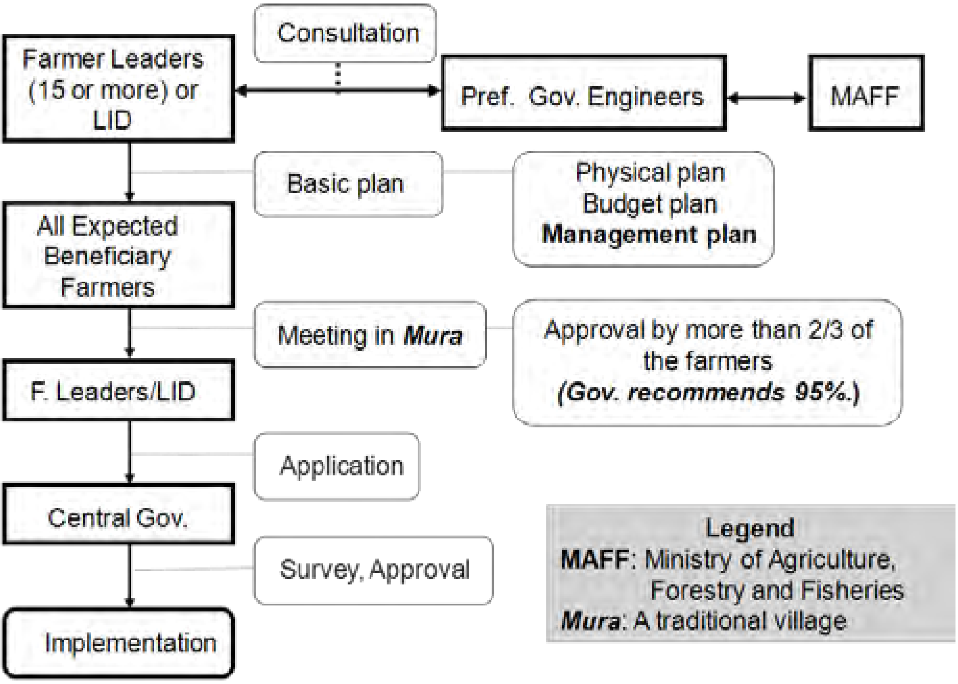

Figure 1: *Procedures for irrigation project formation in Japan.*

Fifteen or more leader farmers should be involved in the application, and may later be permitted to establish an LID by the prefecture Governor. If an LID has already been established, it will be involved in the work from the beginning. For the application to be accepted, applicants need to obtain written approval from more than two-thirds of farmers expected to benefit from the project, according to the LIA. To gather the necessary approval, meetings are held in every traditional village of Mura to explain and discuss the project idea.

Despite the formal criterion of two-thirds approval, the government strongly recommends that leaders

obtain agreements from 90-95% of beneficiary farmers; otherwise, difficulties and inefficiencies might arise during implementation. Once this condition has been satisfied, the application can be submitted to the government. The government (irrigation section) will then determine if the plan is reasonable, and once it is officially accepted, work on the project will begin. In the final stages, there might be some selection of projects from among the many candidates gathered from across the country.

3.2 Project cost sharing (subsidy from governments)

Once the project officially begins, all farmers that expect to benefit must join the project according to the LIA. The concept of the project includes both construction and management. Therefore, even farmers who opposed the project shall be compelled to LID membership and participation. While the government and farmers share construction costs (with some exceptions by type of project), operation and maintenance costs must in principle be shouldered by farmers.

Table 1 shows an example of typical construction cost sharing in national and prefectural projects. The classification of a project depends on the area that will benefit. If that area is equal to or more than 3,000 ha, the project will be implemented as a national project, and thus receive more government input. It should be noted that this cost covers the whole project cost, including that for major facilities such as diversion dams and main canals. Farmers are asked to contribute more than 10% of the total cost. A governmental bank will provide a low-interest-rate loan. This becomes a criterion to help farmers decide whether or not they wish to join the project.

Table 1: *Typical shares of project cost among governments and farmers (%)*

Organization	National Project (3,000ha <)	Prefectural Project (200ha <)
National Gov.	66.6	50
Prefectural Gov.	17	25
Municipal Gov.	6	10
LID (Farmers)	10.4	15

4. Management of LID: The case of Fukuoka-zeki LID, Ibaraki Prefecture

The LIA describes requirements for LID management in detail, based on democratic principles, where justice, equity and information dissemination are important. The government has prepared a template for the development of articles for an individual LID, and thus most LIDs have similar articles, except where differences are necessary based on specific LID conditions like number of member farmers. Therefore, we introduce the management of the Fukuoka-zeki LID (FLID) as an example.

4.1 Outline of the Fukuoka-zeki LID

Fukuoka-zeki irrigation system in Ibaraki Prefecture is located some 40-km northeast of Tokyo (36°2'34" N, 140°1'42" E at the barrage). It was first established in 1625 for paddy development downstream of the Kokai River, a tributary of the Tone River. The LID was established in 1951 after the LIA was enacted

in 1949. It had previously been called the Fukuoka-zeki Irrigation Association, and only landowners were eligible for membership.

The system now irrigates 2800 ha of paddy and 200 ha of non-paddy fields. The FLID has around 3,000 members, which means the average farm size is around 1.0 ha. Like most Japanese farmers, FLID members are small-scale farmers. FLID holds the water rights to 13.6 m^3/s (preparation season) and 10.6 m^3/s (growing season).

Fig. 2 shows the layout of the main irrigation and drainage facilities. They divert water to the left bank of the Kokai RIver and deliver it over the area through two main canals called the Dairori and Kawadori, and then drain the water to the main drain in the lowest part between these canals. The main drain returns the water to the same river again by gravity. The drained water is reused repeatedly downstream. To prevent flood damage in the lowland area, a drainage pump was installed at the mouth of the main drain by the central government.

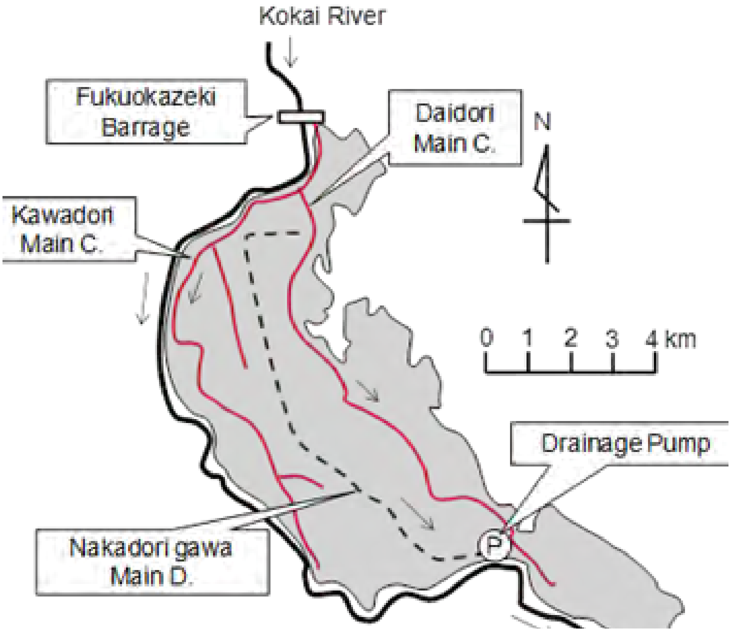

Figure 2: *Layout of irrigation and drainage facilities in the Fukuoka-zeki system*

4.2 Water management

The main facilities, including the barrage and two main canals, are under the management of the FLID; however, local farmer groups control the operation of intake gates for lateral canals. This may lead to partial water allocation between the upstream and downstream. However, this does not cause a problem, because this LID has an abundant source of water, and even downstream farmers can normally access sufficient water. When the available water becomes short, actions for equitable water use must be made. An example of such actions is drainage water reuse for downstream farmers by lifting water in the drain into irrigation canals; the LID would shoulder the cost of this action.

4.3 Organization management

The FLID organization chart is shown in Fig. 3. Based on the LIA, the FLID has introduced a system of representative assembly. The assembly is the highest legislative organ in the LID. Sixty representatives are elected from 13 electoral districts. Public office election law is applied to this election, and every FLID member has an equal voting right (one vote per member), and quota of the numbers to each district is based on the number of LID members.

The electoral districts are formed based on the Muras (70 in number); several Muras are combined to form a district. A Mura must not be divided in this case because the Mura is a basic unit for every social activity in rural areas of Japan. Representatives will attend the assembly for LID management but are also serious about the benefit to their districts. They negotiate with other representatives on water delivery, as well as taking care of irrigation facilities in their districts.

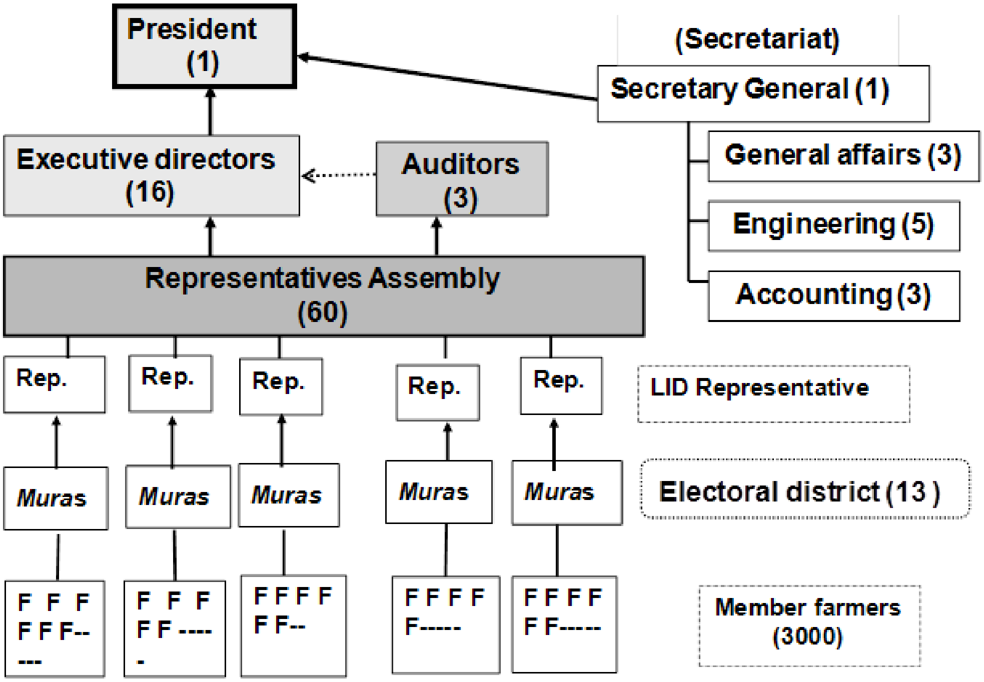

Figure 3: *The management system of Fukuoka-zeki LID.*

Every important matter is discussed and decided in the representative assembly, and all written materials necessary for the discussion are presented there. An LID newsletter describing the results of the assembly discussion and other important information is distributed to all members through the representatives and the Mura system. In this manner, accountability and information disclosure are achieved.

The membership fee for each member is assessed based on the area of irrigated farmland. The present fee for paddy fields is 75,000 Japanese yen/ha, which is equivalent to almost 7% of the crop yield value. Almost all fees are successfully paid by members. The government inspects the management of the LID every 3 years.

5. Implications of Japanese Model

5.1 Resolution of farmer conflicts

Japanese experts have made it clear that one of the most important obstacles to realizing rational water management is regional conflict between farmers or farmer groups (Shinzawa, 1957). Developing water resources for irrigation alone will not provide practical benefits if conflicts and uneven water allocation among farmers is allowed.

As shown in Fig. 1, the central and local Japanese government does not initiate irrigation projects, but requires that farmers apply for projects having already formed a high degree of consensus. There is a tendency for upstream farmers to have an advantageous position compared to downstream farmers. Therefore, most of the downstream farmers asked to shoulder the project cost are not willing to join the project unless equitable water distribution is secured. On the other hand, upstream farmers cannot receive the benefits of the project if the plan is canceled. In such circumstances, negotiation and discussion among farmers on the design of project and future management plan becomes serious. Government engineers also seriously try to support agreement efforts. Therefore, once the agreements are reached, farmers have a clear understanding of their duties and rights. Farmers are encouraged to feel ownership of the project. Some points that should be noted are;

- With the project formation procedure, conflicting farmers are given the opportunity to negotiate directly and develop an agreement on water management.
- Japanese government policy conveys a clear message to promote cooperation of farmers by providing subsidies only to projects for which there is consensus. The farmer cooperation in Japan is a result of the policy, but not the reason for its feasibility.
- The key point for success in water management is farmer participation from the planning stage of an irrigation project.
- To get approval from farmers, thorough explanations of every aspect of the project are necessary. Therefore, information dissemination and accountability are fundamental to success.
- The government demand for a high ratio of agreement provides downstream farmers with a kind of veto power.
- The high ratio of agreement ensures smooth implementation of the project for the government.
- Farmers in a Mura have a common interest in the negotiation because of its fixed location in the project area, and thus the Mura is interpreted as a hydraulic unit.

5.2 Subsidy: A method for inviting a majority of farmers

A project should be economically worthwhile to be implemented for a society, which means that the Benefit (B) is larger than the Cost (C), (B/C>1.0). However, as the project covers many beneficiary farmers, we have to address the problem of different benefits for different farmers. This will lead to differences in willingness to pay for a project. For example, in the case of rehabilitation projects, upstream farmers are generally in a position where water is easy to access. Thus, the rehabilitation has less benefit for them, leaving them less willing to pay for the project.

Project cost is levied equally over benefitted areas in most cases because charging cost based on an estimated benefit in every benefitted plot is difficult and troublesome. Under such conditions, some people's willingness to pay may be lower than the levied cost payment. Such people will not view the project favorably, which could be a serious obstacle to reaching an agreement involving a majority of

farmers. The government must overcome this problem to achieve national goals. Government subsidies or contributions to the project are one effective approach. As shown in Table 1, the Japanese government adopts a subsidy policy for irrigation projects.

Fig. 4 is a conceptual illustration of why it is not easy to get majority of supporters to agree on an irrigation project in a small-scale farming system even under the condition of B>C, and how subsidies work to overcome this problem. Note that the figure simply supposes that the benefit increases just along the canal from upstream to downstream, as an example.

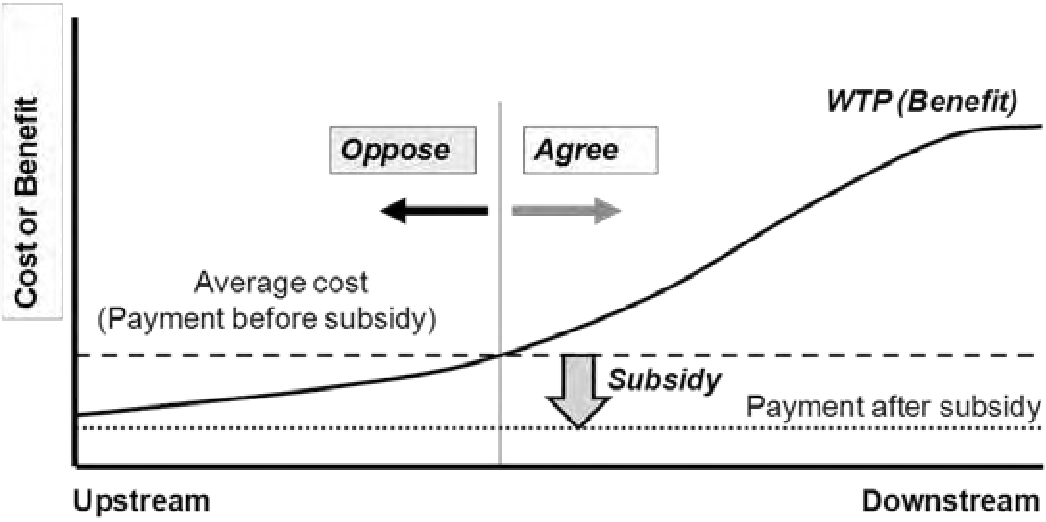

Figure 4 : *Impact of subsidy on increasing the number of farmers to agree*

The following points should be noted;

- The ratio of subsidies for different projects in Japan varies depending on conditions such as the category of the project (irrigation, land consolidation, disaster prevention, and so on), the total beneficiary area, and other conditions specially related to contemporary policies.
- The ratio of subsidy is not fixed and has varied over time.
- An irrigation project subsidy covers the whole project, from water source to terminal plots. It does not introduce the idea of clear demarcation between government and farmer responsibilities.
- The subsidy provided by government is only for construction, not for operation and maintenance in principle. It does not cover farming costs such as fertilizer.
- Japan understands that land improvement projects supported by the government have two aspects: achieving national targets and supporting the private economic activities of farmers. Without subsidies the governments could not achieve its target. This is one of the reasons why the government requires the subsidy policy and also requests farmers to contribute to the projects.

5.3 Constant concern regarding the final results of irrigation

The final goal of government in irrigation projects is stable and higher crop production, which can be achieved only through farmer activities at the terminal level. Therefore, the Japanese government pays constant attention to on-farm irrigation management. As direct control of water distribution is not appropriate or suitable, the government attempts to have indirect control of water management by introducing policies that encourage farmer cooperation and inspection of LIDs at stated periods. The policy is to support on-farm development, including land-consolidation projects, and subsidies are given to such projects as in irrigation projects. This intervention is a reflection of the concern regarding farmer activities at the terminal level.

The Japanese government provides a framework within which farmers discuss, decide and act. The government seeks to make farmers feel responsible and increase their capacity with a deeper understanding of water and society. It is the kind of capacity building that greatly contributes the government's ability to reach its goal with minimum cost.

In some countries irrigation management is divided into categories of government and farmer responsibilities, such as main and on-farm systems. In such cases, water management in lateral canals or field ditches is transferred to farmers, and the government refrains from getting involved in farmer activities at this level (Satoh and Aboulroos, 2017). However, governments must be constantly involved in water management at the field level for substantial success of irrigation projects. Water management transfer should not be introduced for government engineers not to see the water management at the on-farm level.

6. Application of Japanese Methods to Other Countries

It is a big concern whether the Japanese model of PIM is applicable to other countries. If it is totally dependent on Japanese indigenous conditions or background, it may not be transferrable to different countries (Satoh et al., 2013). We consider the basic principles of the model to be based on internationally relevant factors, as discussed above. However, it is also true that some conditions are specifically possible only in Japan. At the same time, we note that not all the conditions need to be exactly like the Japanese ones when the model is applied elsewhere. The following items should be considered before attempting application of the model:

- Legal system: Japan has developed the LIA, and the LID is legally supported in its activities. It is really preferable for WUA to have legal status. However, it should be noted that the basic power of the LID is consensus of member farmers. By developing the cooperation among farmers in irrigation management, many activities can be successful.
- Mura system: Japan uses the Mura system for irrigation projects, for both construction and water management, through the LID. This is a special aspect of Japanese irrigation. However, the Mura can be translated into a hydraulic unit in water management, as discussed above. Moreover, there may be many countries that have a social system similar to the Mura.
- Subsidies: Japan can afford to provide financial support for irrigation projects such as a high ratio of government subsidy. However, Japan has not always been so rich.
- Application system: It may require the cooperation of local farmers and a local irrigation office to begin a development plan. Reliable farmer leaders must also be identified. They are necessary to ensure the involvement of farmers from the construction stage forward. We can provide

examples of participatory irrigation projects for which farmers negotiated before construction. A real problem may be that it can take years before a construction project starts. This can be a challenge for outside donor agencies that have a limited window of time for individual projects (personal communication with World Bank experts).

7. Conclusions

- The Japanese government will only execute projects for which most of the beneficiary farmers have agreed to shoulder a part of construction costs and reached a consensus on rational cooperative water management. This policy promotes farmer cooperation and involves farmers from the initiation of an irrigation project.
- Farmers are wholly responsible for managing the irrigation system once a construction project is completed. For this purpose, they establish an LID based on the LIA. The LID is autonomously managed by the assembly of elected representatives as a legislative organ.
- The government has a policy to let farmers discuss, decide, and act based on consensus, while providing a framework with the LIA so that the farmers are willing to act in line with government policy.
- The government has a constant interest in the final result of irrigation management at the terminal level, and intervenes in an indirect way to guide LIDs, as well as to support land consolidation projects.
- The Japanese system utilizes some of its indigenous characteristics such as the Mura society when implementing irrigation projects. However, the basic ideas and methods might be applicable to other countries, while some items will require translation in different circumstances.

References

Gautum, U. (1997). Clarification on the West Gandak Experience in Nepal, INPIM No. 6, The World Bank, p. 7.

Kono, S., Ounvichit, T., Ishii, A., Satoh, M. (2012). Participatory system for water management in the Toyogawa Irrigation Project. Paddy and Water Environment, 10, 75-81.

MAFF (2017). Basic data for Agriculture, Forestry and Fisheries. MAFF home page. Available at: http://www.maff.go.jp/j/tokei/sihyo/index.html [9 Jan. 2018]

MILT (Ministry of Land, Infrastructure, Transport and Tourism, Water and Disaster Management Bureau). (2017). States of water resources in Japan. Tokyo: MILT, p. 2

Ostrom, E. (1992). Crafting Institutions for Self-Governing Irrigation Systems. San Francisco: Institute for Contemporary Studies Press, pp. 1-17.

Ouchi, T. (1978). Discussions on Japanese Agriculture (Nihon Nogyo Ron, in Japanese). Tokyo: Iwanami Shoten Publishers. p. 321.

Satoh, M., Kono, S., Ounvichit, T. (2007). Principles and Methods for Participatory Irrigation Management and Role Sharing between Government and Farmers, -The 4th Asian Regional Conference and 10th International Seminar on Participatory Irrigation Management &The International History Seminar on Irrigation and Drainage-, Tehran, Iran, CD-ROM, (5).

Satoh M., Ishii A., Yuan X. (2013). Background policy and methods for participatory irrigation management of Japan. In World Irrigation Forum 1, Mardin, Turkey

Satoh, M., Aboulroos, S. (Eds). (2017). Irrigated Agriculture in Egypt –Past, Present and Future. Gewerbestrasse, Switzerland: Springer Nature, p. 192

Shinzawa, K. (1955). Agriculture water use (Nogyo Suiri Ron, in Japanese). Tokyo: Tokyo University Press, p. 2.

Shinzawa, K. (1962). Coordination of river water uses (Kasen Suiri Chosei Ron, in Japanese). Tokyo: Iwanami Shoten Publishers. pp. 222-223.

Shinzawa, K. (1957). Basic characteristics of impacts by agricultural water use systems in Japan (in Japanese). Water Science, 1(1), 66-81.

Vermilion, D. L. (1997). Impacts of irrigation management transfer: a review of the evidence. Colombo: Research Report 11, International Irrigation Management Institute, pp. 1-35.

Participatory irrigation development and management procedures and empirical processes under the small land holding condition: With special reference to Indonesian condition

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Abstract

Within the last few decades, Indonesia had been achieving remarkable progress in water resources development till the beginning of 2000's through intensive implementation of government-initiated water resources development projects. Nevertheless, the institutional and organizational issues for sustaining the developed infrastructures have not got adequate attention. From the underlined practices, a number of lessons are learned till the country suffered from multidimensional crisis. In fact, it has been recognized that the severe crisis had been due to the chronic negligence of the farmers' participation in the routine operation and maintenance (O&M) process of the developed water resources and irrigation infrastructures.

In an attempt to resolve the dilemmatic situation, while keeping pace of the productivity level with the increasing population growth, an emphasis has been given to irrigation development and management based on participatory approach. The program had been set up to reduce central government's burden on O&M costs aiming for sustainable irrigated agricultural productivity through participatory irrigation management (PIM) approach.

For materialization of the said program, a number of policy reforms have been enacted on water resources and irrigated agricultural programs. In line with this policy reform, PIM approach has also been significantly implemented. These include turning over the small-scale irrigation schemes with small land holding circumstances to the Water User Association (WUA); encouragement for irrigation service fee (ISF); small schemes irrigation management transfer (IMT); participatory design and construction implementation program; "field laboratories" for visual process of "learning by doing"; and other such government initiatives. However, it was experienced that the above attempts have been going very slowly and yet less sustainable. This matter has been suspected due to the low economic potential of the farmers and farming conditions under the small-scale land ownership.

To facilitate resolving the problems, the program was supported by Water Law No. 7/2004, together with the Government Regulation No. 20/2006 The Laws and Regulations have been reformulated within the last few years for reducing the burden of the farmers by assisting to operate and maintain the tertiary canals and infrastructures which were previously under the responsibility of WUA.

This paper discusses procedures and empirical processes as well as past experiences on PIM under the small land holding condition. These include technical, institutional, and financial, as well as regulatory instruments, and other such measures toward the future enhancement and sustainability of PIM under the small land holding irrigated agriculture.

Keywords: *implementation procedures and processes; Indonesian experiences; irrigation management; participatory approach; small land holding*

1. Introduction

Indonesia as a populous archipelago had a total population of 72 million at the time of independence in 1945. It has now stepped into the fourth most populous country in the world (263.579 million in 2017). The population growth rate has been reduced significantly from 2.9% fifty years ago to about 1.07% now. It is projected that the population will reach about 280 million by the end of 2025. At that period 52% of the country's population are predicted to live in urban areas.

Meanwhile, the excessively rapid expansion of the country's population concurrently with high rate of urbanization has brought about a special problem on the provision of adequate rice (the staple food) to feed its people. About 70% of the population are traditional rice farmers living in rural areas. This matter has even created more crucial problems to the provision of adequate food supply for the country's population. Fig. 1. provides the general projection of population growth, rice consumptions and demands in Indonesia and Fig. 2 shows province-wide distribution of irrigation land and total areas in the country.

One of the most apparent constraints of the country's rice production is that the land ownership per farming household is relatively too small, that the farmer cannot fully dependent upon the farming income for supporting their livelihood with their families. And hence, the farmers are forced to earn additional non-farming income in the urban areas. This case alone inhibits special problem on the continuity of their agricultural lands being left fallow occasionally and hence unable to maintain consistent care of their plants. More crucial is that the size of land holding has been increasingly decreasing due to the impact of land fragmentation, in addition to the underlying case of land conversion from fertile irrigated agriculture to non-agricultural utilization, as well as continuous case of transferof land ownerships from farmers to non-farmers.

1.1 Present status of land uses for food production

For fulfilling the food demands of the current 263 million inhabitants, it is estimated that at least 50 million tons of paddy rice per year is required. Paddy in Indonesia is produced in irrigated lands, wetlands, as well as in the rain-fed upland areas with a total of about 14.11 million ha (Mha), and with the average cropping intensity at about 1.37.

One of the immediate problems of irrigated agriculture in Indonesia has been associated with the capacity to sustain the food production, for instance with population growth rate of, say 1.5% per annum, rice production should increase by about 900,000 tons per year to catch up the increasing demands of the people. With the same assumption, this food demand is roughly equivalent to about 140,000 ha of additional land areas annually. This figure has yet reckoned the impact of annual land conversion from agricultural lands to other land use categories, which is estimated to be at the range between 25,000 and 40,000 ha annually.

2. Irrigation Development and Management

2.1 Irrigation system and management

The former Government Regulation No. 20/2006 defined irrigation as the means of provision, regulation and releasing of irrigation water for appropriate support to agricultural implementation, having some categories as surface irrigation, swamp irrigation, sub surface irrigation, pumping irrigation and fish ponds.

Basically, the government is responsible for operation and management (O&M) of the main system (primary and secondary networks), while the farmers, through the water users' association (WUA), are responsible for O&M of tertiary irrigation schemes. In this regard, the Central Government is responsible for conducting irrigation O&M for independent irrigation scheme having a cultivable commanding area (CCA) of more than 3,000 ha. The Provincial Government is responsible for managing irrigation schemes having CCA between 1,000 and 3,000 ha. While the local government (Regency or Municipality), is responsible for managing irrigation schemes having CCA of less than 1,000 ha per individual scheme, and the Village Government is responsible for development and management, as well as rehabilitation, reconstruction and upgrading of village irrigation schemes.

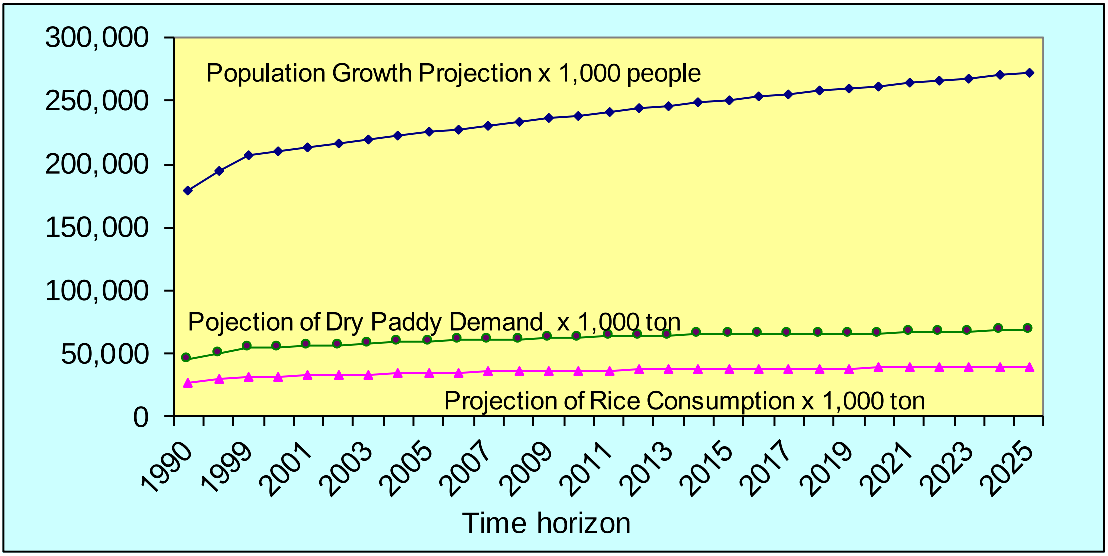

***Figure 1**: Projection of population growth, rice consumption, and paddy production towards the year 2025*

***Figure 2**: Province-wise distribution of irrigated land and total area in Indonesia*

Meanwhile, the water user's community is further responsible for: (1) Implementation of tertiary irrigation development and management; (2) Maintaining an effective and efficient O&M of tertiary irrigation schemes; (3) Approval for development, utilization, as well as reconstruction, rehabilitation and upgrading of tertiary irrigation scheme on the basis of participatory irrigation management (PIM) approach. For this particular case, the PIM and development approach has to involve the farming community from the initial decision making, throughout the entire process of development, management, upgrading, operation, maintenance, as well as rehabilitation of irrigation schemes.

Principally, irrigation water management covers the management of irrigation networks and irrigation water has to be implemented based on participatory, integrated, transparent, accountable and sustainable manner. Water management activities in the main system, which is referred to as **"irrigation water distribution and drainage management"**, are managed by the government while water management at the tertiary and quaternary canals as well as direct application of water to the farm lands, which is referred to as **"on-farm water management"** are managed by the farmers themselves.

2.2 Present status of irrigation development

During the past few decades, the government policy in irrigation development has been implemented in line with the National Development Policy. At present, the status of irrigated lands for paddy production in Indonesia has approximately 9.45 Mha of paddy field (BPS, 2010), which consist of (1) Irrigated paddy field at 7.23 Mha (76%); (2) Tidal lowland paddy field at 488.9 thousand ha (5%); (3) Lowland paddy field at 171.9 thousand ha (2%); (4) Groundwater irrigation paddy field at 92 thousand ha (1%); and (5) Others, such as rain-fed paddy field, traditional paddy field, and un-irrigated agricultural field at 1.47 Mha (16%).

Based on National Survey for Social and Economic (SUSENAS) of 2006 – 2010, rice is still the main source of energy, *in terms of calorie percapita consumption,* in Indonesia. In fact, based upon SUSENAS of

2006-2010, irrigation has contributed to almost 85% of national rice production for both 2009, 2010, and 2011. From the same source, it is apparent that the total production of irrigated paddies from an area of 9.457 Mha was at about 66,809,828 tons of dry un-husked rice, of which irrigation area of 7.23 Mha contributes about 84.48% of the total production of about 66.81 million tons. Hence the upland non-conventional irrigation,and rainfed paddy contributes only 7.696 million tons or 11.52% of the total paddy production of Indonesia (Table 1, Fig. 3).

2.3 Inter-agency coordination for irrigation management

In order to ensure the efficient and effective use of irrigation for supporting coordination of agricultural implementation, there are several categories of irrigation commission namely; Provincial Irrigation Commission; *Kabupaten* (District) Irrigation Commission; and Inter-Provincial Irrigation Commissions. The composition of these irrigation commissions are as follows:

*Provincial Irrigation Commission***:** The commission is established by the Governor composed of the representatives of irrigation commissions of the regencies and/or municipalities within the province concern, representative of WUAs, representative of the provincial government and the representative of water users having proportional representation.

District Irrigation Commission: The commission is established by the Regent (The *Bupati*, or Mayor) composed of representatives of the local government and other government agencies, representative of WUAs, representative of water users having proportional representation.

Indonesia's Paddy Field Area			Rice Production
Total of Indonesia's Paddy Field	9,456,929	Ha	66.809.828 Ton (BPS, 2010)
Irrigated Paddy Field	7,230,183	Ha	84,48%
Tidal Lowland Paddy Field	488,852	Ha	3,37%
Lowland Paddy Field	171,994	Ha	1,18%
Ground Water Irrigation Paddy Field	92,090	Ha	1,01%
Others, such as rain-fed paddy field. Traditional paddy field, and un-irrigated agricultural field	1,473,810	Ha	9,95%

Table 1: *Total of paddy field area and total production in Indonesia (BPS, 2010).*

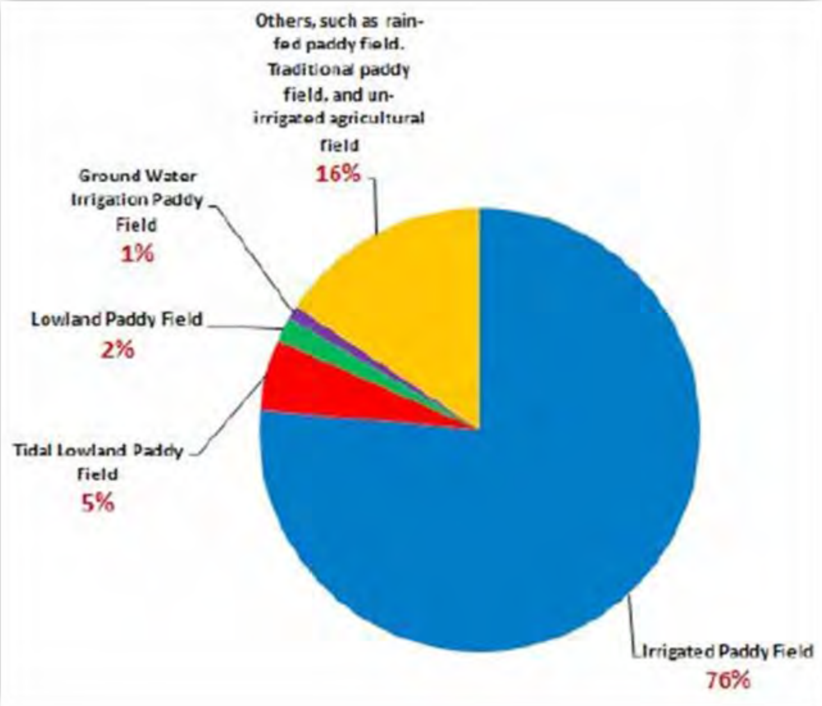

***Figure 3**: Statistical chart of the paddy fields and % of production (BPS, 2010).*

District Irrigation Commission: The commission is established by the Regent (The *Bupati*, or Mayor) composed of representatives of the local government and other government agencies, representative of water users' associations, representative of water users having proportional representation.

Inter-Provincial Irrigation Commission: The commission is established by the concerned Governors composed of the representatives of irrigation commissions of the regencies and/or municipalities within the province concern, vice chairpersons of provincial irrigation commissions, representative of water users' associations, representative of the provincial government and the representative of water users having proportional representation.

Coordination of irrigation activities is usually conducted by irrigation commissions within the provincial government's jurisdiction, district or municipalities as well as for inter-provincial irrigation commission. However, for a large irrigation system, the service area is usually located under more than one provincial or district government administrations. In such the case irrigation development and management are implemented jointly with the provincial or District Irrigation Commissions under the coordination of the inter-provincial or provincial irrigation commission concerned.

3. Experience on Participatory Irrigation Management

Government assistance in irrigation construction has usually been followed by a continuing bureaucratic role in O&M, with farmers' responsibilities limited to their own fields and tertiary areas of a size usually

in the range of 50 to 150 hectares. Management of dams, primary and secondary canals, tertiary gates and the first fifty meters of tertiary canals are the responsibility of the government. Concerning about how irrigation systems could be better operated and maintained, the Indonesia's 1987 Irrigation Operation and Maintenance Policy Statement, advocated the following policies: (1) Gradually turn over irrigation systems smaller than 500 hectares to WUA; and (2) Implementation of irrigation service fees (ISF) for systems larger than 500 hectares; (3) "Starter" on-farm water management development.

3.1 Turnover of small-scale irrigation systems

The main objective of the transfer of small irrigation systems from the government to WUAs is to enable better use of farmers' knowledges, skills and other resources to manage the local irrigation systems, while the intermediate objective is to turn over all irrigation systems smaller than 500 ha to WUA, and gradually handover the larger schemes.

Following the government's policy, the Ministry of Public Works has issued an ordinance as a guideline for turning over of small-scale irrigation system and management authority to the WUA. The scope of activities of the turnover of small scale irrigation including: (a) the turnover of assets of small scale irrigation systems; and (b) the turnover of jurisdiction, duties and responsibilities of O&M.

The World Bank, the Asian Development Bank, and the Ford Foundation were supporting funding of the turnover activities at that stage. Under ISSP-I, the turnover activities began in 1987 in West Java and West Sumatra. In 1988/1989 fiscal year, project activities expanded to four provinces, West Java, Central Java and Yogyakarta, and West Sumatra; and in 1989/1990 the turnover program was expanded to seven provinces, West Java, Central Java, East Java, West Nusa Tenggara, Yogyakarta, South Sulawesi and West Sumatra. Up to the beginning of April 2000, the total areas of 385,000 ha have been turned over to WUAs. The program has been slowing down few years after due to the urgent priority of the government to recover the economic crises.

3.2 Involvement of the farmer (participatory design and construction)

Within the design and construction phase, requests are ranked according to farmers' priorities. These requests are used in the preparation of the technical design for construction and improvement works. In the follow-up stages, involvement of the farmers in the construction and implementation provides an opportunity to strengthen farmer's organization through participation in collecting information, planning improvements and contributing to construction.

WUAs are developed and registered with the *Bupati*, Head of District Government, and then further training is given to the WUAs in O&M activities. After the necessary training has been implemented, the irrigation systems' assets and management responsibility are officially transferred to WUAs. The Provincial Public Works will continue to play a role in supporting the activities in line with the technical assistance which are beyond farmers' capacity to perform by them.

3.3 Pilot schemes (field laboratory) for major irrigation systems

Following the success of turn over of some 385,000 ha of small scale irrigation under the small scheme transfer policy, a number of pilot projects for transferring the larger schemes at the average of 1,000 ha were undergone (for learning by doing process) at 10 schemes in the Eastern Region with the total area of about 15,000 ha, and four schemes in Java with a total area of 62,425 ha, or 77,425 ha altogether.

Similar to the above attempts toward PIM, the pilot schemes also suffered from a number of technical and non-technical constrains parallel with the severe economic crises. Despite that the projects have different level of success; the activities have been slowing down since then.

3.4 Irrigation service fee (ISF)

Irrigation service fee (ISF) is a contribution in the form of money by farmers as the beneficiaries of irrigation water, in order to finance the O&M of irrigation networks. In principle, ISF is not a tax, rather, it is a way to encourage participation of the beneficiary to pay for the sustainable O&M of the schemes by themselves; thus, the farmer only pays this contribution in lieu of irrigation service they obtained.

The introduction of ISF is one of the government policy on irrigation O&M in order to minimize the government subsidy in providing O&M budget, and ultimately this ISF become a major source of O&M budget for irrigation networks. For actual implementation of ISF within the entire irrigation areas in Indonesia, four principles had been suggested: (1) Maintaining a proper balance of ISF collection; (2) Application of direct use of the collected fee; (3) Application of simplified tariff; and (4) Fostering sustainable implementation.

3.5 Lessons from empirical experiences

In an attempt to accelerate the implementation of PIM, a number of efforts have been implemented without considering the problems and constrains of each specific locations. The standardized approach was then implemented nationwide – despite the diversity of social, economy, geography, as well as climate and cultural background. As a result, a number of traditional and local practices have been set aside and apply alien technologies instead. During which, the country's economy has concurrently been suffered from multi-dimensional crisis, and hence the project implementations have also been significantly affected. This had been due to a number of inter-related problems and constrains both internally within the farming circumstances as well as external matters which are beyond the institutional capacity to tackle with. Parallel with the multi-dimensional crisis and the need to implement the policy on "Local Autonomy" within the country, the pilot projects have also been slowing down, and currently suffer from inadequate attention.

In order to quickly recover from the impacts of multi-dimensional crisis the government has taken some policy reforms, including the review of irrigation policy and follow up implementation. This has been stipulated in the subsequently established Water Law No. 7/2004 about Water Resources that was then subsequently reformed; and subsequently followed by Regulation No. 20/2006 about Irrigation. The regulatory instruments have then been established with special consideration on the past empirical experiences, and then the subsequent implementation has then been based on the newly established and updated reviews of legal and regulatory instruments.

4. Constraints of Small Land Holding for PIMF Development

4.1 Irrigation and water resources policy reform

The government of Indonesia in 1987 released a national policy on O&M of irrigation. The purpose of this policy was to ensure adequate funding for O&M and improve irrigation management. The

Government committed to increase budget allocation for O&M, strengthen land and property taxes, as well as mobilizing more resources from beneficiaries. After a long process, the Government of Indonesia conducted subsequent adjustment of Resources Law (UUSDA No.7/2004) and Government Regulation – PP No. 20/2006 through the updated review of Water Law No 11/1974 and the Law of Regional Authorities No. 23/2014. The newly reviewed and the updated Law prescribed delegation of responsibility to local autonomous government to conduct irrigation operation and management based on categorization of irrigation areas in conjunction with the coverage area of the provincial and local government administrative boundary.

4.2 Constraints of small land holding

Farmer's Household: About 50% of households in Indonesia are food crops farmers (mainly paddy, secondary crops, and horticulture). The total farm household (FHs) for food crops in the provinces vary from 46% to 78%. The highest levels of food crop farmers were in Maluku and Papua Provinces at about 78%, while the lowest level was in Sumatra and Java at an average of about 47%.

Agricultural Census of 1983 and 2003 showed an increasing number of land-holding FHs, particularly food crops farm household (FCFH) recorded at 24,458,000 FHs increased to 27,446,000 FHs in 2003 (increased by 12.2%). The total number of FCFH by main islands is shown in Table 2. The national average of land control by the FH is 0.83 ha. The largest is Kalimantan Island at 1.98 ha, followed by Sumatra at 1.24 ha, and Sulawesi at 1.21 ha.

Table 2: *Average land controlled by land holding farm household by main islands in 1993*

No	Province	Land Tenure ((x 10^{-6} ha)	Number of LHFH (x 10^{-6})	Average Land Controlled (ha)
1	Sumatra	5.885	4.765	1.24
2	Java	5.461	1.563	0.47
3	Bali & Nusa Tenggara	1.150	1.323	0.87
4	Kalimantan	2.393	1.207	1.98
5	Sulawesi	2.013	1.664	1.21
6	Maluku and Papua	580	509	1.14
	Indonesia	17.482	21.031	0.83

Source: Agricultural Census 1993, BPS Statistics Indonesia

Land Tenure: Nearly 50% of FHs control less than 0.5 ha of land per household and only 22% control 0.5 – 1.0 ha of land per household. Farm households control two to three ha of land only at about 7.4%. Table 3 shows the Land Holding Farm Household (LHFH) by size of land controlled in 1983 and 1993.

Given the diversity of land holding features in each island within the archipelago in addition to the problem of land fragmentation and land conversion, the most apparent impact is that the number of land holders (especially on Java Island) is increasingly larger and larger.

Table 3: *Land holding farm household by area of land controlled in 1983 and 1993*

Size of Area Controlled (ha)	1983		1993	
	Total LHFH	%	Total LHFH	%
< 0,05	1,271,067	6.52	646,372	3.28
0,05-0,09	1,167,370	5.99	948,296	4.81
0,10-0,24	3,155,471	16.18	3,570,371	18.11
0,25-0,49	3,938,317	20.19	4,417,121	22.41
< 0,5	9,532,225	48.90	9,582,160	48.60
0,50-0,74	2,797,812	14.35	2,934,875	14.89
0,75-0,99	1,445,451	7.41	1,438,870	7.30
0,5 – 0,99	4,243,263	21.80	4,373,745	22.20
1,00-1,99	3,297,609	16.91	3,312,218	16.80
2,00-2,99	1,294,048	6.64	1,457,561	7.39
>3,00	1,134,312	5.82	988,122	5.01
Total	19,501,457	100.00	19,713,806	100.00

(Source: Agricultural Census 1983 and 1993, BPS Statistics Indonesia)

5. Impact of Small Land Holder on WUA'S Management

5.1 Demand for WUA

There are varieties of problems encountering the irrigation water management, among them is the lacking of skill and funds for O&M of the main system has been most obvious. In addition, the inability of the farmer to provide adequate fund for O&M of irrigation networks; low collection rate of O&M funds due to a number of technical; institutional and other non-technical problems are also most dominant. Consequently, the sustainability of irrigation schemes has been declining and eventually entailed with deferred maintenance. Therefore, it is highly important to put special attention on encouraging participation of irrigation beneficiaries to work together through the locally organized association. In this particular context, for accelerating the progress and promoting successful PIM, special attention has been prioritized for empowering the WUA.

5.2 Basic principles of WUA

Establishment ofWUAs: In attempting to foster the participatory approach in irrigation water management at the farm level, since 1980s the government has been actively promoting the WUA as the forum where the farmers are organized to work mutually for managing irrigation water management at the farm level as efficient and as effective as possible. The basic principles of WUAs' establishment are: (1) Demands for working mutually through the management of the group; (2) Establishment based on the initiative of members, by members and for members; and (3) Consistent technical guidance from the government and other related institutions.

Operation principles: The operational guiding principles of the WUAs among others are: (1) Managing the water at the farm level within the tertiary blocks (at an average of about 50 to 100 ha per unit) – depending upon the size of the tertiary block and other administrative boundary of the villages; (2) Operating and maintaining the tertiary or village irrigation systems effectively and efficiently; (3) Determining collecting and managing the resources contribution of the members in terms of money, in kinds, or in terms labor for sustaining the O&M performance of the schemes; (4) Conducting a continuous guidance for their members toward innovative irrigated agricultural implementation.

Present Status of WUA: Basically, there are three categories of the present state of the WUAs: (1) Already developed, for the WUA that has been fully in operation with legally bound status, or the legal status is being processed; (2) Still developing, for the WUA that is being in the process of establishment for technically and legally; and (3) Least developed category for the WUA that has been organized but it may has legal status but has yet had the full capacity to run the organization.

The three categories are currently summing up the national total of 33,078 WUAs, of which 2,660 WUAs are already having the full legal status, 26,835 WUAs are being processed, with the total coverage irrigation areas of 4,011,197 ha or about 36% of the total existing irrigation and drainage lands.

Future requirement for WUA: With an assumption that the commanding area of WUA ranging between 50 and 100 ha or averaging at about 66 ha, the overall requirement for WUAs in Indonesia for 7,230,183 ha irrigation areas, 488,852ha of tidal lowland paddy areas, 171,994 non tidal lowland paddy areas, 92,090 ha of groundwater irrigation, and 1,473,810 ha of other paddy field category or in grand total of 9,456,929 ha, would be at about 143,287 number of WUAs. Therefore, the present status of WUAs altogether at about 43.32% of the total number of WUAs that are currently demanded.

Despite the current pilot schemes for larger irrigation schemes, in order to be able to organize the WUAs in the larger scope of services and geographical distribution, it is highly essential for the future program to establish and strengthen the organizational arrangement of the WUAs – for instance at the large schemes, at secondary level, or scattered areas – in terms of WUA's Federation (WUAF).

5.3 Potential level of farmers' participation – A review

Despite the establishment of such a large number of WUAs mentioned previously, it is evident that the effectiveness of their operation had been very poor. This had been suspected by the impacts of small land holding condition, which brought about farm incomes that are currently far from adequate for the farmers to fully participate in the irrigated farming activities.

Farm Budget Analysis: From analysis conducted by Gany (1978), it was concluded that the optimum size of land holding for irrigated paddies in Indonesia that could be performed by relying the family labor only, is 1.72 ha per farm household. This size of land holding is slightly above the level of marginal subsistence farming. Any size smaller than this figure is potentially suffered from the risk of negative income, and hence not likely possible to contribute adequate financial or labor resources for securing sustainable O&M of PIM irrigation schemes. In fact, the land holding category up to 0.50 ha per farm household – which dominates the irrigated land areas of the country at 48.60% – is considered to be marginal subsistence farming, and hardly expected to participate sharing any contribution for sustainable O&M. The land category of > 0.5 < 1.00 ha and of >1.00 <2.00 ha are currently stood at about 22.2% and 16.80 % of the total agricultural land of the country respectively.

From analysis of financial return, the same analysis concluded that the land holding category of >0.5

ha; 1.0 ha and 2.00 ha produces the net value of production of US$91.6; US$463.51; and US$1,119.53 respectively. These figures have been based on irrigated paddy at 1.30 cropping intensity, after deducting indirect costs such as materials and labor, and indirect costs such as taxes, home consumption, and yet, without imposing any irrigation service fees.

Potential capacity for farmer's participation: Based on the above figures, a review of potential level of farmers' participation is further scrutinized by using some assumptions, including the basis for full participation for the land holding rounded (for simplification) to 2.00 ha per farm household. The size of commanding area for the WUA at 100 ha/WUA, while the average commanding area for water users' association federation (WUAF) at 1,000 ha per WUAF. The estimated potential level of participation for sustainable O&M have been based on farm budget analysis and empirical estimate (expressed in terms of magnitude between 10 and 100), at the magnitude of 20 for the land holding category of smaller or equal to 0.5 ha; the magnitude of 30 for the land holding category of >0.5<1.00 ha; the magnitude of 80 for the land holding category of >1.00<2.00 ha; and the magnitude of 95 for the land holding of >2.00<3.00 ha. The remaining capacity to participate in irrigated farming activity must be dedicated to non agricultural employment in the urban areas (seasonal urbanization).

Form Fig. 3 below, it is apparent that the WUA's institution as amongst the important prerequisites for implementation of PIM suffers from a number of non-technical constraints among others: (1) Too many farmers that are involved as the member in the WUA under the small land holding condition. For illustration, a WUA with an average land holding of 0.50 ha would compose of 200 farmer households working in an area of 100 ha; in addition to the average capacity to participate at the magnitude of 20 out of 100, since they have to seek seasonal employment in the urban areas. For the national average of land holding at 0.83 ha/farm household, a single WUA of 100 ha command area, would involve about 120 farm households, with the capacity to participate at only about 30 out of 100, for they have to share their time for earning non-farming extra income in the urban area.

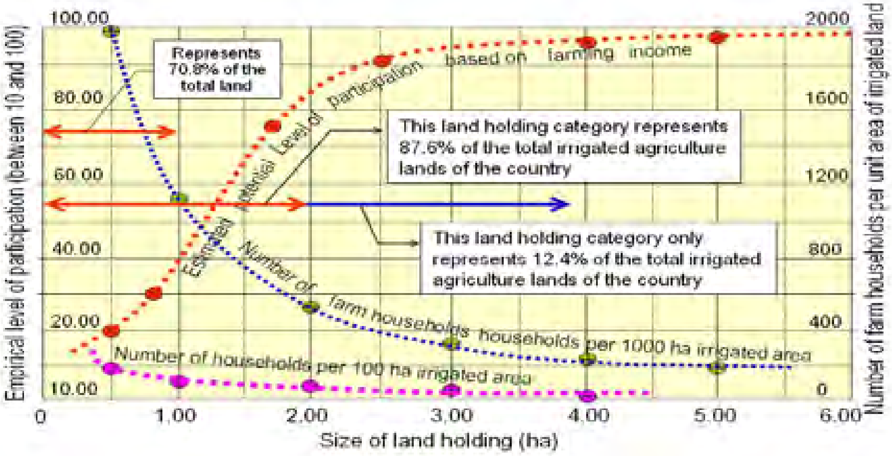

Figure 3: *Analysis result of the farmers' potential capacity to participate for securing the sustainable irrigation O&M.*

During their absences, it is obvious from the above figures that their participation (in person) for the routine irrigation management are hardly possible – a size of irrigated farming organization, too diversified socio-economic conditions, with low level of potential participation, which is far from manageable. If

we take the optimum size of land ownership (2.00 ha/farm household) as the determinant parameter for establishing WUA, the number of members would be 50 farmers, which is reasonably manageable, however, such the optimum size of land holding only represent about 15% of the current total national irrigated agricultural land.

Rationale of the Low Level of Participation: From the analysis results presented above, it is evident that the farmer's participation in O&M of irrigation is not merely the question of technical and economic perse', but far from those matters, there remains a complicated constrain on socio-cultural as well as organizational predicaments. The rationale of the currently low participation of the farmer is not only because of the farmers are unwilling to participate, but it is quite a logic explanation that the farmer, under the extremely small land ownership, would naturally set up own priority in mind, whether to participate partially of seeking non-farm extra-incomes elsewhere.

Alternative Measures to Address the Constraints: Under the diversified levels of education, experience, size of land-holding, and socio-economic as well as cultural backgrounds, it would not be easy to ask the farmer to participate voluntarily in O&M activities, on top of a hardly manageable number of members in the single WUA. In an attempt to address the constrains there are several alternative measures to mention, among others: (1) Transformation of paddy mono-culture (particularly for the land ownership smaller then 2.00 ha per unit) into diversified crops that have significant potential for higher financial returns – this alternative should be followed by consistent, post-harvest processes, storage and maintenance, as well as competitive market; (2) Reformation and reclamation of land ownership plots and land administration into a sort of cooperative farming or corporate farming, operated by professional irrigated agricultural, and agro-based industries; (3) Consistent regulation and subsequent enforcement on the issues of land fragmentation and land conversion into non-agricultural utilization; (4) Consistent water saving and conservation implementation; (5) Provision of incentives to small land holder for cultivating high financial return crops, including encouragement of leisure agriculture in the rural areas for fostering the multifunctionalities of irrigated agriculture – with some leeway for flexibility to make adjustment with local circumstances. These alternatives measures, however, are subject to further scrutiny and comprehensive studies, which are still widely opened for further interdisciplinary studies and experiments in the upcoming years.

5.4 Lessons learned from traditional WUA

Learning from the traditional agricultural irrigated agricultural practices in Indonesia, it is obvious that the WUAs in this country have a long history. Among the most famous traditional WUAs are "*Subak*" in Bali Island, "*Keujreun Blang*" in the Special Province of Aceh; "*Tuo Banda*" in West Sumatra Province; "*Raja Bondar*" in North Sumatra Province; "*Mitra Cai*" in West Java Province; "*Dharmo Tirto*" in Central Java; "*Tudang Sipulung*" in South Sulawesi and several others to mention. In principle, all the traditional practices are embracing the similar democratic principle, mutual aids, cooperative working principles, consensus (oral or written), transparency, participatory, and other such togetherness principles. The following illustration represents the Subak System.

The "Subak" Irrigated Agricultural Management System in Bali: The *Subak* system is an ancient irrigated-agricultural practice in Bali Island. Like most irrigation schemes in Indonesia, the *Subak* system also serves small-land holders where lowland paddy mono-culture is practiced in majority. The exact build date of *Subak* was unknown; however, some stone inscription indicated that the *Subak* system was known to be part of the Balinese life since hundreds of years ago (*DPU Propinsi Bali, 1972*).

Principles of "Autonomous and Religious Ties of the Subak Practice": The *Subak* employs a principle of independence and religiously tied practices in managing irrigation system under the irrigated agricultural endeavor. The Subak members, thus, establish and maintain irrigation infrastructures through mutual cooperation through judicious and fair dispersion of obligation, right, and responsibilities. These activities are implemented through mutually agreed regulation which is referred to as the *Awig-Awig*. The organization structure of Subak is highly autonomous, representing the farmer from the grass-root to the highest organizational entity. The highest representation of Subak member – which is known today as the WUA Federation – has long been practice by Subak through the so called *Sedahan Agung*.

Coverage Area of Subak: The average area covered by one *Subak* organization is about 100 ha, depending upon the magnitude of the area covered by the irrigation command area of the *Subak* system. However, due to individual variation of the topographical condition, one *Subak* organization may cover an area in the range of 10 to 800 ha. Under the very special condition, one independent *Subak* area, however, may cover an area even smaller than 10 ha. *(Gany and Faisol, 1975)*. The boundary area of each individual *Subak* is usually formed by natural creeks, small valleys, small rivers or village roads. In the entire Bali Island, there are 1,283 independent *Subak* systems, with distinct irrigation infrastructure, farmers' organization and awig-awig regulation.

Lesson Learned from Subak: Despite the fact that the *Subak* system and its practices were invented long time ago, it is quite amazing to know that much of their techniques are still convertible to the modern practices that the people understand today. The more we can comprehend the traditional irrigated-agricultural practices the more we learn about their technicalities. In fact, there is a reason to believe that the traditional agricultural practices adopted by the *Subak* organization were based on systematic observations. Today, there remains a lot more phenomenon of the ancient agricultural practice – including PIM Principles – that need to be uncovered from tradidional WUAs in terms of scientific explanation.

6. Concluding Remarks and Recommendation

From series of experiences to implement the irrigation development program, Indonesia has now been concentrating its policy on efficient O&M of irrigation. Since 1987, the Government of Indonesia has formulated a set of policies for addressing fundamental issues related to the provision of financial support for O&M and other expenditures required for sustainable irrigation development and management.

After a long process, the Government of Indonesia conducted subsequent adjustment of Resources Law (UUSDA No.7/2004) and Government Regulation – PP No. 20/2006 through the updated review of Water Law No 11/1974 and the Law of Regional Authorities No. 23/2014. The newly reviewed and updated Law prescribed delegation of responsibility to local autonomous government to conduct irrigation operation and management based on categorization of irrigation areas in conjunction with the coverage area of the provincial and local government administrative units. The regulatory instruments and updated review have been established with special consideration to the past experiences, and then the subsequent implementation will be based on these newly established legal and regulatory instruments.

From the massive effort for establishment of a large number of WUAs, it is evident that the effectiveness of their operation had not been achieving the optimum level. This had been suspected by the impacts of small land holding condition, which brought about relatively low farm incomes which are in fact, still far from adequate for the farmers to fully participate in the irrigated farming activities.

From the analysis review of the underlying practice of agricultural labor, it was concluded that the maximum size of land holding for irrigated paddies in Indonesia that could be performed by relying on family labor only, is 1.72 ha per farm house hold. This size of land holding is slightly above the level of marginal subsistence farming. Therefore, any size smaller than the above figure will potentially suffer from the risk of negative income, and hence not likely possible to contribute adequate financial or labor sources for securing sustainable O&M of irrigation schemes, as expected by the irrigation development and management program.

Learning from the farmer's participation in O&M of irrigation it is evident that the expected level of participation is not merely the question of technical and economic perse', but rather, there remains a series of constrains on socio-cultural as well as organizational predicaments that must be further scrutinized. In fact, we learned from empirical practices that the rationale of the currently low participation of the farmer is not only because the farmers are unwilling to participate, but it is quite a logical explanation that farmers, under the extremely small land ownership or holding, would naturally set up own priorities, whether to participate partially of seeking non-farm extra-incomes. Logically, the remaining capacity to participate actively in irrigated farming activity shall be dedicated, in lieu of non-agricultural employment in the urban areas, which entailed with seasonal urbanization and hence significantly hamper the labour demand for expected participation in irrigation development and management.

With the underlined condition of the highly diversified level of education, experience, size of land-holding, and socio-economic as well as cultural backgrounds, it would not be easy to ask the farmers to participate voluntarily in irrigation management, on top of a hardly manageable number of members in the single WUA. In an attempt to address the constraints, several alternative measures are recommended, among others: (1) Transformation of paddy mono-culture (particularly for the land ownership smaller then 2.00 ha per unit) into diversified crops that have significant potential for higher financial returns – this alternative should be followed by consistent, post-harvest processes, storage and maintenance, as well as competitive market; (2) Reformation and reclamation of land ownership plots and land administration into a sort of cooperative farming or corporate farming, operated by professional irrigated agricultural, and agro-based industries; (3) Consistent regulation and subsequent enforcement on the issues of land fragmentation and land conversion into non-agricultural utilization; (4) Consistent water saving and conservation implementation; (5) Provision of incentives to small land holder for cultivating high financial return crops, including encouragement of leisure agriculture in the rural areas for fostering the multifunctionalities of irrigated agriculture, with some allowance for flexibility to make adjustment with local condition. These alternative measures however, are subject to further scrutiny and studies in the future.

With regards to the traditional irrigated agricultural practices, it is obvious that the existence of WUAs in Indonesia has a long history. In fact, all the traditional practices are embracing similar democratic principles, mutual aids, cooperative working principles, consensus (oral or written), transparency, participatory and other such togetherness principles. In reality, a number of experiences may be adopted from the traditional practices, including the principle of WUA Federation such as *Sedahan Agung* in Bali.

From these evidence of empirical practices and subsequent analysis, it is therefore highly expected that through the accelerated efforts to address the constraints of small land holding irrigated agricultural conditions along with appropriate incentives for encouraging greater participation of water users on the O&M, and making better use of staff resources, the PIM implementation will be more successful, and hence attainthe fully sustainable irrigation practices as well as sustainable water resources development and management within the nearest future.

References

Asian Development Bank (ADB). (1996). Towards Effective Water Policy in The Asian and Pacific Region.

Bappenas, PU. (1993). The Study for Formulation of Irrigation Development Program in the Republic of Indonesia.

Booth, A.. (1987). Irrigation in Indonesia, Part I and II. Bulletin of Indonesian Economic Studies, 13 (3-4).

Departemen Pekerjaan, Umum. and Bappenas. (1982). Water Resources for Sustainable Use in Indonesia. Proceedings of the International Seminar Sponsored by National Planning Agency and Ministry of Public Works, Cisarua, Bogor, October 29th-November 1st, 1992.

Gany, A.H.A., Zakaria, Ir. F. (1975). Persubakan di Bali(Suatu Laporan peninjauan, untuk studi perbandingan dengan permasalahan pengairan di ProvinsiLampung). A Report for the Provincial Government of Lampung.

Gany, A.H.A. (2001). Subak Irrigation System in Bali: An Ancient Heritage of Participatory Irrigation Management in Modern Indonesia, Research Center of Water Resources, MPW. Bandung, Indonesia.

Grader, C.J. (1960). The Irrigation System in the Region of Jembrana, Bali, Studies of Life, Thought and Ritual. Selected Studies on Indonesia, Vol. V. Les Editions A. Manteau S.A., Bruxelles W. van Hoeve Ltd. The Hague and Bandung. Edited by W.F. Wertheim et. al.

IPB and University of Udayana (1974). Subak, Organisasi Tata Guna Air pada Tingkat Desa di Bali, Institute of Agriculture Bogor, And University of Udayana, Bali, November 1974.

Ministry of Agriculture, Indonesia (2013). Water Management and Sustainable Agriculture In indonesia. Presented in Special Seminar on Food Security, Focusing on Water Management on Sustainable Agriculture Niigata, Japan, 5 – 7 September 2013.

Park, K. S. (1976). Subak Irrigation System in Bali, Indonesia. Japan International Cooperation Agency (JICA.

Republic of Indonesia (2004). Laws No. 7/2004 regarding Water Resources.

Republic of Indonesia (2006). Government Regulation No. 20/2006, regarding Irrigation.

Teken, I.B. (1967). Organisasi Pengairan Pedesaan Subak di Bali. A case study: Subak in Desa Luwus, Tabanan, Bali., Bogor Institute of Agriculture.

Winaya, P. D. (1973). Organization of Water Association in Bali., A paper specially prepared and presented as a lecture for the American Students from the Lewis and Clarke College, Oregon, U.S.A., at the Udayana University, Denpasar, Bali.

Participatory river basin planning for water resource management in Kamala Basin, Nepal

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Abstract

Participatory basin planning is an important approach to water resources management. This paper presents a methodology to support such planning in the Kamala River Basin of Nepal. A participatory planning process involves identifying the priorities and aspirations of different sectors and stakeholders, defining options and scenarios for future development, and negotiating how to maximize synergies among development objectives, while minimizing undesired consequences. A river basin planning process also involves assessing how people use water, people's future livelihood and development aspirations, and the role of water use in meeting those aspirations. The process quantifies the water resource available across the basin and distribution during the year using hydrological models. It promotes understanding long-term trends in both water availability, and how users may adapt to changes. Stakeholder participation is therefore essential to understand expectations and priorities, help establish scenarios for future development, and to help define investments needed to obtain desired outcomes for the basin. The methodology was developed through iterative exchange between participatory planning and water resource specialists in Nepal and Australia. This paper also demonstrates how a surface water hydrological model can be used to illustrate a future climate scenario, and its impacts on timing and volume of stream flow. Applying the proposed methodology is expected to improve stakeholder understanding of interventions necessary to improve management of natural resources in the basin and facilitate improved water-related development outcomes.

Keywords: *climate change; irrigation; public participation; strategic basin planning; water management*

1. Introduction

Under Nepal's transition to a federal structure, the national government is revising its policies, institutions and laws across several sectors. One priority area is the development of a National Water Resources Policy, and implementation of strategic planning across Nepal's hydrological basins. In 2017, Water and Energy Commission Secretariat (WECS) initiated a process whereby a set of strategic river basin plans (incorporating strategic environmental and social assessment) will be prepared.

By strategic planning, we mean a process of long-term water-related development planning (as opposed to operational or management plans for water allocation or infrastructure operation at fine temporal scale). The concept of strategic basin planning has evolved since its emergence in the late 20th century. Post-WWII (World War II) water supply infrastructure was planned according to a "technical" paradigm to meet certain objectives (such as irrigated agriculture and hydropower production), with subsequent undesired environmental and social outcomes (Pegram et al., 2013). A less fragmented, more coordinated, and systemic paradigm for water resources planning later emerged, as reflected in the 1992 Dublin Statement on Water and Sustainable Development (ICWE, 1992). The Dublin Statement describes the basin as the most appropriate geographical entity for the planning and management of water resources.

The aspiration of integrated water resources management was subsequently disseminated in the 2000s by development actors. Integrated Water Resource Management (IWRM) is a process that aspires to improve three Es: efficiency, equity, and environmental sustainability (Molle, 2008). However, within a decade of its emergence, IWRM drew criticism for overly optimistic assumptions about how changes to water planning could deliver improved the three Es in unequal societies such as South Africa and Tanzania (Molle, 2008; van Koppen et al., 2016).

Many public and private sector actors in Nepal understand IWRM principles, and the benefits of basin planning (e.g., to manage upstream/downstream competition or cross-sectoral trade-offs). In addition, WECS and other Nepali state agencies formally support the empowered participation of people at the local level. While Nepal has considerable experience implementing water use planning at the local level (Goodrich, 2017), it has not previously implemented participatory river basin planning at higher levels. Meanwhile, countries with elaborate water institutions, such as Australia, have found that making water allocation reforms according to IWRM principles is a highly contested and iterative, long-term process. Although guidelines and discussions of good practice exist (e.g., Aither, 2017; Pegram et al., 2013), it is clear that design and implementation need be tailored to the socio-political context.

In the case of Nepal, that context is complex. Since the enactment of the 2015 Constitution, Nepal has been undertaking a process of state restructuring, involving:

- the devolution of authority, and government revenue, to approximately 753 local government bodies, with representatives elected in 2017 (replacing the previous district and local (Village Development Committee) administrations);
- the creation of a new level of governance known as the province, with representatives elected in late 2017, along with the elaboration of provincial level executive branch agencies;
- at the national level, the reorganization and consolidation of ministries;
- reform of legislation, notably the development of a National Water Resources Policy calling for strategic river basin planning to be undertaken.

In this context the Kamala Basin initiative is an attempt, supported by the Australian Government, to build capacity in the Government of Nepal (GoN) around basin planning and IWRM. The initiative aims to implement a participatory basin planning process, which may result in a stakeholder-agreed basin development strategy. This paper describes the methodology proposed to support such participatory and strategic river basin planning.

2. Kamala Basin – Biophysical and Development Context

The GoN partners nominated the Kamala river basin as an appropriate location to implement a strategic planning process: its spatial extent was considered appropriate for a short-duration project (approx. 24

months), and the basin experiences seasonal water shortages as well as flood risk.

The Kamala basin comprises portions of Siraha, Sindhuli, Dhanusa and Udayapur districts, with an area of approximately 2,050 km^2 (Fig. 1) and a population of nearly half a million people. The maximum elevation of the basin is 2,107 m; the minimum is 50 m above mean sea level (masl). More than 60% of the catchment area lies below 500 m and about 30% between 500–1000 m; the remaining 10% lies above 1000 m. Most irrigated agriculture occurs in the lower basin (State 2)

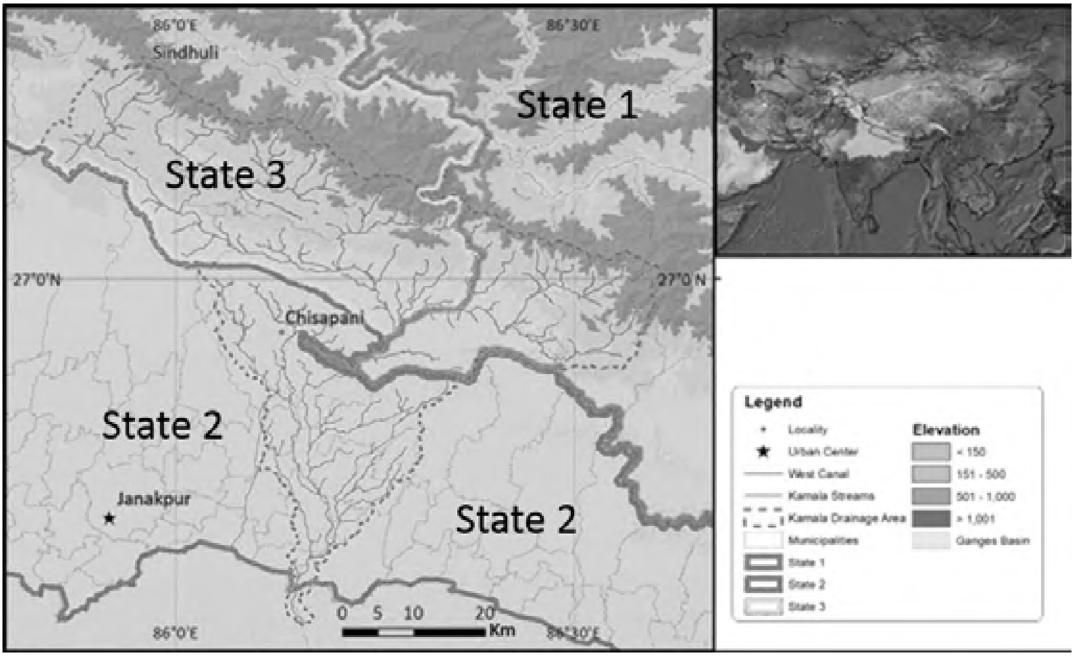

Figure 1: *The Kamala River Basin (dashed outline)*

The Kamala headwaters are in the Chure Ranges of State 1 and State 3. The waters flow down into the agricultural plains of State 2 with irrigation canal systems supplying land to the west and east of the river. The basin's average annual rainfall is about 1,681 mm. The seasonal variation of rainfall in the basin is very high, where 80% of the rainfall occurs during monsoon season, the upper North-Western side of the basin is wetter compared to North-Eastern side.

The annual average stream flow of the basin is around 100 m^3/s, where almost 80% of discharge occurs in four monsoon months (June–October) (Joshi and Shrestha, 2008). The seasonal variation of flow is very high with 303 m^3/s in August and 17 m^3/s in April. The ratio of maximum to average monthly flow is about 3.5; the ratio of average to minimum is 6, resulting in a ratio of maximum to minimum flow of approximately 18. This high ratio indicates the need for adequate water resources management for water and food security (CSIRO, 2017), and helps explain GoN's interest in a planning initiative for the Kamala Basin.

Most people in the basin rely on subsistence-oriented irrigated agriculture as a source of income. Floods during the monsoons are frequent hazard, but water drains rapidly through the alluvial soils. Torrential

rainfall events change the course of rivers and causes erosion. The rivers contain high concentrations of sediment, which have reduced the effectiveness of the irrigation system and barrage downstream of Chisapani. Irrigation is essential for agricultural production since the rainfall distribution is concentrated during the monsoon period, and most of the stream flow occurs during four months of the year. After March, water for irrigation becomes insufficient until monsoons rains start, limiting the production to a maximum of two crops (typically rice and wheat) per year. The existing surface-water canal irrigation systems have water loss caused by uncontrolled seepage and evaporation. The groundwater system provides water for urban supplies, and in some areas is pumped for irrigation. The lack of water storage infrastructure reduces the capacity to use irrigation water more efficiently across the year.

An additional issue to water limitation during the dry season is the small land area per family. This is a strong economic limiting factor, which leads to minimal income generation for families in the region. A better use of the water resources, improved infrastructure, and alternative and higher value agriculture may improve the regional economy (CSIRO, 2017).

3. Kamala Basin Initiative Methodology

The following section presents the procedures and methods proposed to support the Kamala Basin initiative. The initiative will be undertaken as a multi-stakeholder partnership between the GoN and the Government of Australia (GoA). The implementing partners include the Australian research institute CSIRO (Commonwealth Scientific and Industrial Research Organisation), WECS, Nepal and Nepal-based partners PEI (Policy Entrepreneurs Inc.) and JVS (Jalsrot Vikas Sanstha).

***Table 1**: Kamala basin initiative phases of development and respective activities*

Phase	Activities
Inception	Conducting background research into the Kamala region (literature review and discussions with individual experts and stakeholders) Focus on how to engage with those people that have an interest in the Kamala region.
Exploration of Development Pathways	Identify and discuss a range of stakeholders' development goals and visions for the basin, and how they imagine those goals could be met
Scenario Formulation and Assessment	This phase involves two iterations. Each iteration involves: 1) defining future scenarios; 2) supporting participants to discuss the scenarios; and 3) participatory assessment of scenarios against specific criteria and indicators.
Basin Development Strategy	Translate a stakeholder-preferred development scenario into a basin development strategy. Focus on implementation issues and options, explored with stakeholders through discussions and structured meetings.

3.1. Overview

Fig. 2 presents an overview of the proposed methodology. The methodology emerged through a series of face-to-face interactions in 2016–2017 between GoN water resource professionals and CSIRO. GoN representatives initially expressed interest in building their hydrological and associated modelling capacity.

Such capacity would allow GoN officers to provide techno-economic review of proposed infrastructure development. During these initial discussions, some experts expressed the view that a decision support system (DSS) could provide optimal solutions to multi-objective planning. Later, GoN focal points expressed interest in a participatory planning exercise. A literature review was therefore conducted with focus on approaches that were technically-informed, as well as participatory. We reviewed academic as well as practitioner literature. With respect to practitioner literature, we reviewed in detail the terms of reference for a current, World Bank funded strategic planning initiative in Myanmar, another developing country undertaking state restructuring (Union of Myanmar, 2017).

The literature review helped us establish that multi-stakeholder participation requires taking an explicitly deliberative process, guided by fundamental public policy questions (see Table 2 below). By "deliberative" we essentially mean a process involving reasoned argument about a set of options. In such a process, analytic techniques (including DSS) do not provide ultimate solutions, but rather provide one source of expert knowledge, to feed into stakeholders' arguments (e.g. Burgess et al., 2007; Straton et al., 2011).

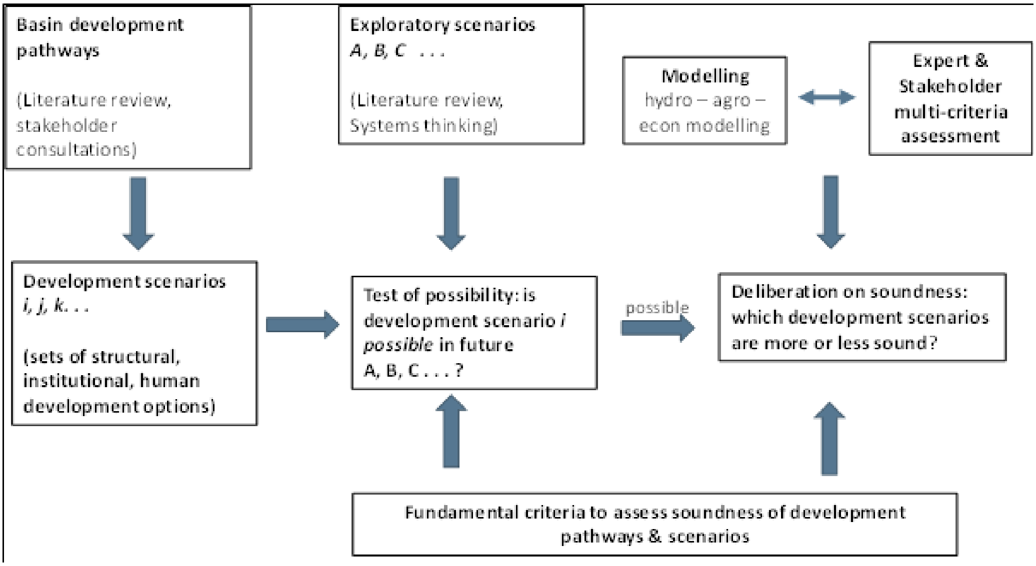

Figure 2: *Overview of methodology for scenario development and assessment.*

Our methodology involves a scenario-based planning process. The process aims to support stakeholders to reach consensus (if possible) on an optimal development strategy for the Kamala Basin. A development strategy is essentially a description of how responsible actors can take particular *actions* in order to realize important development *values*. Values are topics which matter (or arguably could matter) to an actor. For example:

- providing equitable access to water resources across the basin, considering the differentiated needs and capabilities of women, as well as socially marginalized groups;
- producing irrigated crops with high water-use efficiency, which are economically viable;
- sustaining water quality for humans and aquatic life;
- mitigating risks of floods and impact of droughts

Actions include investment projects, as well as the design and implementation of particular policy instruments or policy processes.

In order to derive a preferred development strategy, the methodology begins by eliciting, from the project participants, their development *pathways* (Fig. 2). Pathways are essentially the values as expressed by a stakeholder, including statements about how those values can be attained through development action. We will compile participants' statements into a set of representative development pathways (Section 3.2). Each pathway will then be elaborated into a development scenario. Using a series of assessment techniques, including multi-criteria analysis, the participants will generate a short-list of development scenarios (Section 3.3). We then explore if it is possible for participants to prioritize a set of development goals, then articulate one development scenario which they consider to be the best set of options to attain their development goals. Finally, the preferred development scenario will be elaborated into a basin development strategy (Section 3.4).

Throughout the process, a set of fundamental public policy questions is used (Table 2). The questions help guide the participants to engage in dialogue and deliberation, in order to articulate a development strategy which is feasible, coherent, and desired. Dialogue means communication, usually face-to-face, usually among actors with different interests and positions towards an issue. It attempts to go beyond adversarial debate to mutual, respectful inquiry. The methodology aims to support *deliberation*: a type of dialogue which aims to generate advice on more vs. less desirable alternatives among a set of alternative development strategies or options.

***Table 2**: Public policy criteria used to assess soundness of development scenarios*

Type of criterion	Question	Knowledge sources / linkages
Definition of circum-stances	Are social and biophysical information and development issues represented in a rationally acceptable way?	Modelling Expert and stakeholder consultation
Possibility	Is it logically and technically possible to take the proposed action (i.e. set of investments)?	Exploratory scenario framework Expert consultation Modeling
Acceptability of value	Are the values that underlie the action rationally acceptable?	Stakeholder consultation
Other means (options)	Do alternative actions exist that would also achieve a particular goal?	Expert consultation Modeling
Other public values or goals	Do other values or goals exist that might conflict with the action and whose achievement should have priority?	Stakeholder consultation, informed by multi-criteria analysis (MCA)
Negative consequences or proposed action	What undesired consequences of the action should be taken into account?	Modelling, MCA

Best option	On balance, is the proposed action the most acceptable among the alternatives?	Multi-stakeholder forum

Source: Authors, adapted from Fairclough and Fairclough (2012).

3.2 Exploration of development pathways

A development pathway is defined here as a *policy argument*, made by stakeholders or knowledge providers. Policy arguments contain four components:

- values (defined above);
- representations of a problem or issue;
- goals, which are descriptions of desired future states, in which values are realized;
- means-goal arguments, i.e. arguments about how to move the situation from the problem as represented to the goal, in accordance with the actor's values (Fairclough and Fairclough, 2012).

A development pathway has the structure of a means-goal argument: it states how, given particular circumstances, certain courses of action, may allow particular sets of development objectives to be attained. For example, Foran et al. (2017) compared the policy arguments contained in three independent studies, all of which deal with constraints facing women and equitable agricultural development in the eastern Gangetic Plains of India and Nepal (and upland regions of Nepal) (Khadka et al., 2014; Lahiri-Dutt, 2014; Sugden et al., 2014). They found compatible values and goals. While the three studies attached different priority to particular issues, overall, their issue representations were consistent. The livelihoods strategies of women and lower status groups are rendered precarious by multiple forms of structural inequality and social-ecological vulnerability (Foran et al., 2017). The set of means-goal arguments offered in the three studies can be interpreted as a development pathway. The pathway argues for much stronger investments in rural women and their agriculture, as well as for new forms of production, such as co-operative farming and collective access to groundwater irrigation (Sugden, 2016).

The definition of development pathway as *policy argument* allows a structured way to compare and analyze the various arguments put forward by Kamala Basin stakeholders. The analysis will be guided by the set of public policy questions (Table 2).

The methodology proposes that participants in the planning initiative will engage in structured dialogue, in order to understand their arguments, and those of others; and secondly to explore the possibility for reaching agreement about shared goals and means to attain those goals (i.e. development pathways). Sectoral plans affecting the basin will also be analyzed as policy arguments.

3.3 Scenario formulation and assessment

Scenarios are essentially defined here as structured storylines about how the future may unfold. The methodology makes use of two types of scenario: development scenario and exploratory scenario, defined further as follows:

A *development scenario* is a storyline about how a particular set of interventions (e.g. public initiatives, water storage infrastructure options) may plausibly allow a particular set of water-related development objectives to be attained. A development scenario is essentially a pathway with more detail about what

actions need to be taken, along with useful information about beneficiaries, mode of intervention, resource requirements, and timeframe. However, it contains less implementation detail than a "development strategy" (Section 3.4).

The initial set of development scenarios will be developed by analyzing and building on the development pathways proposed by stakeholders, making use of relevant literature.

Exploratory scenarios by contrast are provocative and relevant storylines which explore "alternative futures" of the development context, for example, alternative futures of the economy, climate, and society of Nepal (e.g. World Wildlife Fund, 2016).

They deliberately go beyond extrapolation of trends to explore "what if" a particular set of driving forces took a particular value or manifestation in the future (e.g. what if on-farm livelihood security was low compared to non-farm livelihoods). *Exploratory scenarios* test the coherence and desirability of particular *development scenarios*. Consider two examples. First, in an exploratory scenario which assumes high rural out-migration (because of low on-farm livelihood security), a development scenario consisting of new large surface water irrigation projects is unlikely to be economically feasible. A scenario that performs better might be smaller-scale, farmer managed irrigation systems.

A second example is an exploratory scenario which assumes future climate change will follow a Representative Concentration Pathway (RCP) 8.5 trajectory (Riahi et al., 2011). This scenario can be used to test the viability of different development scenarios involving strategies for natural disaster risk reduction and management. The RCP 8.5 climate scenario might be including increased risk of storm and flood late in the monsoon period, with greater risk of damage to roads, embankments, and impact on rice and other crops. The viability of alternative risk reduction and management strategies (e.g. programs for regular maintenance of channels) could then be explored against this extreme (and plausible) scenario.

3.3.1 Use of quantitative analysis in scenario assessment

Quantitative analysis will be used to illustrate both types of scenarios. For example, to illustrate an exploratory climate scenario, we used the CSIRO Mk3 climate model to future changes in climate. Fig. 3 shows an example of stream flow may change during the year under a future climate scenario. This may have an impact on water availability for irrigation and crop production.

Similarly, a water allocation model can be used to illustrate imagined future growth in non-farm sectors, with aggregate increase in urban and industrial water demand, which in turn could be met with different levels of efficiency.

The development scenarios will include alternative options for agricultural development based on predictions of water availability from a hydrological model. The model will explore different assumptions about irrigation efficiency, area expansion, as well as crop alternatives and respective water demands.

3.3.2 Agricultural and economic analysis

Scenarios of climate change and water availability will be further illustrated using crop and economic models. These models will show how climate will affect productivity and return to investment on irrigation. The intent is to allow options such as alternative crops, cropping calendar, and irrigation management to be assessed.

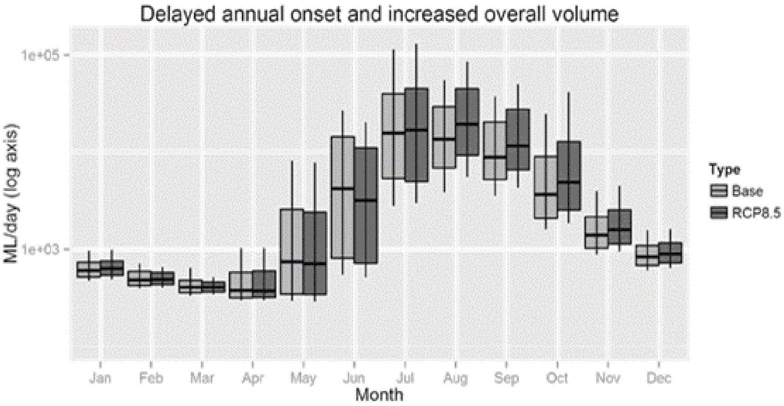

***Figure 3**: Simulation of an RCP 8.5 climate scenario. Source:Authors. Note: Under the CMIP5 RCP 8.5 projection using the CSIRO Mk3 model, the increased rainfall would be more likely to occur later in the monsoon season than previously experienced. However, the dry period shows a similar volume of water between the baseline and RCP 8.5.*

3.3.3 Multi-criteria analysis

The initiative will facilitate stakeholder consultations with federal and basin level stakeholders leading to a multi-criteria analysis (MCA) of a subset of scenarios. The purpose of MCA is to guide stakeholder deliberation about more vs. less preferred development scenarios (e.g. Straton et al., 2011). The groups will first discuss and agree on a set of agreed criteria to assess the scenarios, then assess the scenarios against the criteria.

The criteria represent different dimensions of sustainable development. They could be derived from a range of sources:

- United Nations sustainable development goals (SDGs) and indicators;
- specific objectives or visions for the Kamala basin, as expressed in participants' development pathways;
- existing national development objectives of GoN, particularly those assessed as realistic, and given high priority by participants.

The participants will then compare how the scenarios performed against the assessment criteria, and consider those that appear to have superior assessment results across multiple criteria. The output of this step is a short-list of development scenarios.

3.4 Basin development strategy

A development strategy is defined as descriptions of how responsible actors can take particular actions in order to realize their development values. The set of *actions* includes investment projects, as well as the design and implementation of particular policy instruments or policy processes.

A basin development strategy differs from the output of the previous step in that it contains more information about implementation. For each major action, the strategy needs to describe key implementation-related issues, such as coordination, capability, financial resources, authority, and responsibility (Foran et al., 2017).

These issues will be explored through a deliberative process using structured dialogue. The deliberative dialogues will be designed for stakeholders who are not experts, or are not able to participate in the preceding MCA activities (because of various constraints). However, the process should also include input from technical governance experts (i.e. experts in public administration and development planning). One way to do so is to invite such experts to discuss implementation challenges, and advise on preferred implementation options, as an input to the multi-stakeholder dialogue (cf. citizen's jury process). Another possible input to the multi-stakeholder dialogue is to report on focus group discussions undertaken with selected Kamala community members (e.g. women tenant farmers) to explore feasibility of particular implementation arrangements.

The output sought from the multi-stakeholder dialogue is consensus around each of the major actions, including how each action is to be implemented. The major actions and implementation arrangements will be documented in the form of a draft basin development strategy. A limited number of structured stakeholder workshops with federal and basin level stakeholders will be undertaken to review the draft basin development strategy and finalize the document. GoN partners will advise on precise procedures to finalize the strategy or conclude the planning initiative.

In summary, the methodology proposed for Kamala basin has a clear progression from fundamental questions of public policy (Table 2) to development pathways, to stakeholder ranking of development scenarios, to a possible agreed basin development strategy. We can think of this progression from fundamental basin challenges to specific solutions as a planning journey. The journey has been designed to allow iteration, phasing, and customization, and thus to support stakeholders to reach particular planning outcomes they are satisfied with. This means for example, that if stakeholders cannot reach agreement about detailed development options (and hence scenarios), but can agree on preferred development pathways, t, that is acceptable from a planning perspective. The MCA could still be done at the level of development pathway. This would produce a basin development strategy, which is less detailed, but still useful. It could possibly function as an agenda-setting document, with disagreed issues exported beyond the life of this initiative.

3.5 Stakeholder participation

The Kamala initiative will involve stakeholder participation at two levels of governance: the national (federal) level, and the Kamala basin level. The "basin" level remains to be defined: a detailed stakeholder analysis and engagement strategy will be conducted by PEI and JVS. The structure and identities of state agencies at the new provincial level is expected to emerge by September 2018. The basin level will also include participants from the new local government bodies in the basin.

In general, categories of participant include: elected political representatives, including heads of local government bodies; private sector; and civil society organizations (CSOs or NGOs) that represent ultimate beneficiaries of basin planning. Additional participants, particularly at the national level, include representatives of government agencies.

The project design does not require citizens with relatively high levels of social deprivation or exclusion

to participate in highly technical meetings, or basin-level formal dialogue meetings. However, we will organize a number of focus groups and interviews at district and sub -district level to improve inclusion of perspectives from marginalized social groups and women. The purpose of such discussions is to allow the project to hear more directly from relatively deprived people, in addition to and independently from the arguments made on their behalf by political or civil society representatives.

3.6 Data limitations

In many cases, there will be insufficient quantitative data accurate enough to inform decisions, and an adaptive management approach will be necessary to entrain. For example, Fig. 4 shows how existing data constrain predicted flows of the Kamala River, but are not sufficient to predict when the river will cease to flow. As the low flow period is likely to be important to the long-term feasibility of the irrigation system, it may be worthwhile investing in increased monitoring.

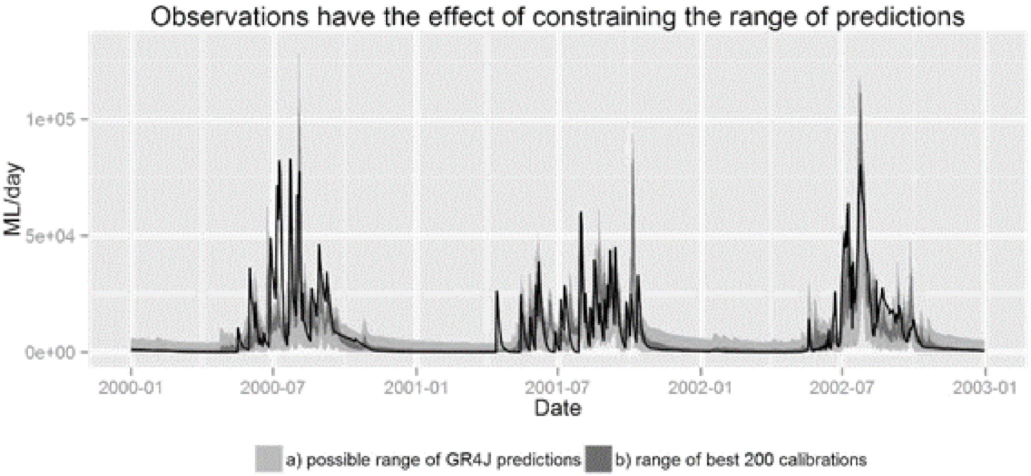

Figure 4: *Effect of observations on range of rainfall-runoff model predictions. Source:Authors. Notes:With three years of observed data (black), calibration reduces the range of GR4J hydrological model predictions from the light grey range ("a") to the dark grey range ("b"). This is especially important if we are to use the model to understanding the low flow periods (where observations are not present).*

4. Conclusion

This paper has presented a methodology for strategic basin planning which emerged through a specific process of collaboration between CSIRO and GoN professionals. The iterative scenario-based methodology attempts to meet the specific needs of GoN for a process that is technically-informed, while also providing for meaningful public participation. The methodology is now in early stages of implementation in the Kamala Basin. As implementation proceeds in a context of state restructuring, we anticipate refinement. For example, more information about the capabilities and interests of a set of essential stakeholders will allow us to define, more precisely and adequately, the scope of particular

components of the method. Such information is needed from stakeholders in order for the project team to define and communicate alternative development options in formats that is credible, accessible, and sufficient to allow participants to make informed choices about desired options. (Options presented with excessive detail may lead to undesired outcomes in that they could deter participants from engaging if they are constrained by time, or have limited technical background, leaving important discussions to be dominated by issue specialists.

In conclusion, the methodology proposed for Kamala basin has a clear progression from fundamental questions of public policy (Table 2) to development pathways, to stakeholder ranking of development scenarios, to a possible agreed basin development strategy. It is hoped that this progression from fundamental basin challenges to specific solutions will be understood by participants as a journey along a planning continuum. It is worth emphasizing that the journey allows for iteration, and customization, and thus to support stakeholders to reach planning outcomes (i.e. pathways, scenarios, strategy) they are satisfied with.

Acknowledgements: This paper is an output of the Sustainable Development Investment Portfolio, funded by the Department of Foreign Affairs and Trade (DFAT) Australia, through the South Asia Regional Development Program. The authors acknowledge the assistance of the Department of Hydrology and Meteorology (DHM) and thank the Government of Nepal for allowing us access to hydro-climate data. We thank S.M. Wahid for comments on an earlier version of the manuscript.

References

Aither (2017). WaterGuide. Setting a path to improved water resource management and use under scarcity. Australian Water Partnership, Canberra.

Burgess, J., Stirling, A., Clark, J., Davies, G., Eames, M., Staley, K., Williamson, S. (2007). Deliberative mapping: a novel analytic-deliberative methodology to support contested science-policy decisions. Public Understanding of Science, 16, 299-322.

CSIRO (2017). Kamala Basin field trip to support Basin Plan process in Nepal. Sustainable Development Investment Portfolio (SDIP) project. CSIRO Technical Report, pp 56.

Fairclough, I., Fairclough, N. (2012). Political Discourse Analysis: A Method for Advanced Students. Taylor & Francis.

Foran, T., Lahiri-Dutt, K., Sugden, F., Neupane, N. (2017). Argument-Representation-Implementation: Improving the policy advice that comes from livelihoods research, Water-livelihoods-gender nexus to advance Koshi Basin Management, International Workshop. http://lib.icimod.org/record/32743, Kathmandu, 24-25 March 2016.

Goodrich, C.G. (2017). Gender and Social Inclusion in Local Water Planning: Lessons from Water Use Master Plan Practices in Nepal. Working Paper 2017/16. ICIMOD.

International Conference on Water and Environment (ICWE) (1992). The Dublin Statement on Water and Sustainable Development.

Joshi, N.M., Shrestha, P.M. (2008). Regional Co-operation for Flood Disaster Mitigation in the Ganges and Brahmaputra River Basin in South Asia. Draft Final Report. Country Paper - Nepal. Jalasrot Vikas Sasntha / Nepal Water Partnership, Kathmandu.

Khadka, M., Rasul, G., Bennett, L., Wahid, S., Gerlitz, J.-Y. (2014). Gender and Social Equity in Climate Change Adaptation in the Koshi Basin: An Analysis for Action, in: Leal Filho, W. (Eds.), Handbook of Climate Change Adaptation. Springer-Verlag, Berlin.

Lahiri-Dutt, K. (2014). Experiencing and coping with change: women -headed farming households in the Eastern Gangetic Plains. Australian Centre for International Agricultural Research, Canberra.

Molle, F., 2008. Nirvana concepts, storylines and policy models: Insights from the water sector. Water Alternatives, 1, 131-156.

Pegram, G., Li, Y., Quesne Le, T., Speed, R., Li, J., Shen, F. (2013). River basin planning: Principles, procedures and approaches for strategic basin planning. UNESCO, Paris.

Riahi, K., Rao, S., Krey, V., Cho, C.H., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P. (2011). RCP 8.5-A scenario of comparatively high greenhouse gas emissions. Climatic Change, 109, 33-57.

Straton, A.T., Jackson, S., Marinoni, O., Proctor, W., Woodward, E. (2011). Exploring and Evaluating Scenarios for a River Catchment in Northern Australia Using Scenario Development, Multi-criteria Analysis and a Deliberative Process as a Tool for Water Planning. Water Resources Management, 25, 141-164.

Sugden, F. (2016). Tenant collectives in North Bihar: A new model for bottom up irrigation and land management for marginal women farmers. http://www.iwmi.cgiar.org/2016/02/tenant-collectives-in-north-bihar/. IWMI. (accessed 19 April).

Sugden, F., de Silva, S., Clement, F., Maskey-Amatya, N., Ramesh, V., Philip, A., Bharati, L. (2014). A framework to Understand Gender and Structural Vulnerability to Climate Change in the Ganges River Basin: Lessons from Bangladesh, India and Nepal. IWMI, Colombo, Sri Lanka.

Union of Myanmar (2017). Request for Proposal for the Services for C1.17 – Development of the Ayeyarwady Decision Support Syatem and Basin Master Plan. 25 May 2017. Directorate of Water Resources and Improvement of River Systems, Project Management Unit.

Van Koppen, B., Tarimo, A., Van Eeden, A., Manzungu, E., Sumuni, P.M. (2016). Winners and Losers of IWRM in Tanzania. Water Alternatives-an Interdisciplinary Journal on Water Politics and Development, 9, 588-607.

World Wildlife Fund (2016). Nepal: Water Risk Scenarios and Opportunities for Resilient Development. WWF Nepal.

Improved water management in Kankai irrigation system, Nepal

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Abstract

Strengthening capacity of Water Users Association (WUA) through improvement in processes of canal water management is instrumental to sustainable performance of an irrigation system. This enables WUA in irrigation management transferred system to conserve facilities with use of adequate water in reliable and equitable manner. A study on canal operation during spring season crops, paddy and maize, for a period of 90 days starting from 02nd March 2016 to 20th May 2016, reveals seasonal operation adequacy as 1.03 with coefficient of variation in reliability as 0.3 at the Sardare Intake. The overall coefficient of variation in equity was found as 0.75 for Group-A and 0.69 for Group-B mode of secondary canal operation at 4 days on and 4 days off basis.

Keywords: *adequacy, efficiency, equity, Kankai; reliability, water management*

1. Introduction

Despite the long history of irrigation development and management; and claim of related stakeholder to provide irrigation facility to almost 75% of the irrigable area in Nepal, the demand for rehabilitation and maintenance of already built hydraulic structures is very high. Hence, the infrastructure intervention alone may not address the sustainability of irrigation system and therefore, operational aspect through effective water management techniques with involvement of Water Users Association (WUA) has been a key issue for continued discussion. The cumulative effect of poor planning and insufficient implementation has resulted in poor performance of irrigation system and low-cost recovery for financial sustainability towards the WUA being actual owner of the system.

At the global level around 18% of cultivated area is under irrigation, producing 40% of all food (Schultz et al., 2005). Expansion of irrigated area with improved water management will result in increase in production. Improved irrigation water management leads to increased cropping intensity resulting in increased overall production, productivity levels per unit of land and water, and eventually farmers' gross income (KC et al., 2011, 2017). Institutional and socio-technological improvement in irrigation schemes means increase in land and water productivity (Goklany, 1998). In addition, effective irrigation water management enhances farmers' income leading to an increased ability to pay irrigation service fees.

Thereby, a strong motivational tool that can convince farmers to pay their service charge to contribute for the sustainable irrigation development is equally important.

There is a strong positive link between irrigation, poverty alleviation and food security because for many rural communities, agriculture is the main source of livelihood (United Nations, 2006). Therefore, improvement in agriculture is a prerequisite to alleviate poverty in the rural areas. According to ICID (2008a), to feed close to 1 billion undernourished people and to address the likely dietary changes along with population increase, food production would have to double within 25–30 years. Globally, both irrigated and rainfed areas have sufficient potential to produce this food requirement by improving current land and water management practices (IWMI, 2007).

The Kankai Irrigation System (KIS) was constructed under the loan assistance from Asian Development Bank (ADB) in two phases. The construction works commenced in 1971 and the first phase was completed in 1981 developing the irrigation networks in about 5000 ha. The first phase consists of four reaches from reach I to IV with thirteen secondary canals from S0 to S12 and thirty direct tertiary outlets from the main canal. The second phase was commenced in 1980 and completed in 1991 with the extension of the infrastructures in about 2000 ha area out of targeted 3000 ha. Likewise, the second phase covers the reach V having nine secondary canals from S13 to S21 and twenty-four secondary canals. Implementation of Irrigation Management Transfer Program under Integrated Water Resources Management Project (IWRMP) component B was started in KIS since December 2009 by signing the mutual agreement between Department of Irrigation (DoI) and main canal water users' committee of KIS. The objective of the program is to improve service performance and service delivery of the selected agency-managed irrigation system (AMIS) where management transfer to WUAs would be completed and consolidated. Major sub-component includes Essential Structural Improvement (ESI) through rehabilitation and modernization; water management using improved techniques; and capacity building of WUA and DoI staffs.

Irrigation water management is crucial for a country like Nepal, where about 70% of the irrigation structure is already developed. Now, irrigation water management with involvement of WUA is the prerequisite for the effective use of irrigation structure and available water sources. Population increment coupled with rapid environmental change is thought to be placing substantial pressure on water resources. Greater pressure on water is forcing us to have improved water management in the irrigation systems (Yadav, 2015). This will lead to expansion in irrigated agricultural area as well as increase in agricultural production and productivity of the irrigated agriculture. In spring season, water availability at source of KIS is not sufficient to meet the irrigation requirement of the command area. In this deficit scenario rotational practice is applied in phase I and Phase II of KIS. At present, the WUAs and the office field staff decide with mutual understanding regarding the rotational delivery of the water sources during the scarcity. During spring season, irrigation water is delivered with one-year rotation between the Phase-I and the extension portion phase II.

The overall objective of this study is to shed light on the operational performance of the KIS located in Jhapa, Nepal.

2. Material and Methods

2.1 Crop water requirements

Prevalent cropping pattern (crop type, area, planting and harvesting date), as in Table 1, soil type and existing irrigation practice were collected from discussion with groups of WUA at Tertiary Irrigation Canal (TIC) level in every Secondary Irrigation Canal (SIC) system. Further, revised cropping pattern was proposed in consultation with WUA considering profitability of crop production, availability of water at Sardare Intake and fallow land during monsoon, winter and spring crop seasons.

Table1*: Cropping pattern in KIS with spring crop in SIC (S0 to S12)*

KIS command area: 6950 Ha					SIC command (S0 to S12): 3810 Ha		
Irrigation Season	Crop	Existing cropped %	Proposed cropped %	First Planting	Last Planting	First Harvesting	Last Harvesting
Monsoon	Rice	92	92	25-Jun	20-Jul	28-Oct	22-Nov
	Sub Total	**92**	**92**				
Winter	Wheat	5	12	12-Nov	31-Dec	12-Mar	30-Apr
	Maize	13	16	15-Nov	31-Jan	20-Mar	4-Jun
	Potato	6	8	20-Oct	21-Dec	7-Feb	10-Apr
	Mustard	7	9	1-Oct	21-Dec	19-Jan	10-Apr
	Vegetable	4	6	15-Oct	30-Jan	18-Jan	4-May
	Pulses	1	2	15-Oct	20-Dec	2-Feb	9-Apr
	Sub Total	**36**	**53**				
Spring	Spring Rice	36	53	7-Mar	27-Mar	5-Jun	25-Jun
	Sp Maize	2	2	15-Feb	7-Mar	19-Jun	10-Jul
	Sub Total	**38**	**55**				
	Cropping intensity	**168**	**200**				

Spring crops in KIS is cultivated covering command area starting from S0 to S12 (Reach-I to Reach-IV) and S13 to S21 (Reach-V) in alternate years. Spring crop season in SICs of S0 to S12 is considered in the study. Proposed pattern of staggered cropwater requirements was estimated using CROPWAT (Version-8). In the absence of climatic and rainfall data ClimWat 2 for CROPWAT model was used to extract monthly data of Chandragadhi, the nearest meteorological station considered. Reference evapotranspiration (ET_0) was estimated using Penman-Monteith method for climatic data. All calculation procedures used in CROPWAT 8.0 are based on the FAO guidelines following the publication No. 56 of the Irrigation and Drainage Series of FAO "Crop Evapotranspiration - Guidelines for computing cropwater requirements". A typical medium type of soil as programmed in CROPWAT model is considered prevalent in absence of classified soil data (texture, saturation moisture content, field capacity, wilting point, infiltration rate

and percolation rate) in the command area. Crop coefficient data were used as built in CROPWAT model with some modification on rooting depth, puddling depth (0.4 m), crop period and crop height to suite local condition of command area in KIS. Field application efficiency of 90% for paddy crop and 70% for non-paddy crops were modeled based on general practice in the terai region of Nepal. Effective rainfall for non-paddy crops was estimated using USDA soil conservation service option in CROPWAT. Maximum percolation rate after puddling and daily decrease in percolation rate during puddling were estimated by using FAO formula in CROPWAT for land preparation for rice crop. Consequently, the precipitation deficit scheme irrigation requirement on monthly basis was the output from CROPWAT model further used in balancing available water at Sardare Intake for Main Irrigation Canal (MIC).

2.2 Water balance

In absence of Kankai river flow data, historical record of 10 years (starting from year 2005/06 to year 2014/15) of available flow data in MIC on daily mean flow basis at Sardare intake were modeled to estimate 50% dependable (normal) flow using Rainbow (Version-2.2). It is a software package for analyzing climatological/hydrological data frequency analysis- test of homogeneity developed at IUPWARE, Belgium. The output of regression analysis as in Fig.1.

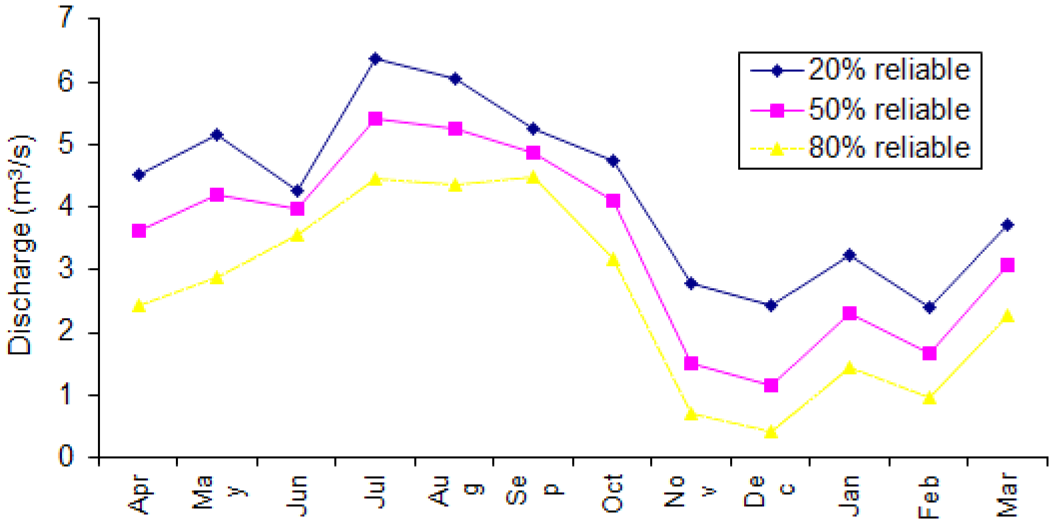

***Figure 1**: Reliable supply through Sardare intake of KIS*

The regressed data of normal flow through Sardare intake is balanced resulting in rotational supply between two Groups (Group-A and Group-B) of SICs during November through March and in June months as in Table 2 and Fig. 2. Irrigation canal efficiencies of 85% for MIC, 85% for SIC and 80% for TIC is considered to accommodate primarily seepage and operation loss during canal operation process.

***Table 2**: Water balance at Sardare intake of KIS*

Particulars	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mode of equal groups of SICs Operation for a delivery period (1:x)	2	2	2	1	1	2	1	-	-	1	2	2
Delivery Period of a group of SICs operation to match irrigation supply interval at field), days	11	7	4	7	7	4	7	-	-	7	7	11
Flow required at MIC head for a group of SICs over a delivery period, l/s	1565	1271	3152	2240	647	2644	1492	-	-	1209	1449	678
50% Dependable (normal) supply at Sardare Intake (MIC head), l/s	2320	1680	3070	3620	4180	3960	5400	5260	4870	4090	1510	1140
Surplus/ Deficit w.r.t. requirement, l/s	755	409	-82	1380	3533	1316	3908	-	-	2881	61	462

Proposed crop area, Ha	3662	3658	4882	3495	2280	6649	6383	6357	6357	6406	6917	3449

It is only during month of March that negligible (3%) deficit in estimated flow during canal operation planning process is observed. This may be expressed as to be compensated by host of empirical factors considered in planning and design of an irrigation system. During the months of August to September estimated precipitation is sufficient to satisfy proposed cropwater requirements. March is the critical as spring crop experiences transplanting and land preparation works (7th March to 27th March) as shown in Table1.

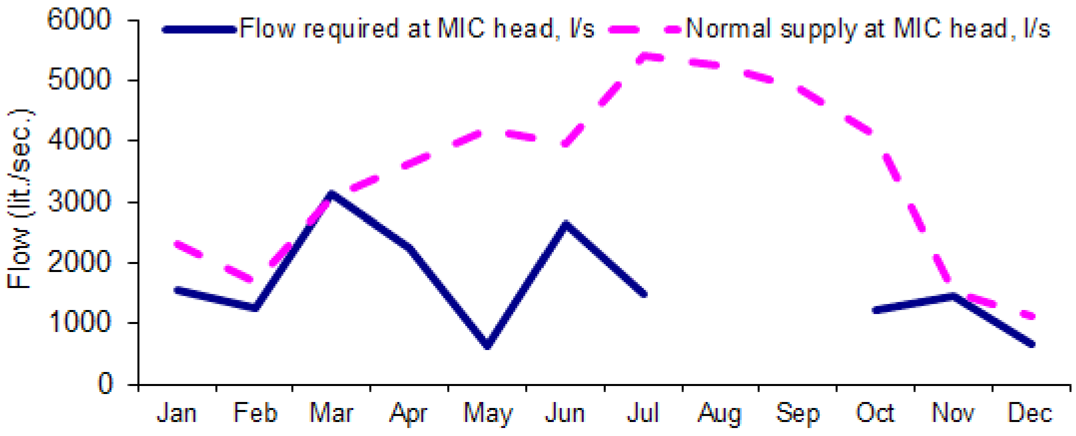

Figure 2: *Water balancing at MIC head*

The balanced water thus culminated in bulk water delivery schedule for each SIC in KIS.

2.3 Delivery schedule

A delivery schedule was prepared for bulk water delivery into respective SIC under proposed rotational mode of operation. The MIC, therefore, was run continuously to accommodate rotational schedule in two groups of SICs during spring irrigation season covering command area of SICs in S0 through S12. The delivery schedule of respective SIC and MIC primarily comprises, date of start and end of irrigation doses, period and quantity of dose, flow head over discharge measuring structure (Parshasll Flume) downstream of each SIC and period of canal closure for other group of SICs operation over an irrigation season including information on off-taking canal location, command area, designed discharge, name of gate operators responsible to enable flow into respective SIC through vertical sliding Head Regulator (HR) and name of respective chairperson of WUA branch committee at SIC level. The delivery schedule of MIC was planned 12 hours ahead of SIC schedule to compensate for travel time and response time to steady state. In order to initiate improved water management process, prepared delivery schedule was further consulted with and endorsement received from WUA main committee at MIC level.

For spring crops, group of SICs operation were scheduled based on 4 days on and 4 days off basis in contrast to continuous flow estimate as in Table 2 in order to accommodate real time precipitation deficit irrigation requirements of crops during hot and dry spring season. SIC operation Group-A consisted of S0, S1, S2, S3 and S4 and Group-B consisted of S2, S4, S5, S6, S7, S8, S9, S10, S11 and S12. The separation of group was based on equal weight for crop irrigation requirements, ease of cross regulators operation by gate operators in MIC.

Trial operation of bulk water delivery for spring season crops first started from 2nd March 2016 through 20th May 2016 in participation with WUA at MIC and respective SIC level.

2.4 Calibration of discharge measuring structure

To ensure measured bulk water delivery as per schedule into respective SIC offtake and MIC head at Sardare Intake, gauge station plan at bifurcation point in MIC and head of SIC were prepared with WUA. Field calibration of such structures resulting in rating table and gauge marks were then established. WUA branch committee of respective SIC was involved during field calibration process of discharge measuring structure to maintain transparent supply and gain confidence on quantity and period of scheduled flow to receiver's end.

2.5 Capacity building of WUA and gate operators

Series of on-farm and off-farm water management trainings to WUA were triggered to make WUA at TIC including SIC and MIC levels aware of hydraulic structure types, functions and limitations within KIS, on farm irrigation scheduling and off-farm water management process together with water auditing and record keeping as part of improved water management process. Gate Operators (GOs) were also included in such training program with WUA to enhance their knowledge of and prepare for improved water management activities in partnership with WUA.

With the delivery schedule in hand, the GOs of MIC together with WUA were oriented to operate respective vertical sliding upstream controlled Cross Regulators (CRs) and Head Regulators as per schedule requirements. Further, roles and responsibilities of WUA and GOs on supply and receiving end were explained by forming number of orientation workshops at locations within command area. Additionally, gauge record (head over discharge measuring structures, HR and CR opening and water level) book keeping by GOs and summative observation/remarks on weekly basis by the engineer responsible to operate MIC were also established. Such activities thus resulted in formation of canal operation plan.

2.6 Canal operation plan

A report on Canal Operation Plan (COP) consisting of proposed cropping pattern, water delivery schedule both for SIC and TIC, canal operation policy including job descriptions of the engineer operating MIC, WUA operating SIC and GO acting interface between the engineer and WUA were prepared for use and record by respective WUA branch committees. The COP dissemination process in each SIC level was achieved.

GOs started to keep discharge and water level records three times a day (8:00 hrs, 12:00 hrs and 16:00 hrs) at MIC/SICs head and bifurcation points respectively based on COP. The GOs further experienced

on the job trainings by the engineer while continuing to maintain gauge book in order to correctly record gauge readings for use in assessment of periodic and seasonal flow through respective SIC at the end of irrigation season and continued improvement in water management process for WUA in the next crop year to come.

2.7 Data preparation for assessment in spring season flow

Branch canals considered under assessment were S0 to S12 (13 nos.) where spring cropwater delivery were scheduled through MIC. However, seasonal flow account of SICs such as S0-head reach, S8-tail reach and S12-tail reach (3 nos.) were not available for assessment. Even though, it will have no significant effect on seasonal performance assessment of MIC.

Hourly flow data of a day were averaged during operation of MIC and respective SIC. The daily mean flow data were grouped in 16 days' period, as SIC operation is multiple of 4 days, to form 5 periodic groups for 80 days of scheduled operation. Volume in million cubic meter of actual water delivery (supply) and scheduled water delivery were tabulated for each period of MIC and SIC operation. Further number of days of MIC and SIC canal actual operation and scheduled operation were also tabulated.

2.8 Canal operation performance measure

Water delivery performance was measured on dimensionless parametric ratio of adequacy (over quantity), reliability (over time) and esquity (over space) basis as proposed by Molden and Gates (1990), Ankum P. (1995) and M. G. Bos (1990), among other researchers such as Abernethy (1986, 1989), Rao (1993), Clemmens et al., (1984, 1990) and Mishra (2004).

2.8.1 Adequacy

Adequacy of water delivery at an offtake is defined as the parametric ratio of volume of water actually delivered over volume water scheduled. On account of being dimensionless ratio, the adequacy may vary as 1 expressing actual delivery is as per schedule under ideal conditions. The adequacy less than 1 suggests actual volume of delivery is less than scheduled. This is the situation where scheduled is overruled/sacrificed and deficient use of water is practiced. Further, adequacy more than 1 indicates actual volume of delivery is more than scheduled. Thus abundant, as against sufficient, use of water is inevitable. It can be expressed as

$P_A = V_a/V_s$; where P_A = operation performance based on adequacy, V_a = volume of actual water delivery (supplied) at an offtake over time, and V_s = volume of scheduled water at an offtake over time.

2.8.2 Reliability

Reliability of water delivery at an offtake is defined as Coefficient of Variation (CV) of flow over time measured as parametric ratio of actual supply volume to scheduled volume. CV for population data set in statistics is defined as standard deviation over mean. In interpretation of CV, the value closer to zero means lesser degree of variability of flow through offtakes over time. Hence, reliable flow through offtakes over time scale is achieved. Further, CV farther than zero suggests higher degree of flow variation experienced by an offtake. Negative value of CV is not possible. It may be expressed as

P_R = CV of (V_a/V_s) averaged over time periods and freezed over space; where P_R = operation performance based on reliability, V_a = volume of actual water delivery (supplied) at an offtake over time, and V_s = volume of scheduled water at an offtake over time.

2.8.3 Equity

Equity of water delivery is defined as CV of flow over offtakes (freezed in time scale) measured as parametric ratio of actual supply volume to scheduled volume. CV nearer to zero suggests higher degree of spatially equitable distribution of flow among offtakes as scheduled. Additionally, CV farther than zero expresses higher degree of inequitable flow distribution. Consequently, some offtakes experience more water delivery and other less water delivery than scheduled. It may be expressed as

P_E = CV of (V_a/V_s) averaged over space and freezed over time period; where P_E = operation performance based on equity, V_a = volume of actual water delivery (supplied) at an offtake over time, and V_s = volume of scheduled water at an offtake over time.

2.8.4 Schedule efficiency

Schedule efficiency is defined as parametric ratio of number of days of actual canal operation over scheduled canal operation days. This indicates ability of an offtake to adherence of scheduled operation over crop irrigation periods and season. Scheduled efficiency nearer to zero means higher degree of inoperability of an offtake. Further, scheduled efficiency nearer to one expresses higher degree of operability of an offtake. It may be expressed as

P_F = (N_a/N_s) over time period; where P_F = operation performance based on schedule efficiency, N_a = number of actual water canal operation days at an offtake over time, and N_s = number of scheduled operation days at an offtake over time.

The performance standard is tabulated based on referenced literature of Molden and Gates (1990) in Table 3.

***Table 3**: Performance standard*

Measure	Performance Classes		
	Good	Fair	Poor
P_A; P_F	0.90-1.00	0.80-0.89	<0.80
P_E	0.00-0.10	0.11-0.35	>0.35
P_R	0.00-0.10	0.11-0.30	>0.30

The Table 3 also expresses weight for performance measure signifying in descending order as adequacy, reliability and equity.

3. Results and Discussion

3.1 Seasonal adequacy and reliability

It is observed in Table 4 and Fig. 3 that volume of water delivery (supply) almost matches with scheduled volume having measure of adequacy as 1.03 (Good) and reliability as 0.3 (Fair). This is on account of fact that flow of MIC head in Period-1 to Period-5 for both groups of operation is variable supplying more than scheduled volume at one period and less than scheduled volume at another period of study.

***Table 4**: Seasonal operation performance of MIC and SICs for spring crops under Trial-1*

Canal ID	Mode of opera-tion	Supply volume, Mm3	Sched-uled volume, Mm3	Actual operation days	Sched-uled operation days	Schedule efficiency	Adequa-cy	Reli-ability
Sardare		17.59	17.03	64	80	0.80	1.03	0.30
S1	Gr.-A	2.92	0.83	40	43	0.93	3.50	0.48
S2		2.30	1.19	57	61	0.93	1.93	0.53
S3		1.25	1.38	52	43	1.21	0.91	0.77
S4		2.21	2.02	61	61	1.00	1.10	0.39
S5	Gr.-B	1.66	1.30	59	44	1.34	1.28	0.52
S6		0.40	0.49	52	44	1.18	0.82	0.33
S7		0.86	0.53	35	44	0.80	1.62	0.67
S9		0.43	0.41	52	44	1.18	1.06	0.30
S10		0.91	0.59	50	44	1.14	1.53	0.42
S11		0.40	0.33	51	44	1.16	1.22	0.88

S1 canal has taken 3.5 times scheduled supply with flow variation over period steps as 0.48. This because of combining fact that S1 did not experienced scheduled flow during Period-4 and CR 495 m downstream of it had produced submergence effect on discharge measuring Parshall flume over flow structure. The submergence effect produces larger upstream head over flow with low discharging capacity and high sedimentation upstream and downstream of discharge measuring structures.

S2 canal behaves in a similar way as S1 canal. Only difference is that at 300 m downstream local water users creates temporary barrier across S2 flow to irrigate their high patch land against natural topography. Therefore, adherence to scheduled flow in S2 canal was found to be sacrificed for all five periods of study.

Characteristics of higher flow variability among periods (reliability as 0.77) with optimum flow (adequacy as 0.91) in a season are observed in S3 canal. This is because S3 in Period-4 takes in 2.42 times more supply and in Period-5 only 0.4 times scheduled supply.

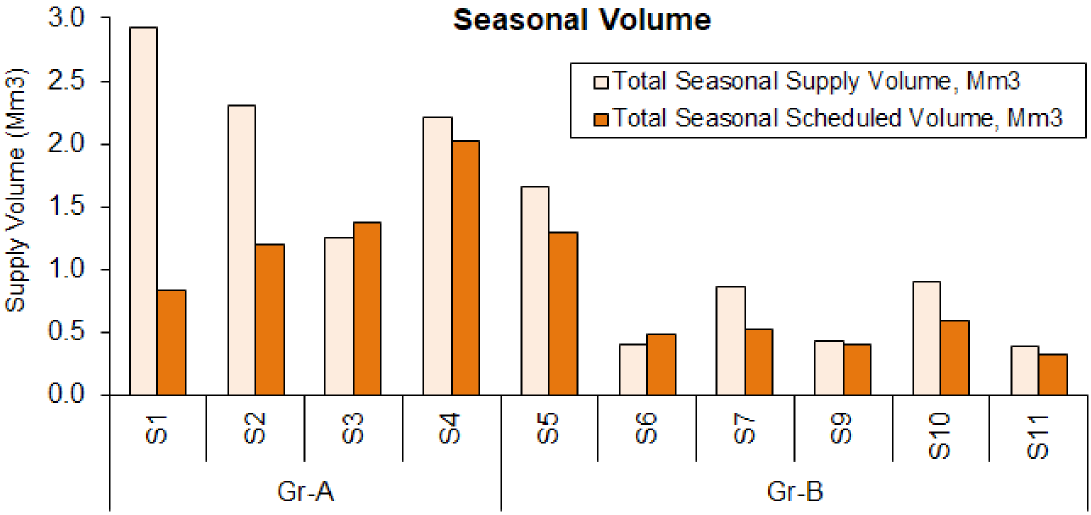

***Figure 3**: Seasonal adequacy and reliability performance*

S4 performs relatively satisfactorily with adequacy as 1.10 and reliability as 0.39 over trial periods of spring crop season. Water supply in S5 is generally more than scheduled over periods with 2.34 times more supply during Period-4 resulting in seasonal adequacy as 1.28 and reliability as 0.52. S6 canal takes in low water supply during its Period-5 as 0.4 and Period-1 as 0.73 times scheduled resulting in seasonal adequacy as 0.82 and reliability as 0.33. Seasonal performance of S7 in terms of adequacy as 1.62 and reliability as 0.67 was observed. This is also due to submergence effect of CR located 200 m downstream of S7 canal. Characteristics of such performance are similar to S1 canal. Operation performance of S9 canal is found optimal with adequacy as 1.06 and reliability as 0.3. Operation performance of S10 and S11 canals in terms of adequacy as 1.53 and 1.22 respectively, and in terms of reliability as 0.42 and 0.88 express either sacrifice by WUA to adhere with scheduled supply or error in flow record keeping by concerned GO.

Eventually, higher flow variations characterized by lower reliability of flow coupled with higher inflow to SIC characterized by higher adequacy of flow over periods of study indicates that WUAs of respective SIC are stretching muscles by adjusting CRs of SIC to compensate for spring season irrigation demand through operation of all TICs at a time or group of TICs at a time.

3.2 Seasonal equity

Considering numbers of SICs operated at a time in Group-A and Group-B mode of operation, the equity of scheduled flow distribution on periodic basis is highly variable as equity of Group-A as 0.75 and Group-B as 0.69 as in Table 5 and Fig. 4. This has resulted due to struggle by WUAs of respective Group of SICs in receiving more than scheduled water during their turn. Further, ability of GOs responsible to adjust cross regulators in MIC and head regulators at the head of respective SICs to match with scheduled supply incapacitated spatial equity. In addition, there are series of Direct Tertiary Outlets (DTOs) off-taking from MIC is located at elevated positions entails operation of CRs by GOs based on personal experience and intuition.

Table 5: Seasonal equity

Period Steps (16 Days)	Equity	
	Group-A	Group-B
Period-1	0.84	0.39
Period-2	0.66	0.28
Period-3	0.37	0.56
Period-4	0.37	0.53
Period-5	1.14	0.63
Overall	**0.75**	**0.69**

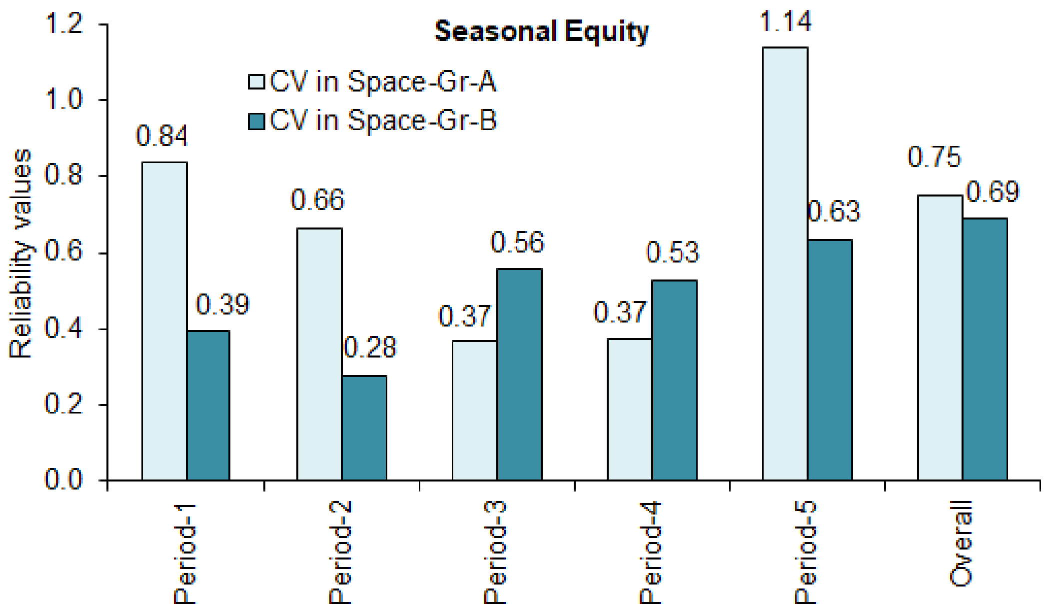

***Figure 4**: Spatial equity of SICs flow over Group-A and Group-B mode of operation*

3.3 Operational Schedule Efficiency

From Fig. 5 scheduled efficiency varies from 0.8 in S7 to 1.3 in S5 under Group-B mode of operation. The scheduled efficiency of respective SICs however varies within 30 percentages. This reveals the fact that adherence by WUA to scheduled opening of respective SICs is yet to be encouraged.

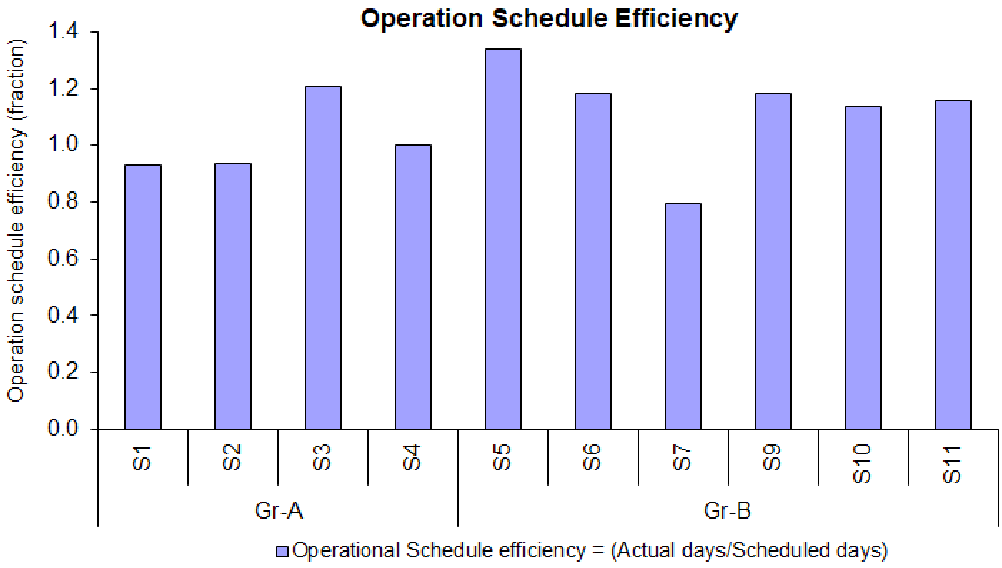

***Figure 5**: Operational schedule efficiency*

4. Conclusions and Lessons Learnt

- Seasonal adequacy of water delivery by Sardare Intake for groups of SICs is 1.03 (Good). However, reliability of flow variation over 5 periods under study is 0.3 (Fair).
- Submergence effect, either due to CR operation or due to temporary obstruction downstream of SIC on discharge measuring Parshall flume structure has enabled GOs to record more head over flow. However, structures have been calibrated only for free flow condition. Therefore, record of discharge comes out to be more than actual flow through structures. In effect, the adequacy and reliability of flow through SIC is impaired.
- The equity of scheduled flow distribution on periodic basis is highly variable as equity of Group-A as 0.75 and Group-B as 0.69. Series of Direct Tertiary Outlets (DTOs) off-taking from MIC is located at elevated positions entails operation of CRs by GOs based on personal experience and intuition. On account of it, struggle by WUAs of respective Group of SICs in receiving more than scheduled water during their turn has become evident. Therefore, target water level of respective CRs in MIC should be predetermined by use of suitable hydro-dynamic model considering discharge requirements of DTOs for given irrigation seasons.
- The operational schedule efficiency of respective SICs varies within 30 percentages on seasonal basis. Therefore, adherence by WUA to agreed water delivery schedule would minimize such variations.

- At the end of the irrigation season WUAs of MIC and SIC and GOs operating MIC should be informed of the outcome of seasonal water management practice and lessons learnt should be incorporated in the next year crop irrigation season in order to fine-tune improved water management process through participation of WUA.

Finally, findings show that there are promising possibilities for increasing productivity of water and land in the studied scheme.

Acknowledgements: This report is part of an outcome of Irrigation Management Transfer (IMT) consolidation process implemented by World Bank (WB) funded Irrigation and Water Resources Management Project (IWRMP) under Department of Irrigation, Government of Nepal.

References

Abernethy, C. L., 1986. Performance measurement in canal water management. ODI/IIMI Irrigation management network paper 86/2d. London: Overseas Development Institute/International Irrigation Management Institute (IIMI)

Abernethy, C. L., 1989. Indicators of the performance of irrigation water distribution systems. Symposium on Performance Evaluation of Irrigation Systems. 23 November 1989. Colombo: International Irrigation Management Institute (IIMI)

Ankum, P., 1995. Lecture Notes, Flow Control in Irrigation and Drainage. IHE Delft, The Netherlands

Clemmens, A.J. and A.R. Dedrick, 1984. Irrigation water delivery performance. Journal of Irrigation and Drainage Engineering, ASCE, 110(1), 1-13

Clemmens, A.J. and M.G.Bos, 1990. Statistical methods for irrigation system water delivery performance evaluation. Irrigation and Drainage Systems. 4: 345-365

International Commission on Irrigation and Drainage (ICID). 2008a. Research paper prepared by ICID in consultation with various experts from different international organizations.

IWMI (2007). Water for Food Water for Life: A comprehensive Assessment of Water Management in Agriculture. International Water Management Institute (IWMI), Colombo, Sri Lanka.

K.C., Birendra, Schultz, B. Prasad, K. (2011). Water Management to meet Present and Future Food Demand. Irrigation and Draiange, 60(3), 348-359

K.C., Birendra, Schultz, B. Prasad, K. (2017). Impact of Irrigation Management Practices on Land and its Productivity in Adressing Hunger and Poverty. Journal of Development Innovations, 1(2), 15-28.

Mishra, S. K., 2004. MSc Thesis (unpublished), Operation Performance of a Modernised Irrigation Scheme. Delft, The Netherlands: UNESCO-IHE Institute for Water Education

Molden David J. and Timothy K. Gates, 1990. Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering, ASCE. 116(6): 804-823

Rao, P.S., 1993. Review of selected literature on indicators of irrigation performance. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI)

Schultz, B., Thatte C. D., & Labhsetwar, V. K. (2005). Irrigation and drainage: main contributors to global food production. Irrigation and Drainage. 54.3.

United Nations. (2006). The united nations world water development report 2. UNESCO- WWAP, World Water Assessment Program. Available in CD-ROM.

Yadav, B. K., 2015. MSc Thesis (unpublished), Assessment of Water Resources and Irrigation Potential in Nepal. Delft, The Netherlands: UNESCO-IHE Institute for Water Education

Rejuvenating Water User Association (WUA) in Malaysia: A case of Muda Agricultural Development Authority

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Abstract

Irrigation development in Malaysia started with construction of two pioneer projects, namely, Muda and Kemubu irrigation projects, after the independence of Malaysia. The current 11th Malaysia Plan (2016-2020) aims to modernize agriculture into a high income and sustainable sector. One of the strategies identified for that is to get the involvement of smallholders farming community to optimize production from agricultural land. It needs rejuvenating water users' association (WUA) and a new approach for that is to make use of small farm units (SFU) in the irrigation blocks as the basis for forming WUA. This paper sheds light on how WUA approach has successfully been adopted for participatory irrigation management (PIM) in Muda Irrigation Project.

Keywords: *Malaysia; participatory irrigation management; rejuvenating WUA*

1. Introduction

Paddy cultivated land in Malaysia is about 6 million ha (Mha), out of which 0.28 Mha is irrigated by the tertiary system and the balance do not have sufficient irrigation infrastructure. There are twelve (12) granary areas, ten (10) in the Peninsular Malaysia (Fig. 1), while the other two (2) are in Sabah and Sarawak. These irrigated areas started to develop since Malaysia's independence in 1957, with the development of Muda Irrigation Project (area = 100,685 ha) (Fig. 1), which uses gravity-fed main system up to secondary level and the Kemubu Irrigation Project (area =29,450 ha), which uses pump lift system at the main water intake. Other 10 projects are developed after the completion of these two pioneer irrigation projects. The irrigation infrastructure density varies between 18m/ha to 48m/ha.

Figure 1*: Location of granary areas, and Muda and Kemubu Irrigation Projects in Malaysia*

This irrigated area has benefited almost 100,000 families, which are now implementing double rice cropping. The government is providing subsidized fertilizer as well as incentives for increasing production. The farmers' income has increased from poverty level (income less than 500 USD) in the 1970's to more than 6,000 USD/yr at the present. Other socio-economic activities were also carried out so that the farmers' income does not solely depend on rice production. Rice self-sufficiency of the country from all the granary areas has now reached to 70%. The balance 30% of the rice production is imported from neighboring ASEAN countries.

Ageing of the infrastructure facilities and "inappropriate" assumption in designing the tertiary systems have resulted a decline in the planned operation by modular water user group in the irrigation blocks. The new approach that makes use of Small Farm Units (SFU) in the irrigation blocks has shown success in revitalizing the water user group in the irrigation blocks. This approach has been initiated by the federal agencies to implement in all the granary by rolling out a master plan in November 2015. It is envisaged that the new approach of using SFU as the basis to form Water Use Association (WUA) in the granary area will derived positive results.

From the rapid appraisal process (RAP) carried out in the year 2004 in Muda Irrigation Area, the overall index of WUA was found as 0.6, which is relatively low compared to other countries where RAP was conducted. With the new approach of developing WUA by leveraging on the strength and potential of the SFU's, the overall index of WUA is projected to increase significantly.

The principle of good governance in WUA is applied in the irrigation blocks that meet the following conditions: i) adequate and reliable water supply; ii) legal status and participation; iii) organization within the hydrologic boundaries; iv) water deliveries are measurable volumetrically; and v) equitable collection of water charges imposed to all WUA members and land plot owners. With this implementation, the fifth national mission of strengthening the institutional and implementation capacity of the farmers in the country will be realized.

1.1 Malaysia's development plan

Development is the thrust of any nation building to uplift the quality of life. Since life begins man needs to satisfy the basic physiological needs of food. Countries in all stages of development focus on providing food to its population, with some exporting for income generation and some to supplement their needs.

After independence as a new nation, Malaya (then Malaysia) has charted its direction to fulfil its development goals. Major development programs were carried out prior to independence as well

as after the independence. It started with First Malaya Plan (1956-1960) and is continuing until the current Eleventh Malaysia Plan (EMP: 2016-2020). All the development plans gave emphasis on agriculture sector development with one of the latest was in the Ninth Malaysia Plan (2006- 2010) to revitalize the agriculture sector as the third engine of economic growth. The emphasis is to promote *New Agriculture* which gives priority to modernization and increased productivity.

The Tenth Malaysia Plan (TMP: 2011-2015) focused on economic growth on National Key Economic Area (NKEA). An NKEA is defined as a driver of economic activity that has potential to directly and materially contribute a quantifiable amount of economic growth to the Malaysian economy. Agriculture is identified as one of the twelve major NKEAs. One of the strategies in the Agriculture NKEA is to set up agriculture cooperatives to commercially intensified paddy production in the granary area. One of the factors taken into consideration was the economics of scale of the farms size to be centrally managed.

In the current Eleventh Malaysia Plan (EMP: 2016 -2020) the agro-food and industrial commodity will be transformed and modernized into a high income and sustainable sector. This sector is expected to grow at 3.5% per annum contributing 7.8% to gross domestic product (GDP) in 2020. Industrial commodities will contribute 57% whereas agro-food will contribute 42.4% to the total agriculture value added in 2020. Seven strategies have been identified in the eleventh plan. The first is to get the involvement of smallholders farming community to optimize production from agricultural land.

1.2 Irrigated agriculture development in Malaysia

The Government launched two major irrigation projects during the First Malaysia Plan (FMP:1966-1970) to increase production of rice, the national staple food. The Muda Irrigation Project (Fig. 1) was initiated in 1966, while the Kemubu Irrigation Project took off in 1968. These projects are integrated in nature, combining engineering infrastructure work and agriculture. The main objective of these projects was to provide sufficient supply of staple food for the nation's population and to reduce poverty among the farmers by increasing their income.

The priority of development was to provide basic irrigation infrastructures which consist of a network of canals and drains, control structures and farm roads to areas producing staple food for the country. Initially Muda Area was provided with infrastructure at a density of 10m/ha only. Realizing the inadequacy of infrastructural density in Muda Area, about a third of its area was later provided with tertiary irrigation and drainage infrastructures with a density of 30m/ha. The other seven granaries were later developed with higher intensity between 35 to 50 m/ha.

Provision of infrastructural development in irrigation projects without addressing the human needs bounds to have problems of implementation. Thus, the need for irrigation extension was realized in the early stage of the implementation of the irrigated agriculture development. Participation from the farmers in the design, operation and maintenance of the tertiary irrigation and drainage infrastructures by conducting *"kursustempatan"* (local engagement). However, the voluntary participation of farmers to operate and maintain the infrastructures leaves much to be desired has failed.

In the era before irrigation infrastructure were provided, farmers helped each other out in the single cropped paddy planting activities which is wholly dependent on rainfall. When modern irrigation facilities were provided and double cropping introduced, farming activities like transplanting and harvesting were still labor-intensive before mechanized land preparation was introduced.

2. Legal Framework of Muda Agricultural Development Authority (MADA)

After the completion of the Muda Irrigation Project, the Muda Agricultural Development Authority (MADA) Act (Act 70 of 1972) was enacted by the Parliament of Malaysia for the purpose of the operation and maintenance of the Muda Area with two main functions;

- To develop, promote, facilitate and execute socio-economic development in the Muda Area.
- To plan and execute in the Muda Area any agriculture development that has been authorized by the State Government of Kedah and Perlis.

Administratively MADA serves the function of three departments of the Federal Agency. The departments are the Department of Agriculture (DOA), Department of Irrigation and Drainage (DID) and the Farmers' Organization (LPP). The administration for the operation and maintenance covers an area of 100,685 ha divided in four regions. Two main activities are carried out by MADA annually. The major part of the activity is planting paddy for double cropping and supplying irrigation water for the double cropping.

To serve the population of over 53,000 farmers, Muda Area is served by 27 Farmers' Organization (FO) formally called locality. The FO law was also enacted as Farmers' Organization Act 110 of 1973. The structure of WUA as per the Act is shown in Fig. 2. The main purpose of the Act is to help the socio-economic development of the farmers under one single organization. The FOs' has been m10andated to carry out business activities under its Act to increase the income of its members.

Figure 2: *Water User Association (WUA) organization chart*

The FO has its vital supporting element called SFU. There are 496 SFUs under the care of the 27 FO's. Each FO has an average of between 15 – 20 SFU each. The SFU has an elected committee with the tenure of two years. The SFU is administered by a special "Procedure to Administer and Manage the Small Farming Units". The highest authority of the SFU is the bi-annual general meeting or the Extra Ordinary General Meeting.

The farmers at the unit level are the main players for the double cropping of rice in the Muda Area. The main activities of paddy planting in Muda Area starts with mechanized land preparation, sowing either in wet or dry condition, pest and disease monitoring, utilizing water supply from bulk supplier and harvesting by combined harvester is very well handled at the unit level.

For coordination purpose between the farmers' organization and the MADA's management, a coordinating committee was set up. This coordinating committee has a representative from each region. The committee meets once a month with the MADA's management to discuss issues related to the farmers' welfare.

2.1 The Muda Area

The Muda Irrigation Project or now commonly known as "Muda Area", is located in the north-west of Peninsular Malaysia (Fig. 1), occupying a flat coastal alluvial plain straddling the states of Kedah and Perlis. This area is the oldest area being planted with paddy since the construction of an irrigation canal constructed by the Prime Minister of Kedah, Wan Muhammad Saman, completed in 1895. The canal is still in use and has dimensions of 35km length, 7m breadth, and 1.5m deep. It runs from the present state capital AlorSetar to the mountain range of Kedah Peak, where the water source comes from during the monsoon period.

The climate in Muda Area is tropical and the area is shielded from direct rain-bearing winds of the north-east monsoon and the south-west monsoon. Rainfall during the wet season is usually sufficient to maintain one crop of paddy per year. However, the "off-season" crop from Mach to September has to depend on irrigated water which has been impounded in three dams in the eastern part of the Muda Area, 100km away from the paddy plain.

The development of the project area has covered three distinct stages;

- Early development which consisted of basic infrastructure and reticulation system including two dams constructed from 1965 to 1975. Canal, drain and farm road density was only at 10m/ha.
- First phase tertiary system development from 1979 to 1999 which aimed at increasing the canal, drain and farm road densities to 35m/ha in 45 irrigation blocks only.
- Second phase tertiary development system under the NKEA to increase the density up to 30m/ha in the remaining 128 irrigation blocks and to establish a centrally managed farm in 50,000ha of the paddy area from 2011 to 2020.

Being the largest granary in Malaysia, Muda Area has been producing almost 40% of the National paddy production. The average gross yield is 6.3 tons/ha with a target to increase production up to 8 tons/ha in 2020 through modernization and technological input in paddy cultivation. Even though the national self-sufficiency level for rice is set at 70%, increasing production in the Muda Area will benefit the farmers directly through increase in paddy production and indirectly to the nation by reducing of the imports of food bill.

3. Participatory Irrigation Management (PIM) in Muda Area

Paddy cultivation in the Muda Area has evolved from the traditional farming by using water buffaloes for land preparation in the pre-Muda era, to mechanized land preparation and harvesting by the combined harvester. Farmers tend to prepare their plot with *"berderau"* (cooperation) spirit among the farmers in the same village. During this time irrigation is totally dependent on the monsoon rainfall and without proper irrigation and drainage infrastructure.

With the development of Muda Irrigation Project, farmers are encouraged to form group farming or *"kelompok"* (group) in the definite irrigation blocks to cooperate among the members to carry out farming activities with the provision of secondary level infrastructure. After the first phase tertiary development, the *"kelompok"* based farming grew into *"semi estate"* entity through the Irrigation Service Area (ISA) which consisted of three to four Irrigation Service Units. The objective of forming *"semi estate"* paddy farming was for the farmers to fully utilize the tertiary infrastructure provided at individual plot level. With the improved facilities in the tertiary irrigation blocks it was recorded increase in yield for farmers in the "semi-estate".

The present NKEA initiated centrally managed *"paddy estate"* is similar to the *"semi-estate"* except the management is carried out by FO. The Government also provides incentives for the farmers' participation in proportion to the area of land owned by the farmers at the rate of RM 2,500/ha. This NKEA *"paddy estate"* started in 2011, with the objectives to form 0.5 Mha of paddy estate in 2020. The formation of the "paddy estate" since 2011 until 2016 is highlighted in Table 1.

***Table 1**: Basic information of NKEA centrally managed paddy estate*

REGION	PPK	Season 2/2011		Season 2/2012		Season 2/2013		Season 2/2014		Season 2/2015		Season 2/2016		MADA		
		GROUP A		GROUP B		GROUP C		GROUP D		GROUP E		GROUP F		GROUP. A+B+C+D+E+F		
		Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	Area (ha)	No. of Farmers	No. of Project	Area (ha)	No. of Farmers
I	A-I	235.166	131	227.113	138	195.192	146	201.488	127	103.995	63	152.721	71	17	1,115.675	676
	B-I	188.870	164	180.823	152	162.577	133	168.279	148	158.951	125	210.264	130	24	1,069.764	852
	C-I	241.320	207	190.190	135	261.580	194	186.097	135	142.891	112	185.099	99	23	1,207.977	882
	D-I	185.356	75	169.047	99	110.768	62	145.348	84	173.105	101	214.674	110	12	998.298	531
	E-I	250.731	147	183.978	131	292.903	172	224.888	138	161.343	96	350.379	153	23	1,464.222	837
Total		1,101.443	724	951.151	655	1,023.020	707	926.900	632	740.285	497	1,113.137	563	99	5,855.936	3,778
II	A-II	151.678	102	218.216	103	275.824	160	338.165	197	355.739	200	190.121	115	14	1,529.743	877
	B-II	107.203	58	116.886	61	218.956	109	200.807	112	297.564	159	190.434	93	19	1,131.850	592
	C-II	143.527	78	264.271	130	168.571	96	227.661	123	141.734	73	171.738	80	20	1,117.502	580
	D-II	127.321	76	64.277	55	148.783	87	161.145	117	138.212	75	224.061	115	26	863.799	525
	E-II	240.580	144	189.607	100	186.202	102	147.574	81	191.311	111	189.132	60	25	1,144.406	598
	F-II	122.170	59	174.750	101	286.563	145	218.203	120	128.128	63	121.888	55	17	1,051.702	543
	G-II	77.380	50	195.295	128	95.742	73	126.542	71	311.629	162	214.115	92	25	1,020.703	576
	H-II	350.912	197	257.528	128	352.132	141	218.284	113	299.434	115	273.864	124	39	1,752.154	818
	I-II	158.924	87	193.361	114	182.020	85	177.128	65	335.788	154	179.614	68	22	1,227.835	573
Total		1,479.695	851	1,674.191	920	1,915.593	998	1,815.509	999	2,199.539	1,112	1,755.167	806	207	10,839.694	5,686
III	A-III	224.688	124	206.566	120	191.485	105	216.923	123	144.652	85	166.570	98	24	1,150.884	655
	B-III	261.623	192	111.656	78	129.675	74	176.078	125	142.293	82	129.330	56	24	950.655	607
	C-III	182.732	93	253.522	132	140.761	68	225.702	93	141.080	64	187.917	76	20	1,131.714	526
	D-III	164.477	132	218.814	113	86.072	53	251.906	81	285.497	118	212.987	78	17	1,119.753	570
	E-III	164.449	69	376.613	91	337.135	88	113.023	58	135.768	65	329.090	98	14	1,356.067	469
	F-III	126.590	87	148.830	95	49.188	34	253.846	119	186.128	100	145.419	38	18	910.001	473
Total		1,124.559	697	1,116.000	629	834.306	422	1,237.478	599	1,035.418	509	1,171.313	444	117	6,519.074	3,300
IV	A-IV	249.027	118	194.465	111	174.204	78	163.794	80	108.731	65	201.450	96	17	1,092.491	548
	B-IV	170.060	106	186.000	113	249.591	116	163.502	84	115.635	46	156.521	62	13	1,041.309	527
	C-IV	163.969	88	198.030	139	213.471	127	179.934	99	188.666	72	177.286	98	20	1,121.356	621
	D-IV	106.884	58	188.291	110	153.299	95	154.617	54	135.053	64	174.545	71	25	912.789	452
	E-IV	380.776	133	186.000	129	175.063	69	194.447	93	390.737	106	348.465	97	19	1,375.488	617
	F-IV	242.039	127	182.691	128	223.450	136	136.236	75	185.259	111	173.678	76	18	1,143.353	653
	G-IV	97.133	42	105.033	54	117.516	85	165.072	100	30.577	22	125.098	70	16	721.689	413
Total		1,310.688	660	1,321.390	824	1,307.094	706	1,157.602	585	1,054.658	486	1,257.043	570	128	7,408.475	3,831
MADA		5,016.385	2,932	5,062.732	3,028	5,080.013	2,833	5,137.489	2,815	5,029.900	2,604	5,296.660	2,383	551	30,623.179	16,595

Table 4 : Basic Information on NKEA Central Management Paddy Estate

Throughout the evolution of over 47 years of the different phases of farming activities i.e. *"kelompok", "semi-estate" and "paddy estate"*, the most important condition to begin the planting season is the preparation on the irrigation schedule at the beginning of each season. The participation of the farmers is through their elected leaders from the unit to locality level and also through their representative in the Farmers Coordinating Committee.

Irrigation management in Muda Area is a **consultative process**. It normally starts with the meeting between the MADA's management with Farmers' Coordinating Committee from the FO. The purpose is to propose and agree to a planting schedule before each planting seasons starts. The consultative process is summarized in Fig. 3.

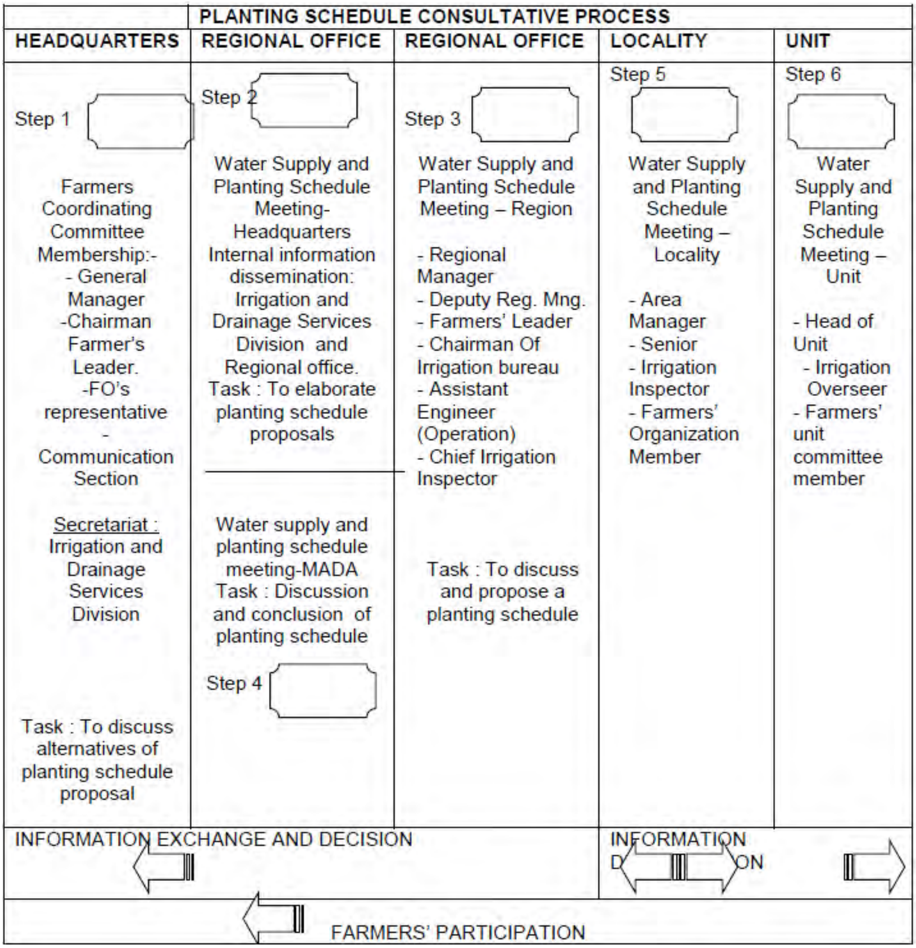

***Figure 4**: Planting schedule consultative process*

The consultative process takes place at four different levels, the headquarters, regional, locality and unit. The crucial process is at Step 1 to Step 4 (in Fig. 3) where decision on the planting schedule starting date is made. In Step 5 and Step 6 the farmers at the locality and unit are informed of the planting schedule decision.

This consultative process for planting schedule is part of the procedure in the Quality Management System (QMS) Malaysian Standard (MS) ISO 9001 of MADA's organization. The implementation of the QMS since the year 2001 has further encompassed Participatory Irrigation Management (PIM) in Muda Area as the system mandatory requirement of *customers' satisfaction* on irrigation management services included in the QMS.

The meeting for the consultative process for the preparation of the irrigation schedule normally occurs twice a year before the start of each season. The first season also known as the "off-season" normally starts in March with harvesting normally occurring in August. The second season or the main season normally starts in August/September and harvesting starts at early December in the same year. This meeting serves as a platform for direct feedbacks from the farmers' to MADA's management.

3.1 Water User Association (WUA) approach of PIM in Muda Area

In the Muda Area it is envisaged to have WUA in all 172 irrigation blocks. Each irrigation block has its definite irrigation and drainage boundaries. The farmers' representation in the irrigation block is through their elected leaders in the village called Small Farming Unit (SFU). An irrigation block may consist more than one small farming units. In an ideal case of a single unit in an irrigation blocks, the elected SFU committee can form the WUA committee. For irrigation blocks with more than one SFU, representative from the different SFU will be nominated or chosen to sit in the WUA committee at irrigation block level.

The structure in the SFU is the same as the proposed organization of the WUA as shown in Fig. 2. It is a strategy to form the WUA in the previously started group farming or *"kelompok" and the "semi-estate"* and NKEA *"paddy estate"*. A study by Kamaruddin et al. (1997) suggested the formation of WUA in the Muda Area will benefit in the following form;

- The WUA will convene to establish their irrigation block schedule to carry out the farming activities.
- The WUA association can reduce conflicts during the supply of irrigation water
- The formation of WUA is to inculcate the awareness on water productivity among the farmers. The farmers will get incentives with the increase in yield and water productivity.
- A more optimized water consumption will be translated among the farmers.

The purpose of the formation of the WUA is to have interaction between the committee of the WUA with the operational staff in the water management section at the locality office. Matters related to field water management, maintenance of waterways and operation and maintenance of tertiary level irrigation and drainage structures is handled by this combined unit called the secretariat of the WUA.

With the present approach of forming WUA based on SFU in the respective irrigation blocks, eight WUA established up to year 2016 in the Muda Area. An intensified approach in 2017 is targeted to establish 19 more WUAs in the selected irrigation blocks. The status of the pioneer group farming and WUA is highlighted in Table 2. The WUA is located in irrigation blocks comprising of an area between 500 to 1000 hectares.

Table 2: *Basic information of WUA in irrigation blocks*

Region	WUA Irrigation Block Area (ha)		
	2015	2016	2017
I	1,124.00	223.7	1221
II	433.83	742	3125
III	137.01	140	1153
IV	136.99	512.33	2018
Total	1,831.83	1,618.03	7,517.00

4. Observed Impacts of Participatory Irrigation Management (PIM)

The performance of the PIM can be assessed by the successful implementation of double cropping, started in Muda Area in 1974 in the form of pilot project in *KubangSepat*. Double cropping has since been implemented annually except for the incidence of drought in 1978. One crop was cancelled in the incident.

The participation of farmer's leaders in the consultative process of the planting schedule thus far has been well accepted. This process will continue in the future. The in-field water management practice needs more participation from the farmers. As what has been planned in the tertiary irrigation development, farmers are indecisive and reluctant to voluntarily taking over the maintenance of waterways (tertiary canals and drains) on the basis that these infrastructures were developed by the Government.

The issues during the tertiary development phase, the concept of *"neighboring in the farm"* is difficult to practice among the farmers due to absenteeism among the farmers in the farm. This is due to the farmers tending their plot are not residing in the locality.

Proposals by the Authority for the farmers to operate tertiary irrigation structures for water supply also were not well received by the farmers. Situations arise, when irrigation turnouts and regulating structures were damaged probably due to unsatisfied individual farmer on water conflicts in the paddy field. The formation of WUA in the irrigation blocks with local participation from the same and neighboring villages in SFU are more acceptable to the farming community.

In the Agriculture component of the NKEA to upscale paddy production in the Muda Area, an approach to amalgamate individual farmers into a central management paddy estate under the management of the FO started in 2011. The program will continue until 2020 with target to amalgamate 50,000 hectares of paddy land. This program is envisaged to further expand with the campaign to form WUA in the remaining irrigation blocks.

Effort to institutionalize the formation of WUA in the remaining 144 tertiary irrigation blocks in the central management of paddy farming will be led by the FO. It is hope that all 172 irrigation blocks will finally institutionalized WUA based on the strength of SFU in their respective irrigation blocks.

5. Challenges of PIM in Muda Area

5.1 Management and soft approach – Internal issues

5.1.1 Building capacity for capable WUA

Building capacity for a capable water user group is based on the country fifth national mission, "to strengthen the institutional and implementation capacity". It is envisaged that the formation of the WUA with the emphasis on in-field water management should arrest the issues of allocation, efficiencies, liberalization of economies, enhanced and enlarged participatory approach in decision making, irrigation management transfer and perhaps a new institutional arrangement.

The objective of building a capable WUA is finally to transfer the "ownership" of the operation and maintenance of irrigation infrastructure to the farmers themselves operated by a central management farming community in a competitive liberalized economic environment. The Government should allow a conducive enabling environment for FO to adopt themselves by introducing policy changes in managing the country water resources in a holistic manner.

As Muda Area is the major contributor/player of irrigated agriculture in the country, the options to manage the water resources available for water savings and conservation needs a policy review for the benefits of other consumer in the region. A comprehensive framework of a regulating charter should encompass an integrated approach which covers the inter sector of use of water resources, water efficiency and water conservation needs in the Muda Area.

5.1.2 Revisiting the present agronomic practice

The present wet seeding culture is widely practiced in Muda Area. It consumed almost 1600mm to 1800mm of water annually. This amount is considered high compared to another alternative of planting method especially direct seeding in standing water in the field. Direct seeding in standing water can reduces water consumption for paddy planting substantially. This will be a useful approach in water management to reduce the impact of water shortage in the Muda Area and the region.

Muda farmers start farming activities on their own capacity with their normal networking with the land preparatory who own tractors, to start their land preparation work to rotor the field with water inundated in the field. The seeding process for rice germination, dry or wet, starts after the land prepared earlier by the tractor is leveled by using power tiller which pulled a wooden bar to 'crest leveled' the field before the seed is broadcasted.

Prior to the seeding process, in wet direct seeding, water is drained out from the field to allow crop establishment. Water is then requested by the farmers after the seed established usually one (1) week after the seeds are broadcasted. A substantial amount of water is 'wasted' during the pre-process of germination of seed. Water is then supplied accordingly and correspondingly through the vegetative height of paddy plant until pinnacle initiation and right to the end before harvesting.

Direct seeding in standing water should be the water saving method of irrigated agriculture in the granaries of the country. By application of this method the water requirement for crop establishment can be reduced. Initial studies at MADA's training plot shows that water seeding can save water up to 12% when compared to the wet seeding planting method. Emphasis on prudent water management in the paddy field is the key to water savings.

The new irrigation method should be the choice between water saving or water wastage method to be applied in the paddy field. The emergence of mechanical transplanting which also require no standing water to allow trans-planter to transplant the seedling does have some impact to the farming community in terms of production cost and income. Additional cost in paddy production will be incurred if this new machine will be widely used in the Muda Area. Planting by mechanical trans-planter seem to be the same as wet direct seeding where MADA's water management practice is concerned.

5.1.3 Integration and optimization of human and natural resources

Rice production in the Muda Area is water dependent on the four (4) major sources of water in the area. The rainfall in the field, uncontrolled flow from river tributaries downstream of catchments, recycled drainage water and releases from the dam were the priorities of water usage practice in the field. The MADA's irrigation management practice is in collaboration with the farmers' leaders when fixing the planting schedule for every season is concerned.

After the process has taken place between the management and the farmers, these messages is widely disseminated to all farmers through radio talks and extending the meeting result through farmers' association staff and regional office staff. This process is also communicated through religious channel by informing the *"jemaah"* through the Friday prayer sermon.

Although the process of communicating on the planting schedule to the farmers is carried out extensively, delay in carrying out planting activities is bound to happen by at least two weeks. This delay although seemed a short period of time but the amount of water needed to be supplied is substantial if this delay is not checked.

A regulatory role in the form of guidelines with reference to the governance of MADA's Act and the Irrigation Area Act should be implemented or guided to the farmers in relation to double cropping activities in the Muda Area. A centralized agronomic and water management concept in the formation of WUA for the paddy cultivation as recommended in the formation of *paddy*estate needs urgent attention especially from the farming community and their institutions.

5.2 External challenges/issues involving Muda Area

5.2.1 Land use conservation in the catchment

Land in the Muda Area encompasses two distinct areas, namely, the plain where double cropping of rice is carried out. The area is almost continuously cultivated with *paddy* since double cropping started in the 1970's. The catchments area of forest reserve for the three dams where here the source of water is drawn from the reservoir to supplement the rainfed paddy field.

The catchment area of the three dams Muda (980 km^2), Pedu (171 km^2) and Ahning (122 km^2) sum up to a total of 1, 277km^2. Muda catchment being the largest has generated a lot of interest because of its valuable natural resources to be derived from logging activities. Besides the area has been identified as one of the richest in Malaysia in terms of wildlife containing 109 species of mammals, 174 species of bird, 54 species of reptiles and 33 species of fishes.

The State Executive Council has principally approved a reduced impact logging (RIL) i.e. Helicopter logging with the condition of an approved Detailed Environmental Impact Assessments (DEIA). The comprehensive studies on the impact of logging initiated by MADA with the collaboration of Drainage

and Irrigation Department (DID), Forest Research Institute of Malaysia (FRIM), Malaysia Institute Nuclear Technology (MINT), Agriculture University Malaysia (UPM), National University of Malaysia (UKM), University Technology Malaysia (UTM) and University Science Malaysia (USM) proves valuable in examining the DEIA report commissioned. With the comments of all parties involved the Federal Government decision to forbid further logging in catchments area is a wise decision indeed.

With the preservation of the catchments, not only domestic water supply to the northern part of Kedah, Langkawi and Perlis are fulfilled but also perhaps the supply of domestic water especially, to the central and southern Kedah and Penang are also safeguarded.

The issues related to the development of Pedu Lake Resort in the Pedu catchments area in the early 1990 was amicably solved. The development level of chalets should be above the maximum storage level whence the construction was carried out far below the maximum storage level due to difference of opinion of the project's consultant that the reservoir seldom reaches its maximum storage level.

Nevertheless, after the resort was completed, Pedu Reservoir reaches its maximum storage level after a year upon completion causing the chalets below the maximum storage level to be submerged under water.

The fact that the maximum storage level is important to retain the reservoir as per designed to make full use of the storage available for the supply of water for irrigation and as well as for domestic. Thus a prudent management decision is taken by the authority to safeguard the interest of the public at large.

5.2.2 Planned urbanization

The impact of Muda Project on the social and economic status of the farmers is obvious and already had been quantified. This leads to the development and expansion of urbanization in the Muda Area since the inception of the project. The demand of land for development is increasing because of land scarcity around the township.

In keeping with the aspiration of the Kedah and Perlis State Government, MADA has allowed the towns and growth centers to be expanded to reflect economies and social achievement of the states. The policy adopted by the management is that all development must be well planned and confined so as to cause minimum disruption on the operation and maintenance of infrastructure in the Muda Irrigation Project.

To achieve that goal, MADA has initiated several urbanization studies with the Local Authorities as well as the Town and Country Planning Department as early as 1979 and a series of development zone has been agreed upon not only in towns like *AlorSetar, Kangar, Jitra* and *Kota SarangSemut* but also small towns like *Kodiang, Air Itam, Jerlun* etc. As a result, urbanization in the Muda Area, more than 3,000 ha of paddy land had been used up and converted for commercial and housing development.

6. The Transformation Model as a Way Forward

The National Transformation Program (NTP) plan to develop Malaysia into a "high income nation economy" requires managing resources efficiently which will definitely contribute to Malaysia 's environmental endowments. In the New Economics Model (NEM), inclusiveness and sustainability are the key indicators of transformation. Inclusiveness is the participation of all levels of farming community to participate in a proper planning for a sustainable management of water resources in *paddy* cultivation.

This paper proposed a model to support the implementation of *paddy* farming commercialization as a strategy in the agriculture component of the NKEA, which can specifically be carried out in the Muda Area and to other IADA's granary.

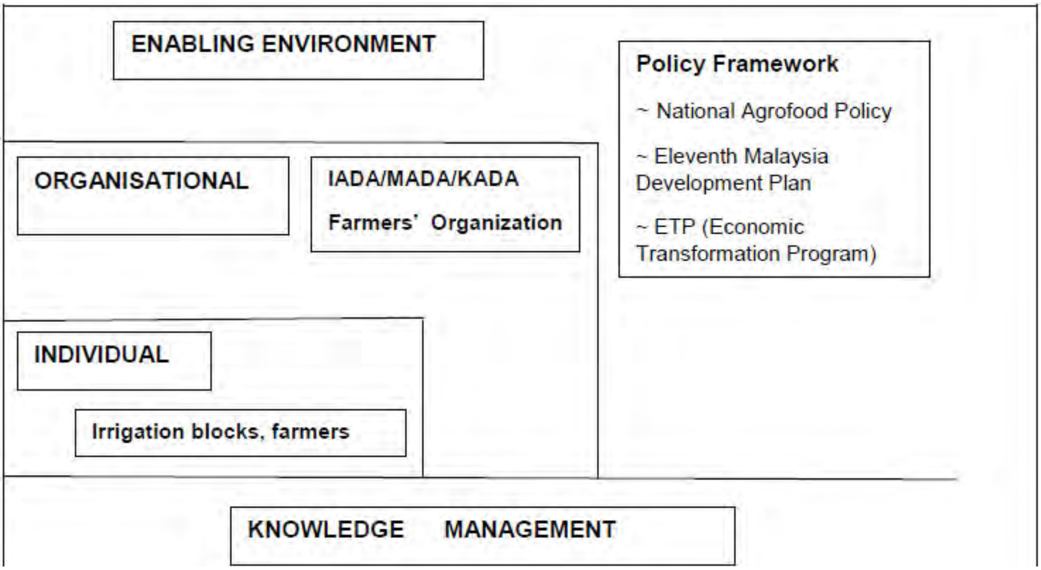

Figure 4: *Model of capacity development for Agriculture Water Management Transformation*

6.1 Description of the model

The model recognizes the needs for continuous capacity development where knowledge management forms the basis of its development. The practical aspect of this model is in its implementation where the management team plays an important role in the successful implementation of commercial group farming. The FO should take this leading role into transforming their role to hinge on commercial *paddy* farming to be turned into their success business arm.

The relation of the management team or system managers and the WUA shall be further enhanced to provide "hands-on" and "in-service" capacity development approach in the country. This will expedite the Irrigation Management Transfer by creating one commercial group farm in one irrigation block as envisaged in this paper.

The proposed transformation is based on works carried out by International Commission on Irrigation and Drainage (ICID). Three levels or domain for capacity development needs to be addressed, which are;

- enabling environment
- organization
- individual

In the context of Malaysian Granary Area, the Government is creating an enabling environment, by supporting in terms of relevant policies to allow the farmers to aggressively participate in the *New Agriculture* initiated in the Ninth Malaysia Development Plan. Malaysia is a country which has good track record in development since independence. Nonetheless, the Self Sufficiency Level (SSL) of 70%, as

spelled out in the National Agrofood Policy, of local *paddy and rice production* may need to be reviewed.

The second level or domain viz organization, in this transformation context is proposed to "change functional role as service provider" for bulk water provider by the Integrated Agriculture Development Area (IADA) and *paddy* growers - farm operators by the FO. This transformation requires change management role of the two organizations among which the FO must take the leading role to aspire as the *"Tuan Padi Tuan Beras"* notion propagated by politicians.

The *New Agriculture* to commercially produce high yielding *paddy* with technology-based inputs at farm level will generate higher income to the farmers. With high production levels the country may be able to export quality rice with the application of green technology. The country can be self-sufficient if all the resources are fully utilized in the Granary Areas.

The IADAs' will distribute water at the irrigation block level and the internal reticulation is controlled by the FO. Water distribution at the field level will be coordinated and managed by the FO. This will enhance water management at the farm distribution level. This will facilitate the farmers grouping into large scale commercial farming.

Emphasis of the model should be at organizational and individual level. The two groups are the enablers of the model which actually translates the implementation of the group commercial farming with high yield target for the agriculture industry. Knowledge generation, management and dissemination are increasingly important features which require the concerned authority for successful capacity development.

6.2 The enabling environment – Government policies

The desire to transform should be understandable to all levels of the "*rakyat"* especially the farmers who are involved in the *paddy* industry. The Ten Big Ideas behind the Economic Transformation Program (ETP) should be made known to the *Farming Community* which comprises of the land owners, the tenants, the farming service providers, the millers and the consumers. Four of the big ideas, transforming to high income through specialization, concentrated growth and inclusive development, supporting effective and smart partnership, and valuing our environmental endowments should be the guiding principle in this national transformation program.

In the context of the country's National Mission, thrust five of the mission viz strengthening the institutional and implementation capacity should be the mission of the *Farming Community* in the development of agriculture sector in the NKEA. Strengthening the institution means to reinvigorate the capacity of the present FO to be a self-sustainable and profitable farmer's business arm. One can imagine what will be the capacity of the FO if their business is put in high profitability.

The development of agro-politan in the major granary area to inject economic growth for a higher income to the farming community to increase *paddy* production will be the target of the transformation model.

6.3 The enablers – the organizations

The situation to enable this economic transformation shall be taken by the government agencies involved in the agriculture water management. Agencies like the Division of Agricultural Irrigation and Drainage, Integrated Agriculture Development Area and Farmers' Association must play the management role for the commercial farming groups. By providing the leading management tools for these groups commercial farming will ensure efficiency and productivity growth in the *paddy* sector.

6.4 The Indicators

Target indicators for success of capacity development should be measurable. Results from Rapid Appraisal Process (RAP) carried out in two major granaries can be use as reference is set out for the capacity development of this new approach and "inclusive development" propagated by the Government. A simple matrix indicator index to the enablers of the development is proposed as shown in Table 3 below.

Table 3: *Indicators for the enablers group*

Enablers Group	Indicators
The Bulk Water Provider (IADAs")	~ Operation Efficiency ~ Conveyance Efficiency ~ Distribution Efficiency ~ Field Application Efficiency
The *Paddy* Grower (Special Purpose Vehicle)	~ Output per Crop Area ~ Output per Unit Irrigation Supply ~ Water User Association (WUA)

6.5 The future direction

As the country is rapidly moving towards transformation for a high-income nation, agricultural development specifically *paddy* production should be the driving force of the Nation Agriculture Policy by providing sufficient food for the people and provide "new spin off" industry to the farming community. The capacity development no doubt will be complex and demanding task for the authority to pursue. Nonetheless, it is indeed crucial to be carried out for successful *transformation.*

Knowledge generation, management and dissemination are important to ensure the success of capacity development. The knowledge pool covers not only policy and matters related to agriculture but also those related to water management and environment. This will enhance awareness level of farmers on the national environmental endowments. With the increasing importance of governance in water sector the knowledge acquired will definitely equip our farmers in development of high income rice growers in the country which will be truly inclusive in nation building.

7. Summary

Water User Association (WUA) exists in the Muda Area although without the legal organization setup. The successful implementation of double cropping and production of nearly 40% of the national rice production from the Muda Area is a testimony to itself. This effort is difficult to implement without the full cooperation of the farmers or entrepreneur farmers in this "Rice Bowl of Malaysia".

The implementation of a formal WUA must be streamlined with the country's fifth national mission to strengthen the institutional and implementation capacity. This mission is a national agenda. A framework for irrigation water governance is required to complement the National Water Policy. In this way the

natural resources of the country can be managed efficiently and holistically. This, however, requires capacity building of human resources involved in the rice production of the country.

Acknowledgements: The author wishes to express his sincere thanks to MADA's Management for allowing the presentation of this paper at the 8th Asian Regional Conference, Kathmandu, Nepal, 2nd to 4th May 2018.

Reference

Nasiruddin, A. (2012). Paddy Production in Muda Area: From Individual Based to Commercial Farming, In: Asia Irrigation Forum, Asian Development Bank, 10th -13th April 2012, Manila.

Franks, T., Garces-Restrepo, C., Putuhena, F. (2008). Developing Capacity for Agricultural Water Management: Current Practice and Future Directions. John Wiley & Sons, Ltd.

Economic Planning Unit. (2010). Tenth Malaysia Plan 2011-2015. Kuala Lumpur.

Ministry of Finance. (2010). Economic Report 2010/2011. Kuala Lumpur

Mukhlis, Z.A. (2010). Participatory Irrigation Management in Malaysia with Reference to Muda Irrigation Project. In: Proceedings of the Workshop on Sustainable Agriculture Water Management from PIM Perspective, Tehran, Iran.

Mukhlis, Z.A., (2009). Food Security and Poverty Alleviation in the Millennium Development Goals: The Role of Muda Irrigation Project. In: 14th MANCID Annual Conference. 14th – 15th February 2009. Merdeka Palace Hotel, Kuching, Sarawak.

Economic Planning Unit. (2006). Ninth Malaysia Plan 2006-2010. Kuala Lumpur.

DID (2004). Training Workshop on Modernization, Management Improvement and Benchmarking. Kuala Lumpur.

Shafie, A.G, Loh, K.M., Dahuli, K. (2003). Role of Irrigation and Drainage in Raising The living Standard of Farmer in The Muda Area,

Ho, N.K., Foong, K.C.K, Dahuli, K. (1998), Sustainable Rice Production – MADA Experience, Rice Conference, AlorSetar .

Geh, Y.L., Kamaruddin, D., Shahrin, S. (1997). Water User Group: MADA Perspective,

Fujii, H., Cho, M.C. (1996). Water Management under Direct Seeding In Recent Advances in Malaysia Rice Production – Direct Seeding Culture in Muda Area Edited by Morooka Y, Jegathesan S and Yasunobu K. MADA/JIRCAS

MADA, (1977), Feasibility Report on Tertiary Irrigation Facilities for Intensive Agricultural Development in the Muda Irrigation Scheme Malaysia, AlorSetar, Kedah.

Teoh, T.S. (1973). The Need of Irrigation Extension in Irrigation Projects (With Special Reference to Muda Irrigation Project) In: National Seminar on Water Management. 22nd – 27th July 1973, AlorSetar, Kedah

Mohammad, A.N.B., Natalia, P.D. (undated). Irrigation System in Rice Granary Area of Malaysia-Challenges and Need for Transformation, Ministry of Agriculture, Malaysia.

Re-organizing Water User Association from flood irrigation system to modernization of irrigation system: A case study of Rani-Jamara-Kulariya irrigation system, Kailali district, Nepal

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Abstract

Rani-Jamara-Kulariya Irrigation System (RJKIS) is one of the largest Farmer Managed Irrigation Systems (FMIS) in Nepal. It has a combined cultivable command area (CCA) of 14,300 ha and draws water from the Karnali, one of the largest perennial rivers in Nepal. The RJKIS was first developed by the indigenous Tharu community between 1896 A.D. (Rani System) and 1915 A.D. (Kulariya System). The Jamara System was developed from 1903 A.D. onwards. The RJKIS is a century old system supporting the livelihood of thousands of farmers in that area. One of the challenges the system is facing is the operation and maintenance. Each year, thousands of farmers (called Desawar) contribute labor to divert water from the river to earthen channels to irrigate the paddy fields. The Water Users Association (WUA) has elaborate organizational structure for resource mobilization. However, farmers have encountered difficulty coping with changes in the river morphology. Typical problems include inability of the farmers to divert water to the irrigation systems during low river flows; uncontrolled flooding affecting the scheme during high flow; and frequent wash-out of temporary diversion. They have to put efforts frequently to control erosion of canal banks and sedimentation of canals. The last village of this system is about 30 km away. The poor road connections make many parts of the command area inaccessible during the monsoon season.

The Government of Nepal, with the support from the World Bank, initiated modernization of the RJKS by providing water control structures in the intakes and main distributaries of the system. The packages of the modernization are institutional development of WUAs, access road development, and agriculture improvement programs. The second order infrastructures for delivery of water at the farm levels are yet to be in place which will be done in the second phase of the project. Effort is made to match the institutional development along with the modernization of the infrastructure and installation of the control structures. This paper attempts to highlight how the modernization of infrastructure has brought changes in the roles and responsibilities of the WUAs at different levels of the system.

Keywords: *Farmer Managed Irrigation System; irrigation modernization; Rani-Jamara-Kularia Irrigation System; Water Users Association*

1. Introduction

The Rani-Jamara-Kulariya Irrigation System (RJKIS) is a century old irrigation system located in the western Nepal. It is one of the oldest Farmer Managed Irrigation Systems (FMIS) that provides livelihood for thousands of farmers in the area. The system has been facing a lot of challenges in operation and maintenance (O&M). The Government of Nepal with the support from the World Bank initiated modernization of the FJKIS. The success of irrigation system modernization depends on its ability to respond to physical, social and economic changes. The modernization breaks the monotony of status quo of socio-institutional, water delivery and water use systems and addresses the changes in agriculture practices and marketing of the products. As per the project document (World Bank, 2011), the modernization program includes following three main components.

1.1 Component-1: Scheme modernization

This component consists of: (i) construction of a feeder canal to link the three main canal systems; (ii) rehabilitation and modernization of Rani (20 km), Jamara (16 km), and Kulariya (16 km) branch canals, mainly focusing on intake structures, control structures, diversion structures, and canal bank protection; (iii) command area protection works against flooding from adjacent rivers such as Karnali, Mohana, and Patharaiya; and (iv) improving and upgrading about 61km of roads within the project area and construction of bridges and culverts.

1.2 Component-2: Strengthening Water Users Associations (WUAs)

The component aims to strengthen WUAs to assume full responsibility for the O&M of the infrastructure constructed under the Component-1. This will require different skills than the WUAs currently have. Most of the current experience of the WUAs is in mobilizing members to carry out certain channel excavation and desilting works, but with the new structures, the WUAs will have to carry out O&M in a more technical and professional manner. In particular, under this component the project will finance:

- Training and support to WUAs in the aspects such as the development and implementation of adequate O&M plans, setting of irrigation service fees, maintenance of records and accounts, participatory monitoring, conflict resolution, and optimizing the higher-order system water management for the benefit of all users. There will also be focus on ethnic and gender issues through awareness creation and training. There will be specific focus on encouraging female landholders to take up WUA executive committee positions and train them in effective committee membership and avoidance of exclusion by women and ethnic minorities in the running of WUA.
- Construction of WUA offices in a central location of each of the WUA command areas;
- Providing office equipment;
- Providing office vehicles such as motorcycles, O&M equipment, and funds for the annual excavation of the Jarahi Nala Channel for diversion of water from the Karnali River;
- Farmers study tours to successful WUA.

1.3 Component-3: Agricultural production support

This component will carry out a series of agriculture production support activities in the project area through demonstrations, farmer field schools (FFS), and other adaptive processes. The component will also carry out several strategic studies on the options for agriculture diversification, value addition, and institutional innovations that can be promoted during phase 2 of the project. It is stressed that the main gains in production increases, diversification of cropping patterns, and assistance to improve the marketing of crops will be made under phase 2 when the command area gets improved.

The following set of specific activities will be undertaken under the project: (i) implementation of demonstration plots and adaptive research; (ii) organizing FFSs; (iii) development of packages for the promotion under phase 2 of crop diversification, integrated pest management (IPM), and integrated plant and soil nutrient management (IPSNM) practices; (iv) strengthening the Agriculture Service Center (ASC) and Agriculture Contact Points (ACP) within the project area; (v) initiation of support to the production of high quality certified seeds through identification and training of interested private contract farmers and community-based seed producing entities; and (vi) training of staff of the District Agricultural Development Office (DADO) to improve the technical knowledge and the ability to advise on innovative practices.

The objective of this paper is to shed light on how the modernization of infrastructure has brought changes in the roles and responsibilities of the WUAs at different levels of the RJKIS. The changes considered are in various aspects such as technical knowledge, shift from labor contribution to financial contribution, use of banking systems, use of digitized recording systems, etc.

2. Description of Project Area

The RJKIS located in Kailali district in Nepal has a combined cultivable command area (CCA) of 14,300 ha. It draws water from the Karnali, one of the largest perennial rivers in Nepal. This century old system was developed by the indigenous Tharu community between 1896 A.D. (Rani System) and 1915 A.D. (Kulariya System). The Jamara System was developed from 1903 A.D. onwards. Each year thousands of farmers contribute labor to divert water from the river to the irrigation channel for paddy cultivation. The WUA has elaborate organizational structure for resource mobilization for the acquisition of water from Karnali river to irrigation systems.

However, farmers started encountering difficulties to cope with changes in the river morphology. Traditional construction materials like logs, bushes and boulders were getting scarcer. Many of the forest areas around this vicinity were either part of national protected forest or under the community forestry program. It therefore became difficult to get access to these forest products. On top of that, migration of young people from those villages made the mobilization of "*Desawar*" difficult. Other notable problems include inability to divert water to the irrigation systems during low river flows; uncontrolled flooding affecting the scheme during high river flows; frequent wash-out of temporary diversion structures; erosion of canal banks from uncontrolled intake of water; sedimentation of canals; and inability to manage the water equitably and efficiently. Accessibility within the villages and among the villages within the command area became a big bottleneck during monsoon period. The Karnali River is an aggressive and unpredictable gravel bed river that often changes its course. As a result, the irrigation systems regularly suffer from either shortage of water or severe. flood damage.

With an objective to improve the resources utilization and water delivery service to the farm, the

Government of Nepal and the World Bank have initiated the scheme modernization program for improving canal infrastructure to ensure smooth operation of canals. This is the first critical step in the modernization process. The second order infrastructures for delivery of water at the farm level are yet to be in place which will be done in the second phase of the project. Another aspect of modernization is strengthening WUAs. The institutionalization of the WUAs is important as roles and responsibilities of WUAs will change along with the modernization of the infrastructure and installation of the control structures. The institutionalization will be carried out in three tiers: The first tier (main committee) comprises of the representatives from all the three systems. The second-tier organization is of Rani, Jamara and Kulariya. The third level organization is at Mauja level managed by Badghars.

3. Traditional Management of Irrigation System

Indigenous Tharu institutions have traditionally managed these three *Kulos*. In this system, each *Kulo* is headed by a *KuloChuadhari*. The first *Chaudharies* were those who had taken initiatives to establish the *Kulos*. They usually came from well-to-do families and the position was often passed from one generation to the next (e.g., Ravi L Chaudhari, the current chairperson of KulariyaKulo). *Chaudharis* held the position and remained active as long as they wanted to. *Chaudhari* has been a voluntary position. Each *Chaudhari* was appointed and were supported by the following members of the traditional irrigation management system

- *Deshawar* - Responsible for mobilizing labour during operation and maintenance of the main and sub-canals.
- *Chiragi* - Responsible for disseminating information regarding irrigation management. There existed two layers of '*Chiragi*' – one is responsible for disseminating information at the sub-branch level whereas the other is at the *mauja* (or settlement) level.
- *Guruwa* - Responsible for conducting irrigation related rituals.
- *Nandarwa* - Responsible for assessing how much work is needed for operation and maintenance of the mains source and sub-canals, and determining which village is responsible for contributing how much labor depending on the size of the village and its total population.
- *Badghar* - usually came from a relatively better-off family, and the position was voluntary, but unlike the *Chaudhari*, a *Badghar* was subject to annual dismissal or re-election. Each year on the day of *Maghi* (or the first day of Maagh), users in each *Mauja* (settlement) elect their *Badghar*. The *Badghar* looks after local public works, community affairs, discharging political as well as judicial duties.

In each *Mauja*, *chiragis* are appointed. They work under the supervision of *Badgar*. The *Chiragi* works as messengers of the village who would relay important messages to the villagers. *Chiragis* were paid in kind (certain amount of paddy harvest from each household). The *Badghars* are the local leaders of *Mauja* (villagers in each settlement). They make their own rules and regulations. The population of the command area and number of sub-canals has increased significantly since the *kulos* were first built to service a limited pool and scale of predominantly Tharu population. As new settlements were established and existing ones expanded, residents started diverting water to where they lived and as per their water requirements. The irrigation management system, too, evolved alongside such demographic shifts. The transformation in the demographic profile of the *Badghar* system serves as an example. Even though the *Badghar* system is an indigenous Tharu institution, recent settlers from the hills too have adopted it. Traditional management of irrigation system in RJKIS is well documented in Pradhan et al. (1987).

4. Transformation in Waters Users Association in the 1980s

Before the early 1980s, each system had two level organization for water distribution. System-level WUA under the leadership of *Chaudharay* and *Mauja*-level WUA under the leadership of *Badgar*. A big flood in the Karnali river took place in the early 1980s, destroying the intakes of these three systems. After the event, an adhoc central committee of these systems formed under the chairmanship of Mr. Khadga Bahadur Singh, who was also the Chairman of Tikapur Development Project and ex-minister of agriculture, having a very good connection in Singha Durbar. He was accepted as the chairman of the central committee with the hope that he will be able to mobilize necessary resources for rehabilitation of these systems.

Beginning in the mid-1980s, formal irrigation users' committees (IUCs) appeared in all three *Kulo* systems. The IUCs worked in three major areas—management of annual source maintenance, management of inter-branch issues and concerns, and communication with external agencies like the Department of Irrigation (DoI). IUCs hardly ever intervene in *Mauja* (settlement) affairs. If the IUCs have to make major decisions at the settlement level, which is rare, they work closely with the local *Badghars*. At the *Maujas* level, *Badghars* more or less autonomously manage the irrigation system and community affairs even if there are branch committees. The IUCs and *Badghars*, for example, collectively manage annual water source maintenance work when tens of thousands of users are mobilized at the source near Chisapani.

5. Water Distribution

Since the *Kulos* have historically practiced a highly decentralized form of governance, the rules for the allocation of water are entirely determined by local communities. Once the source at Chisapani is repaired and water diverted to the individual *Kulos*, the IUCs were normally out of sight and the burden of water allocation falls on *Badghars* and users themselves. In each settlement, *Badghars* set up rules of water allocation based on the amount of water available and the size of land to be irrigated. *Badghars* decide the method of water distribution either by rotation system or continuous flow depending the water availability status. This process continues until the whole settlement is irrigated. Disputes did occur time to time, but most often them were managed amicably and settled locally. Since the IUCs had not instituted water allocation rules, head-enders and tail-enders frequently engaged in water allocation disputes, particularly when water was scarce. In such cases, if the tail-enders felt that the head-enders have used water unfairly, they have the right to go up to the diversion structure upstream and remove the structure. At times, head-enders resist and reconstruct the diversion structure. If the tail-enders still feel that they have been unfairly treated, they repeat the same procedure, that is, sabotaging the diversion structure put up by the head-enders. If serious disputes occur, the *Badhars* normally sit down and set up new allocation rules.

6. System Maintenance

There are three types of major maintenance works—diversion of water from Karnali via Jarinala to individual intakes, *Kulo*, branches and sub-branches. The IUCs are responsible for the management of source maintenance. Unless the branches and sub-branches face significant problems needing external help, the IUCs do not normally intervene in local affairs and *Badghars* and branch committees manage all the problems occurring in branches and sub-branches. Source maintenance is held every year from January-February to May-April. Other types of repair work are carried out as and when necessary. In

fact, the *Kulos* hardly require maintenance (except for the erosion of the embankment, which is not too frequent).

Similarly, branches and sub-branches at times have problems of siltation. In such maintenance works, only those who are directly affected by the problem contribute to maintenance work. Normally if there is a problem in the branch or sub-branch serving settlement, only those in the settlement contribute to maintenance work.

In addition, contribution to source maintenance is much more demanding than other repair and maintenance works. Source maintenance requires several days of work in a year for different crop seasons. In the late 1980s, government provided the support of machines like bull dozers and excavators. They have their own problem of O&M of these machines for desilting and operation purposes. These work of desalting takes place near Chisapani. *Badghars* are responsible for mobilizing users in their settlements for source maintenance. Since the governance structure is highly decentralized, the *Badghars* have the complete authority over how locally-based conflicts are resolved. In the past *Badghars* imposed heavy fines on free riders.

7. Intervention During System Modernization

From 2011, the World Bank supported the systems to modernize the physical facilities along with institutional development of WUA and agriculture development component. The main aim was to address the modernization of the three irrigation systems by constructing control and regulating structures, command area protection and rehabilitation of the road system. The major completed activities were: (i) construction of a 7.6 km feeder canal to link the three main canal systems; (ii) rehabilitation and modernization of Rani (20 km), Jamara (16 km), and Kulariya (16 km) branch canals, along with completion of 15 number of water level and discharge regulators, and 33 number of head regulator structures at different locations of the three systems where the sub-secondary bifurcate from secondary canals; (iii) command area protection works against flooding from adjacent rivers such as Karnali, Mohana, and Patharaiya; and (iv) improving and upgrading of about 117 km roads within the project area and construction of bridges and culverts.

The main objective of institutional development component was to strengthen WUAs to assume full responsibility for the O&M of the infrastructure constructed under modernization. Trainings, workshops, and study tours were organized. They include programs at the project site around the system area. Both observation training programs were organized within Nepal and oversea countries for the WUA officials and to the project officials. WUA office buildings for three systems and for the main committee have been completed. It is hoped that the records of these system will be kept safely in these WUA office buildings. The record of the WUA members of each system is updated and records are kept both in hard and soft copy. These offices are now equipped with furniture and office equipment. The WUA members are given membership cards with the size of land ownership and amount of water fee to be paid. The WUA office started collecting the water fee which will be shared among those three levels. Details on the institutional development (i.e., component-2) are available in Upadhyay (2017).

The project commissioned to a consulting firm to undertake satisfaction level of the farmers in the project area after project implementation. Fifty (50) percentage of the respondents reported satisfaction of the project implementation (SIDEC, 2017). However, efforts are yet to be made to make effective delivery of services to increase satisfactory level of the farmers.

Likewise, the main aim of agriculture component was to increase production and productivity of cereals, vegetables and fruits by introducing modern technologies and practices and using the available water properly to improve the firm outputs and income of farmers. The component has triggered farmers towards increment in yield **(**Table 1**)** as well as changing their traditional cropping pattern from cereals to more profitable crops like vegetables, potato or banana.

Table 1: Increase in irrigated crop yields of rice, wheat and maize (Source: Agriculture Component Implementation Unit, RJKIP, Agricultural Development Strategy for MoRJKIS-2, 2017)

Indicators	Unit	Baseline	Progress, Sep -17		Average productivity	Progress in percentage
			Project's plots	Farmers' plots		
Paddy (Spring)	Mt/ha	2.8	5.0	3.2	4.1	132
Paddy (Monsoon)	Mt/ha	2.6	4.6	3.1	3.8	131
Wheat	Mt/ha	1.6	4.1	3.0	3.5	184
Maize	Mt/ha	1.7	3.9	2.9	3.4	188

8. Re-Allocation of Activities Among Different Committees After Intervention

The irrigation management practices are highly decentralized. At present the system level WUA is responsible for coordinating with the project office, DOI and other stakeholders for operationalization of the modernization process of irrigation system. It is further involved in the formulation of strategies, plan and policies for institutionalization of WUA affairs throughout the system. The branch level WUAs are responsible for the management of annual source maintenance, monitoring the irrigation related activities of *Badghar*, coordination between system and sub-branch level committees including external agencies like DOI and Department of Agriculture (DoA).

In *Maujas* (settlement), the *Badghars* are more or less autonomous indigenous institutions responsible to manage the irrigation system and other social affairs. At present *Badghar* are responsible to collect irrigation service fee from the beneficiary farmers. Out of the total collection around 10% is provided to *Badghar*. In 2016, the rate of water fee was only NRs. 150/ha. However, Jamara has increased water fee to NRs. 300/ha. But, collection rate shown in the official record is less than 50% of potential collection. However, the labor contribution record shows higher amount converted in cash equivalent. Likewise, all decision of the branch level WUA are enforced and implemented by *Badghar*. As traditionally assumed responsibility, irrigation related conflicts also fall within the jurisdiction of *Badghars*. After the establishment of formal irrigation institutions, the role of *Badghars* that they were assuming before is duly recognized. In addition to ISF collection, the *Badghars* are still responsible for irrigation management tasks at farm level including resource mobilization (*Desawar*) during water diversion from Karnali when large numbers of farmers are mobilized at the source river. Table 2 shows the annual labor contributed by farmers.

***Table 2**: Labour contribution status (Source: Implementation Completion Report of MoRJKIS-I Tikapur, Kailali, 2018)*

SN	Name of WUAs	Labor contribution person-day by FY					
		2068/069	2069/070	2070/071	2071/072	2072/073	2073/074
1	Rani WUA	4008	38976	58597	35109	43886	50366
2	Jamara WUA	37923	37797	31368	38699	48362	56396
3	Kulariya WUA	7064	70279	97928	78978	76578	95601
	Total	48995	147052	187893	152786	168826	202363

All three committees have now initiated collecting funds. Membership fee, renewable fee, and irrigation service fees (ISF) are major sources of regular income for all three branch-level WUAs. In addition, the regular income includes penalties collected from the beneficiaries who failed to participate during source maintenance. Out of the collected irrigation service fee, each branch canal provides 10% to the main canal committee and 10% to *Badghars*. The WUA records show that the collection of water service fee stands between 28-50% of the targets (Table 3).

***Table 3**: ISF collection status (Source: Implementation Completion Report of MoRJKIS-I, Tikapur, Kailali, 2018)*

FY	ISF collected by WUAs (Rs)				Progress (%) of target
	Rani	Jamara	Kulariya	Total	
068/69	141000	200778	131282	473060	28.76
069/70	18000	299251	145546	462797	28.14
070/71	17730	593741	161357	772828	34.12
071/72	272677	500345	250581	1023603	45.20
072/73	291817	543341	217335	1052493	46.48
073/74	225962	511865	587041	1324868	49.90

The Kulariya, Jamara and main canal WUA have paid secretarial staff responsible for day-to-day operation including all essential record keeping. In Rani, all documentation including financial records are being kept by the secretary. In all WUAs, a system of regular meeting has been initiated and the meeting minutes are well maintained, the financial records are properly kept and annual transactions are audited by authorized auditors in all four WUAs. The WUAs registrations are regularly renewed, list of beneficiary member with landholding including the number of parcels are maintained in all three-branch level WUA. The system of service fee collection has been started in all three WUAs and the record of service fee collections, dues has been maintained properly.

9. Institutional Reform of WUAs

The three *Kulos* have historical track record of cooperation with each other for maintenance at source river. With the growing prospect of the need of external funding for the upgrading and improvements of the canal system, a formal system-level Karnali (Rani, Jamara, Kulariya) WUA comprising the representatives from all three *Kulo*-level WUAs was formed in 2018. The current organizational structure of WUA is provided in Fig. 1.

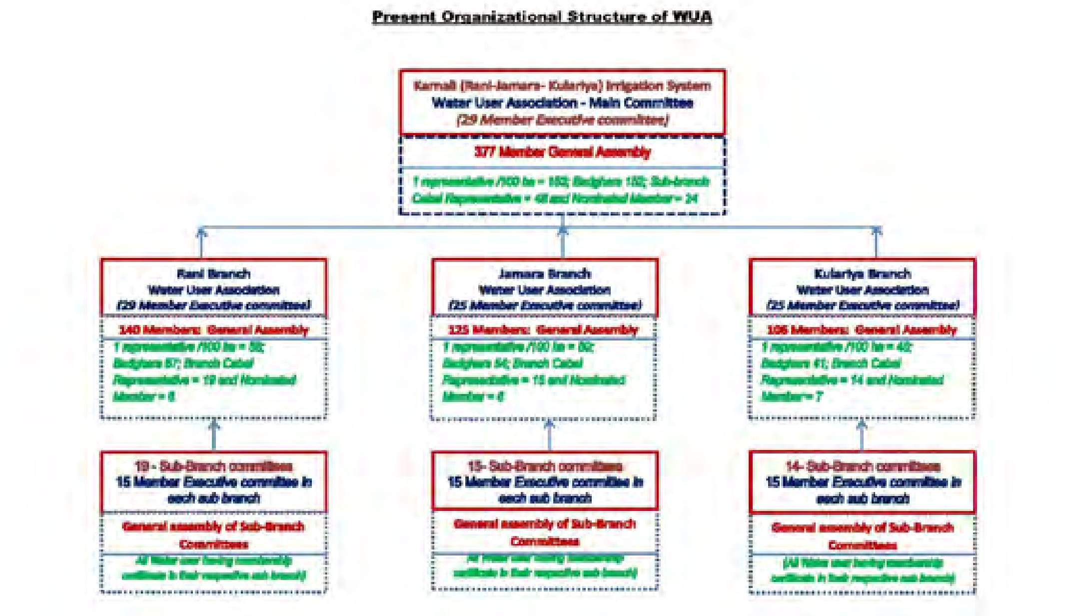

Figure 1: *Present organizational structure of WUA*

These sub-branch committees are the functional committees responsible for under-taking field-level activities ranging from resource generation and mobilization to canal repair and maintenance, dispute settlement among the water users in their respective area.

At the branch canal (*Kulo*) level, three independent WUAs one in each Rani, Jamara and Kulariya are formed. These WUAs are responsible for the management of their own canal systems and also coordination between main and sub-branch level WUAs including external agencies. The branch level executive committee is formed by a general assembly constituted with (a) representative nominated by each sub-branch committee; (b) all *Badghar* within the command area of branch canal; and (c) representatives selected based on land holding. The numbers of representatives are increased or decreased based on the number of the sub-branches and the area served by particular sub-branch canals.

In recent years the *Badghar* system has proved to be a mixed blessing (Gill, 2017). On the one hand, it bestows on the *Badghar* prestige and power at the local level. On the other hand, *Badghars* feel that people have become "unruly" in recent years. Almost every former *Badghar* rued the old "good" days when everyone obeyed them without question. In addition, many *Badghars* feel that they should be appropriately compensated. They are the ones who need to travel to different places, ensure rules and

regulations are adhered to, fines are imposed on transgressors and guests are fed in community feasts whenever necessary. In addition, men of working age are increasingly migrating to cities and/or crossing border to India in search of employment. Consequently, in many settlements users are finding difficulty to elect capable and willing person to hold the position of *Badghar*. In such situations, villagers elect a trustworthy person to hold this position for a year. This position is subject to renewal each year.

10. Lessons Learned from the First Phase of Modernization

This study demonstrates multi-facet changes that the modernization in irrigation system such as RJKIP can bring in to the beneficiaries. New institutions are being created and traditional ones are given new recognition with new responsibilities. One of them is *Badgar* at *Mauja* level. Another important change is the shift from labor-based to cash-based economy. These changes have brought many changes in cash management, banking system, accounting system, and cash saving systems, among others.

Water management is another important aspect of WUA transformation. New set of people are to be trained in gate operation at different stretches of the canal. This requires preparation of canal operation manual and training to the members to WUA on water measurement and management. With modernization of structures, construction of agriculture road and bridges have eased the agriculture market and made accessible to all parts of command area round the year. This has helped to bring tremendous economic and social changes in the command area through modernization of irrigation system in Tikapur. Institutionalization of WUA and agricultural development activities were implemented bringing direct benefit to the farmers. The institutional development activities were matching with their requirements of modernized system. In this way, a century-old indigenous system is transforming to a modernized system with transformation of institutional role and responsibilities of WUA in a successful manner.

References

Agricultural Component Implementation Unit (2017). Agricultural Development Strategy for MoRJKIS-2

Gill, P. (2017). The Water Bringers: On Nepal's largest Island Tharu Local Governance has allowed irrigation practices to survive, The Record, (www.recordnepal.com)

Pradhan, P., Giri, K., Tiwari, D.N. (1987). Resource Mobilization and Organizational Support in Irrigation System Management: Experiences from Kulariya, Jamara and Rani Kulos of Kailali District in Irrigation Management in Nepal, Research Papers from National Seminar, Kathmandu, Nepal: IIMI

RJKIP (2018). Implementation Completion Report of MoRJKIS-I, Tikapur, Kailali

RJKIP (2017). Social Assessment Report of MoRJKIS-II, Tikapur, Kailali

SIDEC (2017). RJK Irrigation Project - A Report on Satisfactory Survey. Kathmandu: Sustainable Infrastructure Development Engineering Consultancy (SIDEC)

Upadhyay, G.L. (2017). Component 2 of Rani, Jamara and Kulariya Irrigation Project, Annual Report, FY 2073-74 (2016-17), Tipakur, Nepal.

World Bank (2011). Modernization of Rani Jamara Kulariya irrigation scheme – Phase 1. Project Appraisal Document, Washington Dc.

Farmers managed irrigation systems of Nepal: Institutional elements contributing to their sustainability

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Abstract

The paper is based on the findings of a case study of two farmers managed irrigation systems (FMIS) of Nepal. The focus of the paper has been placed on analyzing operational arrangements combined with governance characteristics of water users association (WUA), which are the key factors contributing to their sustainability. These FMIS have several elements that may be considered essential for their sustainability. The key elements identified as sustaining factors in these FMIS are: democratically established WUAs compatible with the social and traditional norms; flexible operational rules with firm institutional mechanisms for their implementation; ability of WUA to establish external contacts to diversify their funding basket for system operation and maintenance; and achieving higher economic benefits due to shift from traditional cereal-based cropping to market-oriented agriculture as a result of assured irrigation.

Keywords: *FMIS; improved agriculture; operation and maintenance; sustainability; WUA*

1. Introduction

Nepalese farmers with their own initiatives by using rudimentary material and local knowledge have created amazingly sustainable and efficiently operating systems since centuries to irrigate the farm fields. Evidence of farmer managed irrigation systems (FMIS) could be linked to an edict of King Ram Shah of 17th century BS (Hindu calendar), suggesting development of FMIS since historical ages. It is estimated that about 15,000 units of FMIS in hills and 1,800 in Terai covering 880,000 ha (66% of total irrigated area) exist in Nepal (Pradhan, 1989). FMIS display the power of self-governance, capable of crafting rules to sustainably manage their own systems. The continued survival of significantly larger number of FMIS since long owes

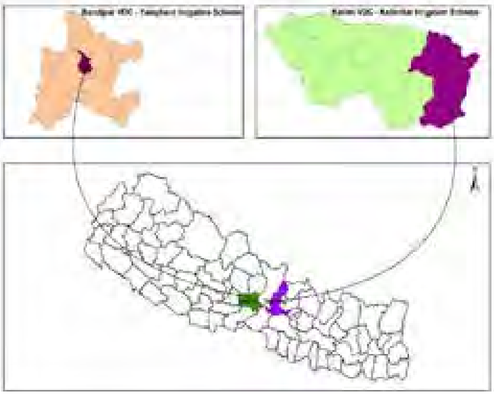

Figure 1: *Location of the two FMISs*

much to their indispensable contribution to ensure food security in the subsistence agriculture ridden rural Nepal. The paper intends to highlight the institutional elements that are instrumental in achieving the sustainability of FMIS. The effort of assessment are placed on analysing the relation between sustainable irrigation management practices and water users association (WUA) institutions with their ability to mobilize internal and external resources. Operational modes and WUA governance characteristics of two FMIS, namely, Yamphaphant Irrigation Scheme (YIS) in Tanahun and Kalleritar Irrigation Scheme (KIS) in Dhading (Fig. 1), have been considered for the purpose of this study.

2. Location, Water Source and Socio-economic Settings

Yampaphant Irrigation System (YIS) is more than a century old FMIS and derives water from a perennial stream fed by spring source, locally called *Aandhi Mool*. The entire command area is situated in Bandipur Municipality, Ward No. 5, in Tanahun district (Fig. 1) and located on the right bank of Marshyangdi River. The system serves irrigation needs of 567 population from 165 households (HHs). Brahmin and Chhetri constitute 85% of the user HHs while remaining 15% belong to Magar, Gurung and other ethnic groups. Agriculture is mainstay of economy of the majority of households who are engaged in commercial vegetable and livestock farming. Most households, at present, have 3-6 dairy animals of improved breeds. Availability of irrigation services created opportunity of year-round and intensive vegetable cultivation, which significantly improved the income and livelihoods of the farmers. The intense vegetable-based cropping pattern have two-fold impacts on socio-economic status of the farmers: (a) constraints of labour force in own HH led to lease out land for share cropping and created opportunity for nearly 30 smallholders and landless farmers to get access to land and engage in vegetable production and, (b) creation of on-farm employment opportunity for around 200 person/day.

Kalleritar Irrigation Scheme (KIS) is situated in the Mahabharat hilly region in the southern part of Dhading district in Nepal. The irrigation water is diverted from two tributaries of the Trishuli, known as *Khani Khola* and *Koshi Khola*. The system provides irrigation service to arable land located at 3 separate tars (upland) of Phosre, Kalleri/Gahate, and Gharti tar placed at the head, middle and tail of the canal system, respectively. Due to water shortage at the source streams, the system provides irrigation service for only two crops, summer and winter. About 1650 population from 290 HHs are directly benefited from the improved irrigation services. Ethnically Brahmins and Chetris constitute the majority of HHs (around 80%) followed by other caste groups like Newars (12%), Majhi (5%) and others (3%). Agriculture remains principle source of livelihoods for majority of the people (88%) of the command area. Around 10% farm families rent in others' land for share cropping as the labour force within HH is constraint, especially during monsoon. The scarce labour is managed by labour exchange known as *Parma,* however about 10% of the requirement is being fulfilled by hiring labour from the nighboring village (*Katalpauwa Tingghare* and *Damari chaur*).

3. System Characteristics

The YIS has had its origin more than 100 years back when the farmers in the area decided to develop the system to cultivate rice in monsoon. The system was adopted for rehabilitation and improvement support under Hill Food Production Project during 1985-1988, which led to improvement in the canal and water control structures Additionally the system received occasional grant support under small irrigation program (SIP) through district agriculture office, which was used to strengthen the conveyance capacity of the system. Since 2017, the system improvement is underway through medium irrigation

program (MIP) supported by the Department of Irrigation (DoI). Following the rehabilitation and improvement in 1988, the irrigation supply in the system became highly reliable and became possible to distribute water more equitably among the users. The intake of system (Fig. 2) includes a low height concrete weir and openside intake. Total length of the main canal is 918 m and then water is divided through a division box to two branch canals- Jaisi Canal (2 km) and Barah Canal (950 m) - which convey water to two different sections of command areas. Water is distributed through 32 outlets in Jaisi Canal and 12 outlets in Barah Canal.

Figure 2: *Intake site of YIS*

The development of KIS was initiated in year 2035 BS (1979). Despite serious efforts by the local farmers, the scheme became operational only after 10 years in 1989. Initially, 11 km long main canal with few water distribution structures were constructed with support from DoI. Because of the difficult hilly terrain and insufficient distribution structures, the system could irrigate only 62 ha of irrigable land. In 2001, the system improvement works were carried under Second Irrigation Sector Project (SISP). The improvement scope largely focused on strengthening the conveyance capacity through constructing 15 distribution outlets, 208 meter covered canal, two super passage and around 1 km canal lining in slide-prone area. The intake system of KIS is shown in Fig.3. As per the information available with WUA, after the system improvement the command area has been expanded to 110 ha. The April 2015 earthquake harshly damaged the canal system at different locations. The restoration efforts of WUA was supported by various institutions such as FMIS Promotion Trust; DoI, Soil Conversation Office, Village Development Committee (VDC) office, and local non-governmental organizations (NGOs).

Figure 3: *Intake site of KIS*

The impacts of modernization support in sustaining the system have been noticed in both the systems. The direct impact has been on expansion of area under irrigation, more reliable irrigation delivery especially in dry season, crop diversification and increase in crop productivity including significant reduction in the labor mobilization needs for annual and emergency repair and maintenance of the system. In YIS for example, reliability of dry season irrigation became the basis for the farmers to make a shift from cereal-based farming to year-round vegetable cultivation where as in KIS, wheat and vegetable farming in winter is sole result of assured irrigation services realized after system modernization.

4. Growth of Institution and Their Collective Role

YIS: In 1985, while the rehabilitation and improvement of system was undertaken with the support of Hill Food Production Project, the famers in the system organized a 15-member executive committee to

look after system modernization and upgrading and mobilization of needed resources. Before this, the farmer used to select a leader *Mukhiya* for the annual repair and maintenance of the system and also to resolve any conflict emerging from water distribution among the users. The role assumed by the *Mukhiya* was gradually tranferred to WUA. All the land owners including the contract farmers, who pay fees and water service charge, are accepted as the member of General Assembly (GA). The GA selects WUA executive, appoints contractor for water management, decides timing and resources for canal cleaning, and decides penalty for water stealers and absentees.

The collective decision-making process adopted by the farmers has promoted transparency and sustainability in the system operation. Informal WUA with inclusive participation, a system of re-endrosement of office bearers annually in GA; clear division of responsibility among the members; transparent decision-making process (decision are not written but high degree of awareness on rules and regulation among beneficiary farmer exists), strong institutional commitment of WUA for maintaining fare decisions on equitable water distribution; and high level of participation (above 95%) in GA meetings are some of the key features of WUA. All these governance characteristics are contributing factors to embrace all the farmers for participating in system O&M.

KIS: The WUA committee was selected unanimously by a GA of water users once canal became operational in year 1988. After four years, the WUA was registered with District Administration Office in 1992. The system has two tier institutional structures. The system level WUA is formed in the meeting of GA of beneficiaries. At present, there is a 13 member executive committee selected from and among the members of GA. The general assembly holds in the month of January each year and endorses the most of the strategic decision like annual maintenance rate and mode of resource mobilization (cash or kind), selection of "Jalpa" and "Dhalpa" and their remuneration, amendment of constitution etc. Below the-system level, there are three Tar-level committees comprising 7-9 members. All members including chairperson are selected by the member farmer of concerned *Tar*. The *Tar* committees are fully responsible for maintaining the branch canal and mobilizing the resource required for main canal maintenance from their share of contribution.

In both of the systems, the functionaries in the user groups are elected/nominated for a fixed tenure, those who demonstrate good leadership and command the faith of the users continue to work for several terms. The founder chairperson of Kalleritar KIS continued for more than 20 years whereas the founding chairperson of the YIS continued for 12 years. Clear division of resonsibility between the tier of WUA in KIS and between the members in YIS is a common feature existed in the mode governance structure. The user groups have been active in mobilizing financial resources from within the system and also from outside to meet the repair and maintenance and system upgrading needs. This ability was noted more strongly embedded in WUA in KIS in comparison to YIS. In KIS, the users' organization succeeded mobilizing internal and external resources to undertake the repair of canal and other physical infrastructures that were damaged in the earthquake of April 2015. The system, from its inception, is regularly receiving partial support for O&M through managing close contact with the system management division of DoI.

5. Institutional Mechanism for O&M of the Systems

The O&M tasks in the system include annual repair and maintenance of the system; allocation of irrigation water among head middle and tail; distribution of water among the farmers based on available supply at the source; monitoring of water distribution schedule; and penalizing those found violating the rules or making unauthorized use of irrigation.

In **YIS**, the regular maintenance is being carried by the farmers two times a year for which they contribute around 2 person-days/year. An unique and effetive instituional mechanism for water distribution has been placed deploying contractor through open bidding since the last eight years. The farmers have to collect a water allocation receipt from WUA after clearing irrigation service fee (ISF) and other dues. The contractor distributes water to the farmers' land as mentioned in the receipt. Three types of rotational water distribution systems are practiced: (i) Type A- The rotational distribution starts alternatively from head and tail supplying water to entire farm in turn by turn basis- locally called *Vijuwa Palo*; (ii) TypeB - water distribution is managed through six outlets with three outlets opened for 20 hours in turn when water is insufficient for rotation through Type A; (iii) Type C - when water becomes further insufficient for type-B rotation, time-based rotation is applied alternatively from head and tail by dividing the area for 20 hours supply. Generally, a farmer having 0.05 ha land is entitled to receive water for eight minutes. The well-established practice of farmer informing the next in queue after completing irrigation supports the notion that sustainability in a system can only be achieved through coordination and cooperation that is deeply rooted as a culture and social norms in the community.

In **KIS**, regular O&M of the irrigation scheme is undertaken by mobilizing the paid staff. The system operation is well defined and carried out accordingly. A water rotation process is adopted and strictly followed. The farmland of Kalleritar and Ghartitar observe a 3 day rotation for each sector whereas Phosretar receives one day irrigation water. Farmers hire two patrolman (locally known as Dhalpa) for the operation of intake and main canal who are principally responsible for conveyance of water in the main canal. Likewise, 3 Jalpa (distribution man) are also hired for allocating water and rotating it amongst the various branches or off takes and field channels. In case of emergencies, each HH has to contribute the labour force regardless of the size of land holding. The Dhalpa and Jalpha are employed only for 3 months during main paddy season for which the are paid 20, 000[1] each per season. In case of the need for emergency repair and maintenance, each HH has to contribute according to the need and nature of repair requirements.

Assurance of labor mobilization, at the time of needs, for maintenance and upkeep the system is the key challenge for attaining the sustainability of the FMISs. This ability of FMISs, at present, is stressed due to declining working hands in the system. The scarcity of labor to work in maintenance of the canals has become particularly problematic in large and complex system like KIS, where frequent damages and labor requirement in annual repair and maintenance is required. To deal with the problem of labor scarcity, both WUAs started mobilizing cash instead of labor for regular repair and maintenance, with the labor mobilization from users limited only to annual and emergency repair and maintenance needs.

6. Agricultural Practice

YIS facilitated the farmers to cultivate three crops in a year. In the absence of irrigation water, they were able to cultivate only monsoon paddy in the past. But these days, the cropping pattern in YIS is largely dominated by vegetable farming. The major crops grown are monsoon paddy (90%) with vegetable; whereas vegetable dominates winter crop in 65% area and spring crop in 60% area. The reason behind the adoption of fairly advanced cropping practices is the outcome of extensive research and extension efforts carried out by Lumle Agricultural Research Centre (LARC). The centre used the area as its laboratory for trials for a number of years (1987-1998). Likewise, extension-focused field trials were conducted in farmers' field which made farmers recognize the profitability of new crop varieties. Additionally, access to both input and output markets and the influence of the LARC

1 *The fee structure decided for last main paddy season*

encouraged farmers to try new technology. Irrigation increased 129% paddy productivity (5.5 from 2.4 t/ha). Cultivation of wheat and vegetables was possible only after system construction. Farmers use on an average 100 kg of urea, 90 kg DAP and 45 kg Potash per hectare for vegetable supplemented by 6 to 8 ton of compost manure/ ha in each crop. Similarly, almost all farmers use improved/hybrid seeds. This contributed to achieve production of all crops and vegetables at the higher level (Table 1). Farmers are gradually reducing the use of chemical fertilizer after increased availability of organic manure due to increase in cattle farming in each HH. The use of farm labor in daily wage for supporting in agricultural and animal husbandry is a unique feature of YIS. Around 200 labors a day are hired in by the farmers from Chyangli village of neighboring Gorkha district.

This shift from traditional cereal based cropping to year-round vegetable cultivation created strong incentives for the farmers to invest in the irrigation system. The users of this system are now in the pursuit of next stage of intensification of agricultural production by focused investment in livestock enterprise integrated to the farming system. Instead of vegetable many farm lands can be seen covered with fodder grass.

Table: 1: *Productivity comparison of major vegetables in YIS. The values are in Metric Ton.*

Irrigation scheme	Cauli flower	Cabbage	Green pee	Radish	Cucumber	Bitter guard	Sponge guard	Brinjal
Scheme average	26.07	30.01	12	15	20	18	16	17
National	15.4	7.1	9.5	14.5	14.3	13.9	14	13.4
District	10	12	6	10	6	10	10	10

Farmers in this irrigation system do not face any problem with the marketing of their produce. Nearly 90% of the farmers bring their produce to a collection center owned and operated by a local entrepreneur. The farmers receive the payment for their produce either on the same day or at the most within two days of the sale. The entrepreneur then supplies the collected vegetables for sale in the adjoining markets of Damauli, Gorkha, Pokhara and Narayanghat and also some vegetables are transported to Kathmandu depending on the demand.

Two observations that are apparent from Table 2 are that profitability with the vegetables is much higher than that with the cereal crops. Of all the vegetables grown by famers, green pea was found the most profitable in winter with net return to input cost ratio of 2.70, followed by cauliflower and cabbage. Among the spring season vegetables, cucumber was noted the most profitable options followed by bitter guard, sponge guard and brinjal. Opportunity of making high return with the vegetable production while operating on small landholding size has been the incentive for majority of the farmers to shift to vegetable farming in the command area of the system.

Table 2: *Economic benefits from major vegetables in YIS*

Crops	Gross Value of Produce (NRs./ha)	Input Cost (NRs./ha)	Gross Margin (NRs./ha)	Gross Return/Input Cost Ratio
Monsoon Paddy	168,000	91,000	77,000	0.84
Wheat	115,000	77,000	38,000	0.49
Cauliflower	500,000	147,000	353,000	2.4
Cabbage	396,000	127,000	269,000	2.12
Green pea	300,000	81,000	219,000	2.7
Radish	150,000	70,000	80,000	1.14
Maize	100,000	66,000	51,000	0.77
Cucumber	500,000	124,000	376,000	3.03
Bitter guard	180,000	52,000	128,000	2.46
Sponge guard	240,000	114,000	126,000	1.11
Brinjal	306,000	126,000	180,000	1.43
Potato	360,000	174,000	186,000	1.07

KIS: Predominantly rainfed maize in the monsoon season with some rainfed paddy, groundnuts and millet followed by winter pulses (especially black gram), mustard and some vegetables were the major crops grown before irrigation. Soon after the construction of the irrigation system, and a major modernization investment in year 2001 created possibility of dependable irrigation during monsoon and winter, the farmers got motivated to increase the area under rice and vegetable in monsoon, wheat, maize and vegetable in winter. Due to the shortage of water in the source, farmer cultivate rainfed maize during spring season. In monsoon, around 90% area is covered with paddy followed by 6% with brinjal and 4% with chilli. Around 50% wheat, 20% musterd, 7% tomato, and 10% potato and cauliflower each are predominent winter crops grown. The development and use of irrigation has been associated with increased and more intensive use of agricultural inputs for all crops. The agriculture practices were further strengthened after the trail demonstration of integrated cropwater management exercises in the project area for more than five years. As a result, almost all the farmers apply improved varieties, mostly the hybrid seeds to get optimum level of production. This evidence with the fact that the productivity of the crops is fairly higher than both national and district average.

Table3*: Productivity comparison of major vegetables in KIS. The values are in Metric Ton.*

Irrigation scheme	Cauli Flower	Potato	Cabbage	Chili	Tomato	Brinjal
Scheme average	18	20	23	8	21	21
National	15.4	13.64	7.1	6	15.1	13.4
District	14	13.3	15	0	18	12

Bairani, Galchi and Keurani bazar are the nearest major market centers where farmers sell their products. The local merchants buys the farm produce and supply to Kathmandu, Pokhara and Narayanghat. The price of the produce are determined by enterpreneurs and, based on mutual understanding, some farmer are paid on the same day and some receives the payment on seasonal basis. Table 4 shows that the profitability with the vegetables is much higher than that with the cereal crops. Of all the vegetables grown, tomato was found the most profitable in winter with a net return to input cost ratio of 352%, followed by cauliflower (207%) and cabbage(171%).

***Table 4**: Economic benefits from major vegetables in KIS*

Benefit Analysis	Present Crop Budget of Major Crops in Irrigated Condition (NRs./ha)								
	Paddy	Wheat	Cauli Flower	Cab-bage	Chili	Toma-to	Maize	Brinjal	Potato
Gross Re-turn	181	100	450	345	144	315	75	252	440
Production Cost	90.68	76.68	146.56	127.08	81.04	69.56	66.02	126.00	174
Net Return	90.32	23.32	303.44	217.92	62.96	245.44	8.98	126	266
Net Re-turn (%)	**99.60**	**30.41**	**207.04**	**171.48**	**77.69**	**352.85**	**13.60**	**100**	**152.87**

(Source: FGD, 2017)

7. Key Findings and Conclusions

WUA governance mechanism: Stronger and active WUA is the key for successful operation of any FMIS. Transparent decision-making process where key rules/practices, function of office bearer are reviewed revised and endorsed in each annual GA meeting; clear division of responsibility with high degree of awareness on rules and regulation among beneficiary farmers boost their confidence on WUA to receive full collective support. In both the FMIS discussed, all decisions regarding canal operation including contribution structures, collection mechanism are decided in GA. The transparent system adopted by both WUAs is a key element that embraced all beneficiaries in obeying canal operation rules in an effective and efficient manner.

Institutional mechanism for canal O&M is instrumental in FMIS sustainability: In both the systems, the responsibility of day to day monitoring of canal and making adjustments in the rotational distribution schedule has been given to one or more paid appointees- "Dhapla-canal guards" and "Jalpa-water distributer" in Kalleritar whereas water distribution task has been outsourced to contractors in Yampaphant. The need for appointing water guard in systems like Kalleritar is essentially to keep watch on canal passing through hilly terrain to make sure that any likely emergency in the system could be identified in advance to take-up corrective actions to ensure reliability of the system. The practice of appointing paid staff/contractor and making them responsible for day to day canal operation, instead of the functionaries in the water users' organization responsible for this task, seems a good practice worth sustaining the system. The system adopted by FMIS are further supportive to overcome the present scarcity of labor required to work in the repair and maintenance of the canals.

Quick responsive mechanism with flexible operational rules are key: The case studies revealed that prompt decision making and flexible operation rules are key to address the operational requirements in particular stages of water availability. Both FMIS have flexible rules supportive in making adjustments in the water distribution schedule based on seasonal cycle of water adequacy and deficiency.Three types of rotation based on water availability in YIS and two forms in KIS are the examples of the flexibility in water allocation and distribution rules ensuring the equality in water distribution The quick responsive mechanism that includes the day to day monitoring of available supply at the source and in the system, prompt decision making to make adjustment in the distribution schedule, and communicating the changes to the users are the three critical functions contributing to the sustainability of system operaton.

External intervention for system improvement have multifaced impacts in sustainability: The intervention in system improvement created possibility and expansion of irrigation coverage in winter and spring in the middle and tail reaches in both the canal systems. Diversification of cropping in winter and spring, reduction in labor mobilization need for annual and emergency repair and maintenance, more reliable irrigation operation throughout the year are key impacts of system improvements. In YIS, for example, the system upgrading and modernization under Hill Food Production Project (1985-1988), which involved construction of a permanent intake, canal strengthening and lining at the critical sections, significantly improved the reliability of dry season irrigation which subsequently became the basis for the farmers to make a shift from cereal-based farming to year-round vegetable cultivation. Similarly the system improvement under SISP, supported by Asian Development Bank, resulted the expansion of command area from 62 ha to 110 ha with shift from traditional cereal-based cropping to commercial vegetable in winter. Significant reduction in the labor mobilization needs for annual and emergency repair and maintenance is contribution of external intervention in both the systems. In YIS, farmers had to mobilize 2 person per week during entire monsoon period which is now reduced to 1-2 persons per year. Likewise in KIS, more than 50% reduction in labour contribution has been reported after system modernization.

Ability of WUA mobiizing internal and external resource has positive correlation with system sustainability: The ability of WUA to establish contacts with government agencies and development organizations was found instrumental in mobilizing external support and diversifying the funding basket to sustain O&M functions. This ability was noted more strongly embedded in WUA in KIS in comparison to YIS. After initial development of the system, the WUA in KIS took continued initiative in establishing contacts with Irrigation Division, VDCs, Agriculture Office and other NGOs and succeeded mobilizing external support to undertake system upgrading and modernization at different stages. Moreover, the devastating earthquake of April 2015 resulted to intense damages at various sections of canal alignment that needed immediate investment to make the canal run for forthcoming season of monsoon cropping beginning June. The KIS WUA mobilized more than 63 gabion nets, and 400,000 Rupees to repair the canal damaged by the earthquake.

High economic benefit from irrigated agriculture encourage farmers to invest in system operation: The noticeable change has been increase in the productivity of the crops which has been possible only with the adoption of improved crop farming, increase in the level of input use and improvement in crop cultivation practices. Availability of dependable irrigation created opportunity for the farmers to invest in the improvement in the crop production technology and practices. Similar is the case in YIS, where a shift from traditional cereal-based cropping to year-round vegetable cultivation created strong incentives for the farmers to invest in the irrigation system. This was supported by the fact that the WUAs in KIS and YIS started paying cash instead of food grain because the farmers find it economically more viable to appoint paid staff for canal operation rather than they themselves working in the system.

References

Angood, C. Chancellor, F., Hasnip, N., Morrison, J., Smith, L. (2002). Contribution of Irrigation to sustaining Rural Livelihood. Nepal Case Study: HR Wallingford

Ansari, N, Pradhan, P. (1990). Assistance to Farmer-Managed Irrigation System: Experience from Nepal.

Asian Development Bank (2007). Project Completion Report: Second Irrigation Sector Project

Laitos, R., Shah, M., Parajuli, U., Early, A., Pradhan, P. Baxter, J., Gautam, U. (1986). Rapid Appraisal of Nepal Irrigation System. Water Management Synthesis Report-43, Fort Collins, Colorado State University.

Pande, P.R., Pandey, D. R. (2015). Assessment of the Best Practices of the Farmer Managed Irrigation System of Nepal. Asian Development Bank- Nepal Resident Mission Kathmandu.

Pradhan, P. (1989a). Patterns of Irrigation Organization. Colombo: International Irrigation Management Institute (IIMI), p.3.

Pradhan, P. (1989): Pattern of irrigation Institution in Nepal. A comparative study of 21 Farmer Managed irrigation systems, Colombo Sir Lanka

Pradhan, R., Pradhan, U. (1997). Negotiating Access and Right: A cash study of disputes over right to an irrigation water source in Nepal.

MoAD (2013). Statistical information on Nepalese agriculture 2012/2013. Ministry of Agricultural Development (MoAD), Agri-Business promotion and Statistics Division

Sukla, A., Shakal, N.H. (2016). Managing Dry Season Water Deficiency in Farmer Managed Irrigation Systems. Case Studies on Community of Practices in Managing Dry Season Water Deficiencies. Asian Development Bank- Nepal Resident Mission Kathmandu

THEME – V

Irrigation, Ecosystem Services, and Aquatic Biodiversity

Eco-engineering decision scaling (EEDS): A new approach to integrating ecosystems within engineered water management systems

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Abstract

Eco-Engineering Decision Scaling (EEDS) is an approach that explicitly and quantitatively explores tradeoffs in stakeholder-defined engineering and ecological performance metrics across a range of possible management actions under unknown future hydrological and climate states. The EEDS framework significantly contrasts with approaches typically used to assess the environmental impacts of water infrastructure projects by evaluating tradeoffs in the initial stages of planning and development rather than as a post-hoc "impact" assessment. Such early evaluation of ecosystem vulnerability is needed to reveal a range of potential design and management options in complex social-ecological systems.

EEDS has been designed as a stakeholder-centered process mediated with technical inputs, which assumes that engagement with and service to stakeholders is critical to the ultimate success of adaptive resource management in a multi-institutional management context. It follows an iterative five-step process that includes defining system performance criteria, building a systems model, conducting a vulnerability analysis, evaluating options, and identifying a preferred decision (and, if necessary, reevaluating management options and/or criteria).

The EEDS approach was developed by a joint team of ecologists and with the support of the US National Science Foundation to integrate adaptive species and ecosystem management, especially when water infrastructure design and operations decisions may be an important component of the management decisions. It is based on a more general method of decision scaling that was developed within the water resources management community to address complex multi-stakeholder decisions associated with high levels of uncertainty in future hydrological conditions. Although newer, EEDS is rapidly growing in acceptance: a national-scale application of EEDS is underway in Mexico with the Mexican Water Commission (CONAGUA) and WWF-Mexico, while a guidance publication published by the US federal government UNESCO water center ICIWaRM (housed by

the US Army Corps of Engineers is forthcoming in late 2017 / early 2018.

Keywords: *ecosystems; infrastructure; uncertainty; vulnerability assessment*

1. Introduction

The desire to manage water sustainably has broad support, but defining "sustainable" water management has proven difficult for policymakers with instruments such as the Sustainable Development Goals (SDGs), but the goals are no less challenging at an operational level. An important question for defining sustainability in an operational context is the most relevant timescale for measurement: can you define sustainability over a year? a decade? a century? longer?

In practice, much of our management of water occurs through the medium of long-lived infrastructure — infrastructure which can easily endure for a century or more (e.g., Li and Xu, 2006), even outlasting the financing and governance mechanisms that created that infrastructure (Hallegatte, 2009). At these timescales, decisions made today about design, allocation, governance, and operations may have impacts decades away, which is a timescale very relevant to the current period of climate change (Dominique, 2013). Indeed, climate change has been identified as a potential risk for water managers for some decades already, but extensive disagreement exists about how to best address climate as a risk (and opportunity). Since 2008, however, the level of discussion for water managers and planners has intensified as high-profile thinkers began to question the assumption that analyzing past hydrology is a sufficient means of understanding future water conditions (Milly et al., 2008; Wilby and Dessai, 2010).

Understanding the degree, form, and severity of climate risks facing water management and planning is necessary to achieve sustainable resource management and development goals for energy, food production, sanitation and supply, and ecosystems. Many authorities acknowledge that water is central to understanding human impacts from climate change (Sadoff and Muller, 2009), but widespread disagreement remains about where, when, and how climate change is important for water management decisions. Climate change is not relevant to all water management decisions, nor are climate change impacts equally significant when they do show an influence (Stakhiv, 2011). Beyond these basic truisms, however, little consensus exists around how we identify current and projected risks and then develop adaptive strategies that are robust to those risks.

These risks do not weigh evenly on all disciplines involved in water management. For decision making on aquatic ecosystems, for instance, the tolerance for qualitative over quantitative knowledge is relatively high; an awareness of how climatic trends are proceeding may be sufficient for environmental decision-makers in many cases. For infrastructure investments, however, quantifying risks is necessary for accurately meeting goals, especially if those goals have been defined through an economic or financial lens. Because water infrastructure is so necessary for meeting the demands of modern economies, much of the burden for constraining climate risks falls on engineers and engineering-informed positions.

In a simple sense, engineers build structures. These structures are often challenging to design and construct, expensive, and difficult to move, modify, or tear down. As investments, water infrastructure will often influence ecosystems, economies, and communities for very long periods, even outlasting their own operational lifetimes (Hallegatte et al., 2011).

This paper will provides insights into how climate change influences the work of water managers and planners, focusing on some recent approaches to identifying and responding to those risks.

2. The Significance of Climate Change: Uncertainty as a "New" Risk

Neither climate change nor uncertainty about the future are new to engineers or water managers. Indeed, the assumption that past water conditions were sufficiently accurate to describe future hazards and water availability (e.g., designing a levee to meet 1:100-year flood conditions based on 30 years of monitoring data) was known to be a "wrong" but useful approximation. Climate was assumed to be fixed or "stationary" (Milly et al., 2009, Wilby et al., 2009).

The water community has become uncomfortable with these assumptions, perhaps as the pulse of climate change has quickened in recent decades and climate scientists have felt more comfortable attributing the role of anthropogenic forcing to particular events. Certainly, the level of awareness of a potentially disruptive connection between climate change and water management has intensified. The appearance of new hydrological conditions, apparent shifts in climate variability and the widespread suspicion that many decades-old structures no longer match their current climate conditions appear to have fostered an increasingly wide dissatisfaction with longstanding approaches of quantitative analyses to support design, planning, and operations (e.g., Lins and Cohn, 2011).

Since the 1990s, climate models have been used as a tool to project the pace and extent of future climate impacts in order to inform more robust water management solutions. As a tool, downscaled climate models enabled a quantitative approximation of future climate. In many ways, these models allowed engineers to introduce new data without significantly changing how they designed and made management decisions.

However, the use of these models has proven controversial given their limitations in approximating the water cycle and in providing practical, high-confidence guidance. Discussions about the wise use of climate model information have often centered on how to reduce or constrain the uncertainties within and between models and scenarios. Technical discussions of "uncertainty" have often proven confusing and unhelpful to decision-makers seeking simple, plain-language technical recommendations. Hearing that models were unable to have consensus about increases or decreases in annual water availability may have even tainted the reputation of credible methods for incorporating climate information into water management decisions (Kundzewicz and Stakhiv, 2010, Brown and Wilby, 2012).

While future models and scenarios are likely to improve in their resolution and accuracy, many water managers and planners have found climate models dissatisfying for decision making when quantitative long-term outputs are necessary. Moreover, climate shifts on the water cycle will not simply alter design and operating specifications for availability and variability; climate change is already shifting many aspects of water demand as well. While bleached "bathtub rings" behind aging reservoirs and overtopped flood control levees may show how large changes in water availability can disrupt managed systems, there are also responses by water users that may have a comparable or even greater influence than direct climate impacts. Shifts from rainfed to irrigated agriculture, manufacturing to service economies, demographic shifts from immigration and shifts in reproduction and health, the rise of mega-cities, and population influxes from drying to wet regions may be among the easiest trends to predict, but all of these trends will interact in complex patterns. Together, the combination of direct and indirect climate impacts and socio-economic shifts has been called as "deep uncertainty" by some observers to reflect the challenge of making long-lived, high-impact decisions despite large knowledge gaps about future trends (Hallegatte et al., 2012, Walker et al., 2013).

The types of engineering approaches necessary for a well-understood, clearly-defined future would be quite different than those necessary for an "untrustworthy" future or even an unknown and unrecorded past (Brown, 2010). The widespread level of dissatisfaction among engineers, water managers, and decision-makers around the usefulness of projected climate information has led to two general concerns:

- how do we make long-term decisions about specific projects given deep uncertainty about the future of climate impacts in particular places; and
- how do we scale lessons from particular places and projects to ensure that climate information is appropriately mainstreamed within the design and operations of all engineered water management systems at an institutional level?

These two concerns differ from each other primarily in their level of analysis (individual project scale vs generalized decision-making processes): developing a single-project solution is not the same as ensuring that all projects initiated by a potentially large, diverse water management institution have successfully assessed and addressed climate risks. For the project scale, emphasizing the best, most appropriate, and effective practices is essential. At an institutional level, the approach should begin by examining how existing decision-making processes function and then modifying the most relevant steps in those processes to match successful project-scale methodologies.

3. Normalizing Climate Adaptation: Addressing Climate Uncertainty at Both Project and Institutional Scales

Formal engineering-based design processes for water infrastructure follow a similar structure and decision-making cycle globally. Using the US Army Corps of Engineers (2000) as a typical example, these steps usually include:

- Step 1 - Identifying problems and opportunities
- Step 2 - Inventorying and forecasting conditions
- Step 3 - Formulating alternative plans
- Step 4 - Evaluating alternative plans
- Step 5 - Comparing alternative plans
- Step 6 - Selecting a plan

Including climate information in a water management project should include two elements: the need to first assess the potential relevance of climate change to an existing or planned project in a way that realistically accounts for climate uncertainty and then to develop a strategy (or set of strategies) to reduce or avoid future identified climate risks. From a sustainability perspective, an ideal solution should also take account of ecological impacts and interactions. Recent methodological developments have led to the creation of a new framework that does just that.

4. Integrating Ecosystems into Long-term Water Management

Any credible definition of long-term sustainability should include ecological parameters. In recent decades, ecosystem consideration in infrastructure projects has typically occurred through environmental impact assessments, which often are relegated near the end of a design and planning process. There are few standard methodologies for these assessments, and their credibility is often questioned, particularly since projects are often well developed and difficult to modify at this stage.

The gaps between the disciplines of engineering and ecology around water management issues have

been significant and durable, particularly around the translation of issues of ecological concern into an operational framework that can be evaluated using engineering-oriented performance indicators. "Ecosystem services" have been the most widespread approach to integrating ecological variables by assigning monetary values to functions supplied by ecosystems that are comparable to infrastructure functions such as water purification, flood risk reduction, and water storage (Sappelt et al., 2011). The development and assignment of economic value to ecosystem services is often challenging and may be overwhelmed by promised investment returns on planned infrastructure services. While ecosystem services have had some partial success, they have not proven to be a panacea (Schröter et al., 2014).

Recently, a team of ecologists and engineers developed a framework using decision scaling (eco-engineering decision scaling, or EEDS) as a basis for facilitating tradeoffs between infrastructure and ecological performance indicators in the context of climate resilience (Poff et al., 2016). Developed through support by the US National Science Foundation (NSF), EEDS defines performance indicators for both ecosystem and infrastructure without reference to economic valuation, ecosystem services, or other systems that attempt to translate ecological qualities within a finance or economic framework. Instead, EEDS establishes the water-climate criteria that can meet stakeholder or expert standards for success and failure and uses a stress-test approach to develop and compare green, hybrid and gray solutions for their impacts on ecosystems and water management needs.

EEDS is a powerful approach because it explicitly blends the needs and insights from diverse stakeholders and regulatory limits into a management tool that can quantitatively visualize tradeoffs between human needs and ecological performance under future climatic uncertainty. This occurs in the initial stages of planning and development rather than as a post-hoc "impact" assessment. Such early evaluation of ecosystem vulnerability is needed to reveal a range of potential design and management options in complex social-ecological systems.

5. The Five-Step EEDS Process

EEDS has been designed as a stakeholder-centered process mediated with technical inputs, which assumes that engagement with and service to stakeholders is critical to the ultimate success of adaptive resource management in a multi-institutional management context. The EEDS process has five key steps (Fig. 1). In practice, these steps are iterative, cycling back to step 1 for confirmation of technical work as the stakeholders themselves develop more insight into the process of defining long-term solutions and confront levels of risk tolerance. The first two steps involve defining a set of ecological performance indicators in the same terms as the relevant engineering indicators, with steps 3 and 4 (and 5, if necessary) comparing and evaluating approaches to balance and tradeoff risks and opportunities between ecological and engineering concerns

6. Applying EEDS in Mexico

The Alliance for Global Water Adaptation (AGWA) has begun collaborating with WWF-Mexico on analyzing the effects of climate change on environmental flows (e-flows) as they relate to Mexico's National Water Reserves Program. In terms of environmental protection, water reserves seek to provide legal support to ensure that the ecological flow is respected in selected basins that present high terrestrial and freshwater biodiversity and a low pressure on water demand.

Given the trend of economic development growth in the country, it is expected that for several of the basins in the water reserves program, the demand for concessions of water use will increase in the near

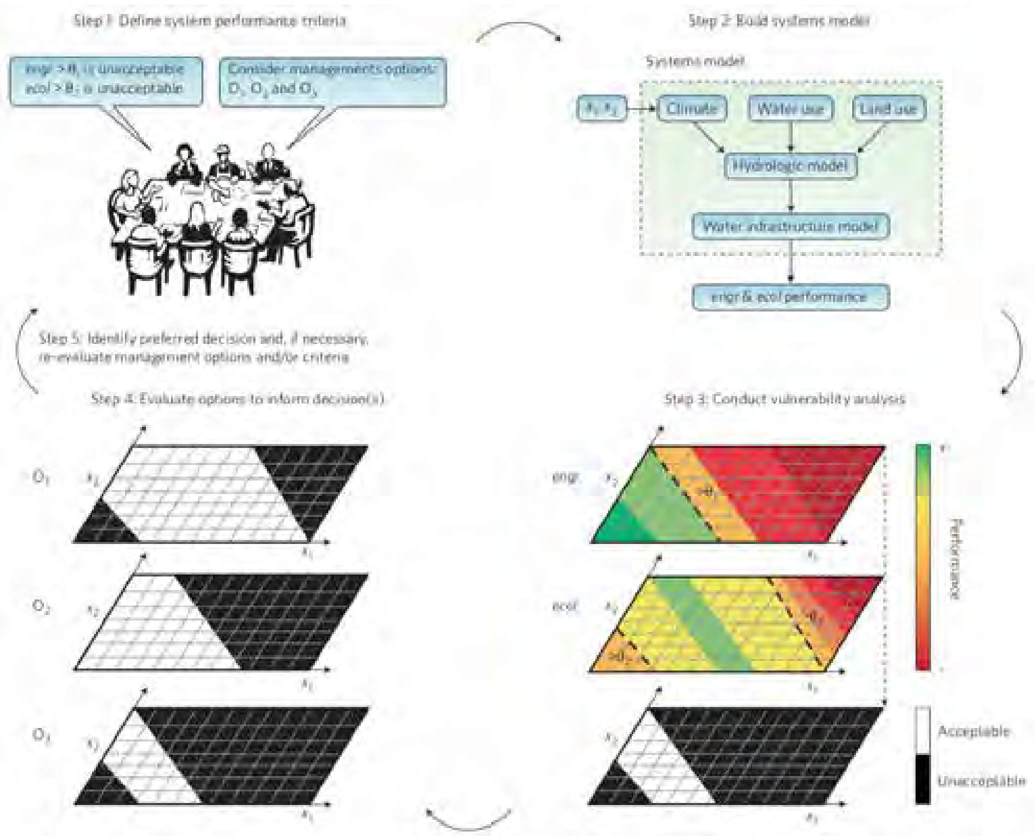

***Figure 1**: An overview of the process of eco-engineering decision scaling (EEDS). (Source: Poff et al., 2016).*

future, putting at risk the occurrence of the ecological flow and the provision of all its environmental services. In this sense, the degree of water reserves for environmental use represents a preventive instrument against the unsustainable use of the surface water in the country.

This project aims to quantify the climate adaptation benefits of the water reserves program in Mexico in order to demonstrate how environmental flows contribute to ecological and social resilience. The results of this work should be applied in the form of a tool or set of tools and methodologies that can guide national and regional CONAGUA staff in applying water reserves in basins throughout Mexico.

In this current project, seven pilot catchments (Fig. 2) are selected and used as case studies, identifying the vulnerabilities of their water resources allocation at the watershed level considering different drivers of change, including climate change and non-physical drivers, such as demographic growth, increased water demands and land use changes, among others. The bottom-up EEDS approach is followed, identifying current hydrological processes and analyzing their vulnerability under future scenarios. Those scenarios represent alternative development pathways for river basins that either establish protections of environmental flows (at various water reservation levels) or fail to implement water reserves. System responses are assessed by stakeholder-defined performance indicators that represent critical features, services, or threats to the system.

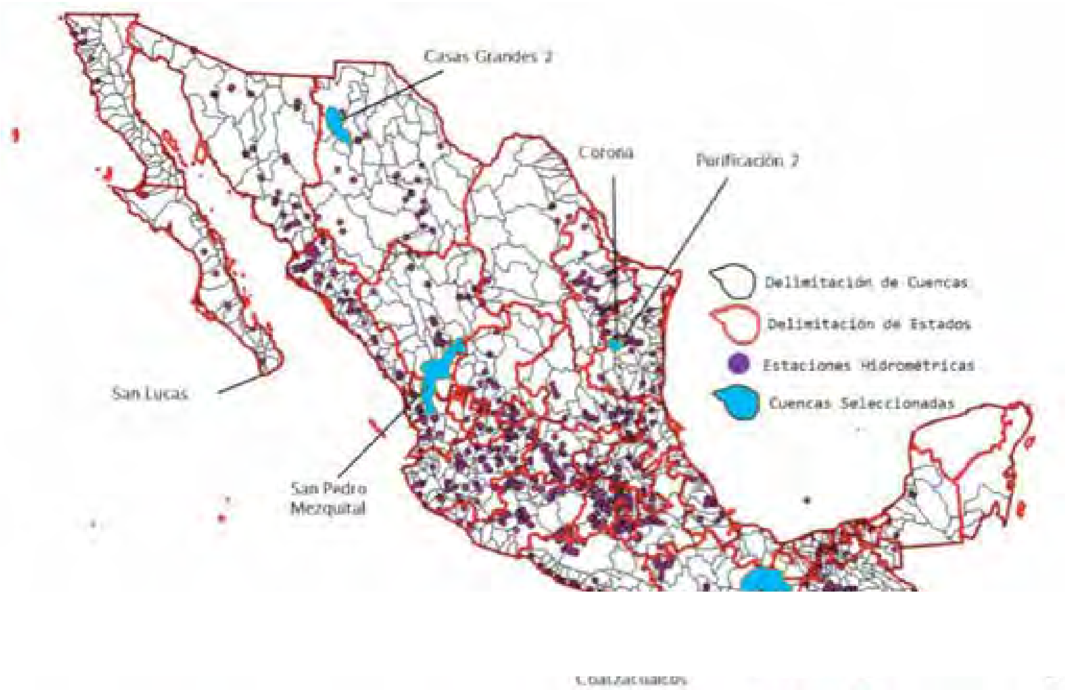

Figure 2: *The location of the seven selected pilot catchments*

This project is near its conclusion and a final report is being prepared. Results will be presented to CONAGUA, WWF-MX, and the Inter-American Development Bank. Using these early results as a proof of concept, the methodology applied in these case studies can be extrapolated to other watersheds or for the entire country, to allow an overall evaluation of the environmental water reserves, climate change projections and the impact of water demand in Mexico.

7. Embedding Ecosystems within Decision Making Processes: The CRIDA Framework for Climate Resilience and EEDS

EEDS as a process has also been embedded within a more comprehensive framework called Collaborative Risk Informed Decision Analysis (CRIDA), which is a decision support system developed by the Dutch Water and Environment Ministry, the US Army Corps of Engineers, SIWI, Deltares, UNESCO, and the Alliance for Global Water Adaptation to mainstream a new generation of resilient water management practices. Some six years in development with a global team of more than 100 contributors from a wide variety of disciplines, CRIDA is designed for technical water decision-makers who wish to assess and then reduce the influence of climate change on water resources management planning, design, and operations and combines state of the art approaches to develop robust solutions with stakeholders while assessing risk (decision scaling) with flexible and governance-sensitive approaches operations and implementation ("adaptation pathways"). EEDS can be seen as an application of the CRIDA approach by both setting main objectives and deriving a comprehensible set of performance metrics and thresholds (Mendoza et al., 2018). CRIDA builds on existing approaches to technical water management decision making processes, inserting direction for aspects relevant for resilient actions.

8. Conclusion

A key continuing challenge for rational water resource management is to provide a practical approach to assist planners and decision-makers in navigating complex problems and diverse interest groups who are confronted by uncertain and changing conditions. As effective adaptive decision-making is most likely to succeed where stakeholders are fully engaged, we believe the EEDS offers the potential to serve as the foundation of a new management platform that advances freshwater sustainability while meeting human needs for water. Further refinement could include how to accommodate future changes in societal cost functions (for example, due to population growth) and shifts in ecological requirements under transient climate and socioeconomic conditions, as well as how to sequence management actions in a fashion that promotes long-term success. Managing the future will necessarily occur in an adaptive context; therefore, equally robust monitoring and evaluation plans will be needed to ensure that decisions are drawing upon the best available information when evaluating the consequences of alternative decision options and management strategies.

References

Brown, C. (2010). The end of reliability. Journal of Water Resources Planning and Management, 136(2), 143–145.

Brown, C., Wilby, R. (2012). An Alternate Approach to Assessing Climate Risks. Eos, Transactions, American Geophysical Union, 93(41), 401–402.

Dominique, K. (2013). Water and Climate Change Adaptation: Policies to Navigate Uncharted Waters (No. WPBWE(2013)2/REV1) (p. 121). Paris, France: OECD Publishing.

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. Global Environmental Change, 19(2), 240–247.

Hallegatte, S., Shah, A., Lempert, R., Brown, C., Gill, S. (2012). Investment Decision Making Under Deep Uncertainty: Application to Climate Change. Washington, DC: World Bank.

Kundzewicz, Z. W., Stakhiv, E. Z. (2010). Are climate models "ready for prime time" in water resources management applications, or is more research needed? Hydrological Sciences Journal, 55(7), 1085–1089.

Lexén, K., Dominique, K., Matthews, J., Widforss, S., Koeppel, S., Skyllerstedt, S. (2015). Integrating water in future climate architecture. In A. Jägerskog, T. J. Clausen, T. Holmgren, & K. Lexén (Eds.), Water for Development (35 ed., pp. 54–58). Stockholm, Sweden. Retrieved from http://www.siwi.org/wp-content/uploads/2015/08/2015-WWW-report-digital.pdf

Lexén, K., Matthews, J. H., Eriksson, M. (2013). Reducing Greenhouse Gases While Building Resilience–Cooperation towards Climate Mitigation and Adaptation Coherence. Cooperation for a Water Wise World, 51.

Li, K., Xu, Z. (2006). Overview of Dujiangyan Irrigation Scheme of ancient China with current theory. Irrigation and Drainage, 55(3), 291–298.

Lins, H., Cohn, T. (2011). Stationarity: Wanted Dead or Alive? Journal of the American Water Resources Association, 47(3), 475–480.

Mendoza, G., Jeuken, A Matthews, J. H., Stakhiv, E., Kucharski, J., Gilroy, K. (2018). Climate Risk Informed Decision Analysis (CRIDA): Collaborative Water Resources Planning for an Uncertain Future. UNESCO and ICIWaRM Press: Paris and Alexandria, VA.

Milly, P., Betancourt, J., Falkenmak, M., Hirsch, R., Kundzewicz, Z., Lettenmaier, D., Stouffer, R. (2008). Stationarity Is Dead: Whither Water Management? Science, 319, 573–574.

Poff, N. L., Brown, C. M., Grantham, T. E., Matthews, J. H., Palmer, M. A., Spence, C. M., et al. (2016). Sustainable water management under future uncertainty with eco-engineering decision scaling. Nature Climate Change, 6, 25-34.

Ray, P. A., Brown, C. M. (2015). Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework. Washington, DC: The World Bank. http://doi.org/10.1596/978-1-4648-0477-9

Sadoff, C., Muller, M. (2009). Water Management, Water Security and Climate Change Adaptation: Early Impacts and

Essential Responses. Stockholm, Sweden: Global Water Partnership.

Schröter, M., Zanden, E. H., Oudenhoven, A. P., Remme, R. P., Serna□Chavez, H. M., Groot, R. S., Opdam, P. (2014). Ecosystem services as a contested concept: a synthesis of critique and counter□arguments. Conservation Letters, 7(6), 514-523.

Seppelt, R., Dormann, C. F., Eppink, F.V., Lautenbach, S., Schmidt, S. (2011). A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. Journal of applied Ecology, 48(3), 630-636.

Stakhiv, E. Z. (2011). Pragmatic Approaches for Water Management Under Climate Change Uncertainty. Journal of the American Water Resources Association, 47(6), 1183–1196.

Walker, W., Haasnoot, M., Kwakkel, J. (2013). Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty. Sustainability, 5(3), 955–979.

Wilby, R.L., Dessai, S. (2010). Robust adaptation to climate change. Weather, 65 (7), 180–185.

Wilby, R. L., Troni, J., Biot, Y., Tedd, L., Hewitson, B. C., Smith, D. M., Sutton, R. T. (2009). A review of climate risk information for adaptation and development planning. International Journal of Climatology, 29(9), 1193–1215.

Wilby, R. L., Vaughan, K. (2010). Hallmarks of organizations that are adapting to climate change. Water and Environment Journal, 25(2), 271–281.

River health assessment for sustainable water resource management in Western Nepal

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Abstract

Sustainable water resource management has become a key challenge in this 21st century. Ever-going demands of water for domestic consumption, irrigation and energy have stressed river ecosystems immensely than ever before worldwide. In Nepal, amongst others, mountain headwaters are highly threatened due to constructions of multiple irrigation channels along their water courses. Many of the springs and streams have been dried before they get confluence to main river channel. The consequences might be enormous for mobility of aquatic organisms and overall biodiversity. However, study on impacts of irrigational water abstraction in river ecosystems and biodiversity are largely lacking. This study aims to (i) assess the impact of altered flow regimes on benthic macroinvertebrates communities downstream of water diversion and (ii) identify sensitive biotic metrics for assessing the impact of altered flow regimes. Over 1100 benthic macroinvertebrates samples were collected from middle mountain rivers in Mahakali and Karnali river basins of western Nepal during post-monsoon, baseflow and pre-monsoon seasons in the years 2016 and 2017. Multiple water diversion projects from a single river have worsened river health, which is very well reflected in the altered benthic macroinvertebrates' abundance and composition. Species diversity indices, Ephemeroptera, Plecoptera and Trichoptera (EPT) diversity and community abundance have been identified as candidate biological metrics that are well responsive to flow regimes caused by such water diversion projects. Here, the paper presents the results of post-monsoon study only.

Keywords: *benthic macro invertebrates; environmental flows; river health; water resources management.*

1. Introduction

Rivers provide goods and services to people and are vital for maintaining and functioning of the ecosystems. People are continuously being benefited from its resources as energy, water for drinking, cleaning and food production. Today, over 50% of the rivers have been somehow modified or altered (Nelson et al., 2005) that have consequently changed natural river morphology, flow regimes, riparian

vegetation, bed sediments etc. (Nelson et al. 2005; Waters, 1995). Among others, hydrological alterations lead to habitat fragmentation, riparian habitats loss, disappearance of adjacent wetlands and floodplain (e.g., Rosenberg et al., 1997) which increase the chances of genetic isolation (e.g. Pringle, 1997). Reduced flow regime can also influence nutrient cycling and primary productivity (e.g. Pringle, 1997; Rosenberg et al., 1997) in ecosystem–level processes that affect to biodiversity (e.g. Master et al., 1998; Richter et al., 1998; Rosenberg et al., 1977; Wilcove et al., 1998). Kingsford (2000) found that loss of floodplain wetlands has declined native fish and invertebrate population. Alterations in flow regimes affect organic materials in the floodplain which provide food and nutrients to several wetland-dependent invertebrates and flora (Kingsford and Thomas, 2000).

Flow regimes play an important role in shaping fluvial environment and biotic composition, diversity and function within river ecosystems (Arthington and Pusey, 1993; Richter et al., 1996). With reduced flow, riffle sections of the rivers disappear and fine sediments deposit on river bed substrates. A study conducted by Waters (1995) showed that diversity of Ephemeroptera, Plecoptera and Trichoptera significantly reduced when riffle sections were covered by fine sediments. Deposition of fine sediments increase embeddedness of river habitat and over 33% of embeddedness in riffle habitat could decline 50% of faunal abundance (Bjornn et al., 1977). The effects of flow alteration in fluvial environment and biodiversity have been well documented around the world (e.g. Bjornn et al., 1977, Clausen and Biggs, 2000; Poff et al., 1997; Poff et al. 2015; Poff and Ward, 1989; Puckridge et al., 1998; Richter et al., 1996, 1997; World Commission on Dams, 2000). In the context of Nepal, study on effects of hydrological changes to river ecosystems and biodiversity is limited to small river catchment (HimBioCliC, unpublished). Water diversion could have serious impacts to river health, however, lack of a detail study on bio-assessment in river impede better understanding of the effects. To overcome the knowledge gap, International Water Management Institute (IWMI) and Kathmandu University conducted a comprehensive ecological study in rivers of Mahakali, Karnali and Mohana basin in western Nepal in the years 2016 and 2017. This study is the first of its kind which aims to determine the impact of water diversion on aquatic macroinvertebrates. The study hypotheses are - (i) richness and abundance of benthic macroinvertebrates would differ in abstracted sites compared to natural sites; and (ii) some taxa would be highly sensitive to flow alteration. The outcomes of the study help to contribute in better understanding of aquatic responses to flow modification that allow to design sustainable flow for preservation and conservation of aquatic ecosystems that also ensure goods and services to human beings.

2. Materials and Methods

2.1 Study area

The study was carried out in three major river basins in far western Nepal, namely, Mahakali, Mohana and Karnali. Mahakali and Karnali are the two out of five major rivers of Nepal. Only about 35.4% of Mahakali basin drains through Nepal (Mool et al., 2001). The Karnali river is the longest river with 507 km in length and originates in southern Himalayas of Tibet. About 55% of the basin falls in Nepal (WSHP, 2007). Tributaries of Mohana River originate in the Chure hills. The region receives more winter precipitation; however, annual rainfall is low compared to eastern and central regions of the country.

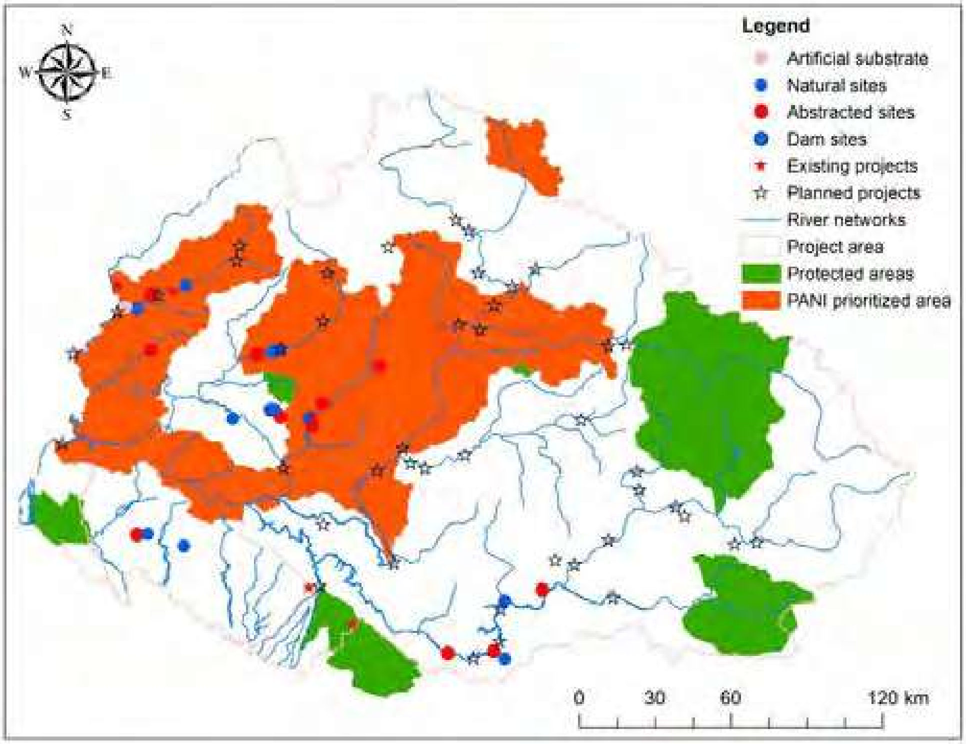

Figure 1: *Distribution of sampling sites in rivers of Mahakali, Karnali and Mohana basins of far western Nepal*

2.2 Sampling sites

A total of 32 sampling sites were selected in the Karnali, Mahakali and Mohana basins (Fig. 1), in which 10 represent natural sites and 22 represent hydrologically disturbed sites. The rivers with alteration in flow regimes for domestic, agricultural, and industrial activities such as operating water mills, irrigation, micro/hydro-power generation have been considered as disturbed sites.

2.3 Sampling of benthic macroinvertebrates

At each sampling site, 10 benthic samples were taken from 50-100 m river stretch following multi-habitat sampling approach (Tachamo Shah et al., 2015). A standard hand net of 25 cm * 25 cm metallic frame with mesh 500 μm was used to collect the samples. Prior to benthic samples, substrate, depth and velocity were recorded. Velocity was measured at 0.6 times of total water depth from water surface by using Global Flow Probe. Velocity measurement was taken at 1-meter distance interval from one bank to next bank of the river channel. The collected benthic samples were preserved in 99% ethanol for laboratory analysis. All specimens were counted and identified to genus or family level in the laboratory.

2.4 Data analysis

Non-metric multidimensional scaling (NMDS) was used to analyze the community composition for groping the sites based on similarity of biotic assemblages. The NMDS used a maximum acceptable variation of two standard deviations and the Sørensen (Bray-Curtis) as a distance measure. The biological data set are transformed to log(x+1) prior to multivariate analysis. In the first step, NMDS was performed for all the 32 data sets including rivers of Mohana basin and later data sets of Mohana basin were removed as the sites were isolated from other sites regardless of disturbance levels. So, final NMDS was performed only for mountain streams of Karnali and Mahakali river basins. Taxa with only one individual were removed from the analysis. Statistical test- an Adonis test was carried out for significant variations among the NMDS cluster. All the test and analysis were conducted in R package (R core Team, 2016).

3. Results

3.1 Community assemblages

A total of 127 taxa were recorded belonging to orders/classes/groups Ephemeroptera, Plecoptera, Trichoptera, Odonata, Coleoptera, Diptera, Oligochaeta, Mollusca and other (Acari, Lepidoptera, Megaloptera). Trichoptera was the most dominant order followed by Diptera (Fig. 2).

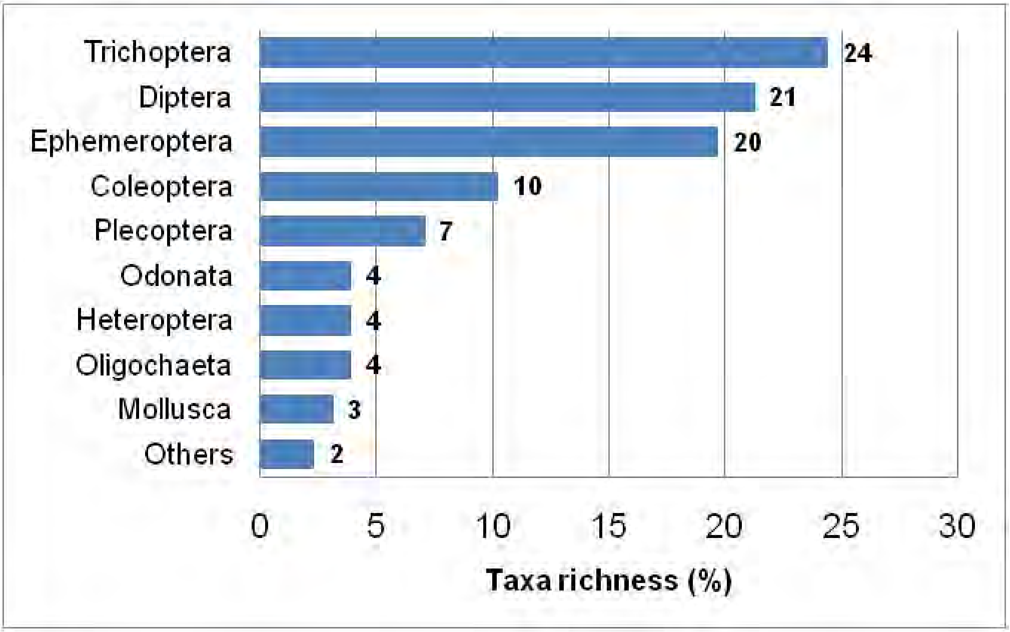

Figure 2: *Diversity of macroinvertebrates in rivers of far western Nepal*

Richness and abundance metrics were found to be sensitive with altered flow regime (Fig. 3). However, the changes observed were different among taxonomic groups and between metrics. Oligochaeta and Mollusca groups were recorded mainly in abstracted sites.

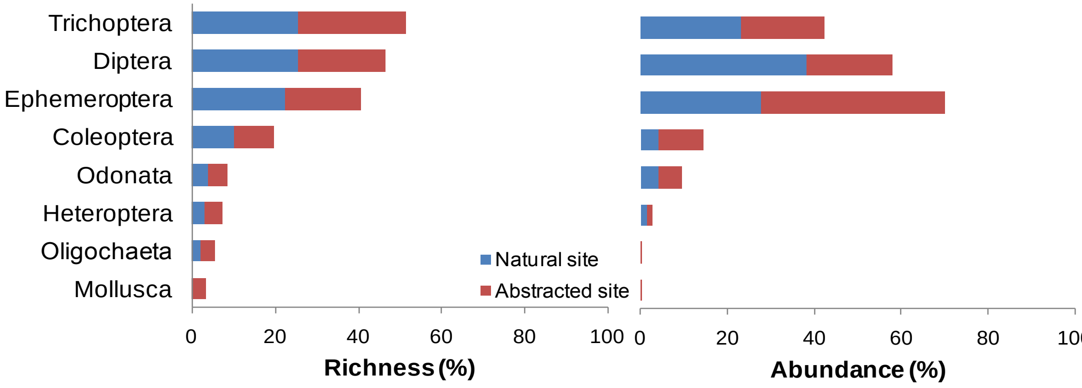

Figure 3: *Variation in taxa richness and abundance in different taxonomic groups*

Non metric-multidimensional scaling (NMDS) differentiated the sites of Mohana basin as a distinct group (Fig. 4). This indicated that the community composition is different in rivers of Mohana basin compared to streams of Mahakali and Karnali.

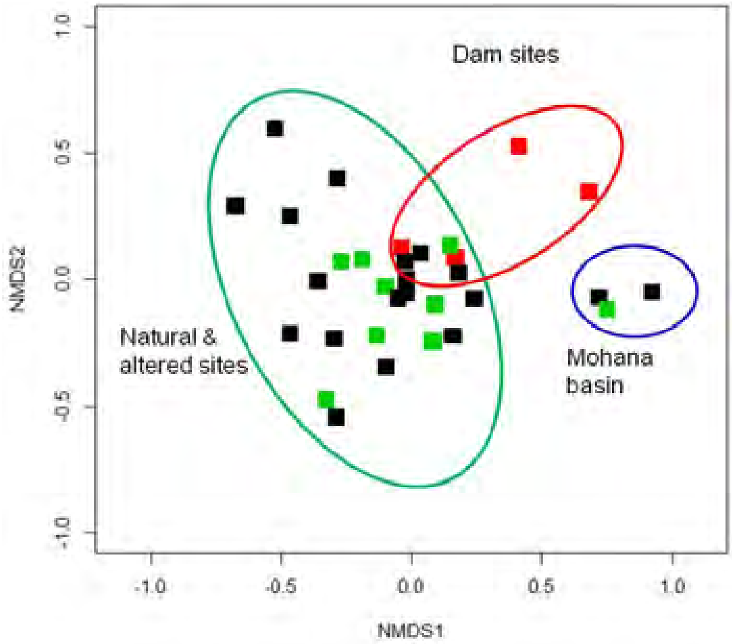

Figure 4: *NMDS plot clustering the sites for the Mahakali, Karnali and Mohana basins (stress value: 0.16)*

3.3 Classification of altered sites

Sites were classified into six Classes. **River Class "1"** represents no/minimal sites with flow alteration up to 20%. Similarly, **Class "2"**, **Class "3"**, **Class "4"** and **Class "5"** are the sites with flow alteration

of **20-40%**, **40-60%**, **60-80%** and **80-100%**, respectively. **Dam site** i.e., early still water was considered as **Class "6"**.

The variation in river discharge was found significant among the abstraction river classes (Kruskal-Wallis chi-squared = 19.71, df = 4, p <0.001). Class 1 was found to be highly variable compared to abstracted sites (Fig. 5). Water temperature elevated with increased River Class (Fig. 6)

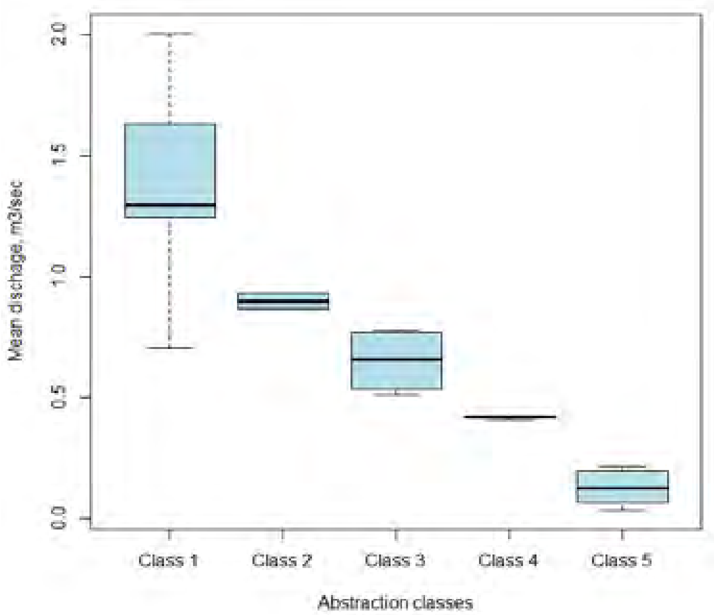

Figure 5: *Mean discharge in various abstraction levels*

(Note: dam sites are not included in the box plot diagram)

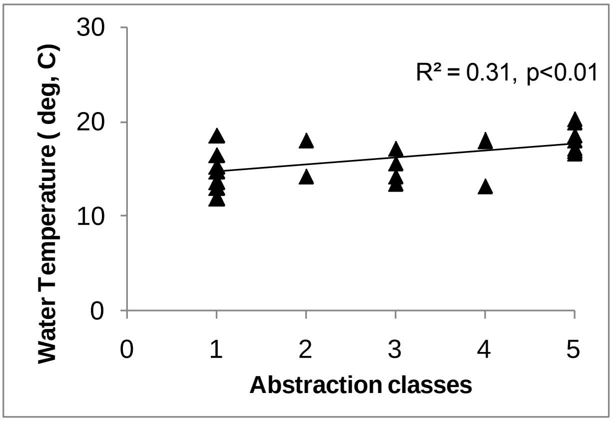

Figure 6: *Variation in water temperature in various abstraction levels*

(Note: dam sites are not included in the scatter plot)

A second NMDS without sites from Mohana basin revealed that the community composition is significantly different among the sites of **river classes 1234**, **Class 5** and **Class 6** (F= 1.8175, df =1, p=0.04).The sites of **Class 5** and **Class 6** seemed to be seriously affected from water diversion projects in the middle mountain rivers of western Nepal (Fig. 7).

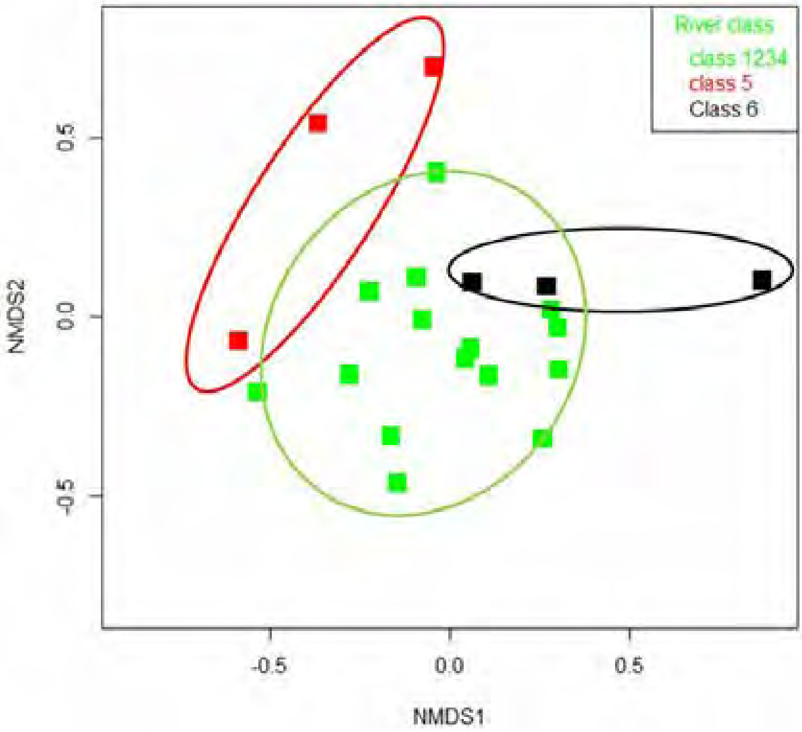

Figure 7: *NMDS plot for grouping sites as per flow alteration river classes basins (stress value: 0.16)*

4. Discussions and Conclusions

This study provides an approximation of consequences that water abstraction can have on river biota. Our results corroborated with finding of similar studies in other parts of the World (Waters, 1995). Water abstracted reduced velocity in the rivers, changed river substrates and elevated water temperature which has favoured opportunistic species of Ephemeroptera, Trichoptera, Coleoptera, Heteroptera and Mollusca. In particular, *Baetis sp*. and *Torleya sp.* of Ephemeroptera order was found flourished in reduced flow regime (Fig. 3). Decline in taxa richness was mainly attributed to habitat loss in abstracted sites (ADEQ, 2004). Increased taxa abundances of Heteroptera and Coleoptera in abstracted sites was mainly due to deposition of fine sediments.

Though this study has not looked at the direct impact of embeddedness by fine sediments, deposition of fine sediments has reduced taxa richness in altered and dam sites in the study river stretches. Thus, it can be stated that the embeddedness is another factor of habitat loss.

References

Gippel, C. J., Stewardson, M. J. (1998). Use of wetted perimeter in defining minimum environmental flows. Regulated Rivers: Research and Management, 14, 53-67.

King, J., Tharme, R. E., de Villiers, M. S. (2000). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Pretoria: Water Research Commission.

Kingsford, R. T., Thomas, R. F. (2000). Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee River in arid Australia. Report to Environment Australia.

Master L. L., Flack S. R., Stein B. A. (1998). Rivers of Life: Critical Watersheds for Protecting Freshwater Biodiversity. Arlington (VA): Special Publication of the U.S. Nature Conservancy.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Stromberg, J. C. (1997). The natural flow regime: A paradigm for river conservation and restoration. BioScience, 47(11), 769-784.

Poff, N.L., Brown, C.M., Grantham, T.E., Matthews, J.H., Palmer, M.A., Spence, C.M., Wilby, R.L., Haasnoot, M., Mendoza, G.F., Dominique, K.C., Baeza, A. (2015). Sustainable water management under future uncertainty with eco-engineering decision scaling. Nat. Clim. Change, 6, 25-35

Pringle C. M. (1997). Exploring how disturbance is transmitted upstream: Going against the flow. Journal of the North American Benthological Society, 16, 425–438.

Richter, B. D., Braun, D. P., Mendelson M. A., Master L. L. (1998). Threats to imperiled freshwater fauna. Conservation Biology, 11, 1081–1093.

Rosenberg D. M., Berkes F., Bodaly R. A., Hecky R. E., Kelly C. A., Rudd J. W. M. (1997). Large–scale impacts of hydroelectric development. Environmental Reviews, 5, 27–54.

Stalnaker, C. B., Lamb, B. L., Henriksen, J., Bovee, K., and Bartholow, J. (1995). The Instream Flow Incremental Methodology: A Primer for IFIM. Washington, D.C.: U.S. Geological Survey.

Tachamo Shah R. D., Sharma S., Haase P., Jähnig S., Pauls S. (2015). The climate sensitive zone along an altitudinal gradient in central Himalayan rivers: a useful concept to monitor climate change impacts in mountain regions. Climatic Change, 132 (2), 265-278.

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. (1998). Quantifying threats to imperiled species in the United States. BioScience, 48, 607–615.

Application of updated MIP method 2016 for estimation of monthly flows and environmental flows of Nepalese rivers

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Abstract

Most of the rivers in Nepal are ungauged. Estimation of reliable monthly and environmental flows (e-flows) in the ungauged rivers quickly and cost-effectively is very important for the design of water resources projects such as medium irrigation projects, and micro/mini hydropower projects. Updated Medium Irrigation Project (MIP) method (2016), developed by Water Resources Project Preparatory Facility (WRPPF) is a very useful tool for the estimation of monthly flows and e-flows in ungauged rivers of Nepal. The MIP method (hydrological estimation method), developed in 1982, divides Nepal into seven hydrological regions based on data from 34 gauging stations and a large number of discharge measurements taken during the low-flow season. The result was non-dimensional hydrographs for the seven hydrological (assumed to be homogeneous) regions. The updated MIP (2016) method has delineated 22 different hydrological regions based on climate, vegetation, soil and other geological elements, land use, flow characteristics, and other physiographic characteristics such as elevation, and slope. The flow is characterized based on data from 103 gauging stations established by Department of Hydrology and Meteorology (DHM). The MIP (2016) method is easy to apply which does not need complex hydrological models, complicated equations and long-term hydrological or meteorological data. It has provision for monthly flow estimation to both snow-fed and rain-fed rivers. Input of one-time discharge and date of measurement will give a yearly mean hydrograph as well as hydrograph of 80% dependable flows. This method is customized to Grass GIS; and a spread sheet is also available for quick estimation. This method is applicable for estimation of e-flows which is one of the key hydrological parameters for river diversion/reservoir projects. This paper focuses on introduction of the updated MIP method for monthly flow estimation and its application on dependable and e-flow estimation.

Keywords: *e-flow; hydrological regions; MIP method; ungauged basins*

1. Introduction

Assessing and maintaining the downstream release as an environmental flow (e-flow) to minimize the negative environmental impacts are very crucial in water resources development projects. It is necessary for the sustainability of freshwater ecosystems. The term e-flow was defined in Brisbane Declaration

(2007) in this way: "Environmental flow describes the quantity, quality and timing of water flows required to sustain freshwater ecosystems and the human livelihoods and well-being that depend on these ecosystems". In Nepal, from the early human civilization, river water has been used for different purposes by constructing hydraulic structures. Farmers have interfered with river flows by diverting water for irrigating their crop lands from thousands of years ago. Beside irrigation, people have been using rivers as means of water transportation and water mills. The hydropower for electricity was initiated a century ago, by constructing a hydropower project in Pharping, Kathmandu in 2011. The modern irrigation system started in 1922 during the Rana regime by constructing *Chandra Nahar*. The hydropower plant (Pharping Hydropower Plant) is one of the oldest hydropower plants of Asia and the first hydropower plant of Nepal (Adhikari, 2006). River characteristics with fast flowing, perennial rivers and waterfalls are generally used as sources of energy, via watermills and hydroelectric plants. In Nepal, from the past few decades, river flows have been regulated at an increasingly rapid rate with the construction of diversion weirs, barrages, inter-basin transfer tunnels, dams and embankments. Besides these, domestic and industrial wastes have been discharged with no or little treatment. For such constructions, many developed countries have their environmental laws, regulations, and comprehensive methodologies for setting flow regimes for waterway management.

Due to the spatial and temporal distribution of water resources availability and increased demand for different purposes, water stress is gradually increasing. The current tendency is diverting or extracting almost all available water from river to get maximum benefit from irrigation, hydropower and drinking water supply projects. This adversely affects the downstream area. There is a provision of maintenance of minimum flow (downstream release) in the river as an environmental flow in the water resources projects. The Water Resources Act enacted in 1992 has made legal provisions for environmental study before developing any water resource projects. It describes that submission of one environmental study is mandatory along with submission of the project report by water resource-related project developers. The Hydropower Development Policy introduced in 2001 specifically states that "Downstream release shall be maintained, either 10% of minimum mean monthly discharge or the quantum identified in the EIA study (Rijal and Alfredsen, 2015).

It is important to know the flow or hydraulic channel data to get an idea about the e-flow requirement of a river system. Hydrological methods are based on historical flow data and therefore are simple and quick to use, which is called as desktop approach (Jayasiri et al., 2015). Hydraulic rating methods can be used when the past flow records are absent but these methods are not suitable for assessing seasonal flow requirements. Tennant method is one of the oldest and widely used methods, which assumes a linear relationship between flow and stream environment. A study based on this method has concluded that at least 10% of the mean annual flow is needed to survive the system and 30% is for living satisfactorily (cited in Jayasiri et al., 2015). Before e-flow estimation, assessment of seasonal flow is required. At ungauged locations, estimation of flows is required to develop seasonal flow hydrograph. The updated MIP (2016) method is one of the simple methods for seasonal flow assessment developed by Department of Irrigation (DoI), the Government of Nepal. This method divides Nepal into 22 hydrological regions for flow assessment purpose. This paper focuses on the MIP (2016) method for estimation of long-term monthly flow and e-flow.

2. MIP Method

The MIP (1982) method is updated recently as MIP (2016) under the Water Resources Project Preparatory Facility (WRPPF) projected implemented by DoI under the Grant Assistance of Asian Development Bank (ADB). The MIP (1982) method presents a technique for estimating the distribution

of monthly flows throughout a year for ungauged locations. For application to ungauged sites, it is necessary to obtain at least single flow measurement in the low-flow period from November to April. It divides Nepal into 7 hydrological regions (Fig. 1a). The primary sources were data from 34 gauging stations and a large number of discharge measurements taken during the low flow season. These regions were developed based on the area-ratio method and discharge data was normalized by the catchment area of the gauging stations. The seven regions do not reflect the high variation in the rainfall pattern. MIP (2016) method has been derived based on data from gauging stations, meteorological stations and watershed characteristics, such as physiography, land use and soil. In total, 22 hydrological regions have been delineated, each with different hydrological characteristics (Fig. 1b). The parameters included in this new method are hydrograph shape, difference between maximum and minimum flows, timing of peak and minimum flow, rainfall and other parameters (topography, soil type and land use).

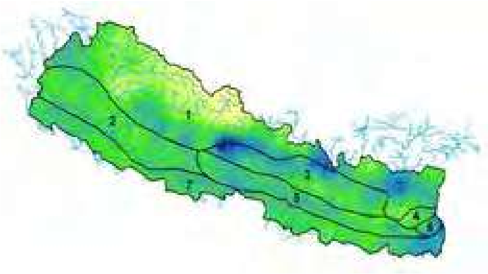

***Figure 1a**: Seven hydrological regions in MIP (1982) method*

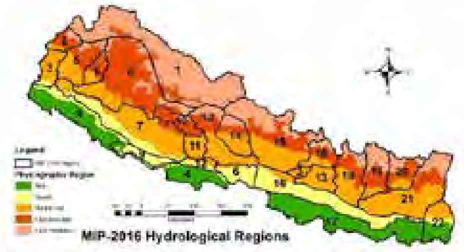

***Figure 1b:** 22 hydrological regions in MIP (2016) method*

The MIP (2016) method is based on a single spot measurement. A hydrograph can be developed for the entire year at bi-monthly time step. However, as the spot measurement plays a crucial role in the estimation of the overall water availability, it is essential that the discharges derived from the spot measurement are representative for that location.

This method gives 4 sets of data for each region, i.e. average specific discharge (l/s/km²), 80% dependable discharge (l/s/km²), maximum envelope for snow-fed catchment areas (l/s/km²) and maximum envelope for rain-fed catchment areas (l/s/km²). An example of full hydrographs for regions 2 and 16 are shown in Fig.s 2a and b, respectively.

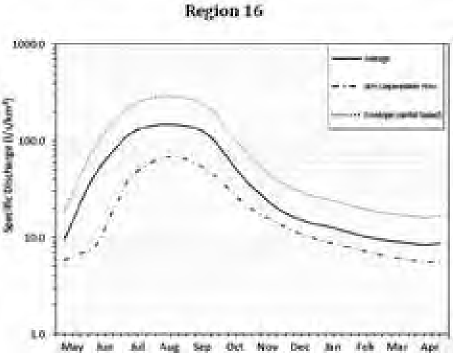

***Figure 2a**: Hydrograph region 2*

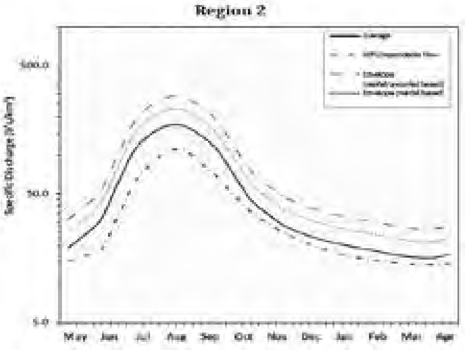

***Figure 2b**: Hydrograph region 16*

3. Monthly Flow Estimation from MIP (2016) Method

Since, MIP (2016) method is particularly developed to estimate the monthly flows throughout a year for ungauged locations. The flows can be obtained either from tables and hydrographs in the manual or from the software developed for this method. The manual contains all the information necessary to perform pre-hydrological calculations. In addition, an excel spreadsheet and QGIS application is produced for more advanced uses. The limitation of the software is that it does not give maximum envelope. If the spot measurement is much higher than the average curve, one can manually calculate upper limit curve from the given hydrographs of 22 regions (Fig. 2b).

The calculation of monthly flow from MIP 2016 method needs both desk and field work. The following steps are involved in this method:

- Visit the proposed site for the project
- Take geo-location of site from GPS/Cell Phone
- Single flow measurement in the low-flow period
- Note the date of measurement
- Using topographic map or Google earth, determine the catchment area

After filling up the above information in software (Fig. 3), we can obtain

- Catchment area of the scheme;
- Hydrological zone; and
- Monthly flow data and hydrograph (e.g. Fig. 3b)

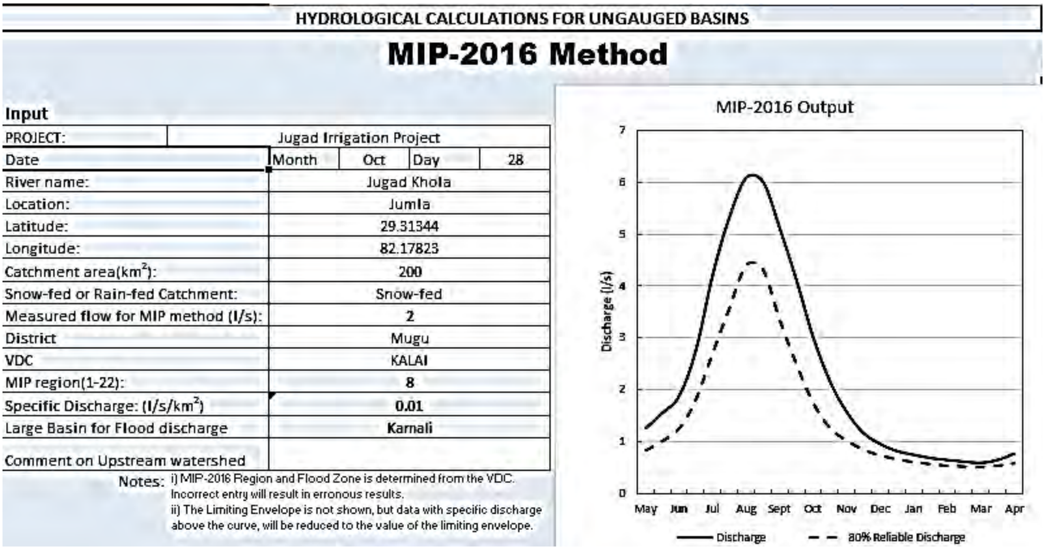

***Figure 3**: MIP (2016) software data entry sheet*

It software is not available; the long-term average monthly flows can be obtained by multiplying with the measured catchment area (Table 1a). If one-time measurement during low-flow season is higher than average value given in Table 1a, the upper limit table (Table 1b upper limit flow) in the manual could be used to get monthly flows. An example of table from region 10 from manual is presented in Table 2.

***Table 1a**: Mean monthly and 80% dependable flows*

	Average Monthly flows l/s/km2												80% dependable flows l/s/km2											
Hydrological Region	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1	14.4	29.2	53.3	66.6	36.4	16.2	9.0	7.0	6.0	5.3	6.6	7.6	8.9	14.6	26.4	42.3	18.7	10.7	7.1	5.4	4.6	4.2	4.7	5.4
2	20.0	49.2	134.1	131.1	129.1	50.0	40.0	24.3	20.0	18.0	16.0	15.9	15.5	19.7	75.0	119.0	76.1	39.6	26.4	20.5	16.6	15.5	14.2	14.1
3	7.9	27.9	62.9	96.4	77.9	24.9	14.0	9.0	8.0	7.0	6.6	9.6	4.0	5.1	27.7	54.1	33.9	18.8	10.1	7.2	5.6	4.2	4.1	3.5
4	4.0	14.3	48.9	53.1	38.4	16.2	7.8	5.3	4.4	4.0	3.5	3.1	2.1	2.3	9.6	14.7	14.2	7.4	4.0	3.3	3.4	2.0	2.4	2.0
5	13.0	28.6	112.8	79.1	72.9	22.5	13.0	13.0	11.5	10.5	8.5	9.5	10.0	12.4	39.8	60.6	40.6	21.7	14.8	11.8	9.7	8.7	7.8	8.1
6	15.9	32.9	139.7	181.7	129.1	48.5	22.7	15.3	12.5	13.8	11.9	8.9	5.7	9.4	60.0	114.8	62.8	24.0	18.9	13.5	8.9	8.5	6.6	3.9
7	8.7	28.6	75.6	40.1	17.9	48.6	14.6	10.1	8.5	7.6	7.8	5.6	4.1	6.0	25.8	36.7	39.1	17.5	10.3	7.4	6.2	5.3	4.6	4.0
8	10.0	26.2	63.7	80.1	60.0	31.6	16.3	11.0	9.1	8.0	7.5	10.7	11.4	17.3	40.8	62.1	38.7	17.7	11.4	8.8	7.2	8.5	6.4	7.5
9	4.0	22.3	75.6	38.4	72.5	20.5	12.7	7.5	6.9	6.1	4.7	4.0	1.7	2.4	23.6	37.5	31.3	14.2	7.3	5.4	4.6	3.8	3.2	2.3
10	21.0	48.5	190.9	204.2	158.5	46.6	22.1	14.7	12.4	8.8	8.2	13.4	10.5	13.4	71.2	129.5	79.3	25.1	14.7	10.2	9.2	5.6	6.0	9.2
11	17.0	45.1	156.8	154.4	90.6	46.6	19.0	14.1	8.5	8.8	7.0	9.5	9.5	10.0	58.1	88.6	45.3	25.1	17.7	10.7	8.8	6.6	5.1	6.5
12	5.0	27.3	74.6	28.1	72.9	18.0	15.0	10.2	9.0	8.8	6.6	6.6	2.8	4.4	14.5	17.4	20.6	11.9	8.8	7.3	7.5	5.3	4.4	4.4
13	20.0	31.7	176.9	181.7	120.0	46.6	21.7	15.5	13.8	9.6	8.5	10.8	5.8	17.6	71.5	84.5	56.7	20.0	15.4	10.7	8.7	7.5	6.7	7.1
14	32.6	37.6	247.5	293.3	207.4	100.1	40.0	28.0	24.0	20.0	18.0	23.4	19.8	33.0	145.4	185.0	124.1	54.5	30.4	21.7	17.0	14.2	13.3	15.5
15	23.2	70.7	172.2	169.8	152.2	62.6	31.3	19.0	14.0	12.0	15.7	14.2	14.9	27.8	101.3	130.1	90.8	40.8	24.5	16.1	12.5	10.2	9.7	10.6
16	17.0	50.7	184.7	154.4	179.1	46.6	27.7	14.1	13.6	11.8	9.8	8.1	6.1	9.4	50.7	72.9	54.7	24.9	15.3	10.6	8.6	7.2	6.1	3.5
17	4.0	22.3	62.6	53.1	38.4	16.2	7.8	5.3	4.4	4.0	3.5	3.2	1.4	1.4	23.6	25.3	16.3	8.7	5.4	3.8	2.8	2.4	2.4	2.1
18	27.0	75.5	190.9	246.0	191.1	100.1	50.0	30.0	22.0	15.0	15.0	10.0	17.6	30.2	101.1	153.9	111.6	52.7	31.9	20.2	15.6	12.9	11.7	13.5
19	23.6	58.3	219.2	297.7	158.5	78.6	35.8	22.2	12.1	12.4	12.2	15.9	13.4	26.9	120.0	145.5	97.5	42.4	24.2	16.9	11.7	10.8	9.9	10.3
20	67.6	87.6	156.8	181.1	129.1	78.6	45.0	40.0	20.0	17.0	14.2	15.9	18.5	44.8	83.9	97.5	83.7	44.1	29.0	18.6	15.8	11.5	9.5	9.5
21	37.6	90.5	190.9	224.3	129.1	79.6	30.0	19.0	15.0	11.8	11.4	15.9	20.1	44.7	113.4	120.7	81.3	36.1	21.4	13.7	10.4	8.8	7.9	10.7
22	21.6	68.3	173.4	203.0	138.7	65.9	25.0	16.0	15.0	11.0	10.0	10.6	10.1	20.6	64.5	67.1	60.3	30.2	17.3	11.7	9.3	8.0	7.1	7.3

***Table 1b**: Upper boundary for snow and rain-fed rivers*

	Maximum envelope (rain-fed) l/s/km2												Maximum envelope (snow-fed/rain-fed) l/s/km2											
Hydrological Region	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1	17.5	96.5	175.1	215.5	126.9	53.1	29.7	23.0	19.8	17.8	18.5	25.1	50.6	120.7	220.1	270.7	158.6	66.0	37.1	26.7	24.0	21.7	21.1	31.3
2	26.7	40.4	180.1	243.0	172.6	66.0	40.1	31.0	20.7	24.1	21.4	21.2	53.4	80.5	225.2	303.7	215.0	82.6	50.1	38.6	23.4	30.1	26.7	26.5
3	15.6	44.0	124.2	194.5	144.2	52.1	27.7	17.8	15.8	13.8	12.9	11.1	17.8	55.0	155.2	243.1	180.3	65.1	34.6	22.2	19.8	17.3	16.1	13.9
4	16.7	44.4	102.6	727.1	149.8	60.4	37.4	27.7	18.4	15.6	14.8	14.4	20.9	74.2	228.3	276.4	199.9	84.2	40.5	37.7	22.9	20.8	18.5	16.6
5	32.1	70.6	156.0	192.7	18–	80.3	47.0	32.1	28.4	25.9	23.5	13.6	50.1	88.3	193.8	240.9	226.1	100.1	58.8	40.1	35.5	32.4	29.3	29.5
6	20.5	53.4	221.6	200.3	232.6	75.7	37.4	25.1	20.6	22.4	10.5	14.7	32.7	66.7	277.4	374.1	265.8	89.6	46.8	31.3	25.8	28.0	23.6	18.4
7	14.7	52.4	138.6	150.5	133.7	65.8	30.4	15.5	15.5	13.4	12.8	10.5	24.4	87.4	231.0	250.3	222.8	106.3	50.6	32.5	25.6	22.4	21.4	27.2
8	40.9	71.3	175.2	225.0	163.1	86.0	44.4	29.9	24.7	21.7	20.3	19.2	54.3	79.1	190.5	261.1	181.3	95.5	49.8	37.7	27.6	34.7	27.6	29.4
9	6.1	33.8	115.0	149.5	110.9	49.4	19.9	11.4	10.5	9.0	7.1	6.1	10.2	56.4	196.6	249.2	184.6	82.4	32.1	19.0	17.5	15.4	11.9	10.1
10	27.3	63.2	248.4	291.8	206.2	60.6	28.8	19.1	10.9	11.4	10.7	17.4	34.1	70.0	308.5	364.7	257.8	75.7	36.0	23.8	16.5	14.3	13.4	21.8
11	22.8	40.5	200.8	205.6	121.4	62.4	25.5	13.7	11.3	11.8	3.4	12.8	28.4	62.7	263.0	257.0	151.7	78.0	31.5	24.6	14.2	14.7	11.7	16.0
12	11.1	49.6	188.5	173.9	162.5	62.4	33.4	23.7	20.1	19.6	12.5	12.5	15.9	70.8	240.7	248.4	232.1	89.1	47.7	33.9	28.6	28.0	17.8	17.9
13	39.1	79.5	292.9	364.4	175.7	68.0	47.6	27.6	14.6	13.4	17.4	16.8	35.4	94.4	320.8	331.7	219.1	85.0	39.6	28.7	18.3	17.4	15.6	19.7
14	54.5	140.5	356.2	459.2	298.5	144.1	57.5	40.3	34.5	28.8	25.3	33.7	67.6	175.6	445.3	520.0	373.1	180.1	72.0	50.1	43.2	36.0	32.4	42.1
15	37.4	114.0	277.5	302.7	240.5	101.0	50.5	30.7	22.5	13.4	10.8	23.0	46.7	141.7	347.4	380.9	307.0	126.2	63.1	38.3	28.2	24.2	23.5	28.7
16	82.8	118.1	280.2	295.3	243.4	89.5	42.8	28.4	26.3	22.9	17.4	16.0	51.8	118.1	280.2	296.3	249.4	89.9	42.8	28.4	26.3	22.9	17.4	25.0
17	23.3	109.6	294.2	251.5	181.9	76.6	36.8	25.2	20.8	13.9	16.8	15.1	19.0	105.8	293.3	292.4	181.9	76.6	36.8	25.1	20.8	18.9	16.8	15.1
18	40.6	113.7	187.4	371.2	297.7	150.7	75.3	45.2	33.1	28.6	24.1	27.1	50.8	142.1	369.2	464.0	369.6	188.4	94.1	56.5	41.4	35.8	30.5	33.9
19	24.5	85.5	274.1	202.3	190.1	92.1	44.8	29.1	22.8	15.2	17.7	19.8	30.9	106.8	342.6	402.8	247.7	115.1	56.0	36.3	28.3	24.0	22.2	24.0
20	61.0	158.3	251.7	294.7	309.4	119.4	73.0	48.7	32.4	27.8	23.0	25.7	76.2	197.9	319.9	368.4	261.7	149.3	91.2	60.8	40.6	34.5	28.7	32.2
21	45.5	109.3	231.1	271.4	156.3	88.1	36.3	23.0	18.2	14.3	13.9	19.2	56.9	136.6	288.6	339.3	195.3	111.4	45.4	28.7	22.7	17.9	17.4	24.0
22	38.5	171.7	289.6	369.3	230.0	117.8	44.5	37.0	23.1	19.8	17.8	19.3	48.8	195.2	340.9	460.9	364.5	136.4	48.4	35.6	25.7	20.0	19.8	31.5

***Table 2**:A sample of MIP 2016 results for region 10*

Month / Unit	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-31
Specific Discharge (l/s/km²)	19.0	24.1	32.2	60.8	110.1	146.5	170.0	168.6	142.2	109.3	69.8	45.0
80% Dependable Specific Discharge (l/s/km²)	15.0	16.4	18.6	33.5	61.2	86.0	108.0	108.3	86.8	67.0	48.7	36.3
Maximum Snow-fall / Rain-fed Envelope (l/s/km²)	31.7	40.2	53.8	101.7	184.0	244.8	284.1	281.7	237.8	182.7	116.6	75.2
Maximum Rain-fed Envelope (l/s/km²)	25.4	32.2	43.0	81.4	147.2	195.8	227.3	225.4	190.2	146.2	93.3	60.2

Month / Unit	November 1-15	November 16-30	December 1-15	December 16-31	January 1-15	January 16-31	February 1-14	February 16-28	March 1-15	March 16-31	April 1-15	April 16-30
Specific Discharge (l/s/km²)	35.0	28.3	24.9	22.4	20.8	19.5	18.5	17.5	16.5	16.0	15.9	16.9
80% Dependable Specific Discharge (l/s/km²)	29.7	24.8	21.7	19.3	17.5	16.3	15.6	14.9	14.4	14.2	14.1	14.4
Maximum Snow-fall / Rain-fed Envelope (l/s/km²)	58.5	47.3	41.7	37.5	34.8	32.6	30.9	29.3	27.6	26.7	26.6	28.2
Maximum Rain-fed Envelope (l/s/km²)	46.8	37.9	33.3	30.0	27.8	26.1	24.7	23.4	22.1	21.3	21.3	22.6

4. Environmental Flow (e-flow) from MIP (2016) Method

The Hydropower Development Policy (2001) has quantified a minimum flow in rivers, downstream of any hydropower plants. It states the minimum release should be such that it is higher of either at least 10% of the minimum monthly average discharge of the river/stream or the minimum required quantum as identified in the EIA study report. For gauged rivers, the percent needed could be obtained from flow records but for ungauged rivers, monthly flow data will be required to estimate e-flows.

There are many methods for e-flow estimations. The methods vary from simple ones to more modern holistic methods. Based on levels of detail there are 3 levels: low resolution, medium resolution, and high resolution. Low resolution is usually desktop based and simple. It needs hydrological or hydraulic data for analysis and it derives standard indices as recommended flows and no detail on the responses of habitat or species required. The MIP 2016 falls in the low resolution method. The monthly flows are first estimated using this method. The e-flow is then estimated as mean monthly flow of dry season x 0.1 (10 % of flows) for survival of the system or mean monthly flow x 0.3 (30%) for living satisfactorily (cited in Jayasiri et al., 2015) or the percent of flow that can be acquired from EIA demand.

5. Conclusion

Estimation of e-flow with river flow records (gauged rivers) is easier but always involves complicated process for ungauged rivers. One such simple and reliable method is MIP 2016 which has been derived based on data from gauging stations, meteorological stations and watershed characteristics, such as physiography, land use a55nd soil. In total 22 hydrological regions have been delineated, each with different hydrological characteristics. On the basis of a single spot measurement, a hydrograph can be developed for the entire year in ungauged basins. However, as the spot measurement plays a crucial role in the estimation of the overall water availability, it is essential that the discharges derived from the spot

measurement are representative for that location. This method is reliable as one needs to measure flow at least once in low flow to assure the water flow in river. After identifying hydrological zone, delineating catchment area of the scheme and one-time flow measurement, a monthly hydrograph can be easily determined. The estimated monthly flows could be used to estimate e-flow for the river, which is a key for sustainable water resources development in Nepal.

Acknowledgements: The MIP update was carried out with the aid of a grant from Asian Development Bank under grant 229-WRPPF (Package 4) Project. The implementing agency of this project is Department of Irrigation, Government of Nepal.

References

Adhikari, D. (2006). Hydropower Development in Nepal. Nepal Rastra Bank NRB Economic Review, 18, 70-94

Joubert, A., King, J., Brown, C. (2016). Comparing incomparable in DRIFT E-Flows assessments, 19th River Symposium, New Delhi, Sept 2016.

Gopal, B. (2016). A conceptual framework for environmental flows assessment based on ecosystem services and their economic valuation. Ecosystem Services, 21 (Part-A), 53–58.

Brisbane Declaration (2007). Summary findings and a global action agenda of the 10th International River symposium and International Environmental Flows Conference, 3-6 September 2007", Brisbane, Australia.

Orth, D. J., Maughan, O.E. (1981). Evaluation of the "montana method" for recommending instream flows in Oklahoma streams. Proceedings of the Oklahoma Academy of Science, 61, 62-66.

DoI (2016). Report on Methodology for the Update of the Flow Assessment Method. WRPPF package 4, Draft Report.

JVS/GWP-Nepal (2016). Assessment of the Environmental Flow in the Gandaki River Basin: A Case of Modi Khola. Research Document, Jalsrot Vikas Sanstha (JVS)/GWP Nepal.

King, J.M. (2009) Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions, Volume 1-4, Report No: 07/2009

Jayasiri, M. M. J. G. C. N., Dayawansa, N. D. K., Gunawardena, E. R. N. (2015). Comparison of methods to assess environmental flows: a review. Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka. International Research Symposium on Engineering Advancements 2015 (RSEA 2015) SAITM, Malabe, Sri Lanka

Rijal, N., Alfredsen, K. (2015). Environmental flows in Nepal: An evaluation of current practices and an analysis of the Upper Trishuli-I hydroelectric project. Hydro Nepal, 17, 8-17

Linnansari, T., Monk, W.A., Curry, R. A. (2012). Review of approaches and methods to assess environmental flows across Canada and internationally. Research Document 2012/039, Environment Canada, Canadian Rivers Institute, University of New Brunswick

Prioritizing land and water interventions for climate smart villages

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Abstract

Climate smart villages (CSV) involve implementing portfolio of best locally suited climate smart agricultural (CSA) practices in an integrated manner to build resilience of local communities. Land and water interventions (LWI) form a significant part of CSA practices portfolio with water availability being the key limiting factor. Generally, practices are implemented based on stakeholder consultations and perceived benefits with limited quantitative impact analysis due to limited capacity to develop complex and data-intensive methods/models. To aid in this decision-making process of prioritizing LWI, we have developed a simple and robust excel-based water balance tool that could provide useful insights to prioritize interventions via linking their impact on water balance to CSA objectives of agricultural productivity, climate change adaptation/resilience and mitigation. The tool involves simulating water balance with modified Thornthwaite-Mather method with runoff calculated using SCS runoff method, evapotranspiration using Hargreaves method and appropriate crop coefficients. Multiple LWI are integrated in the tool with their impact categorized under physical processes or parameters of surface storage, groundwater recharge, water application efficiency, runoff and soil moisture availability. Resultant impact of interventions is quantified in four metrics of change in yield, irrigated area, drought resilience and greenhouse gas (GHG) emission intensity. To prioritize CSV interventions, impact metrics of LWI practices are compared along with the cost.

This approach is implemented in CCAFS-ITC project villages of Barbakheri, Sehore District, and Sitaljhiri located in Betul district, Madhya Pradesh, India. Multiple LWI scenarios based on local context and stakeholder consultations LWI were developed and applied. Water balance tool performs well in simulating village water balance and its impact on yield of rainfed and irrigated crop areas. Analysis points that only combination of supply, demand and moisture conservation practices have a significant impact in improving village productivity, resilience and GHG emission reduction. Results indicate the utility of tool to be used along with stakeholder consultations to prioritize interventions. In the next step, findings could be generalized based on clustering of village (typologies) which could be used to transpose the findings to similar villages.

Keywords: *climate smart agriculture; climate smart villages; land and water interventions; prioritization framework, water balance*

1. Introduction

Agriculture plays a vital role in India's economy with more than 50% of population engaged in agricultural activities contributing to 17% of the country's gross value added (GVA) producing 252.22 million tons of food grains thus ensuring food self-sufficiency (DAC and FW, 2017). However, to meet the future demand for food, the annual food grain production needs to reach about 333 million tons by the year 2050 (Kapur et al., 2015). This becomes challenging when agriculture is increasingly coming under stress from natural resource degradation and increased competition of limited natural resources, specially water and land. This necessitates the need to increase productivity and resource use efficiency in agriculture which is much below the global average (Kapur, et al., 2015; OECD, 2014). Climate change would exacerbate this challenge impacting both the distribution and variability of water availability, with the Intergovernmental Panel on Climate Change (IPCC) predicting water-related disasters to increase in both frequency and severity (IPCC, 2012; Smakhtin et al., 2015).

Indian agriculture relies heavily on monsoons with almost 53% of its gross cropped area being rainfed, and water storage for supplying irrigation relying on annual monsoonal rainfall (Gulati et al., 2013). Deficit monsoon in 2002 is estimated to have caused a decline of rice production by 20.7 million tons and 18% decline in overall food production from the previous year's levels (Govindan, 2009; Mall et al., 2006). Also, expected rise in temperature would have direct impact on the Rabi crop (November –April) with every 1 °C rise expected to reduce wheat production by 4 to 5 million tons (MOSPI, 2015). On the other hand, Indian agriculture contributes 17% of the total greenhouse gas (GHG) emissions from the country (INCAA, 2010). Thus, agriculture by increasing yield and reducing GHG emissions can play an important role in achieving India's target to reduce the emissions intensity of its gross domestic product (GDP) by 33 to 35% by 2030 from 2005 level under national determined contribution under Paris Agreement (MoEF, 2015).

Climate-smart agriculture (CSA) that increases yields/production, reduces vulnerability to climate change, and reduces/removes GHG emission, is one of the means of achieving these simultaneous challenges (FAO, 2010; Kaczan et al., 2013). One model of implementing and upscaling climate-smart agriculture is "Climate-Smart Villages (CSV)", which is a combination of local actions that build around promoting and implementing portfolio of best suited CSA practices in an integrated manner to build resilience of local communities. CSV involves researchers, local partners, farmers' groups and policy makers collaborating to select the most appropriate technological and institutional interventions based on global knowledge and local conditions to enhance productivity, increase income, achieve climate resilience, and enable climate mitigation (Aggarwal et al., 2013).

CSV involves prioritizing and implementing CSA practices revolving around seed, water, land energy, nutrients and risk averting instruments helping farmers in reducing climatic risks in agriculture (Khatri-Chhetri et al., 2016). The model of CSVs envelops 5 dimensions of climate smartness encompassing all farm agricultural activities: water, weather, nutrient, carbon and energy smart. Water smart practices, i.e. land and water interventions (LWI), form a critical and significant part of CSA practices portfolio. LWI consists of a range of practices including rainwater harvesting, recharge, soil and water conservation practices, raised bed planting, etc. They help in increasing agricultural productivity by increasing water availability through increasing storage in surface reservoirs, enhancing groundwater recharge, improved soil moisture, and increasing water application efficiency.

Impact of LWI interventions in the vulnerable districts of India to enhance resilience of agriculture to climate change and climate variability is well documented (Sikka et al., 2017). However, different interven-

tions come with varying costs and economic impacts and their implementation involves making important investment decisions (Shirsath et al., 2017). Therefore, prioritization of climate-smart practices and portfolios for making right investment is one of the major challenges for policymakers and implementing organizations (Andrieu et al., 2017). To prioritize, it becomes important to understand the individual and combined impact, tradeoffs and synergies of interventions on three main objectives of CSA: productivity, adaptation and GHG mitigation. Multiple prioritization frameworks exist consisting of four-phase prioritization framework proposed by Andrieu et al. (2017), consensus-driven decision support framework "target CSA" by Brandt et al. (2017), and climate-smart agriculture rapid appraisal (CSA-RA) by Mwongera et al. (2017). Though, there are limited studies that provide a tool/method to do quantitative impact analysis and few that exist are data-intensive and involve subject matter expertise (Shirsath et al., 2017; Webber et al., 2014).

There is a need of simple, easily replicable and conceptually robust framework that can help stakeholders and implementing organizations to evaluate impact of different LWI individually and in combination. In this paper, we provide a Microsoft Excel spreadsheet tool with minimum data requirements to aid in prioritization of LWI individually and in an integrated manner. The framework is based on water balance of village linking impact of practices on village crop production, resilience and GHG emissions. This could provide useful insights to the stakeholders and implementing organizations in the decision-making while planning and prioritizing LWI for adaptation to climate change and establishing CSVs.

2. Methodology

The tool employs monthly water budget approach in balancing the water resources availability and water demand within a village. Water balance is calculated at monthly time step to update soil moisture storage, evapotranspiration, groundwater recharge and surface runoff. Demand consists of monthly cropwater requirements, domestic and livestock needs. Monthly cropwater requirements are met from rainfall, depletion in soil moisture storage and if demand from these two sources are not met and area is irrigated, then from storage in surface reservoir (captured runoff) and groundwater. Any deficit in cropwater requirement is translated to loss in yield using FAO yield response function (Steduto et al., 2012). Human and livestock demand is met through surface and groundwater storage.

Land and water interventions impact on physical processes and parameters in water balance is integrated which manifests itself in changing water source availability and demand. The framework is modelled in Microsoft Excel spreadsheet for simplification. Impact of interventions is quantified in four metrics of change in yield, irrigated area, drought resilience and GHG emissions which could be compared along with their cost to select best portfolio of climate smart intervention in consultation with stakeholders and their perception. The tool requires data on local climate, hydrology, land use, soil and crops that can be acquired easily from combination of village census data, district/regional database and existing literature.

2.1 Water balance

Water balance is calculated at monthly time steps to estimate availability of water for fulfilling demand.

$$P = Q + AET + GWR \pm \Delta SM \pm \Delta SR \quad (1)$$

where, P = Precipitation; Q = Surface runoff; AET= Actual evapotranspiration; GWR = Groundwater

recharge; SM = Soil moisture storage and SR = storage in surface reservoirs; Δ represents change.

Surface runoff is estimated using soil conservations service (SCS) curve number method (USDA, 1972) which is a simple, stable and conceptual method. Daily rainfall data is used to calculate daily runoff and then aggregated on monthly time step. Part of the runoff can be captured in surface reservoirs (SR) based on the available storage capacity (ST). Surface reservoirs lose water though evaporation and seepage.

Mean village actual evapotranspiration (AET) is calculated by averaging crop evapotranspiration from crop areas and evapotranspiration from other land uses (non-crop area) where AET is assumed equal to reference crop evapotranspiration (ET_o). Monthly reference evapotranspiration (ET_o) is calculated using Hargreaves method (Hargreaves and Samani, 1985) requiring only monthly average, minimum and maximum temperature along with solar radiation. Crop evapotranspiration (ET_c) is calculated from reference evapotranspiration by multiplying it with crop coefficients (K_c).

Monthly soil water balance is simulated with Thornthwaite-Mather method (Thornthwaite and Mather, 1955; 1957). It is modified by accounting beforehand surface runoff to get effective precipitation (P_e) as an input to the model and replacing potential evapotranspiration with AET. Maximum soil water storage is defined by soil available water content (AWC) and overflow, when maximum soil storage is reached, is partitioned into groundwater recharge (GWR) and surface runoff (Q). If change in soil moisture (SM) is positive, soil moisture increases and if negative, soil moisture is depleted through evapotranspiration.

2.2 Demand

Crop water requirement (CWR) is estimated as a function of ET_c and water application efficiency (η). Model simulates cropwater requirements based on the consideration that cropping pattern of village is limited by maximum two major crops each month. Water application efficiency (η) of 50 % is considered in case of no efficiency improvement measures. The FAO yield response function (Steduto et al., 2012) is used to calculate resulting yield based on how much of CWR is met.

$$\left(1-\frac{Y_a}{Y_m}\right)=K_Y\left(1-\frac{ET_a}{ET_m}\right) \qquad (2)$$

Y_m and Y_a are the maximum and actual yields, ET_m and ET_a are the maximum and actual evapotranspiration and K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses. Yield (as percent of maximum yield) is calculated at the end of crop duration by summing up cropwater requirement (ET_m) and part of it is met (ET_a). Yield is averaged at village level by taking area weighted average of rainfed and irrigated crop yields.

CWR can be met through P_e, depletion in SM or through irrigation via GWR and SR. In case of rainfed areas, water source is restricted to effective precipitation and soil moisture. For irrigated area, in addition to effective precipitation and soil moisture, irrigation can be done through water stored in surface reservoirs and groundwater (equal to groundwater recharge) restricted by storage which is updated at monthly time step.

Human and livestock demand is based on village census data on domestic and livestock population and is input as a constant demand for each month, which is used before water is made available to agricultural uses.

2.3 Emissions

GHG emissions from crop production are calculated as a sum of emissions from crop production and management, and emissions from pumping irrigation water. Crop production and management emissions per hectare are taken from CCAFS-MOT tool (Feliciano et al., 2017) and pumping emissions are calculated as a function of fuel requirement (diesel or electricity), type of irrigation (surface or groundwater) and volume of irrigation water pumped.

2.4 Land and water interventions (LWI)

LWI are integrated in the framework by listing and categorizing their impact on 5 physical processes or parameters: SR, GWR, Q, CWR and soil moisture SM. Table 1 gives the process and rules through which different interventions' impact in the tool are integrated along with their impact and cost. Quantified impact of interventions on these processes and their cost is based on existing literature and assessments.

Table 1: *List of practices and their associated impact values and cost*

Practices	Impact on Physical process or parameter	Parameter	Cost (INR)
Farm pond	Increase storage (+ ST)	Storage (SR) = volume of structures	Cost =50/m^3 Maintenance cost = 5 % Life =20 years
Stop dam/check dam [a]	Increase storage (+ ST)	Storage (SR) = volume of structures	200/ m^3 Maintenance cost = 5 % Life =20 years
Groundwater recharge wells	Increased recharge (+ GWR)	GWR = monthly recharge from wells	Cost: 4000/m Maintenance: 5% Life= 20 years
Groundwater infiltration ponds	Increased recharge (+ GWR)	GWR = monthly recharge from infiltration	Cost: 50/ m^3 Maintenance: (5%) Time 20 years
Sprinkler irrigation	Increases efficiency (+ η)	Efficiency of 75 %	Cost = 63600/ha Maintenance: 10% Life= 10 years
Drip irrigation	Increases efficiency (+ η)	Efficiency of 90%	Cost = 31600/ha Maintenance: 10% Life= 10 years
Land levelling	Increases efficiency (+ η)	Efficiency increase by 15%	Cost =3000 /ha Maintenance cost = 5 % Life =3 years
Broad bed furrow[b]	Reduced runoff (- CN number) and increase soil moisture (+AWC)	CN reduction by 4 AWC: 100 %	Cost = 1800/ha Maintenance cost = 10 % Life =3 years
No tillage	Reduced runoff (- CN number) and increase soil moisture (+AWC)	CN reduction by 5 AWC: 100 %	Reduction/saving in cost of 2000/ha Application annually

Crop Mulching	Reduced runoff (- CN number) and increase soil moisture (+AWC)	CN reduction by 6 (5 t/ha mulching) AWC: 100 %	Cost = 5000/ha Maintenance cost = 10 % Life =3 years
Bunding (contour/ vegetative barriers)	Reduced runoff (- CN number) and increase soil moisture (+AWC)	CN reduction by 6 AWC: 100 %	Cost: 125/m Maintenance cost = 10 % Life =10 years

[a] Runoff contribution from outside village is considered. In case of stop dam, % of runoff from village is a separate variable based on total watershed area of stop dam. If value is 5%, then 95% of storage is from runoff outside village (which in included in runoff)

[b] It is assumed that without intervention only 80% of AWC is achieved and can be used. With interventions, AWC could be increased to 100 % potential. This is similar to method used by (Garg et al,, 21012)

2.5 Impact metrics

Impact of interventions is quantified in four metrics; change in yield, irrigated area, drought resilience and GHG emission intensity. Change in yield, irrigated area and GHG intensity is taken as the relative change from existing or no intervention scenario. Drought resilience (DR) is the relative change in mean village yield with interventions in drought year as compared to average year with no interventions

$$DR = \frac{Y_{village(I-D)} - Y_{village(0)}}{Y_{village(0)}} * 100 \qquad (3)$$

where, $Y_{village(I-D)}$ is the yield with interventions in a drought year, $Y_{village(0)}$ with no interventions in average year.

2.6 Assumptions and simplifications

Making the Excel tool simple and replicable involves taking certain assumptions and simplifications. Impact on yield is considered as function of evapotranspiration in this study. Also, framework is more suited to evaluate impact of water deficit on yield and is yet not capable of actually simulating negative impact of excessive rainfall other than that through water balance. In mitigation, reduction in GHG emission intensities are only calculated as function of change in yield and irrigation pumping emissions with direct impact of interventions on GHG emissions reduction not considered. Estimate of costs are solely based on capital and maintenance requirements.

To simplify, cropping pattern is limited by maximum of two major crops each in Kharif and Rabi seasons. Impact of interventions is represented by average single number as obtained from literature. Also, village is considered as a whole unit depicting average village results masking any difference in between farms. Though, this is partly done on purpose as objective of CSV is to improve village adaptation and resilience rather individual farms. Despite assumptions and simplification which is required for simplification of tool, robustness of framework, and reliability to provide critical quantitative information to stakeholders.

3. Model Implementation and Scenarios

Model is implemented in two villages of Barbakheri in Sehore district and Sitaljhiri in Betul district, in Madhya Pradesh situated in semi-arid central India where CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is involved in upscaling CSV model. Fig. 1 gives the location of villages and Table 2 gives their basic characteristics. Stakeholder consultations have been held in both the districts to understand local context, challenges, identify vulnerabilities and possible suit of climate smart practices. In both villages, livelihoods of people are centered around farming, livestock and labor in dry season. Similarly, both villages face issues of low yield, water scarcity during non-monsoon season, soil erosion and migration to work as farming is difficult to practice in non-monsoon season. Climate is semi-arid with most of the rainfall received in monsoon months of June-September. In Sitaljhiri, overall irrigation is low but a larger part (25%) of crop is irrigated by lifting water from nearby river/streams. For simulation, it is assumed that all crop area is planted in two main cropping seasons of Kharif (June-October) and Rabi (November – April) thus simulated yield is indicative of available supply of water which would govern actual cropping pattern.

Table 2: *Study villages' characteristics and input data*

Parameter	Barbakheri	Sitaljhiri
Rainfall	Average annual 1141 mm Drought Year(2002): 886 mm	Average annual 1189 mm Drought Year (2002): 1206 mm
Temperature (1966-2002)	Monthly Mean, Min and Max	Monthly Mean, Min and Max
Soil	Black cotton soil (AWC = 210 mm/m, depth = 80 cm)	Black cotton soil (AWC = 210 mm/m, depth = 80 cm)
Land use (CN)	Village area: 283 ha Crop land: 259 ha (88) , Fallow: 4 ha (91), Built-up: 17 (90), Water: 3 (0)	Village area: 643 ha Crop land: 591 ha (88) , Pasture: 11 ha (79), Built-up: 31 (90), Forest: 3 ha (70) Water: 7 (0)
Crop	Kharif (June- October): Soybean , Maize ; Rabi (November – March): Wheat, Chickpea	Kharif (June- October): Soybean , Maize ;Rabi (November – March): Wheat, Chickpea
Irrigated	93 ha, Groundwater: 88 ha, river/ stream: 5 ha	111 ha, Groundwater: 84 ha

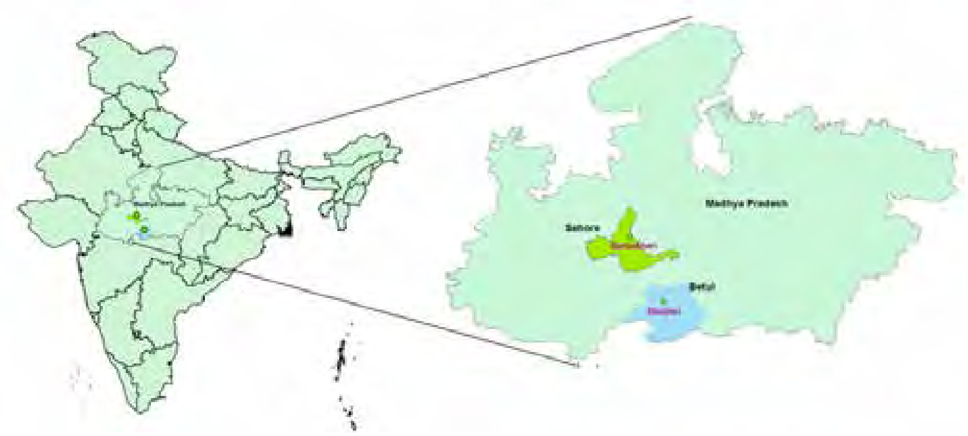

Figure 1: *Location of study village Barbakheri and Sitaljhiri*

3.1 Scenarios

Multiple scenarios with individual and combined interventions are tested for their impact on CSA objectives of productivity, adaptation/resilience and mitigation. They are based on regional context and stakeholder consultations involving farmers, non-governmental organizations (NGOs), government staff and experts that were held to select portfolio of best practices (Khatri-Chhetri et al., 2016). Based on that, following 14 scenarios were analyzed for the study villages (Table 3). All scenarios are analyzed for implementation saturation rate of 50 % which assumes that practices are implemented at only half of the feasible areas.

Table 3: *List of scenarios tested for impact of interventions*

	Scenario	Practice	Barbakheri (ha)/ number	Sitaljhiri (ha)/ number
Supply	S1	Farm pond (~ every 2 ha crop area)	65	148
	S2	Stop dams	1	2
	S3	Groundwater recharge (GWR)	10	20
Demand	D1	Sprinkler (ha) [only on irrigated field]	46.5	55.5
	D2	Land levelling (ha) [only on irrigated field]	46.5	55.5

Soil Moisture	SM1	Broad bed furrow (BBF) (ha)	129.5	295.5
	SM2	Contour bunds/farm bunds	129.5	295.5
	SM3	Conservation tillage (ha)	129.5	295.5
Combined interventions	S1+D1	Farm pond + Sprinkler	-	-
	S3+D1	GWR + Sprinkler	-	-
	S1+SM1+D1	Farm pond + BBF + Sprinkler	-	-
	S3+SM1+D1	GWR + BBF + Sprinkler	-	-
	S1+SM3+D1	Farm ponds + Sprinkler + CT	-	-
	S3+SM3+D1	GWR + sprinkler+ CT	-	-

4. Results and Discussions

4.1 Water balance

Village water balance simulated without any interventions is given in Table 4. It shows the present situation of water resources availability in the normal and drought year. In Barbakheri, runoff is 248.7 mm (~ 22%) and recharge 113.9 mm (~ 9.9%) of annual rainfall and in Sitaljhiri, runoff is 260.3 mm (~ 20%) and recharge 141.3 mm (~ 12.3%) of annual rainfall. Lower runoff and high recharge in Sitaljhiri could be partly be attributed to the presence of pasture and forest area reflecting the importance of land use and management. In both villages, most of the rainfall (> 90 %) and all of the runoff and recharge occurs in monsoon months which make rainfed agriculture highly vulnerable to any deficit. In Barbakheri, drought year of 2002 was characterized by annual rainfall deficit of ~ 22.4 % and severe rainfall deficit in the month of July of ~ 88 % and 37 % in September. In contrast, annual rainfall in Sitaljhiri in 2002 is marginally higher than average year but with a deficit of ~ 89 % in month of July. This is followed by more than average rainfall (> 30 %) in the month of August. Impact of this on water balance is characterized by two things: limiting recharge and very high runoff due to very high concentration of rainfall in one month. Limitation in methodology of not considering recharge via cracks also plays a role in this low recharge value.

Table 4: *Simulated water balance of Barbakheri village*

	Barbakheri				Sitaljhiri			
	Average		Drought		Average		Drought	
	Annual	Monsoon	Annual	Monsoon	Annual	Monsoon	Annual	Monsoon
Rainfall	1141.2	1035.3	886.0	802.7	1189.2	1066.1	1206.6	1090.2

Runoff	248.7	248.7	396.7	396.7	260.3	260.3	586.6	586.6
Recharge	113.9	113.9	4.8	4.8	141.3	141.3	34.6	34.6
ET	778.6	538.5	624.0	466.0	807.7	544.0	739.9	508.5

4.2 Crop yield and water requirements

Table 5 captures the impact of water availability on crop yield and Table 6 gives how much monthly cropwater requirements are met for rainfed and irrigated areas under average and drought years. In Barabakheri, for average year, cropwater requirements are met completely in Kharif season by rainfall and soil moisture for both rainfed and irrigated areas. Impact on crop yield due to water deficit is only seen in Rabi season limiting rainfed yield to just~ 16.6 % of maximum yield as soil moisture at the end of monsoon is mostly depleted by November. Though better than rainfed, even irrigated areas run out of water in Rabi season starting early next year (February) with last phase of crop facing water scarcity reducing potential yield to ~ 79 % of maximum yield. Both the results affirm the observation made in village of difficulty in taking Rabi rainfed crop due no additional water supply and water scarcity in irrigated fields during the Rabi season as wells start going dry starting February.

In Sitaljhiri, rainfed areas face the same issues of low yield due to very limited water availability in Rabi season reducing yield to ~ 21.1 % of maximum yield. Though, irrigated areas show no deficit in both season (yield at 100 %) due to higher recharge and low proportion of irrigated area limiting its abstraction relative to Barbakheri. This indicates that even without any interventions, groundwater recharge is enough to bring more area (~ 68 hectares) under irrigation highlighting the importance of groundwater storage.

In drought year, deficit rainfall can cause unmetcropwater requirements even in Kharif season for both villages (Table 6). Reduced recharge due to drought also has an impact on irrigated area with water requirement deficit in both Kharif and Rabi season impacted severely reducing yield. Impact is felt more in Barbakheri where recharge is almost negligible. This explains that not only rainfed area but irrigated areas are also highly reliant on monsoon rainfall. People might adapt to these by deepening wells with unsustainable groundwater extraction but that is limited in these two villages where most of the wells are open wells. Though, regular deficit is leading to people installing deep bore wells which might lead to unsustainable groundwater abstraction and also excludes poor farmers which lack access to financial resources to do so.

Table 5: *Yield for rainfed and irrigated crop in Kharif and Rabi season under normal and drought year*

	Barbakheri				Sitaljhiri			
	Average		Drought		Average		Drought	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Rainfed	100%	16.6%	76.2%	11.3%	100%	21.1 %	80.9%	16.2%
Irrigated	100%	79.5%	77.4 %	11.3%	100%	100%	81.5%	54.5%

***Table 6**: Monthly cropwater requirement met (in %) for rainfed and irrigated areas in normal and drought year for Barbakheri and Sitaljhiri*

		Kharif season						Rabi season					
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Barbakheri													
Average	Rainfed	100	100.0	100.0	100.0	100.0	100	51.4	25.1	13.9	16.7	51.7	No crop
	Irrigated	100	100.0	100.0	100.0	100.0	100	100.0	100.0	97.8	16.7	51.7	No crop
Drought	Rainfed	100	31.8	100.0	85.9	75.2	100	13.5	6.5	21.0	19.8	100.0	No crop
	Irrigated	100	31.8	100.0	90.6	75.2	100	13.5	6.5	21.0	19.8	100.0	No crop
Sitaljhiri													
Average	Rainfed	100	100.0	100.0	100.0	100.0	100	53.9	27.6	18.1	22.8	62.1	No crop
	Irrigated	100	100.0	100.0	100.0	100.0	100	100.0	100.0	100.0	100.0	100.0	No crop
Drought	Rainfed	100	30.0	100.0	98.0	100.0	100	29.5	15.1	32.0	7.0	57.8	No crop
	Irrigated	100	30.0	100.0	100.0	100.0	100	100.0	100.0	39.4	7.0	57.8	No crop

4.3 Impact of interventions

4.3.1 Barbakheri

The impact of intervention scenarios on four metrics (defined in section 2.5) along with the cost is given in Table 7. Supply side augmentation measures of farm pond and groundwater recharge perform well in increasing overall yield, decreasing emission intensity but are not enough to meet all demands of irrigation as indicated by 0% increase in irrigated area. Stop dam alone shows relatively low impact on overall indicators and this could be because limited overall storage from only one stop dam in comparison to overall storages of farm ponds and groundwater recharge. It does play an important role in combination with other supply-side measures. Soil and moisture conservation practices do well in increasing yield and reducing emission intensity at a lower cost. Demand side interventions (sprinkler and land levelling) alone have little impact but contribute significantly when applied in combination with supply side augmentation and conservation measures.

Limited impact of demand interventions during drought year is constrained due to limited water availability for irrigation. Combined intervention scenarios offer the best solution to achieve higher resilience with lowest decrease in yield and highest increase in irrigated areas. In terms of cost, groundwater recharge is much more economical than farm ponds. Conservation tillage by reducing cost of production is a very attractive option with increased yield resilience and decreased emissions. Results show that at 50% saturation, interventions are not enough thus necessitating the need for higher saturation which would entail higher investments.

Table 7: *Impact of scenarios under four metrics of climate smart village on Barbakheri*

	ΔY	ΔIrr	ΔGHG_{int}	DR	Cost (INR)
No intervention	-	-	-	-33.9 %	0
S1	4.0%	0	-3.5%	-30.5 %	₹ 56,48,864
S2	0.3%	0	-0.2%	-33.4 %	₹ 28,51,356
S3	4.0%	0	-3.5%	-31.8 %	₹ 21,73,466
D1	2.1%	0	-2.0%	-33.8 %	₹ 32,86,900
D2	0.4%	0	-0.4%	-33.9 %	₹ 5,36,951
SM1	3.3%	0	-3.1%	-30.5 %	₹ 9,96,453
SM2	3.3%	0	-3.1%	-30.5 %	₹ 38,62,380
SM3	3.9%	0	-3.6%	-30.0 %	-₹ 26,46,016
S1+D1	6.8%	0	-6.1%	-30.2 %	₹ 89,35,764
S3+D1	6.8%	0	-6.0%	-31.3 %	₹ 54,60,366
S1+SM1+D1	10.3%	7.9%	-8.9%	-26.7 %	₹ 99,32,217
S3+SM1+D1	10.3%	7.9%	-8.9%	-27.2 %	₹ 64,56,818
S1+SM3+D1	11.0%	11.4%	-9.5%	-26.1 %	₹ 62,89,749
S3+SM3+D1	11.0%	11.4%	-9.5%	-26.7 %	₹ 28,14,350

4.3.2 Sitaljhiri

In contrast to Barbakheri, impact of supply and demand interventions have a significant impact on increasing irrigated area as demand for irrigated area is already met without any interventions too. This increases overall village yield by converting rainfed area to irrigated area. Combination of interventions can increase irrigated area up to 145% (274 hectares additional) but still not enough to irrigate all rainfed area of 480 hectares. Similar to Barbakheri, these interventions help in increasing resilience but could not completely mitigate drought impact. Supply-side measures like farm pond and groundwater recharge perform well and their performance gets enhanced when used in combination with demand side measures. GHG emission intensity could be reduced up to 8.5% even when extra irrigated areas are added highlighting the importance of increasing productivity.

Table 8: *Impact of scenarios under four metrics of climate smart village on Sitaljhiri*

	ΔY	ΔIrr	ΔGHG_{int}	DR	Cost
No intervention	-	61.5%	-	-27.2%	0
S1	3.6%	97.5%	-3.2%	-24.0%	₹ 1,28,62,030
S2	0.3%	64.3%	-0.3%	-27.0%	₹ 57,02,713
S3	3.4%	94.8%	-3.0%	-25.0%	₹ 43,46,932
D1	2.4%	85.8%	-2.4%	-26.6%	₹ 39,23,075

D2	0.8%	69.1%	-0.8%	-27.0%	₹ 6,40,877
SM1	2.6%	73.6%	-2.4%	-23.9%	₹ 22,73,759
SM2	2.6%	73.6%	-2.4%	-23.9%	₹ 88,13,385
SM3	3.0%	77.9%	-2.8%	-23.6%	-₹ 60,37,819
S1+D1	6.6%	126.7%	-5.9%	-22.9%	₹ 1,67,85,104
S3+D1	6.3%	124.4%	-5.7%	-24.1%	₹ 82,70,006
S1+SM1+D1	9.2%	142.1%	-8.1%	-19.9%	₹ 1,90,58,863
S3+SM1+D1	9.0%	140.1%	-7.9%	-20.7%	₹ 1,05,43,765
S1+SM3+D1	9.7%	147.1%	-8.5%	-19.6%	₹ 1,07,47,285
S3+SM3+D1	9.5%	145.1%	-8.3%	-20.4%	₹ 22,32,186

Increase in yield and irrigated area/number of irrigations can be seen as building biophysical resilience whereas cost depicts the economic resilience of interventions. Results indicate that impact of severe drought in 2002 can only be mitigated and not eliminated via land and water interventions thus necessitating the need for other interventions like crop insurance and other safety nets to manage risks and build livelihood resilience. Best portfolio of practices would depend on local context and objectives. Analysis suggests combination of groundwater recharge/farm ponds, sprinkler irrigation and conservation tillage give the best result in terms of increasing production, increasing resilience and reducing emission intensity with minimum cost.

4.4 Stakeholders perception analysis

Quantitative information for impact analysis is one part of prioritization frameworks (Andrieu et al., 2017; Brandt et al., 2017; Mwongera et al., 2017), as it doesn't shed light of stakeholders perspetive on technical feasibility, economic feasibility, acceptibility and local policies. As part of CSA portfolio prioritization work, CCAFS organized stakeholder workshop in Madhya Pradesh to rank practices suited to their agro-ecology and socio-economic situations (Khatri-Chhetri et al., 2016). Perception analysis based on stakeholder workshop has been used here for comparison though perception analysis is not for specific village but district Sehore where Barbakheri village is located.

A total of 34 practices consisting of climate smartness under water, energy, nutrient, carbon, weather and knowledge were included in the prioritization workshop. Our results from analysis broadly align with stakeholders' inclination towards supply-side augmentation measures of rainwater harvesting, demand-side measure of sprinkler irrigation and soil moisture activities of broad bed furrow and conservation tillage. Added value of our results can be seen in providing impact of combination of practices in comparison to ranking of individual practices by stakeholders. Also, our results give impact at village scale whereas stakeholder's perspective, especially for farmers, could be biased by impact at farm level. For example, sprinkler irrigation can increase farm productivity and adaptation performing well on farm with irrigation supply but its impact is only limited to existing irrigated area without increasing supply thus less effective for rainfed farms. This can also exclude activities that are not taken at individual farmer scale like of groundwater recharge and stop dam. Thus, pre and post analysis of such results with stakeholder consultation can give important insights.

Stakeholder consultations also provided their perspective on technical feasibility, inclusivity and synergy with government plans which is equally important to prioritize interventions. Sprinkler irrigation and rainwater harvesting are highly technically feasible and have good synergy with government schemes. Minimum tillage shows low score on all aspects. This is a reflection of what was seen in the field in terms of adoption of various practices. This could add extra weight to the prioritized interventions based on quantitative information when difference between two interventions in only marginal. But the same time, if difference in impact between interventions is significant, quantitative information on impacts could provide a base to increase efforts in making practice with higher impact more feasible and including it in government policies and programs.

4.5 Framework for upscaling results

Clustering of villages based on their characteristics of climate, land use, cropping pattern and performance on CSA indicators can provide a way to generalize the results. CCAFS has developed a framework for classification of villages on three parameters, namely, yield, emission intensity, and resilience (Khatri-Chhetri et al., 2016). This could be used in prioritizing situation-specific interventions based on their potential of contributing to above indicators. Under this, each parameter was divided into high and low based on which villages were put under one of the 8 clusters formed by combination of indicators. As the first step, clustering of villages based on climatic, land use, crop, hydrology and soil could be done which impacts both feasibility as well as the result of interventions. For example, Sehore district where Barbakheri village is located has more than 42 villages with majority of them sharing similar bio-physical factors thus result can be generalized over villages. Whereas second clustering, based on yield, emission intensity and resilience can put them under different CSA indicators that could help in prioritizing interventions based on different indicators.

4.6 Future work

Currently, the tool is limited to interventions prioritized for Madhya Pradesh though the concept is generic. Thus, the next step involves including more practices from other states where land, soil and cropping pattern is different. It also requires specific knowledge in terms of what interventions are applicable for given areas. Thus, putting suggestions and in built restrictions is the next step to making the tool user friendly. Direct impact of interventions on emissions is also being inbuilt in the model. Feedback from users, stakeholders and experts are being taken to ensure that it could be used easily and widely adopted by the field implementing agencies.

5. Conclusion

Development and application of a simple Microsof Excel spreadsheet tool based on water balance to prioritize LWI in CSA practices portfolio has been demonstrated. The framework integrates the impact of LWI on village water balance to prioritize interventions via linking their impact on crop production, climate adaptation and mitigation. Results of its application in Barbakheri and Sitaljhiri villages of Sehore and Betul districts respectively of Madhya Pradesh in central India have been encouraging. Results have clearly demonstrated the superiority of combining local/micro level water resources augmentation interventions with demand-side management for prioritizing land and water interventions in establishing climate-smart villages. The comparison with stakeholder's perception analysis on prioritization has also

provided broader agreements and has added value to perception analysis. The framework of integrating results with village clustering is suggested to generalize the results on a broader level. Overall, this can provide a simple and convenient tool for prioritizing land and water interventions. Further work is underway to test the tool at various locations and make the spreadsheet-based tool more user friendly. Prioritization of interventions is only a first step in upscaling and implementing CSA interventions that is faced with a host of other issues in adopting prioritized interventions including finance, availability of machinery and extension services, farmer knowledge and acceptability. Thus, prioritization tool should be seen as one but critical part of the long-drawn process.

Acknowledgements: This study was undertaken as part of the CGIAR Research Program on Climate Change, Agriculture and Food security (CCAFS). It also contributes to the CGIAR Research Program on Water, Land and Ecosystems (WLE). The contributions by CCAFS colleagues including Dr. Paresh Shirsath, Kunal Pandey, Dr. Arun Khatri Chhetri and Dr. Pramod Aggarwal for providing data and suggestions are gratefully acknowledged.

References

Aggarwal, P, Zougmoré, R., Kinyangi, J. (2013). Climate-Smart Villages: A community approach to sustainable agricultural development. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Andrieu, N., Sogoba, B., Zougmore, R., Howland, F., Samake, O., Bonilla-Findjia, O., et al. (2017). Prioritizing investments for climate-smart agriculture: Lessons learned from Mali. Agricultural Systems , 154, 13-24.

Aryal, J. P., Mehrotra, M. B., Sidhu, H. S. (2015). Impacts of laser land leveling in rice–wheat systems of the north–western indo-gangetic plains of India. Food Security, 7, 725-738.

Brandt, P., Kvakić, M., Butterbach-Bahl, K., Rufino, M. C. (2017). How to target climate-smart agriculture? Concept and application of the consensus-driven decision support framework "targetCSA". Agricultural Systems , 151, 234-245.

Carr, E. (2016). Pathways to the adoption of climate smart agricuture. Retrieved January 4, 2018, from https://www.wilsoncenter.org/sites/default/files/csa_carr_presentation_-_wwc_-_final_0.pdf

CRED and UNISDR. (2015). The human cost of weather realted disasters: 1995-2015. United Nations Office for Disaster Risk Reduction (UNISDR) & Centre for Research on the Epidemiology of Disasters (CRED).

DAC and FW. (2017). Annual report. Department of Agriculture, Cooperation & Farmers Welfare, Govt of India.

FAO (2010). "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO) .

FAO (2015). The impact of disasters on agriculture and food security. Food and Agriculture Organization of the United Nations (FAO).

Feliciano, D., Nayak, D. R., Vetter, S. H., Hillier, J. (2017). CCAFS-MOT - A tool for farmers, extension services and policy-advisors to identify mitigation options for agriculture. Agricultural Systems, 154, 100-111.

Garg, K. K., Karlberg, L., Barron, J., Wani, S. P., Rockstrom, J. (21012). Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. Hydrological Processes, 26, 387-404.

Govindan, A. (2009). Poor Monsoon Impact on Agricultural Production. USDA foreign agricultural service.

Gulati, A., Saini, S., Jain, S. (2013). Monsoon 2013: Estimating the Impact on Agriculture. INDIAN COUNCIL FOR RESEARCH ON INTERNATIONAL ECONOMIC RELATIONS.

INCAA. (2010). India: Greenhouse Gas Emissions 2007. Ministry of Environment and Forests, Government of India.

Jat, M. L., Chandna, P., Gupta, R., Sharma, S. K., Gill, M. A. (2006). Laser Land Leveling: A Precursor Technology for Resource Conservation. New Delhi: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Jat., M. L., Gathala, M. K., Ladha, J. K., Saharawat, Y. S., Jat, A. S., Kumar, V., et al. (2009). Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil

physical properties. *Soil and Tillage Research , 105 (1), 112-121.*
Kaczan, D., Arslan, A., Lipper, L. (2013). *Climate-Smart Agriculture? A review of current practice of agroforestry and conservation agriculture in Malawi and Zambia.* FAO.
Kapur, R., Chouhan, S., Gulati, S., Saxena, V. (2015). *Transforming Agriculture Through Mechanisation:A Knowledge Paper on Indian farm equipment sector.* Grant Thornton /FICCI.
Karlberg, L., Garg, K. K., Barron, J., Wani, S. P. (2015). Impacts of agricultural water interventions on farm income: An example from the Kothapally watershed, India. *Agricultural Systems , 136, 30-38.*
Khatri-Chhetri, A., Aryal, J. P., Sapkota, T. B., Khurana, R. (2016). Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. Current Science, 110 (7), 1251-1256.
Khatri-Chhetri, A., Sharma, B., Pant, A., Arumugam, P., Shrisath, P., Sikka, A., et al. (2016). *Developing climate smart villages in Madhya Pradesh.* CGIAR research program on Climate Change, Agriculture and Food security (CCAFS).
Loo, Y. Y., Billa, L., Singh, A. (2015). Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geoscience Frontiers, 6 (6), 817-823.*
Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., Rathore, L. S. (2006). Impact of climate change on Indian agriculture: A review. *Climatic Change, 78 (2-4), 445-478.*
MoEF (2015, October 2). India's intended nationally determined contribution. Retrieved January 2, 2018, from Press Information Bureau : http://pib.nic.in/newsite/PrintRelease.aspx?relid=128403
MOSPI (2015). *Statistics related to Climate Change-India 2015.* New Delhi : Ministry of Statistics and Programme Implementation, Government of India.
MoWR (2009). *Report of the Ground Water Resource Estimation Committe: Groundwater resource estimation methodology.* New Delhi: Ministry of Water Resources, Goverenment of India.
Mullins, J., Zivin, J. G., Cattaneo, A., Paolantonio, A., Cavatassi, R. (2017). The Adoption of Climate Smart Agriculture: The Role of Information and Insurance Under Climate Change. *Climate Smart Agriculture, 52, 353-383.*
Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Asten, P. V., et al. (2017). The Adoption of Climate Smart Agriculture: The Role of Information and Insurance Under Climate Change. *Agricultural Systems, 151, 192-203.*
NIH. (2000). *Applicability of SCS runoff method to different agroclimatic regions.* Roorkee: National Institute of Hydrology.
OECD (2014). *India Policy Brief.* Organization for Economic Cooperation and Development (OECD).
Poapongsakorn, N., Meethom, P. (2011). Impact of the 2011 Floods, and Flood. In Y. a. Sawada, *Economic and Welfare Impacts of Disasters in East Asia and Policy Responses* (pp. 247-310). ERIA.
Prasanna, V. (2014). Impact of monsoon rainfall on the total foodgrain yield over India. *Journal of Earth System Science, 123 (5), 1129–1145.*
Shirsath, P. B., Aggarwal, P. K., Thornton, P. K., Dunnett, A. (2017). Prioritizing climate-smart agricultural land use options at a regional scale. *Agricultural Systems, 151, 174-183.*
Sikka, A. K., Islam, A., Rao, K. (2017). Climate-Smart Land and Water Management for Sustainable Agriculture. *Irrigation and Drainage , Special Issue Paper.*
USDA (1972). *National Engineering Handbook, Section 4: Hydrology.* Washington: United States Department of Agriculture (USDA).
Van Wie, J. B., Adam, J. C., Ullman, J. L. (2013). Conservation tillage in dryland agriculture impacts watershed hydrology. *Journal of Hydrology, 483, 26-38.*
Wagan, S. A., Memon, Q. U., Wagan, T. A., Memon, I. H., Wagan, Z. A. (2015). Economic Analysis of Laser Land Leveling Technology Water Use Efficiency and Crop Productivity of Wheat Crop in Sindh, Pakistan. *Journal of Environment and Earth Science, 5 (15), 2224-3216.*
Wagan, S. A., Memon, Q. U., Wagan, T. A., Memon, I. H., Wagan, Z. A. (2015). Economic Analysis of Laser Land Leveling Technology Water Use Efficiency and Crop Productivity of Wheat Crop in Sindh, Pakistan. *Journal of Environment and Earth Science , 5 (15), 21-26.*
Webber, H., Gaiser, T., Ewert, F. (2014). What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa? *Agricultural Systems, 127, 161-177.*

Impacts of dairy farming systems on quantity and quality in Brazil, Ethiopia, Nepal, New Zealand and USA

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Abstract

There is a need for better understanding of various dairy farming systems and their effectiveness in terms of milk production, water use and nutrient leaching, to adopt systems that maximise production whilst minimising adverse impacts on water quantity and quality. This study examined the performance of dairy farming systems in five countries: Brazil, Ethiopia, Nepal, New Zealand and USA, to identify water-related common features, issues and needs, to support sustainable dairy farming systems. The study was based on existing databases of the Food and Agriculture Organization of the United Nations (FAO) (FAOSTAT/AQUASTAT), and country-specific data sources. Key similarities and differences, primarily in terms of dairy farming operation, milk production, and irrigation management practices were identified.

There are primarily three types of dairy farming systems within the studied countries. The dominant dairy farming system in Brazil and New Zealand is pasture-based open grazing to take advantage of warm climatic conditions that favour grass production and allow stock to be grazed outside almost all year round. In the USA, stall-feeding dairy farming is more popular as in many states a pasture-based system solely cannot support high milk-producing genetically improved Holstein cows. Mixed dairy farming is traditionally adopted in Ethiopia and Nepal, where cows are housed inside during the night and move outside during the day for grazing. The stall-feeding dairy system mostly depends on concentrated feed, while the pasture-based dairy system heavily depends on grass feed. The mixed dairy system depends on both grass and concentrated feed.

Over the study period, milk production per cow per annum was the highest in the USA stall-feeding system, followed by the New Zealand pasture-based system, with the mixed approach in Ethiopia producing the least. Dairy farming is expanding extensively in water-scarce warm areas, where irrigation is essential to enable more intensive dairy farming, which adds pressure on water resources. Compared to the mixed and pasture-based systems, the stall-feeding system places more pressure on water quantity, as the water requirement to produce a given amount of concentrated feed is higher than to produce an equivalent amount of grass, crop residues and fodder.

In many types of irrigated dairy farming, irrigation scheduling does not properly account for the soil's Plant Available Water (PAW), soil moisture status, and plant growth stages. This makes it difficult to match irrigation applications to actual cropwater requirements. Thus, excessive irrigation applications fill the soil beyond its water-holding capacity in the root zone, potentially resulting in percolation or overland flow. This approach wastes water and leaches nutrients into groundwater and surface water. Nitrate leaching, and subsequent contamination of groundwater and surface water, is the biggest common environmental problem in the studied countries, with the high intensity stall-feeding system in USA, followed by the pasture-based system in New Zealand, being the most challenging in terms of managing nutrient losses.

Irrigation networks with sufficient and appropriate flow control structures, and irrigation scheduling that incorporates PAW, soil moisture and plant growth stages, are prerequisites for conversion of low productive agricultural land into high productive dairy farming where minimising the impact on water quantity and quality is of concern.

Keywords: i*rrigation scheduling; mixed dairy farming; nutrient leaching; pasture-based dairy farming; stall feeding dairy farming.*

1. Introduction

Due to population growth and the dietary shift to animal proteins, demand for dairy products is growing rapidly, resulting in dairy farming intensification (Mekonnen and Hoekstra, 2012). Increasing dairy farming is posing increasing pressure on the world's freshwater quantity and quality. Out of a total 9,090 billion m^3 (BCM) of global average annual water use in the agricultural, industrial and domestic sectors, around 27% is responsible for animal production of which 19% is related to dairy cattle (Mekonnen and Hoekstra, 2010; Mekonnen and Hoekstra, 2011). The water requirement to produce a given amount of protein from milk is 1.5 times larger than from pulses (Mekonnen and Hoekstra, 2012).

Agriculture is responsible for about 70% of total global freshwater withdrawal. Pasture production solely contributes 10% of the total global annual water use (Mekonnen and Hoekstra, 2011). To meet the food requirement of 9.5 billion population projected for 2050, we may need between 10,000 to 14,000 BCM water, creating huge pressure on already stressed water resources (Schultz et al., 2007). However, efficient utilization of irrigation water would reduce additional water need to produce food demand of 2050 by 80% (de Fraiture et al., 2010).

If current scenarios of irrigation management are continued, it will lead to water crises in many parts of the world (de Fraiture et al., 2010). Large proportions of existing irrigation schemes associated with dairy farming are performing below their potential. This is not only wasting water, but also discharging nutrients from animal manure and chemical fertilizers to water systems through percolation and overland flow (Anthony and KC, 2017; Cameron et al., 2012). Nitrate leaching from agricultural farms to groundwater and surface water sources is by far the biggest environmental problem associated with the increasing dairy industry (Cameron et al., 2012). As a result, the dairy industry receives widespread public criticism about its adverse impact on the environment (Baskaran et al., 2009). There is a critical need to improve dairy farm irrigation efficiency to minimise pressure on water quantity and quality (Dairy NZ, 2013b).

Dairy farming operations can be broadly divided into three groups: i) stall feeding; ii) pasture based; iii) mixed system (Gerbens-Leenes et al., 2013). In stall feeding, dairy farm stock is always confined inside a

house, which is in contrast to pasture-based dairy farming systems, in which stock are always left outside for grazing. In a mixed dairy farming system, stock are enclosed in a house for specific hours in a day and left outside for the rest of the time for grazing (Falk et al., 2012; Legrand et al., 2009).

To address the issue of growing pressure on water quantity and quality, there is a need for greater understanding of various dairy farming systems in order to adopt systems that maximise production whilst minimising adverse impacts on water quantity and quality (Falk et al., 2012; Legrand et al., 2009). This study examined different dairy farming systems to identify key similarities and differences, primarily in terms of dairy farming operation, milk production and water use, which led to an assessment of the impacts of different dairy farming systems on water quantity and quality. This study also reviewed agricultural water management strategies associated with dairy farming, to reduce important irrigation management gaps, to support sustainable dairy farming systems.

2. Study Description

Five countries were selected to cover various dairy operating systems and geographic locations: Brazil, Ethiopia, Nepal, New Zealand and the USA. For the comparative study, selected countries were divided into three groups with similar land and water management capabilities:

- mixed approach dairy farming were compared between Ethiopia and Nepal;
- pasture-based dairy farming were compared between Brazil and New Zealand;
- grazing and zero-grazing (stall feeding) dairy system were compared within the USA.

For Ethiopia and Nepal, long-term milk production data were available only at the country level. Therefore, to maintain consistency for comparison, country-level data were used for all countries. However, for USA, individual dairy farm data are also compared.

In the study, the following assumptions were made:

- total milk production in Ethiopia and Nepal comes from mixed dairy farming;
- total milk production in Brazil and New Zealand comes from pasture-based systems.

As the dominant dairy farming system in Brazil and New Zealand is pasture-based, and the vast majority of dairy farmers in Ethiopia and Nepal are practising mixed dairy farming, the above assumptions should not have a significant impact on the outcome of the study.

This study is based on secondary data obtained from different information sources along with existing databases of the Food and Agriculture Organization of the United Nations (FAO) (FAOSTAT and AQUASTAT). Information on total numbers of milking cows and milk production were obtained primarily from country-specific data sources. In cases of multiple data sources, the most reasonable ones were adopted after comparative scrutiny.

3. Comparative Discussions

3.1 Milk production

Among the studied countries, Brazil and USA have the longest history of dairy farming (16th century) (Veiga et al., 2002; Weimar and Blayney, 1994), followed by New Zealand (18th century) (Stringleman and Scrimgeour, 2008), then Nepal and Ethiopia (mid-19th century) (Food and Agricultiral Organisation

(FAO), 2010). In Ethiopia and Nepal the majority of milking cows are local breeds, while in the other three countries cows primarily belong to genetically improved species (Brazil: a cross between the tropical Zebu and Holstein Breed, New Zealand: a cross between Holstein-Friesian and Jersey, USA: a cross between Holsteins and Jerseys) (Benson, 2008; Livestock Improvement Corporation (LIC) & DairyNZ, 2015; Passetti et al., 2016).

In Ethiopia and Nepal, the traditional mixed dairy system is the most common. In Brazil and New Zealand, due to warm weather suited to pasture production and open grazing, the majority of cows are grazing outside almost all year round. This is in contrast to USA where cows are mostly confined and are fed grain-based food, as a pasture system alone can not support genetically improved Holstein cows.

In terms of total numbers of milking cows, Brazil has the largest numbers, while Nepal has the smallest (Table 1). In terms of total milk production, USA leads and Nepal is lagging. In terms of milk production per cow, USA leads and Ethiopia is lagging. Over the period between 2000 and 2013, the percentage increase in total milking cows and milk production was by far the highest in Ethiopia and the lowest in the USA. During the same time period, USA witnessed a 20.4% increase in total milk production with only 0.5% increase in total milking cows, indicating that the most efficient livestock farming in terms of milk production exists in the USA. Per cow milk production in USA is significantly higher than in other countries, with per cow milk production in Ethiopia being up to forty times less than in the USA. The percentage increase in milk production for each country is consistently higher than the percentage increase in numbers of cows, indicating an improvement in productivity.

Table 1: *Summary of milking cows (million head) and milk production (million kg) in the studied countries*

Countries	Years				Increase between 2000 and 2013 (%)
	2000	2005	2010	2013	
A. Total milking cows (million head)					
Ethiopia	4.3	3.1	10.7	10.9	151
Nepal	0.9	0.9	1.0	1.0	20
Brazil	16.0	15.1	17.6	20.5	27
New Zealand	3.5	3.8	4.5	4.8	37
USA	9.2	9.0	9.1	9.2	0.5
B. Total milk production (million kg)					
Ethiopia	900	2,140	4,060	4,000	344
Nepal	343	385	447	492	44
Brazil	22,100	24,300	29,900	32,400	46
New Zealand	12,900	14,700	17,300	18,900	46
USA	75,900	80,300	87,500	91,400	20
C. Milk production per cow (kg/head					
Ethiopia	207	687	380	367	77
Nepal	402	427	459	480	19

Brazil	1,380	1,610	1,700	1,580	15
New Zealand	3,710	3,840	3,830	3,950	6
USA	8,270	8,910	9,630	9,910	20

Source: (Dairy Companies Association of New Zealand (DCANZ), 2014; DairyNZ, 2013a; Food and Agriculture Organisation of the United Nations Statistics Division (FAOSTAT), 2015; Livestock Improvement Corporation (LIC) & DairyNZ, 2012; Ministry of Agricultural Development (MoAD), 2013; Statistics New Zealand, 2014; United States Department of Agriculture (USDA), 2013, 2014)

In 2000, milk production per cow per annum (kg/cow/year) was nearly two fold higher in Nepal compared to Ethiopia; while in 2005 Ethiopia achieved around 40% more than Nepal (Fig. 1). Between 2000 and 2013, per cow milk production in Nepal increased by about 20%, while in Ethiopia it increased by nearly 80%. This showed that, while Nepal still had higher milk production per cow per annum by 2013 Ethiopia was implementing practices that were improving production and narrowing the productivity gap. As dairy breeds in both countries are local species, the driving factor for higher milk productivity might be attributed to better farm management.

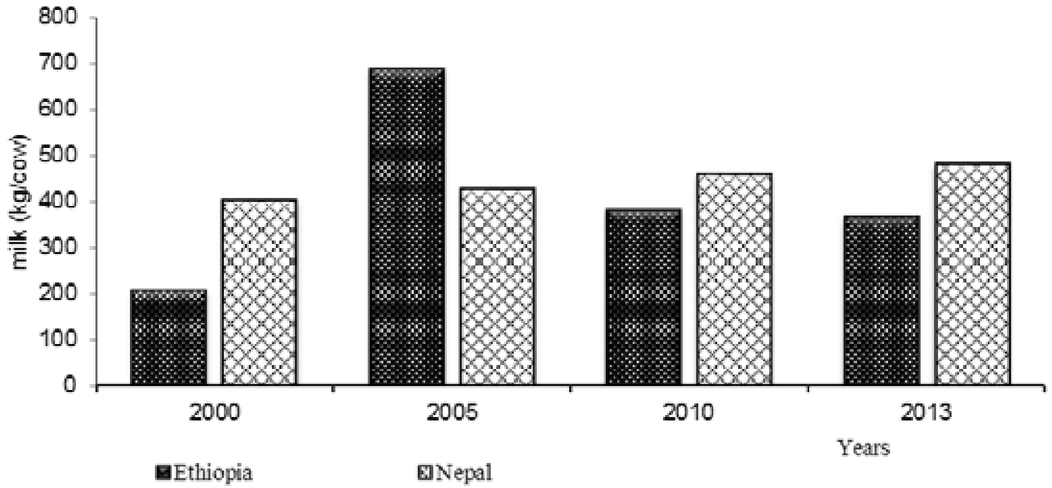

Figure 1*: Per cow milk production (kg/ cow/year) in Ethiopia and Nepal in 2000, 2005, 2010 and 2013*

As seen in Figure 2, milk production per cow per annum (kg/cow/year) from 2000 to 2013 was consistently more than double in New Zealand than in Brazil. Over this time period, milk per cow per annum (kg/cow/year) increased by 15% in Brazil and only by 6% in New Zealand, implying that cows in New Zealand have already achieved close to optimal milk production. Higher milk production per cow per annum in New Zealand compared to Brazil might be associated with better farm management, as the dominant dairy breed in both countries belong to high milk producing genetically improved species.

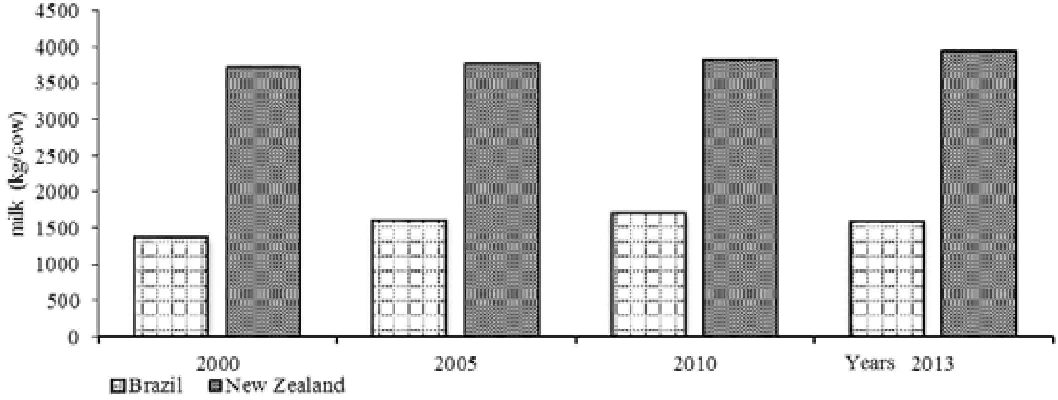

***Figure 2**: Per cow milk production (kg/ cow/year) in Brazil and New Zealand in 2000, 2005, 2010 and 2013*

Fig. 3 compares milk production per cow per year (kg/cow/year) under a pasture-based system with the confinement system used in the USA. Results from a single farm or a small number of farms cannot represent a whole country due to the variability in milk production across farms. Therefore, a comparison was made by averaging the results from a large number of dairy farms. For example, in Fig. 3, data for 2010 include the average from 1915 observations from 26 states representing 90% of the US dairy farm population (Gillespie and Nehring, 2014). Milk production data for large numbers of grazing and zero-grazing systems beyond 2010 was not available. The available information clearly indicates that per cow milk production is higher in the confinement system compared to the pasture-based systems. The finding is in agreement with previous research by Bargo et al. (2003), who claimed that generally confinement systems are characterized by high milk output per cow compared to pasture-based and mixed systems. This implies milk production can be increased by increasing the amount of grain fed to the dairy cows.

In terms of per cow net profit margin, grazing systems outperform zero-grazing systems, due to the latter's high operating costs, such as feed, energy, technology and labour. Several past studies such as Hamilton (2002), Kreigl and Frank (2005) and Benson (2008) have shown higher profit margin per cow for pasture-based systems over the confinement systems. In New York, USA, in a year with a low milk price, the net farm income per cow per year was US$449 in the pasture-based farms, versus US$ 193 in the stall feeding farms (Benson, 2008). For the same dairy farms, in a year with high milk price, the net farm income per cow per year was US$652 in the pasture-based farms, versus US$ 571 in stall feeding farms (Benson, 2008).

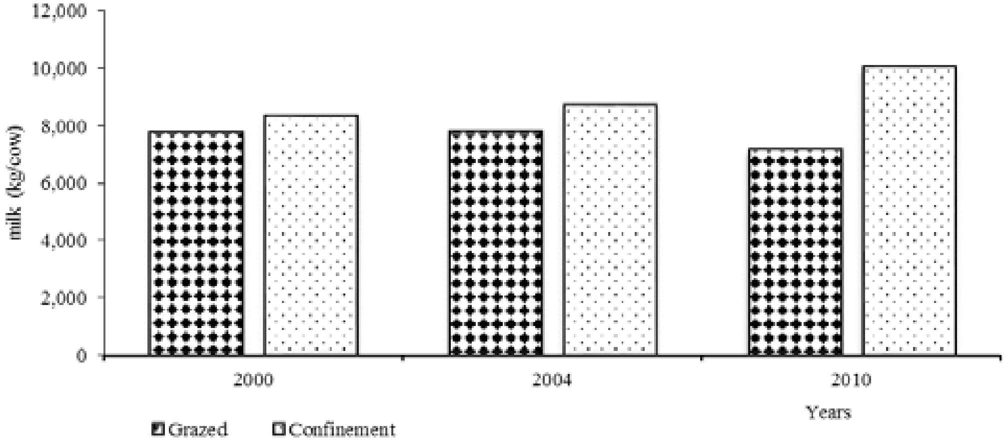

***Figure 3**: Per cow milk production (kg/ cow/year) in pasture-based and confinement system in US. (Sources: Benson, 2008; Gillespie & Nehring, 2014; Muller, 2017)*

The number of cows that a grazing farm can support is constrained by the availability of pasture and the distance milking cows can walk. Herd size is less constrainted in stall feeding systems as the transport of forage crops is the main issue. Therefore, opportunities to increase herd size and thus, increase overall economic benefit is greater under a confinement system (Benson, 2008). However, adoption of a mixed or pasture-based system is preferable for small and medium landholders, especially in the least developed countries such as Ethiopia and Nepal, due to the high operating cost and advanced technology required for modern confinement systems (Cooner et al., 2009).

3.2 Pressure on water quantity and quality

Dairy farming is primarily expanding in warm climates that support grass production. However, irrigation is usually required in those areas to meet cropwater requirements, which adds to pressure on water resources (Martin et al., 2006). In USA, dairy farming is primarily shifting from the water resource rich eastern regions to the water scarce west and southwest areas, which is creating a huge pressure on water resources (Zhou et al., 2010). Due to over-exploitation of groundwater, aquifers are severely depleted in some of those regions (Wada, 2012).

In New Zealand, dairy farming is extensively expanding in regions such as Canterbury that are vulnerable to summer droughts and rely on irrigation to support pasture growth. Due to increased water use, many water resources in Canterbury have either already reached or are close to their water allocation limits. The significant increase in groundwater use associated with dairy farming intensification has contributed to a decline in groundwater levels and reduced flows in rivers and streams, leaving less for other water users (Baskaran et al., 2009).

Confinement dairy farm systems mostly depend on feed grain, while pasture-based dairy systems heavily depend on grass feed. The mixed dairy system depends on both grass and feed grain. Water requirements to produce same amount of dry mass (DM) of feed grain (1000 m^3/tonne DM) is five times higher than to

produce equivalent DM of a mixture of grass, crop residues and fodder (200 m^3/tonne DM) (Hoekstra, 2012; Mekonnen and Hoekstra, 2010). This implies that grain-based confinement dairy farming systems put more pressure on water quantity than pasture-based or mixed dairy farming systems.

The expanding dairy industry is also putting pressure on water quality due to nitrate leaching from dairy farms to water bodies. The confinement dairy farming systems in USA often disposes animal wastes from manure onto small land areas, exceeding the waste absorption capacity of the land. Under high rainfall events, concentrated animal waste leaches to water bodies, causing detrimental impacts on the environment such as contamination of surface water and groundwater quality (Croney and Anthony, 2011; Fraser, 2008; Smith and Alexander, 2000; von Keyserlingk et al., 2013). Studies conducted in California (Harter et al., 2012) and Washington (US Environmental Protection Agency (US EPA), 2012) found that 10% of the sampled public wells in California and 20% in Washington exceeded the maximum allowable nitrate contamination limits for drinking water (10 mg of nitrate per litre). In some areas of California with large dairy farms, more than one-third of domestic wells exceeded the Drinking-Water Standards (Harter et al., 2012).

The situation is similar in New Zealand, with long-term water quality monitoring revealing continued water quality deterioration from diffuse N and P sources in some aquifers, and lakes such as Lake Taupo and Lake Rotorua (Baskaran et al., 2009; Gourley et al., 2014). In Canterbury, nitrate concentrations in some aquifers exceed New Zealand Drinking-Water Standards (11.3 mg of nitrate per litre) (Ministry for the Environment (MFE), 2007). About 39% of groundwater sites and 44% of lakes in New Zealand have nutrient levels above natural background levels as the result of leaching of fertilizer and stock effluent (New Zealand Institute of Economic Research (NZIER), 2014).

Dairy farming in Brazil is also inviting widespread criticism and those are calls for mitigation of the environmental effects associated with livestock farming (McManus et al., 2016; Sparovek et al., 2009). In Ethiopia and Nepal, solid manure is stored in open heaps for long periods before it is applied on the land, and is often washed away by rain, resulting in contamination.

Urine of grazing animals is the main source of nitrogen (N) on grass-fed dairy systems. The N content of consumed pasture exceeds a cow's absorbtion capacity, which means that 60% to 80% of the N and P consumed is excreted (American Society of Agricultural Engineers (ASAE), 2005). The N loading rate under a urine patch is about 1,000 kg N ha^{-1}, which exceeds pasture and crop N absorption capacity (Haynes and Williams, 1993). Therefore, pasture and crops cannot utilize all available N. The surplus N, when converted to NO_3^-, is prone to leaching if there is an excess of water due to heavy rainfall and/or irrigation application (Di and Cameron, 2002). Use of nitrogen fertilizer and the amount of animal waste produced are expected to climb with increasing dairy farming intensity and will accordingly impact water quality (Gourley et al., 2014).

Difficulty in managing urine and liquid manure is a reality. In New Zealand and the USA, effluent management systems are becoming more sophisticated with continuing dairy farming intensification (Heubeck et al., 2014; Key, 2016). In New Zealand, manure is primarily stored in liquid form. In the USA, manure is stored in both solid and liquid form, with solid form primariy stored in the humid regions and liquid form in more arid parts of the country. In New Zealand and USA, manure is applied in a wider area to maintain an equilibrium between pastures' nutrient uptake capacity and nutrient availability (Heubeck et al., 2014).

Farm productivity and environmental management greatly depends on how manure is captured, stored, treated, and used (Key, 2016). When applied based on the agronomic needs of crops, manure not only

enhances farm productivity, but also reduces the need for commercial fertilizer use and nutrient losses (Key, 2016; Teenstra et al., 2014). In the USA and New Zealand, manure application rate is primarily based on a crop or pasture need while in Brazil, Ethiopia and Nepal, manure is applied without any assessment of need.

In grazing systems, the greatest proportion of excreted N is deposited directly on to land, as discrete urine patches, while in confinement systems almost 100% of excreted N is captured in sheds or yards. As captured effluent can be applied according to plant requirement, theoritically, confinement systems should perform better than pasture-based systems, with less impact on water quality. However, many researchers such as Arsenault et al. (2009), Benson (2008) and Cooner et al. (2009) have confirmed that in terms of the water quality issues, pasture-based systems actually perform better than stall feeding systems. This is because the use of concentrated feeds and commercial fertilizers (N), which are dominant contributors to environmental impacts, are highest in confinement systems (Arsenault et al., 2009).

Therefore, in the face of increasing water scarcity and deteriorating water quality, pasture-based and/ or mixed dairy farming offers a better alternative, since grain-based stall-feeding dairy systems put more pressure on water quantity and quality. In pasture-based and mixed systems, if cattle stocking rate matches the N and P absorption rate of the surrounding land, and cattle are confined during heavy rainfall events, the risk of nutrient loss can be reduced significantly (Cooner et al., 2009; Falk et al., 2012; Legrand et al., 2009). Precision agriculture, including adjusting irrigation to plant and soil requirement, is a promising way forward.

3.3 Irrigation management

In Ethiopia and Nepal, one hectare of pasture land supports less than one cow with slightly above one cow in Brazil versus an average 2.85 cows in New Zealand (Assunção and Chiavari, 2015; DairyNZ, 2013a). Brazil is rich in terms of fertile soils and favourable climate with pasture production capacity up to 30,000 kg DM/ha/year (Carvalho, 2006). So, with an average of just above one cow/ha this implies dairy farming in Brazil is under performing. In New Zealand, estimatedly pasture production with irrigation can be increased by 5,000 kg DM/ha/year resulting in 23,000 kg DM/ha/year, which is almost two-fold more than unirrigated production for New Zealand (Rockpoint Corporate Finance Limited, 2012). The gap between prevailing and potential productivity levels indicates an opportunity to increase pasture production for dairy farming. For this, irrigation is an important input.

In Ethiopia and Nepal, irrigation is limited and pasture productivity is low, resulting in limited feed available to animals. The shortage of feed and water during dry seasons are prominent constraints affecting livestock production. The potential for irrigation is untapped and there is great opportunity for producing irrigated pasture and forage (Mengistu, 2006). Half of the total nutrient requirement for animals comes from forestry, fodder, shrub and natural grass, which relies solely on rainfall (Pariyar, 2008), while crop residues and by-products of paddy, maize, millet, wheat, mustard, soybean, sorghum, teff and vegetables contribute half. Therefore, improvements in water management practices on existing cultivated land could contribute significantly to improving agriculture production and feed availability for animals (International Food Policy Research Institute, 2014).

In Ethiopia and Nepal, surface irrigation is the dominant irrigation supply technology (KC, 2008; KC et al., 2011). Irrigation schemes are based on run-of-the river systems where water is diverted from flowing rivers to canal systems. Water volumes in canal networks vary with the discharge in rivers, and irrigation scheduling is based on water availability in canals rather than on cropwater demand on farms.

The majority of small scale irrigation schemes are managed by farmers on a self-help basis. There are no flow control structures at farm inlets in the traditional farmer-managed irrigation schemes (KC et al., 2017). However, in modern medium and large scale irrigation schemes, fixed-crest weir proportional divisional boxes are provided at farm inlets. Water is distributed uniformly from canal to farm because variable water supply is not possible with fixed-crest proportional division boxes (KC, 2008).

In spite of the control, there is still no means of supplying water depending on plant requirements. Furthermore, there is a spatial issue: irrigation supply is non-uniform with head-reach farmers in irrigation schemes obtaining and applying too much water, which causes waterlogging and salinization of land. Tail end-farmers in irrigation schemes often get insufficient water to meet crop demand, resulting in production loss.

In Brazil, pastureland is primarily irrigated by surface irrigation (flood irrigation) and sprinkler systems that cover 49% and 45%, respectively, of the irrigated areas (Food and Agricultiral Organisation (FAO), 2015). In the surface irrigation systems, up to 85% of the total water diverted from a water source is lost in the irrigation distribution network due to leakage from canal and perhaps only 15% reaches to the farms (Silva et al., 2016). Water use efficiency in sprinkler systems is only around 60% (Food and Agricultiral Organisation (FAO), 2015).

In New Zealand, spray irrigation (78%) and border-dyke irrigation (5%) methods are commonly used to apply water to pasture farms (Dark et al., 2017; KC, 2016). In USA, sprinkler irrigation and surface irrigation cover 50% and 43%, respectively, of the area under irrigation (Schaible and Aillery, 2016). In New Zealand and USA the remaining area is irrigated by micro-irrigation or drip irrigation for horticulture, which is more efficient than sprinkler irrigation and surface irrigation (New Zealand Institute of Economic Research (NZIER), 2014). However, area under micro-irrigation or drip irrigation is very small.

In all the studied countries, a large proportion of farmers pay little attention to when to start irrigation and how much water to apply based on Plant Available Water (PAW), crop-growth stage and soil moisture to satisfy actual cropwater demand (KC, 2008, 2016; KC et al., 2016). In New Zealand, while many farmers recognise the need to measure soil moisture in crop root zones, less than 10% of farmers use measured soil moisture in their daily irrigation planning (Rockpoint Corporate Finance Limited, 2012). Thus, irrigation applications often result in the soil's water storage capacity being exceeded in the crop root zone. This leaches nutrients from chemical fertilizers, animal manure and effluent into soil and water systems, creating water loss and impacting on water quality.

Changes in irrigation practices are essential if water use and nutrient losses are to be minimised. For example, in Ethiopia and Nepal, introduction of sufficient and flexible flow control structures in irrigation networks is essential in order to apply irrigation based on variable cropwater demand. In all the studied countries, irrigation scheduling based on PAW, crop development stages and soil moisture monitoring is required for conversion of low productive agricultural and pastureland into high production dairy farming. As irrigated dairy farms in the western US states often experience windy conditions, a large proportion of the irrigation water is lost through evaporation or blown away before it reaches the ground. Thus, possible approaches to refine irrigation practices would be adopting drip irrigation system to minimize wind effect and limiting irrigating to the night to reduce evaporation loss (Zhou et al., 2010).

As a basic rule, to maximise plant yield, irrigation application should aim at maintaining soil moisture above the management allowable deficit (MAD), to ensure soil moisture in the root zone is within the readily available soil moisture range (United States Department of Agriculture (USDA), 1997). However, irrigation application up to 100% of PAW is prone to creating drainage if rain follows the irrigation

events. Likewise, irrigation starting only when soil moisture drops down to 50% of PAW can be risky in warm weather, which may push soil moisture below MAD, leading to production loss.

Therefore, it is advised to investigate threshold soil moisture limits to start and stop irrigation, based on local climate and soils, to capture potential rainfall and provide a buffer for evapotranspiration. The effects of different irrigation strategies on water use and pasture production can be tested with computer modelling. In this way, both environmental risk, caused by excess drainage, and production risk caused by soil moisture stress would be minimised. Investigation and application of such an irrigation strategy (Fig. 4) can contribute to reducing the negative impact on water quantity and quality caused by an expanding dairy industry, without impacting on pasture and crop production. This would support a more sustainable dairy farming industry.

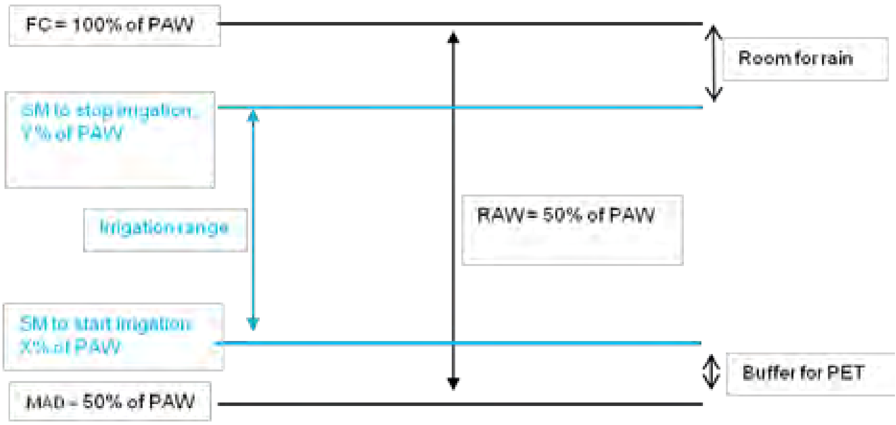

***Figure 4**: Schematic representation of an optimal irrigation range to account for potential precipitation and evapotranspiration. FC = field capacity, PAW = plant available water, RAW = readily available water, SM = soil moisture, PET = potential evapotranspiration.*

4. Conclusions

This study has looked at some of the approaches of dairy farming in five countries: Brazil, Ethiopia, Nepal, New Zealand and USA, to identify water-related issues and needs, to support sustainable dairy farming systems. Dairy farming is expanding in the studied countries. The majority of milking cows in Ethiopia and Nepal are local breeds, while in the other three countries cows dominantly belong to genetically improved species. There are primarily three types of dairy farming systems within the studied countries. Brazil and New Zealand are dominated by pasture-based systems to take advantage of prevailing warm weather favoured for grass production and open grazing. The most common dairy operating system in the USA is stall feeding as a pasture based system is unable to support high milk producing genetically improved Holstein cows. The vast majority of farmers in Ethiopia and Nepal are practicing traditional mixed approach.

Milk production is highly variable between countries as a result of different cow breeds and different feed availability for crows. Milk production per cow per annum (kg/cow/year) is by far the highest in the USA stall feeding system, followed by the New Zealand and Brazil pasture-based system, with the

mixed approach in Ethiopia lagging behind Nepal. Within the USA, milk production per cow per annum (kg/cow/year) under the stall feeding system is on average 20% higher than on grazing systems. Pasture-based systems in New Zealand outperform Brazil with milk production per cow per annum (kg/cow/year) in New Zealand being more than twice that in Brazil. Mixed dairy systems in Nepal produce two times more milk per cow per year than in Ethiopia.

Increasing dairying will have an impact on water quantity and quality. Stall feeding dairy systems put more pressure on water quantity, as water requirements to produce same amount of feed grains are five times higher than to produce a mixture of grass, crop residues and fodder. Stall feeding dairy systems often bring effluent and animal manure onto a much smaller area, exceeding the absorption capacity of surrounding land, resulting in water pollution due to nutrient leaching. Therefore, mixed or pasture-based dairy farming systems are a better choice for small and medium landholders, as modern confinement systems require more water, high operating cost and advanced technology.

Each country faces different issues in the irrigation sector. In Ethiopia and Nepal, irrigation water is divided uniformly between farms regardless of variations in cropwater needs, using simple fixed control proportional division structures. Even in technologically-advanced countries such as the USA and New Zealand, the prevailing irrigation planning does not account properly for Plant Available Water (PAW), soil moisture and crop growth stages.

Water quantity and quality issues can be minimized by improving irrigation management by adopting irrigation networks with sufficient and adjustable flow control structures, and irrigation scheduling based on PAW, soil moisture and crop growth stages. This would contribute to convert low productive agricultural and pastureland into high productive dairy farming. In addition, milk production can be increased by using genetically improved cow breeds.

It is also advised to investigate threshold soil moisture limits to start and stop irrigation, based on local climate and soils, to address both precipitation and evapotranspiration uncertainty thereby minimizing environmental risk, caused by excess drainage, and the production risk caused by soil moisture stress.

Acknowledgements: The authors would like to extend great gratitude to Dr Magdy Mohssen, Otago Regional Council, Dunedin, New Zealand, and Dr Majeed Safa, Lincoln University, Christchurch, New Zealand for their constructive review input.

References

American Society of Agricultural Engineers (ASAE). (2005). Manure production and characteristics. ASAE Standard D384.2, Niles Rd, USA.

Anthony, P., KC, B. (2017). Improving irrigation water management using agent technology. New Zealand Journal of Agricultural Research, pp. 1-15. DOI: 10.1080/00288233.2017.1402788

Arsenault, N., Tyedmers, P., Fredeen, A. (2009). Comparing the environmental impacts of pasture-based and confinement-based dairy systems in Nova Scotia (Canada) using life cycle assessment. International Journal of Agricultural Sustainability, 7(1), 19-41.

Assunção, J., Chiavari, J. (2015). Towards efficient land use in Brazil. Climate Policy Initiative, the new climate economy: the Global Commission on the Economy and Climate, Retrived from: https://climatepolicyinitiative.org/wp-content/uploads/2015/09/Towards-Efficient-Land-Use-in-Brazil.pdf.

Bargo, F., Muller, LD., Kolver, ES., Delahoy, JE. (2003). Invited review- Production and digestion of supplemented dairy cows on pasture. Journal of Dairy Science, 86 (2003), 1–42.

Baskaran, R., Cullen, R., Colombo, S. (2009). Estimating values of environmental impacts of dairy farming in New Zealand. *New Zealand Journal of Agricultural Research, 52*(4), 377-389.

Benson, GA. (2008). Pasture-based and confinement dairy farming in the United States: An assessment. *Journal of International Farm Management, 4*(2), 14-29.

Cameron, KC., Di, HJ. Moir, JL. (2012). Nitrogen losses from the soil/plant system: a review. *Annals of Applied Biology ISSN 0003-4746, review article*. doi:10.1111/aab.12014

Carvalho, PCF. (2006). *Country Pasture/Forage Resource Profiles Brazil.* Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre - RS, Southern Brazil, Retrieved from http://www.wzw.tum.de/public-html/lattanzi/Lit/Brazil.htm

Cooner, D., Rozeboom, D., Campbell-Arvai, V. (2009). Literature Review: A comparison of dairy production systems. *Department of CARRS, Michigan State University.*

Croney, CC., Anthony, R. (2011). Invited review: ruminating conscientiously: scientific and socio-ethical challenges for US dairy production. *Journal of Dairy Science, 94*(2), 539-546.

Dairy Companies Association of New Zealand (DCANZ). (2014). *New Zealand Milk Production*. Retrievedfrom:http://www.dcanz.com/files/New%20Zealand%20Milk%20Production%2016Apr2014.pdf

DairyNZ. (2013a). *Dairy Statistics 2012-13*. Retrieved from http://www.lic.co.nz/132FD1C8-2C8C-4811-AFE7-DD963A62C46C/FinalDownload/DownloadId-F554348D1DF8CABB95C0410EC79E4358/132FD1C8-2C8C-4811-AFE7-DD963A62C46C/user/file/DAIRY%20STATISTICS%202012-13-WEB.pdf

DairyNZ. (2013b). Making Dairy Farming Work For Everyone: Strategy for Sustainable Dairy Farming, 2013-2020. Hamilton, New Zealand. Retrieved from http://www.dairynz.co.nz/media/209786/strategy-for-sustainable-dairy-farming.pdf

Dark, A., KC, B., Kashima, A. (2017). National Irrigated Land Spatial Dataset: Summary of methodology, assumptions and results. *Aqualinc Research Limited*, Christchurch, New Zealand.

de Fraiture, C., Molden, D., Wichelns, D. (2010). Investing in water for food, ecosystems, and livelihoods: An overview of the comprehensive assessment of water management in agriculture. *Agricultural Water Management, 97*(4), 495-501.

Di, HJ., Cameron, KC. (2002). The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. *Soil Use and Management, 18*(4), 395-403.

Falk, AC., Weary, DM., Winckler, C., von Keyserlingk, MA. (2012). Preference for pasture versus freestall housing by dairy cattle when stall availability indoors is reduced. *Journal of Dairy Science, 95*(11), 6409-6415.

Food and Agricultiral Organisation (FAO). (2010). Dairy Sector Study of Nepal, Pulchowk, Nepal. Retrieved from http://nepalagritech.com.np/wp-content/uploads/2016/10/Dairy-Sector-in-Nepal-FAO.pdf

Food and Agricultiral Organisation (FAO). (2015). *Regional report:* Southern America, Central America and the Caribbean. Italy Roam. Retrieved from http://www.fao.org/nr/water/aquastat/countries_regions/BRA/

Food and Agriculture Organisation of the United Nations Statistics Division (FAOSTAT). (2015). Livestock data. Italy, Roam, Retrieved from http://www.fao.org/faostat/en/#compare

Fraser, D. (2008). Animal welfare and the intensification of animal production. In: Thompson P.B. (eds) The Ethics of Intensification. *The International Library of Environmental, Agricultural and Food Ethics, vol 16, Springer, Dordrecht.*

Gerbens-Leenes, P., Mekonnen, M., Hoekstra, A. (2013). The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. *Water Resources and Industry, 1*, 25-36.

Gillespie, J., Nehring, R. (2014). Pasture-based versus conventional milk production: Where is the profit? *Journal of Agricultural and Applied Economics, 46*(4), pp.543.

Gourley, CJ., Dougherty, W., Aarons, S., Kelly, K. (2014). Improving nitrogen use efficiency: from planet to dairy paddock. In: Nutrient Management for the Farm, Catchment and Community. *Fertilizer and Lime Research Centre*, Massey University, Palmerston North, New Zealand.

Hamilton, SA. (2002). Success of Grass-based Dairies. *Presentation at The Sustainable Dairy Workshop, Spring Hill, Tennessee, United State.*
Harter, T., Lund, JR. (2012). Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board Report to the Legislature, Center for Watershed Sciences. *University of California*, Davis, USA. Retrieved from http://groundwaternitrate.ucdavis.edu
Haynes, RJ., Williams, PH. (1993). Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy, 49*, 119-199.
Heubeck, S., Nagels, J., Craggs, R. (2014). Variability of effluent quality and quantity on dairy farms in New Zealand. In: Nutrient Management for the Farm, Catchment and Community. (Eds Currie, LD. and Christensen CL.). *Fertilizer and Lime Research Centre*, Massey University, Palmerston North, New Zealand.
Hoekstra, AY. (2012). The hidden water resource use behind meat and dairy. *Animal Frontiers, 2*(2), 3-8.
International Food Policy Research Institute. (2014). *Irrigation and smallholder resilience in Nepal.* Washington DC, USA. Retrieved from http://www.ifpri.org/book-6330/node/9633
KC, B. (2008). Improvement in land and water productivity of the irrigated area in emerging and least developed countries for food security. Master thesis, *UNESCO-IHE Institute for Water Education*, Delft, the Netherlands.
KC, B. (2016). Irrigation scheduling: A Soft Adaptor to Weather Uncertainties and Irrigation Efficiency Improvement Initiatives. PhD Thesis, *Lincoln University*, Christchurch, New Zealand.
KC, B., Mohssen, M., Wai, CH., Curtis, A., Cuenca, R., Bright, J., Srinivasan, MS., Cameron, K. (2016). Determining the Optimal Irrigation Strategy for Rotational Grazing Systems. *Paper presented at the 2nd World Irrigation Forum*, Chiang Mai, Thailand, 6-8 November 2016.
KC, B., Schultz, B., Prasad, K. (2011). Water management to meet present and future food demand. *Irrigation and drainage, 60*(3), 348-359.
KC, B., Schultz, B., Prasad, K. (2017). Impact of Irrigation Management Practices on Land and Its Productivity in Addressing Hunger and Poverty. *Journal of Development Innovations, 1*(2), 15-28.
Key, N. (2016). Crop & Livestock Practices. *United State Department of Agriculture (USDA), USA.* Retrieved from https://www.ers.usda.gov/topics/farm-practices-management/crop-livestock-practices/manure-management/
Kreigl, T., Frank, G. (2005). A Ten Year Look at Wisconsin Diry System. *University of Wisconsin Center for Dairy Profitability*, Madison, Wisconsin, USA.
Legrand, AL., von Keyserlingk, MA., Weary, DM. (2009). Preference and usage of pasture versus free-stall housing by lactating dairy cattle. *Journal of Dairy Science, 92*(8), 3651-3658.
Livestock Improvement Corporation (LIC) and DairyNZ. (2012). *New Zealand Dairy Statistics.* Retrieved from http://www.dairynz.co.nz/file/fileid/45159
Livestock Improvement Corporation (LIC) and DairyNZ. (2015). *New Zealand Dairy Statistics.* Retrieved from http://www.dairynz.co.nz/media/3136117/new-zealand-dairy-statistics-2014-15.pdf
Martin, RJ., Thomas, SM., Stevens, DR., Zyskowski, RF., Moot, DJ., Fraser, TJ. (2006). Improving water use efficiency on irrigated dairy farms in Canterbury. *In Proceedings of the conference-New Zealand grassland association, 68*, 155.
McManus, C., Barcellos, JOJ., Formenton, BK., Hermuche, PM., Carvalho, OAd Jr., Guimarães, R., Gianezini, M., Dias, EA., Lampert, VN., Zago, D., Neto, JB. (2016). Dynamics of cattle production in Brazil. *PloS one, 11*(1), e0147138.
Mekonnen, MM., Hoekstra, AY. (2010). The green, blue and grey water footprint of farm animals and animal products. *UNESCO-IHE Institute for Water Education*, Delft, The Netherlands.
Mekonnen, MM., Hoekstra, AY. (2011). National water footprint accounts: the green, blue and grey water footprint of production and consumption. *UNESCO-IHE Institute for Water Education*, Delft, The Netherlands.
Mekonnen, MM., Hoekstra, AY. (2012). A Global Assessment of the Water Footprint of Farm Animal Products. *Ecosystems, 15*(3), 401-415.
Mengistu, A. (2006). Country Pasture/Forage Resource Profiles: Ethiopia. *Addis Ababa University, Faculty of Science,*

Biology Department, Addis Ababa, Ethiopia.

Ministry for the Environment (MFE). (2007). Environment New Zealand 2007. Wellington, New Zealand, Retrieved from http://www.mfe.govt.nz/sites/default/files/environment-nz07-dec07.pdf

Ministry of Agricultural Development (MoAD). (2013). Statistical information on Nepalese agriculture. *Agribusiness Promotion and Statistics Division, Agri Statistics section*, Singha Durbar, Kathmandu, Retrieved from http://www.moad.gov.np/yearbook/YearBook2013Whole.pdf

Muller, L. (2017). Pasture-Based Systems for Dairy Cows in the United States. *The Pennsylvania State University, USA*. Retrieved from http://extension.psu.edu/animals/dairy/nutrition/forages/pasture/articles-on-pasture-and-grazing/pasture-based-systems-for-dairy-cows-in-the-united-states

New Zealand Institute of Economic Research (NZIER). (2014). Water management in New Zealand: A road map for understanding water value, *NZIER public discussion paper 2014/01*. Retrieved from http://nzier.org.nz/static/media/filer_public/d2/ce/d2cef6fa-3b58-4f11-bb0b-7b2a684ac181/nzier_public_discussion_paper_2014-01_-_water_management_in_nz.pdf

Pariyar, D. (2008). Country Pasture, Forage Resource Profiles: Nepal. *Food and Agricultiral Organisation (FAO)*, Pulchowk, Nepal. Retrieved from https://www.scribd.com/document/346786985/FAO-Forage-Profile-Nepal

Passetti, RAC., Eiras, CE., Gomes, LC., Santos, JF., Prado, IN. (2016). Intensive dairy farming systems from Holland and Brazil: SWOT analyse comparison. *Acta Scientiarum. Animal Sciences, 38*(4), 439-446.

Rockpoint Corporate Finance Limited. (2012). *Irrigation in New Zealand*. Retrieved from http://www.rockpoint.co.nz/pdfs/Irrigation-in-New-Zealand-2012-Rockpoint.pdf

Schaible, G., Aillery, M. (2016). How Important is Irrigation to U.S. Agriculture? Retrieved from https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/background/

Schultz, B., Zimmer, D., Hofwegen, P. (2007). Agriculture food water: concept note in preparation for *5th World Water Forum*. Marseille, France.

Silva, CL., Bassi, NSS., Rocha Junior, WF. (2016). Technologies for rational water use in Brazilian agriculture. *Revista Ambiente & Água, 11*(2), 239-249.

Smith, RA. and Alexander, RB. (2000). Sources of nutrients in the nation's watersheds. *US Geological Survey*, Reston, Virginia, USA.

Sparovek, G., Barretto, A., Berndes, G., Martins, S., Maule, R. (2009). Environmental, land-use and economic implications of Brazilian sugarcane expansion 1996–2006. *Mitigation and adaptation strategies for global change, 14*(3), 285-298.

Statistics New Zealand. (2014). Agricultural Production Statistics: June 2013 (final). Retrieved from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/AgriculturalProduction_final_HOTPJun13final.aspx

Stringleman, H., Scrimgeour, F. (2008). Dairying and dairy products - Beginnings of New Zealand's dairy industry. *Te Ara - the Encyclopedia of New Zealand*. Retrieved from https://teara.govt.nz/en/dairying-and-dairy-products/page-1

Teenstra, E., Vellinga, T., Aektasaeng, N., Amatayakul, W., Ndambi, A., Pelster, D., Germer, L., Jenet, A., Opio, C., Andeweg, K. (2014). Global assessment of manure management policies and practices. Report 844, *Livestock Research: Wageningen University & Research centre*, Netherlands

United States Department of Agriculture (USDA). (1997). *National Engineering Handbook*. USA, Retrieved from http://directives.sc.egov.usda.gov/FC01D391-099B-4C31-9251-8C67A6DE2EA3/FinalDownload/DownloadId-893248D977F8919998CCFB59B4CC8DAD/FC01D391-099B-4C31-9251-8C67A6DE2EA3/OpenNonWebContent.aspx?content=17837.wba

United States Department of Agriculture (USDA). (2013). Dairy: World Market and Trade. USA, Retrieved from http://apps.fas.usda.gov/psdonline/circulars/Dairy.pdf

United States Department of Agriculture (USDA). (2014). *Brazil Dairy, Milk, Fluid cows milk production by year*. USA,

Retrieved from http://www.indexmundi.com/agriculture/?country=br&commodity=milk&graph=cows-milk-production

US Environmental Protection Agency (US EPA). (2012). Relation between nitrate in water wells and potential sources in the lower Yakima Valley, Washington States. Washington, D.C. USA.

Veiga, J., Tourrand, J., Poccard-Chapuis, R. and Piketty, M. (2002). Cattle ranching in the Amazon Rainforest. *Animal Production, 24*, 253-256.

von Keyserlingk, MAG., Martin, NP., Kebreab, E., Knowlton, KF., Grant, RJ., Stephenson, M., Sniffen, CJ., Harner, JP., Wright, AD., Smith, SI. (2013). Invited review: Sustainability of the US dairy industry. *Journal of Dairy Science, 96*(9), 5405-5425.

Wada, Y. (2012). Non-sustainable groundwater sustaining irrigation. *Department of Physical Geography, Faculty of Geosciences, Utrecht University*, the Netherlands. Retrieved from http://www.globalwaterforum.org/2012/02/13/non-sustainable-groundwater-sustaining-irrigation/

Weimar, MR., Blayney, DP. (1994). Landmarks in the US dairy industry: *US Department of Agriculture, Economic Research Service*. Retrieved from https://dairymarkets.org/PubPod/Reference/Library/Weimar&Blayney.1994.pdf

Zhou, Y., Zwahlen, F., Wang, Y., Li, Y. (2010). Impact of climate change on irrigation requirements in terms of groundwater resources. *Hydrogeology Journal, 18*(7), 1571-1582.

Pollution of groundwater due to extensive use of fertilizers

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Abstract

During the last four decades, there have been many changes in the foothill (Tarai - Bhabar) region of Western Himalayas including Nainital and Udham Singh Nagar districts in Uttarakhand State, India. Intensive use of nitrogenous fertilizers has been on increase for better crop production. As a consequence, in the last few years there have been reports of changes in groundwater quality by the people inhabiting the area. Keeping in view the above, a study was conducted on the groundwater quality of the area. The groundwater samples from "Long Term Fertilizer Trial Fields" showed higher values for total alkalinity, chloride, total hardness, Ca and Mg hardness. This indicates that long-term usage of fertilizers lead to infiltration of nutrients like Ca and Mg in the groundwater, which may ultimately lead to changes in chemical characteristics of water. The analysis of various forms of nitrogen, in groundwater, from agricultural fields (Long and Short - Term Fertilizer Trials) revealed that nitrate content was high in groundwater. However, in all cases values were quite low as compared to the maximum permissible limits of 45 mg/l. The data of present study indicate gradual accumulation of nitrogen in groundwater but the levels are still relatively low. However, as nitrate percolation to groundwater is a slow process, there is danger of high levels of NO_3 accumulation in groundwater in the next few decades.

Keywords: *BOD; COD; electrical conductivity; fertilizer; groundwater; pollution*

1. Introduction

Introduction of new high responding varieties, the necessity for higher economic yields and low fertilizer costs have resulted in rapid increase in fertilizer consumption. This increase in the use of fertilizers has raised many questions concerning nutrient pollution of the surface and ground waters. When fertilizers are applied to agricultural lands, a portion usually leaches through the soil and to the water table. The primary fertilizers are compounds of nitrogen, phosphorus, and potassium. Phosphates and potassium fertilizers are readily adsorbed on soil particles and seldom constitute a pollution problem. But nitrogen in solution is only partially used by plants or adsorbed by the soils, and it is the primary fertilizer pollutant. A number of comprehensive reviews have been published concerning nitrate contamination in the environment and nitrate toxicity and health effects (Kaushik, 1963; Keeney, 1982; Kehew *et al.*,

1996; Narayana and Suresh, 1989). There have been numerous studies related to nitrate contamination of groundwater. A number of scientists have reported nitrate contamination of groundwater, in different parts of the world, due to excessive use of fertilizers (Keeney, 1986, 1987; Pratt, 1984; Saxena and Mehra, 1991; Singh and Sekhon, 1976, 1977, 1978; Walker, 1973). The high probability of leaching, combined with large N inputs, results makes the irrigated agriculture a major potential source of nitrate to groundwater (Pratt, 1984). Singh and Sekhon (1976, 1977, and 1978) analysed water samples from Ludhiana and observed a significant positive correlation between amount of nitrogen fertilizer used and the nitrate concentration in groundwater. They found that the amount of NO_3 contained in the soil profile down to 2.10 m depth reached the water table during the rainy season. The projected geometric mean nitrate concentration was found to be 35.8 mg/l. Ramachandran *et al.* (1991) studied the nitrate concentration in groundwater of cultivated areas in North Madras. The study revealed that ground quality was not affected by the application of inorganic nitrogen fertilizers. Saxena and Mehra (1991) found that groundwater in the intensive farming belts of western U.P., Haryana and Punjab contain very high nitrate content (120 mg/l to 1310 mg/l) due to the rising trend in the consumption of nitrogen fertilizers. Kehew *et al.* (1996), in a study, concluded that nitrogen application coupled with shallow water table and permeable soil, make groundwater contamination a virtual certainty. The results of the study confirm the common occurrence of nitrate-N at level higher than the drinking water standards of 10 ppm for both domestic and observation wells. The nitrate-N concentrations were found near zero in all wells screened below 30 m. above this level the vertical distribution was quite variable.

Tarai region of Udham Singh Nagar district in Uttarakhand and adjoining district of Rampur, in the north-west Uttar Pradesh in India, is endowed with very fertile soil coupled with good rainfall. Due to this and other favourable agro-climatic conditions, the area has been under intensive agriculture for the last four decades or so. During this period there have been many changes in the area. Not only the dense forests have been cleared, there has been an unprecedented increase in urbanization, industrialization and agricultural activities. Many new industries such as pulp and paper mills, sugar factories, oil mills, rice mills, chemical factories, distillery etc. have come up. As a consequence, in the last few years there have been reports of changes in groundwater quality by the people inhabiting the area. Considering the above, the present study was undertaken to assess the pollution level in this area, due to extensive use of fertilizers. This study was selected because of the fact that the drinking water in the region is largely drawn from the shallow aquifers and if polluted it might have adverse effects on the health of the inhabitants.

2. Materials and Methods

2.1 Study area

The study was conducted at the Crop Research Centre (CRC) of the G.B. Pant University of Agriculture and Technology, Pantnagar located in the *Tarai* region of Udham Singh Nagar district of Uttarakhand in India. The farm area extends almost rectangular, measuring about 12 km east-west and almost 5 km north-south. The total university farm spread over an area of 57.5 km^2 and is located between 28^0 59' to 29^0 03' N latitudes and 79^0 23' to 79^0 30' E longitudes in the *Tarai* belt, as shown in Fig. 1. The climate of the area is subtropical temperate humid marked by extreme winter and very hot summer. The maximum temperature reaches occasionally beyond 46^0C. The annual rainfall ranges from 1140 to 1900 mm.

2.2 Collection of water samples and their analysis

For the study of the water quality in the area under consideration, the samples of water were collected in sterilised plastic containers of 2 litre capacity from the agricultural farm lands, long term and short term fertilizer trials' field of CRC, Pantnagar. The collected samples of the ground water were analyzed, for their physical and chemical characteristics, in the laboratory using standard methodology.

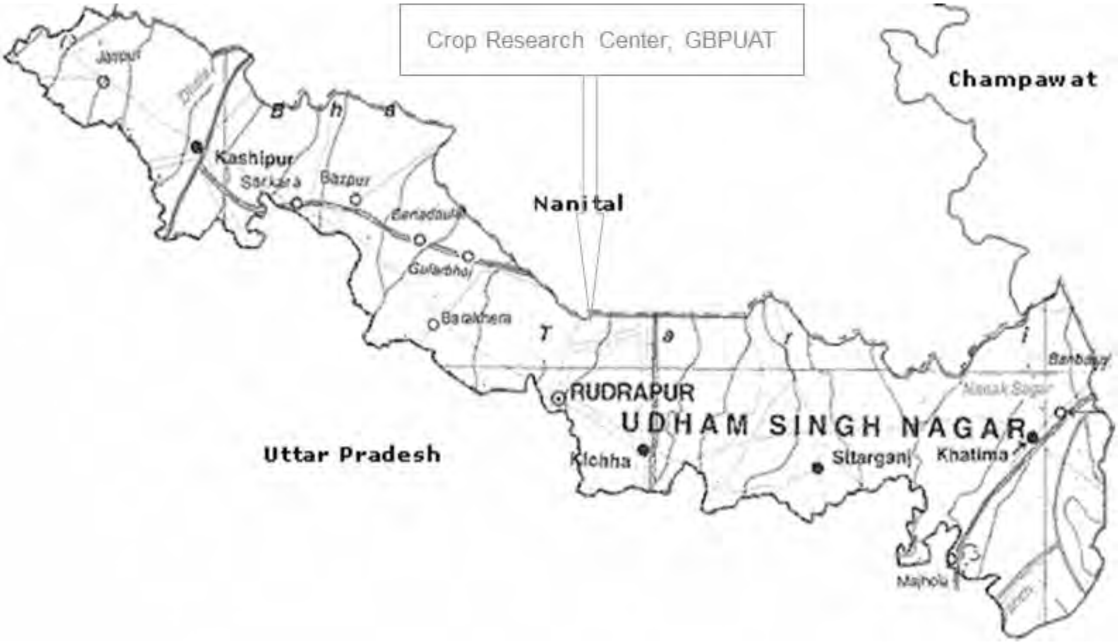

Figure 1: *Index map of the study area.*

3. Results and Discussions

3.1 Physical characteristics

The mean values of the physical characteristics of the groundwater samples are indicated in Table 1 and described hereunder.

Temperature: Temperature of the water samples collected from different places ranged from nearly 19°C to 21.50°C which was within the tolerance limit prescribed for groundwater.

pH: The pH of the water samples collected from different places was nearly 7.5, and was within the permissible limits.

Table 1: *Mean values of physical characteristics of groundwater in different polluted zones in Tarai region of Uttarakhand.*

Zone	Temperature (^0C)	pH	Colour (H.U.)	Turbidity (NTU)	Electrical Conductivity (µmho)	TS (mg/l)	TDS (mg/l)	TSS (mg/l)
Agricul. Farm Land	18.9	7.53	11.7	6.83	347	487	166	320.0
Long Term Fertilizer Trial Field	21.5	7.53	13.5	2.77	929	650	513	137.0
Short Term Fertilizer Trial Field	20.2	7.48	10.0	3.28	720	358	280	78.0

Colour: Colour of the water samples was determined in terms of Hazen units. The lowest and the highest mean values of colour intensity of groundwater for agricultural areas varied within the ranges of 10 to 13.50 H.U. with highest in long-term fertilizer trial field and minimum in the waters from the short-term fertilizer trial fields. The values show the presence of chemical pollutants in the groundwater as colour of the groundwater is concerned.

Odour: The groundwater samples were odourless.

Turbidity: The lowest and the highest mean values of turbidity of water samples collected from different places ranged from 2.77 to 6.83 NTU. Maximum permissible limit for turbidity as per International Standards of Drinking Water-WHO Geneva, 1963 is 25 NTU. Thus, the turbidity ranged within the permissible limits.

Electrical conductivity: The electrical conductivity value reflects the salt content in the water sample. The mean electrical conductivity of the water samples varied from 346.66 µ mho at agricultural farm lands to 929.40 µ mho for long term fertilizer trial field. This indicates leaching of salts below into the groundwater of the area.

Solids: Three types of solids are analysed and discussed. They are

- *Total solids (TS):* Total solid content of different samples varied from 358.0 mg/l to 650.0 mg/l. The highest value of the total solids was found in the groundwater samples collected from the long-term fertilizer trial fields, whereas the lowest value was observed for the water from the shortterm fertilizer trial fields.
- *Total dissolved solids (TDS):* The total dissolved solids mainly consist of bicarbonates, carbonates, sulphates, chlorides, nitrates, and possibly phosphates of calcium, magnesium, sodium and potassium with traces of iron, manganese and other substances. The lowest and the highest mean values of total dissolved solid concentration varied from 166.67 mg/l to 513 mg/l for all the samples collected from different places of agricultural areas. The groundwater in the area under study may be used for human consumption without harmful physiological effect.
- *Total suspended solids (TSS):* The TSS value is generally used to evaluate the strength of domestic waste waters and to determine the efficiency of treatment unit. BIS has recommended the maximum permissible limit of TSS for drinking water as 30 mg/l. The lowest and the highest mean values of total suspended solid concentration varied from 78 mg/l to 320 mg/l. Since the values

were above the safe permissible limits, use of groundwater from the agricultural fields was not safe for drinking purposes.

3.2 Chemical characteristics

The chemical characteristics of the groundwater samples are summarized in Table 2.

Dissolved Oxygen (DO): The lowest and the highest mean values of DO concentration of different samples varied from 4.64 mg/l for long-term fertilizer trial field to 8.20 in agricultural farm lands. The higher values in agricultural farm lands in comparison to the long-term fertilizer trial fields may be due to higher and/or unbalanced fertilizer input.

Biochemical Oxygen Demand (BOD): The lowest and the highest mean values of the BOD of different samples varied from 2.12 mg/l for agricultural farm land to 3.75 mg/l for long term fertilizer trial field.

Total Alkalinity: The lowest and the highest values of total alkalinity for agricultural areas varied within the range of 281.7 to 359.7 mg/l for agricultural farm lands and long-term fertilizer trial field, respectively. Under the present study the alkalinity of the groundwater from the agricultural farm lands was more than the total hardness, indicating the presence of basic salts -Na and K in addition to those of Ca and Mg.

Acidity: Total acidity for the samples was found in the range of 83.3 mg/l to 231.2 mg/l. The lowest value of 83.3 mg/l was observed for the well water collected from agricultural farm, while the highest value of 231.2 mg/l was observed for the observation wells of short-term fertilizer experiment field, CRC.

Table 2. *Mean values of different bio-chemical parameters of groundwater in different polluted zones in Tarai region of Uttarakhand.*

Zones	DO (mg/l)	COD (mg/l)	BOD (mg/l)	Total Alkalinity (mg/l)	Acidity (mg/l)	Cl (mg/l)	Free CO_2 (mg/l)	Hardness			Ca (mg/l)	Mg (mg/l)
								Total (mg/l)	Ca (mg/l)	Mg (mg/l)		
AFL	8.20	19.18	2.12	281.7	83.3	15.1	33.35	248.3	100.7	147.6	40.2	35.5
LTF	4.64	36.89	3.75	359.7	184.1	43.6	56.40	456.0	189.2	266.8	75.7	63.5
STF	7.62	31.38	3.20	297.6	231.2	41.2	63.60	310.0	124.0	186.4	49.4	45.6

Free carbon dioxide: The lowest and the highest mean values of free CO_2 for agricultural areas varied within the range of 33.35 to 63.60 mg/l, respectively, for agricultural farm land and short-term fertilizer trial field.

Chloride: The lowest and the highest mean values of chloride for agricultural areas varied within the range of 15.10 to 43.60 mg/l, for agricultural farm land and short-term fertilizer trial field, respectively.

Hardness: Following three types of hardness are analysed;

- *Total hardness*: The mean value of total hardness of the samples in terms of $CaCO_3$ was found to be in the range of 248.3 mg/l to 456.0 mg/l. The lowest value was found for the well water of agricultural farm land while the maximum value of 456.0 mg/l was observed for the sample collected from plot no. T5 of long-term fertilizer experiment field, CRC.
- *Calcium hardness*: The mean value of Ca hardness of the samples ranged between 100.7 to 189.2 mg/l. The lowest value was found for the well water of agricultural farm while the maximum value of 189.2 mg/l was observed for the sample collected from plot no. T5 of long-term fertilizer experiment field, CRC.
- *Magnesium hardness*: The lowest and the highest mean values of Mg hardness for agricultural areas varied within the ranges of 147.6 to 266.8 mg/l. The lowest value was found for the well water of agricultural farm while the maximum value was observed for the sample collected from plot no. T5 of longterm fertilizer experiment field, CRC.

Calcium: Ca is an essential element and human body requires approximately 0.7 to 2.0 g of Ca per day as a food element. Ca deficiency is the most common nutritional lack in many parts of the world. However, waters with high Ca content are undesirable for household uses such as washing, bathing etc., because of the hardness requiring more soap and other cleaning agents. Ca is essential for plant growth and is desirable in water for irrigation up to some extent. Ca content is directly related to hardness. Ca content for the samples ranged between 40.2 mg/l and 75.7 mg/l. All the observed values were within the permissible limit of 200 mg/l set by BIS.

Magnesium: Mg is one of the essential elements, which is relatively non-toxic for human beings. However, higher concentrations may cause unpleasant taste to water. At high concentrations, Mg salts have a laxative effect particularly where present as magnesium sulphate. Mg is essential for crop growth. Ca and Mg ions in irrigation water tend to keep soil permeable and in good tilt. For groundwater samples of the area, the maximum Mg content was 63.5 mg/l. This value was observed for the same samples as in the case of total hardness.

Nitrogen: To study the presence of the nitrogen in groundwater, water samples were analysed for various forms of nitrogen. The mean values of the various forms of nitrogen present in the samples are presented in Table 3. The current public health standards for safe drinking water require that maximum contaminant level (MCL) should not exceed nitrate concentrations of 10 ppm as nitrate-N or 45 ppm as nitrate (10 ppm nitrate-N is same as 45 ppm nitrate).

Table 3: *Chemical characteristics of groundwaters in terms of nitrogen in different pollution zones in Tarai belt of Uttarakhand.*

Zone / Well Location	Well No.	NO_3-N (mg/l)	NO_3 (mg/l)	Total N (mg/l)
Agricultural Farm Land				
Pantnagar Farm	4A	0.08	0.3544	1.03
	5A	0.16	0.7088	1.16
	6A	0.18	0.5227	1.07
	8A	0.18	0.7974	1.06

Short-Term Fertilizer Trial Field				
	1N	0.41	1.8163	5.00
	2N	0.31	1.3733	6.20
CRC, Pantnagar	3N	0.25	1.1075	8.40
	4N	0.46	2.0378	4.50
	5N	0.67	2.0821	9.20
Long-Term Fertilizer Trial Field				
	11N	0.06	0.2561	4.48
	13N	0.58	2.5694	7.56
	14N	0.51	2.2593	3.64
CRC, Pantnagar	15N	0.12	0.5316	5.04
	16N	0.08	0.3544	5.60
	17N	0.33	1.4619	5.88
	18N	0.29	1.2847	4.20

Nitrate – N: Nitrate - N concentration for different samples from the agricultural farm were observed between 0.08 mg/l to 0.18 mg/l. The NO_3-N concentration for the samples of groundwater collected from different plots of fields under short-term and long-term fertilizer experiment trials varied from 0.25 to 0.67 and 0.06 to 0.58 mg/l, respectively.

Nitrate: It has been reported in literature that nitrate concentration above 20 mg/l may cause 'methamoglobinemia' in infants, a disease characterised by blood changes. The disease 'cyanosis' in which the haemoglobin apparently becomes incapable of transporting oxygen is also attributed to the high concentration of nitrates in the waters used for preparing feeding formulas. The maximum limit for nitrate in drinking water as per USPHS Drinking Water Standards is 45 mg/l as nitrate. Nitrate concentration for different samples of ground water was observed between 0.2544 mg/l to 2.5694 mg/l. The highest concentration of 2.5694 mg/l was observed for the samples of well no. 13 N of the long-term fertilizer trial field of Crop Research Centre whereas the lowest concentration was observed in groundwater from well no. 11 N of the longterm fertilizer trial field of Crop Research Centre, Pantnagar.

Total nitrogen: Total nitrogen concentration in water samples varied from 1.03 mg/l to 9.2 mg/l. The highest value was observed for the sample collected from observation well located at the centre of the short-term fertilizer experiment field. The total-nitrogen content in case of short-term fertilizer experiments varied from 4.50 mg/l to 9.20 mg/l. No direct correlation could be found between the concentrations of nitrate in ground water. The total nitrogen content in case of long-term fertilizer experimental field varied from 3.64 mg/l to 7.56 mg/l. The nitrogen concentration for all the groundwater samples was found well within the prescribed limits of the nitrogen in groundwater for human consumption.

4. Conclusions

A comparison of data on main physical properties of groundwater from various regions reveal that groundwater from long-term fertilizers trial field of CRC, reflected some sort of chemical pollution with higher values of total alkalinity, chloride, total hardness, Ca and Mg hardness. This indicates that long-term uses of fertilizer lead to infiltration of nutrients like Ca and Mg to the groundwater which may ultimately lead to changes in chemical characteristics of water. Comparison of mean values of various forms of nitrogen shows that nitrate content was high in groundwater from the fertilizer trial areas. However, in all cases values were quite low as compared to the maximum permissible limit of 45 mg/l. Total nitrogen (inorganic and organic forms) in water was highest for agricultural areas. The high values of total nitrogen in groundwater of agricultural areas clearly indicate percolation of nitrogenous fertilizers to the groundwater but the levels are still relatively low. However, since nitrate percolation to groundwater is a slow process, there is a danger of high levels of NO_3 accumulation in ground water in the next few decades.

References

Kaushik, N.K, et al. (1963). A study of well waters in rural Delhi. Indian Jl. of Environ. Health, 5, 128-138.

Keeney, D.R. (1982). Nitrogen management for maximum efficiency and minimum pollution. In: Stevenson, F.J.(Eds.), Nitrogen in Agricultural Soils. Agronomy Monographs, 22, 605-649.

Keeney, D.R. (1986). Sources of nitrate to ground water. Critical Review in Environment Control, 16, 257-304.

Keeney, D.R. (1987). Nitrate in groundwater - Agricultural contribution and control. (In): Agricultural Impacts on Ground Water. National Water Well Assoc., Worthington, OH, 257-304.

Kehew, A. E., Thomas S. W., Willium, K. Steinmann, P. G. Barrace, H.P., Wei-Shyuan P. (1996). Ground water quality and flow in a shallow glaciofluvial aquifer impacted by agricultural contamination. Ground Water, 34(3) , 491-500.

Narayana, A.C., Suresh, G.C. (1989). Chemical quality of ground water of Manglore City, Karnataka. Indian Jl. Environ. Health, 31(3), 228-236.

Pratt, P.P. (1984). Nitrogen use and nitrate leaching in irrigated agriculture. Ch 21. In: (R.D. Hauck, ed.) Nitrogen in Crop Production. Amer. Soc. Agon., Madison, WI.

Ramchandran, S., Narayanan, N., Pundarikanthan, N.V. (1991). Nitrate and Pesticide - Concentrations in groundwater of cultivated areas in north Madras. Indian Jl. Environ. Health, 33(4), 421-424.

Saxena, S. K., Kavita M. (1991). Ground water pollution due to nitrogenous fertilizers. Indian Jl. Environ. Health. 33 (1), 91 - 95.

Singh, B., Sekhon, G.S. (1976). Nitrate pollution of ground water from Nitrogen fertilizers and animal waste in Punjab, India. Agric. Environ., 3 (1), 57 - 67.

Singh, B., Sekhon, G.S. (1977). Impact of fertilizer use on environmental pollution in Punjab. Present Status and Future Projection. Fert. News, 22, 1.

Singh, B., Sekhon G. S. (1978) . Nitrate pollution of ground water from farm use of nitrogen fertilizers - A review. Agric. and Environ., 4, 207-225.

Walker, W.H. (1973). Ground water nitrate pollution in rural areas. Ground Water, 11, 19-22.

Variations of dissolved and total phosphorus concentrations in irrigation, flooding, and drainage water of paddy fields

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Abstract

Runoff export of phosphorous from paddy field could affect adjacent water environment. In order to understand the characteristics of phosphorus in the paddy field, this study analyzed PO_4-P and T-P concentrations of irrigation water, flooding water, and drainage through field monitoring. In addition, the correlation between pH, EC, and DO in flooding water was analyzed and the factors affecting phosphorus behavior in paddy water were investigated. The concentration of T-P in flooding water was high during the survey period, and the concentration of T-P in drainage was decreased by dilution by irrigation and rainfall. On the other hand, the ratio of PO_4-P to T-P in flooding water was lower than that of irrigation water, which was interpreted to be due to the fact that the phosphorus fertilizer was applied in the paddy field but the adsorption was rapid in the paddy field by the soil. The similar ratio of PO_4-P to T-P in flooding water and drainage suggest that the form of phosphorus outflowed from the paddy is determined by the form of phosphorus in the flooding water of paddy field. Furthermore, the PO_4-P concentrations in flooding water were affected by DO level of irrigation water. Irrigation water quality affected flooding water quality and flooding water quality affected water quality of drainage sequentially. Soluble form of phosphorous could be readily available for algal bloom. Management of irrigation water quality should be considered since irrigation water quality would play an important role for sound ecosystem conservation.

Keywords: *algae; eutrophication; paddy field; water quality*

1. Introduction

Water quality improvement efforts in Korea primarily have focused on reduction of point source pollution. As of 2010, over 85% of domestic wastewater generated nationally was collected and treated by public sewers (MOE, 2011). However, water quality of many streams and reservoirs often does not correspond to the established standards (Song et al., 2009). It is considered that the control and management of nonpoint source (NPS) pollution discharges is important to improve water quality of

streams and reservoirs. There is an urgent need to accurately identify the pollution characteristics, both qualitatively and quantitatively, from different land uses for the successful implementation of measures.

The Korean government has initiated the Total Maximum Daily Load (TMDL) program to improve the water quality of the major rivers. Biochemical oxygen demand (BOD) and total phosphorus (T-P) are chosen for TMDL program (Jung et al., 2016). According to the 'Second Comprehensive Measures for Nonpoint Source Pollution Management', the nonpoint pollution load of T-P to the total load entering the water system is expected to gradually increase from 58.9% in 2010 to 68.6% in 2020 (Relevant Ministerial Consortium, 2012). In particular, the T-P contribution of the land use among various sources (domestic waste, industrial waste, land use, livestock waste, aquaculture, and landfill) was reported to be the largest up to 57.5% (Relevant Ministerial Consortium, 2012).

Choi and Jang (2014) estimated that the contribution of non-point pollution of agricultural land to total water pollution is more than 30%, and it is necessary to reduce agricultural pollution to improve water quality. In terms of land use, agricultural land accounts for 20.2% (paddy field 11.4%, upland 8.8%), followed by forests (63.8%), in Korea (KOSIS, 2017). Runoff from forests is considered to be natural, whereas drainage water from farmland is suspected to be a significant source of pollution. Since most rice fields are located near rivers and the pollutants flowing into rivers can have a negative impact on the water environment, it is important to develop appropriate management plans by analysing the characteristics of the pollutants flowing out of the paddy fields in order to manage river water quality (Choi et al., 2012).

Diffuse pollution from agriculture or forestry has not received as much attention in Korea as urban diffuse pollution because it was generally believed that the concentration of diffuse pollutants from rural area is relatively low and non-toxic. However, the rainfall of the Asian monsoon region, including Korea, is concentrated and intensive during the crop-growing season; consequently, substantial amounts of nutrients are lost from paddy fields (Kim et al., 2004; Jin et al., 2010; Jeon et al., 2005; Yoon et al., 2003a). In addition, unique feature of non-point source pollution from paddy field is that it is influenced by climate characteristics (rainfall, rainfall intensity), soil characteristics, and the agricultural activities such as irrigation and fertilization (Jung et al., 2014; Kim et al., 2010).

In order to achieve reasonable and scientific management, it is important to have long-term on-site monitoring of runoff and water quality data collection reflecting various environmental conditions (Roh et al, 2006; Shin, 2007) and understanding of pollutant export pathways (Lee et al., 2011; Park et al., 2004). Several studies were conducted on the export of the nitrogen and phosphorus from paddy field in Korea (Cho et al, 2008; Jeon et al., 2003; Yoon et al, 2006). Hwang et al. (2004) analysed T-N and T-P export characteristics of paddy fields using surface water and groundwater, and reported that T-N and T-P runoff loads by surface water irrigation were greater than those by ground water irrigation. Yoon et al. (2003a) reported that rice paddies behave as T-N and T-P sink rather than source when annual rainfall is less than 800mm during farming period, and suggested that the effective use of rainfall and less irrigation to reduce the pollutant load by controlling excess water. Kim et al. (2004) evaluated the nutrient reduction efficiency of a pond system receiving drainage from paddy field. Many researchers have analysed the runoff characteristics through monitoring the rice fields, proposed management of the pollutant reduction; tillage method, use of the slow-release fertilizer, control of the amount of fertilizer, and water management, and suggested reduction efficiency according to each method (Kim et al., 2004; Lee et al., 2005; Yoon et al., 2002; 2003b; Sohn et al, 2004).

Phosphorus exists in various forms in the rice paddy field, and the seasonal runoff characteristics are different. In particular, it is reported that the phosphorus released as return flow during non-storm period is predominant in the dissolved form, and that most of the sediment-bound phosphorus is discharged during the storm period (Lee et al., 2011; Oh et al., 2009). The dissolved phosphorus is directly used for algal growth. The sediment-bound phosphorus in aquatic system is separated from the soil particles by anaerobic conditions and changes into dissolved form, which promotes eutrophication and subsequent phytoplankton growth (Kim et al., 2002; Song et al, 1995). Therefore, studies about interaction of soil, fertilization, rainfall, irrigation and drainage characteristics, regarding outflow behaviour of dissolved and sediment-bound phosphorous from rice paddy fields are important. However, the previous researches have focused on the quantification of the contaminants that flow out from paddy field.

Phosphorus is supplied not only by fertilization but also by irrigation water. Although the amount of phosphorus introduced into rice paddies by irrigation is lesser than that of fertilizer, but it is not a small amount compared to the T-P unit load set by the Ministry of Environment (Choi et al., 2012). Nevertheless, studies on interaction of phosphorous concentration among irrigation water, flooding water, and drainage are still lacking. This study was carried out to investigate the phosphorous concentrations of irrigation water, flooding water and drainage of paddy fields and their relationship to figure out implication of management.

2. Materials and Methods

2.1. Study site

The study was conducted during a period of five crop-years (from May 1, 2008, to September 30, 2012) in a rice cultivation area Hakya district located in Emda-myun, Hampyeong gun, Jeollanam-do, Korea (Fig. 1). The study paddy field area is 13.7 ha and is composed of several paddy plots (100 m x 50 m) separated by irrigation and drainage canal. The soil of the experimental paddy field is of Pyeongtaeg series (silt loam, mixed, mesic family of Typic Endoaquepts) (National Institute of Agricultural Science and Technology, 2009). The site does not have external influent; accessibility is good for monitoring. Irrigation water was supplied from the Daedong reservoir, which is managed by the Korea Rural Community Corporation.

***Figure 1**: Schematic representation of study area and location of sampling stations.*

The crop period was from the beginning of May to the end of September. Rice was transplanted from May 26 to June 5 and basal fertilizer was applied between late May and early June. Additional fertilization (tillering and panicle fertilization) was conducted during late June and early August. Basal fertilizer doses

were 55.5 kg N ha^{-1}, 45.0 kg P_2O_5 ha^{-1}, 45.0 kg K_2O ha^{-1}, at tillering, fertilizer dose was 59.2 kg N ha^{-1} and Panicle fertilizer was applied at the rate of 23.2 kg N ha^{-1}.

2.2 Hydrological survey and water quality analysis

In this study, the hydrological and water quality monitoring at the end of the drainage canal was conducted during storm and non-storm periods. The monitoring period was from 2008 to 2012. Rainfall, irrigation and drainage amount were measured for the water balance analysis of the Hakya district. Rainfall data were obtained by installing rainfall gauge (TBRG, CASELLA, UK) on the roof of the nearby building. The amount of irrigation was measured by using a water level gauge (Orphimedes, OTT Hydromet, Germany) at the inlet and outlet of irrigation canal and the gauge was installed at the outlet of the drainage canal to measure water outflow from the paddy fields. Flow velocity in the irrigation and drainage canal was measured by flow velocity meter (OTT model C2, Germany). The measured water levels were converted to flow rates using a water level-flow rate relationship regressed from the measured data.

The irrigation water samples of the Hagya district were collected 24 times from 2008 to 2010, and the samples of the flooding water were collected 50 times from 3 spots. Drainage samples were collected 51 times during storm period and 13 times for non-storm period. The collected water samples were transported to the laboratory and analysed according to the standard analysis method. The pH was measured with a 1:5 distilled water suspension with a pH meter (pH meter, ISTEK, Korea) and EC with an EC meter (Orion star series, Thermo scientific, Singapore). DO was analysed using a DO meter (Orion star series, Thermo Scientific, USA). To analyse T-P, 50 mL of unfiltered water samples were taken with 10 mL of potassium persulfate solution (4 W / V%) and heated in a high pressure steam sterilizer (120°C) for 30 minutes and determined by ascorbic acid colorimetric method. PO_4-P (dissolved phosphorus) was analysed in the same way as T-P analysis method using a sample passed through glass fibre filter paper (MOE, 2004).

2.3 Correlation analysis

To investigate the effects of pH, EC and DO on the changes of PO_4-P and T-P concentrations in flooding water, Pearson correlation analysis of phosphorus concentration (PO_4-P, TP) and pH, EC and DO was carried out, respectively. The correlation coefficient takes a value from -1 to +1, which means that the closer the absolute value is to ±1, the stronger the correlation.

3. Results and Discussions

3.1. Paddy water balance

The rainfall, irrigation, and drainage during the cultivation period in the Hagya district were 678.0 ~ 927.4 mm (average: 817.3 mm), 682.9 ~ 1.091.6 mm (average: 916.4 mm) and 503.7 ~ 794.2 mm (average: 694.2 mm), respectively (Table 1). In 2008, when rainfall was the least at 678 mm, the amount of irrigation was the highest at the1,091.6 mm. The water balance components consist of precipitation, irrigation, drainage, evapotranspiration, and infiltration. The irrigation to the study sites (average: 916.4 mm) was moderate when compared to those of other studies conducted in Korea, which ranged from 490 mm ~ 1498 mm (Yoon et al., 2006). Therefore, the average drainage from the study fields (694.2 mm) was also moderate when compared to those of other studies, which ranged from 593 to 1,617 mm. During the

study period, irrigation volume accounted for more than half of the total influx (rainfall + irrigation). Lee et al. (2014) also showed that the ratio of irrigation amount to total inflow was 66%, which indicates a likelihood for higher ratio during rice cultivation.

The evapotranspiration was estimated using the Penman-Monteith method since field measurement of evaporation was incomplete. The evapotranspiration amount was 652.5 mm (618.1~720.9mm) and the infiltration amount was 386.4 mm (233.6 ~ 488.3mm). The average temperature during the study period was 23.4 ℃ (22.6 ~ 24.0 ℃). The amount of irrigation is consumed by evapotranspiration and infiltration lost in paddy fields. The amount of evapotranspiration and the amount of infiltration of the previous researchers were found to be significant, with an average evapotranspiration of 593.5 mm and an average infiltration of 650.8 mm (Choi and Choi, 2001; Choi and Han, 2002; Im et al., 2007; Jang et al., 2012; Lee et al., 2013a; Yoon et al., 2006).

***Table 1**: The amount of rainfall, irrigation and drainage for the study paddy field (unit: mm)*

Year	Inflow			Outflow
	Rainfall (A)	Irrigation (B)	Total (A+B)	Drainage
2008	678.0	1,091.6	1,769.6	503.7
2009	846.6	974.6	1,821.2	784.8
2010	927.4	682.9	1,610.3	794.2
Average	817.3 (47.1%)[a]	916.4 (52.9%)	1,733.7	694.2

[a] *Values in the parentheses are % contribution of rainfall or irrigation to the total water inflow.*

3.2 Irrigation water quality and phosphorus concentration

The pH, DO and EC of the irrigation water were 8.0 ± 0.2, 8.8 ± 0.4 mg L^{-1} and 168.5 ± 12.1 µS cm^{-1}, respectively (Table 2). When the pH, DO and EC values of the agricultural water quality standard (An et al., 2006) and those of the observed irrigation water are compared, pH is mostly within the water quality standard (6.0 ~ 8.5), DO meets the agricultural water quality standard (above 2.0 mg L^{-1}) and EC is also below 470 uS cm^{-1}, which is the limit for agricultural water quality in Korea.

***Table 2**: Minimum, maximum, and average values of pH, DO, EC of irrigation water for the study paddy fields measured from 2008 to 2010 (n=24).*

	Min	Max	Avg.	Standard error
pH	7.0	9.4	8.0	0.2
DO (mg L^{-1})	4.5	11.4	8.8	0.4
EC (uS cm^{-1})	40.0	317.0	168.5	12.1

The concentrations of PO_4-P were 0.09 ± 0.02 mg L^{-1}, 0.07 ± 0.02 mg L^{-1} and 0.09 ± 0.01 mg L^{-1} during 2008 to 2010, and the TP concentrations were 0.12 ± 0.02 mg L^{-1} and 0.34 ± 0.08 mg L^{-1}, and 0.17 ± 0.01 mg L^{-1} in irrigation water, respectively (Fig. 2). The concentration of PO_4-P showed no significant difference annually, but the concentration of T-P in 2009 was about 3 times higher than that of 2008. The ratio of PO_4-P to T-P concentrations in 2009 was 0.24 ± 0.07, which was relatively low compared to the other years. The closer the ratio of PO_4-P to T-P to 1 is, the higher the ratio of dissolved phosphorus is, and the closer to 0, the higher the proportion of sediment-bound phosphorus (Fig. 2).

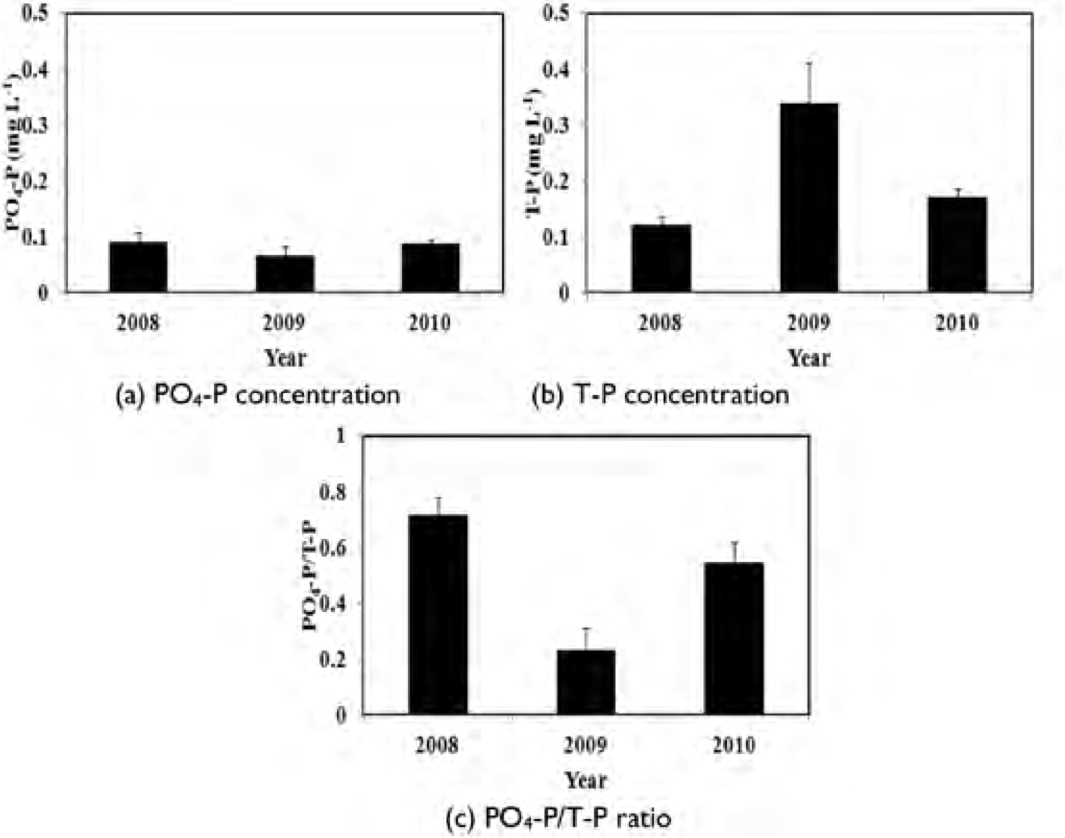

Figure. 2*: Annual mean concentrations of (a) PO_4-P and (b) T-P and (c) their ratio for irrigation water of paddy fields during the study period from 2008 to 2010*

3.3 Paddy flooding water quality

The concentrations of PO_4-P and T-P were 0.21 ± 0.04 mg L^{-1} and 1.25 ± 0.02 mg L^{-1}, respectively, and the average pH, DO, and EC of the paddy flooding water were 7.57 ± 0.08, 7.42 ± 0.32 mg L^{-1} and 268.0 ± 25.7 µS cm^{-1} (Fig. 3). Water in paddy plot is reduced by depletion of oxygen due to the interruption of oxygen supply and activity of soil microorganisms under flooding conditions (Chung, 2009), which can be confirmed by the fact that the DO of flooding water is lower than that of irrigation water. Concentrations of EC and PO_4-P and T-P in the flooding water were higher than those in the irrigation

water because the solubility of the metal ion such as iron adsorbed on the soil was higher when the soil was in the reduced state (Vepraskas and Faulkner, 2001) and by the addition of phosphorous fertilizer.

The ratio of PO_4-P to T-P concentrations in paddy water was 0.29 ± 0.03. The ratio of PO_4-P concentration to T-P concentration in 2008 was relatively high (0.44 ± 0.04), because there was relatively less rainfall than the other years and the flooding period was longer, desorption of soil phosphorus might have occurred. The ratio of PO_4-P to T-P concentrations in flooding water in 2010 was 0.21 ± 0.09, similar to 0.25 reported by Lee et al. (2014).

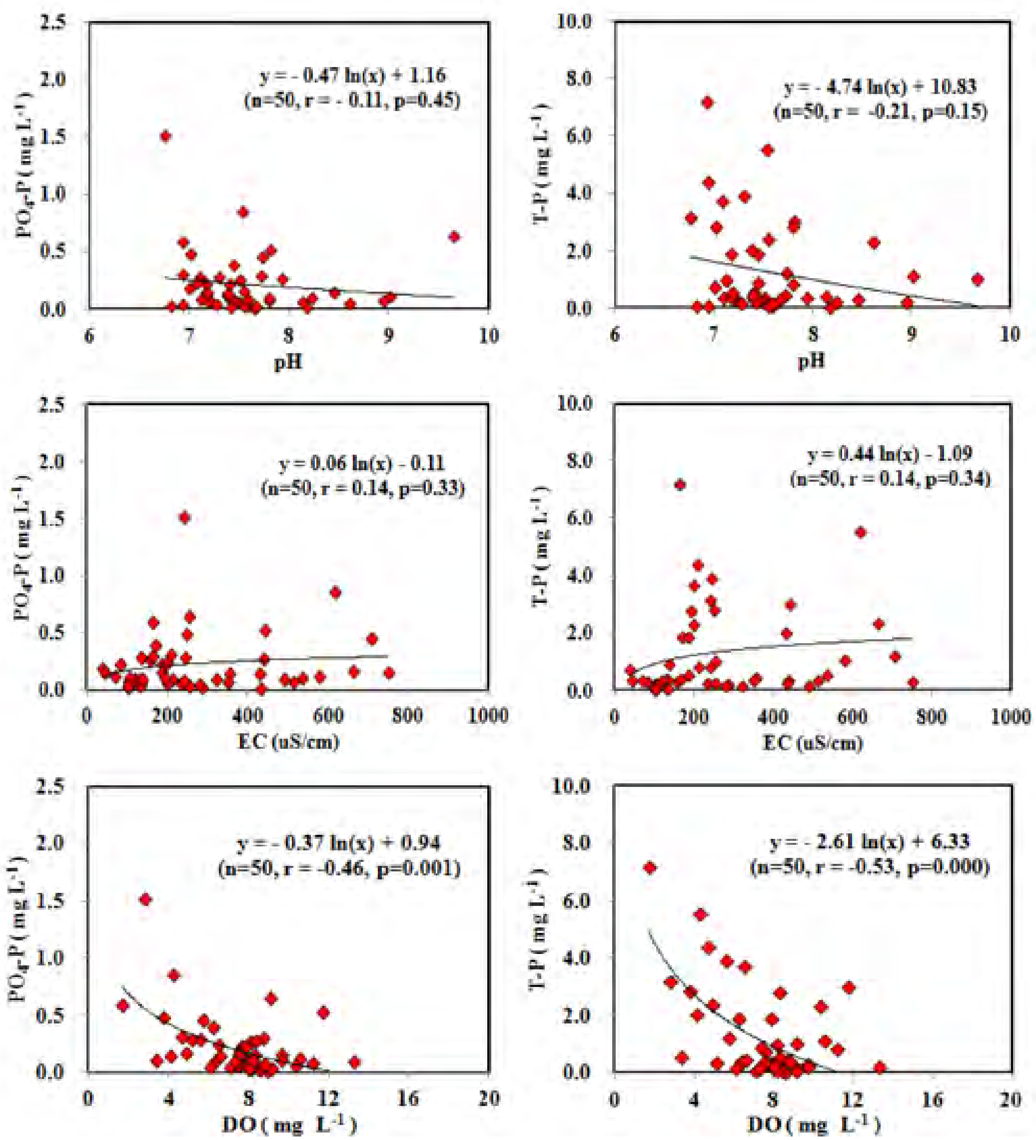

Figure. 3: *Correlation between the concentrations of PO_4-P and T-P and pH, EC, and DO of flooding water in paddy fields.*

The concentrations of PO_4-P and T-P were not correlated with pH or EC (Fig. 3). On the other hand, the PO_4-P and T-P concentrations showed a negative correlation with DO. Under reduction condition, DO decreased and the oxidation-reduction potential (Eh) decreased, phosphorus bound to metal ions dissolved and would be released into flooding water (Vepraskas and Faulkner, 2001). Although not analysed in this study, Eh in flooding water is affected by oxidation-reduction of various ions (Fe^{3+}, Mn^{5+}, SO_4^{2-}, NO_3^-) as well as dissolved organic matter content, data of those ions in flooding water can be used to determine the concentration change characteristics of phosphorous in the flooding water (An et al., 2006; Chung, 2009).

The oxidation and reduction environment of flooding water is affected by various factors, but it is also affected by irrigation water quality. Because the DO changes easily due to the organic matter of the irrigation water and the ion concentration of the oxidation / reduction form, more frequent irrigation water quality monitoring data is needed to analyse the behaviour of phosphorus in the paddy field system.

3.4. Water quality of drainage water from paddy fields

The pH and EC were higher in the drainage of non-storm period (n = 13) than those in the drainage of storm period (n = 51), while the concentrations of DO and PO_4-P concentrations and the ratio of PO_4-P to T-P were similar during storm and non-storm period. However, the T-P concentration of drainage was higher in the storm period than in the non-storm period (Table 3). Although the concentrations of PO_4-P in the storm period is similar to those of the non-storm period, the reason for the higher concentrations of TP in the storm period is that sediment-bound phosphorous is disturbed by the rainfall energy and exported (Oh et al, 2009). However, the ratio of PO_4-P / T-P was not much influenced by rainfall. This result is considered to be the result of the solubilisation of some particulate phosphorous during transportation to the drainage end. The average concentration of T-P in drainage in this study was 0.40 ± 0.04 mg L^{-1} (range: 0.05-1.74), similar to that of Lee et al (2013b).

Choi et al. (2015) studied the non-point pollutant characteristics of the Imha lake basin and found that there was a high correlation between the suspended solid load and the T-P load. This study suggests the necessity of reduction of soil loss caused by rainfall runoff from agricultural land in order to improve lake water quality. It is known that the sediment-bound phosphorus exported from the agricultural land is eluted into PO_4-P under the anaerobic condition of the lake bottom and acts as a cause of eutrophication (Lee et al., 2001; Kim et al., 2008; Yoon et al., 2007). Therefore, in order to prevent eutrophication, it is important to educate farmers based on the understanding of the characteristics of phosphorus export from sources. Advanced water management technology is needed to reduce runoff along with fertilization strategies such as reduction of phosphorus fertilizer and solubilisation of soil phosphate. In addition, it is necessary to understand the amount of phosphorus supplied through irrigation water and the forms of phosphorus. Although many agricultural reservoirs are currently being used for irrigation sources (56.2%) (Park et al., 2010), Korea Rural Community Corporation conducts a quarterly water quality measurement, so it is important to understand the water quality characteristics of irrigation water supplied from agricultural reservoirs by increasing the number of measurements.

***Table 3**: Minimum, maximum, and average values of water chemistry of drainage from paddy fields during storm (n=51) and non-storm (n=13) period for the study period from 2008 to 2010*

Statistical parameter	Storm period						Non-storm period					
	pH	EC	DO	PO_4-P	T-P	PO_4-P/T-P	pH	EC	DO	PO_4-P	T-P	PO_4-P/T-P
Minimum	6.0	55.5	4.5	0.01	0.05	0.04	6.8	141.1	3.7	0.04	0.10	0.18
Maximum	7.8	513.0	9.2	1.23	1.74	0.86	7.6	790.0	12.9	0.15	0.77	0.58
Average	6.9	157.5	6.5	0.11	0.40	0.32	7.3	270.8	6.7	0.09	0.31	0.33
Standard error	0.1	14.6	0.1	0.02	0.04	0.03	0.1	45.3	0.6	0.01	0.06	0.03

※ *pH: no unit, EC: uS cm^{-1}, DO: mg L^{-1}, PO_4-P: mg L^{-1}, T-P: mg L^{-1}, PO_4-P/T-P: no unit*

4. Conclusions

In this study, we analysed the PO_4-P and T-P concentrations of irrigation water, flooding water, and drainage of paddy fields from 2008 to 2010 to understand the characteristics of phosphorous behaviour in the paddy field system. The form of phosphorous in irrigation water, flooding water, and drainage of the paddy was also investigated using the ratio of PO_4-P to T-P. In addition, the correlation between pH, EC, and DO concentration in flooding water of paddy field was analysed and the factors affecting soluble phosphorus were investigated. The average concentration of T-P during the study period was 0.19 ± 0.03 mg L^{-1} for irrigation water, 1.25 ± 0.22 mg L^{-1} for flooding water, 0.40 ± 0.04 mg L^{-1} for drainage of storm period and 0.31 ± 0.06 mg L^{-1} for drainage of non-storm period, respectively.

The concentration of T-P in the flooding water was high due to application of phosphorous fertilizer and the concentration of T-P in the drainage was lowered by dilution due to irrigation and rainfall. The ratio of PO_4-P to T-P was 0.54 ± 0.06 for irrigation water, 0.29 ± 0.03 for flooding water, 0.32 ± 0.03 for drainage for storm period and 0.33 ± 0.03 for drainage for non-storm period, which was lower in flooding water and drainage than that of irrigation water. The phosphorus fertilizer was applied in the paddy field but the adsorption by the soil rapidly changed the soluble form to the sediment bound form. The similar proportions of PO_4-P to T-P in flooding water and drainage suggest that the exporting form of phosphorus from the rice paddy field could be determined by the form of phosphorus in the flooding water. In the present study, there was a negative correlation between DO and PO_4-P concentrations of flooding water in the paddy field, which is considered to be due to easily solubilisation of adsorbed phosphorus at lower values of soil Eh. Therefore, in order to analyse the form of phosphorus in the drainage, it is necessary to understand the water chemistry of the flooding water, especially DO or Eh. Since the environment of oxidation and reduction of flooding water would be affected by irrigation water constituents, management, especially DO or BOD of irrigation water, could be important for phosphorous export control from paddy fields.

Acknowledgements: This study was carried out by the Yeongsan River Basin Environmental Agency's Environmental Fundamental Research Project [Project title: Monitoring of major non-point source pollutant outflow monitoring].

Reference

An, Y. J., Lee, W. M., Yoon, C. G. (2006). Evaluation of Korean Water Quality Standards and Suggestion of Additional Water Parameters. Korean Journal of Limnology, 39(3), 285-295. [Korean Literature]

Cho, J.Y., Choi, J. K. (2001). Nitrogen and Phosphorus Losses from a Broad Paddy Field in Central Korea. Communications in Soil science and Plant Analysis, 32, 2395-2410.

Cho, J. Y., Han, K. W. (2002). Nutrient Losses from a Paddy Field Plot in Central Korea. Water Air, Soil Poll, 134, 215-228.

Cho, J. Y., Son, J. G., Choi, J. K., Song, C. H., Chung, B. Y. (2008). Surface and Subsurface Losses of N and P from Salt-affected Rice Paddy Fields of Saemangeum Reclaimed Land in South Korean, Paddy and Water Environment, 6, 211-219.

Choi, D. H., Yoon, K. S., Jung, J. W., Choi, W. J., Lee, K. S., Lim, S. S., Lim, B, J. (2012). Water Quality and Load Characteristics of Irrigation Water from Agricultural Reservoir, Korean National Committee on Irrigation and Drainage, 19(2), 71-80. [Korean Literature]

Choi D. H., Jeon, J. H., Kim, T, D. (2015). Delivery Analysis of Nonpoint Source Pollutants at Imha Lake Basin: SS Load Characteristics. Journal of the Korean Society of Urban Environment, 15(2), 109–116. [Korean Literature]

Chung, J. B. (2009). Effect of Nitrate on Iron Reduction and Phosphorus Release in Flooded Paddy Soil. Korean Journal of Environmental Agriculture, 28(2), 165-170. [Korean Literature]

Hwang, H. S., Kong, D. S., Shin, D. S., Jeon, J. H. (2004). Characteristics of Nutrient Export from Paddy Rice Fields with Irrigation Practices, Journal of Korean Society on Water Quality, 20(6), 597-602. [Korean Literature]

Im, S. J., Park, S. W., Jang, T. I. (2007). Application of SCS Curve Number Method for Irrigated Paddy Field. KSCE Journal of Civil Engineering, 11(1), 51-56. [Korean Literature]

Jang, T. I., Kim, H. K., Sung, C. H., Lee, E. J., Park, S. W. (2012). Assessing Nutrient Losses of Reclaimed Wastewater Irrigation in Paddy Fields for Sustainable Agriculture. Agricultural Water Management, 104, 235-243.

Jeon, J. H., Yoon, C. G., Choi, J. K., Yoon, K. S. (2005). The Comparison of Water Budget and Nutrient Loading from Paddy Field according to the Irrigation Methods. Korean J. Limnology. 38(1), 118-127. [Korean Literature]

Jin, S. H., Jung, J. W., Yoon, K. S., Choi, W. J., Choi, D. H., Kang, J. H., Choi, Y. J. (2010). Probability Distribution of BOD EMC from Paddy Fields. Journal of the Environmental Science, 19(9), 1153-1159. [Korean Literature]

Jung, J. B. 2009. Effect of Nitrate on Iron Reduction and Phosphorus Release in Flooded Paddy Soil. Korean Journal of Environmental Agriculture, 28(2), 165-170. [Korean Literature]

Jung, J. W., Choi, D. H., Yoon, K. S. 2014. Selecting Probability Distribution of Event Mean Concentrations from Paddy Fields. Journal of Environmental Impact Assessment, 23(4), 285-295. [Korean Literature]

Kim, J. H., Han, K. H., Lee, J. S. (2008). Characteristics of Agricultural Non-point Source Pollutants by Rainfall Events in Rural Watersheds. Journal of Korean society on Water Quality, 24(1), 69-77. [Korean Literature]

Kim, M. K., Roh, K.A., Lee, N. J. Seo, M.C., Koh, M. H. (2005). Nutrient Load Balance in Large-scale Paddy Fields during Rice Cultivation. Korean J. Soil Sci. Fert., 38(3), 164-171. [Korean Literature]

Kim, M. S., Chung, Y. R., Suh, E. H., Song, W. S. (2002). Eutrophication of Nakdong River and Statistical Analysis of Environmental Factors. Algae 17(2), 105-115. [Korean Literature]

Kim, H. S., Kim. J. S., Kim. Y. I. Cheong, B. H. (2004). Analysis of the Characteristics of Nutrients Loading and the Water Purification Function in the Paddy-fields. Korean National Committee on Irrigation and Drainage, 11(1), 36-44. [Korean Literature]

Kim, Y. H., Kim, J. S., Jang, H. (2010). Variation of Phosphorus Concentration and Redox Potential in a Paddy Field Plot during Growing Season. J. KSAE., 52(5), 47-52. [Korean Literature]

Korean Statistical Information Service (KOSIS) (2017). http://kosis.kr/(assessed Feb. 2017). [Korean Literature]

Lee, K. B., Park, C. W., Park, K. L., Kim, J. G., Lee, D. B., Kim, J. D. (2005) Nitrogen Balance in Paddy Soil of Control Release Fertilizer Application, Journal of Soil Science and Fertilizer, 38(3), 157-163. [Korean Literature]

Lee, H. D., Ahn, J. W., Bae, C. H., Kim, W. J. (2001). Estimation of the Unit Loading and Total Loading of Nonpoint Source in Paldang Watershed by Runoff Loading during the Rainfall. Journal of Korean Society on Water Quality, 17(3), 313-326. [Korean Literature]

Lee, H. J., Son, J. G., Choi, J. K., Jang, T. I. (2013a). Assessing Water Balance in an Experimental Paddy Fields. Korean National Committee on Irrigation and Drainage, 20(1), 80-89. [Korean Literature]

Lee, H.W., Choi, N. H., Lee, Y. S., Choi, J. H. (2011). Estimation of Pollutants Loading from Non-Point Sources Based on

Rainfall Event and Land Use Characteristics. Korean Society of Environmental Engineers, 33(8), 572-577. [Korean Literature]

Lee, J. B., Lee, J. Y., Li, S. H., Jang, J. R., Jang, I. G., Kim, J. S. (2014). Nutrient Balance in the Paddy Fields Watershed with a Source of River Water. Journal of the Korean Society of Agricultural Engineers, 56(5), 11-19. [Korean Literature]

Lee, K. D., Hong, S, Y., Kim, Y, H., Na, S. I., Lee K. B. (2013b). Characteristics of TN and TP in Runoff from Reclaimed Paddy Field of Fine Sandy Loam. Korean J. Soil Sci. Fert., 46(6), 417-425. [Korean Literature]

MOE (2004). Official Testing Method with respect to Water Pollution Process. 2004-188. Ministry of Environment. [Korean Literature]

MOE (2011). http://etips.me.go.kr/EP/web/etips/TP/m_statistic/TP_statistic04.jsp, Sewage Statistics.Ministry of Environment. [Korean Literature]

Oh, Y. T., Park, J. C., Kim, D. S., Rhyu, J. K. (2004). Pollutant Characteristics of Nonpoint Source Runoff in Okcheon Stream. Journal of Korean Society on Water Quality, 20(6), 657-663. [Korean Literature]

Oh, K. Y., Kim, J. S., Oh, S. Y. (2009). Behavior of Nutrients in Runoff Water from a Small Rural Watershed. Journal of the Korean Society of Agricultural Engineers. 51(2), 51-57. [Korean Literature]

Park, S. D., Kim, H. S., Kim, C. H. (2010). Efficient Use and Management of Rural Water, ISBN 89-89225-81-7 93520. Korea Rural Economic Institute, pp.1-154. [Korean Literature]

Park, Y. H., Park, S. S. (2004). Development of Non-Point Source Pollution Loading Function Base on Rainfall Intensity and Land Use Type. Korean Society of Environmental Engineers, 26(10), 1070-1078. [Korean Literature]

Park, J. Y., Oh, J. M., Kim, Y. C. (2001). Runoff Characteristics of Major Pollutants at the Inflow Stream to Lake Sap-Kyo in Rainy Periods. Korean Society of Limnology, 34(1), 62-69. [Korean Literature]

Relevant Ministerial Consortium, (2012). The 2nd Comprehensive Plan on Nonpoint Source Management, 11-1480000-001222-01. Ministry of Land, Infrastructure and Transport. [Korean Literature]

Roh, S. D., Kim, J. H., Lee, D. K., Kim, S. S., Sohn, B. Y., Chun, Y. K. (2006). Characteristics of Pollutant Discharge from Hoengseong Watershed during the Dry and Rainy Season. Journal of Korean Society on Water Quality, 22(4), 67-77. [Korean Literature]

Shin, D. S. (2007). Basic Monitoring Concept for Revised Unit-Load on NPS. Journal of Korean Society on Water Quality, 23(4), 429-433. [Korean Literature].

Sohn, S. H., Park, K. J., Chung, S. O. (2004). Analysis of water balance for ponding depth treatment in paddy fields. Journal of the Korean Society of Agricultural Engineers, 46(4), 13-21.

Song, H. W., Lee H. W., Choi, J. H., Park, S. S. (2009). Application of HSPF Model for Effect Analyses of Watershed Management Plans on Receiving Water Qualities. Korean Society of Environmental Engineers, 31(5), 358-363. [Korean Literature]

Song, K. O., Seo, I. S., Shin, S. K., Lee, S. M., Park, C. K. (1995). Evaluation of Algal Growth Limiting Factor in the Nakdong River by MBOD Method, J of the Korean Environmental Sciences Society. 4(5), 469-479. [Korean Literature]

Vepraskas, M. J., Faulkner, S. P. (2001). Redox Chemistry of Hydric Soils, ed. Wetland Soils: Genesis, Hydrology, Landscapes, and Classification, CRC Press LLC. 85-105.

Yoon, C. G., Hwang, H. S., Jeon, J. H., Ham, J. H. (2003a). Analysis of Nutrients Balance during Paddy Rice Cultivation. Korean Journal of Limnology, 36(1), 66-73. [Korean Literature]

Yoon, C. G., Ham, J. H., Jeon, J. H. (2003b). Effects of Ponded-water Depth and Reclaimed Wastewater Irrigation on Paddy Rice Culture, Paddy and water Environment, 1(2), 1205-1216.

Yoon, K. S., Choi, J. K., Im, S. J. (2002). Effect of Tillage Management of Paddy Field on Runoff and Nutrient Losses during Non-Cropping Season. The Korean Society of Agricultural Engineers, 44(7), 53-63. [Korean Literature

Yoon, K. S., Han, K. H., Cho, J. Y., Choi, C. H., Son, J. G., Choi, J. K. (2002). Water and Nutrient Balance of Paddy Field Irrigated from a Pumping Station during Cropping Period. J. Kor. Soc. Rural Plan, 8(1), 3-14. [Korean Literature]

Yoon, K. S., Cho, J. Y., Choi, J. K., Son, J. G. (2006). Water Management and N, P Losses from Paddy Fields in Southern Korea. Journal of the American Water Resources Association, 42, 1205-1216.

Yoon, M. H., Hyun, J. T., Hug, N. S., Kwon, S. H., Cho, D. C. (2007). A Study on Release Characteristics of Lake Sediments under Oxic and Anoxic conditions. Korean Society Environmental Engineers, 29(9), 1003-1012. [Korean Literature]

ANNEX

Conference Program

Conference Program at a Glance

Time	Plenary/Parallel Sessions			
	Room			
	Regal 1	Regal 2	Dynasty	Crystal
Day 1: Wednesday, May 02, 2018				
07:00 - 11:00	Registration/Networking			
11:00 - 12:30	Inaugural Session			
12:30 - 13:30	Lunch/Networking			
13:30 - 15:00	Plenary 1 - Opening Session			
15:00 - 15:30	Coffee/Tea/Networking			
15:30 - 17:00	Plenary 2 - Symposium: Modernization of Irrigation Systems [DoI/WB]	TS-01	TS-02	TS-03
17:00 - 17:15	Coffee/Tea/Networking			
17:15 - 18:45	Plenary 2 - Symposium Contd..			
18:45 onwards	Welcome Reception (Including Cultural Program) - Regal			

Time	Plenary/Parallel Sessions			
	Room			
	Regal 1	Regal 2	Dynasty	Crystal
Day 2: Thursday, May 03, 2018				
08:00 - 09:00	Registration/ Tea/Coffee			
09:00 - 10:30	Plenary-3 Symposium: Irrigation, Ecosystem Services, and Aquatic Biodiversity [PANI]	Plenary-4 Symposium: Sustainable Irrigation [IWMI/ICIMOD]	TS-05	TS-06
10:30 - 11:00	Coffee/Tea/Networking			
11:00 - 12:30	Plenary-3 Symposium [Contd. ...]	Plenary-4 Symposium [Contd. ...]	TS-07	TS-08
12:30 - 13:30	Lunch/Networking			
13:30 - 15:00	Plenary-5 Symposium: Nexus Challenge to Irrigation institutions [FMIST]	Plenary-6 Symposium: Climate Change & Adaptation/Mitigation to Floods/Droughts [ICEWaRM]	TS-09	TS-10
15:00 - 15:30	Coffee/Tea/Networking			
15:30 - 17:00	Plenary-5 Symposium [Contd. ...]	Plenary-6 Symposium [Contd. ...]	TS-11	TS-12
Day 3: Friday, May 04, 2018				
08:00 - 09:00	Registration/Tea/Coffee/ Networking			
09:00 - 10:30	TS-13	TS-14	TS-04	
10:30 - 11:00	Coffee/Tea/Networking			
11:00 - 12:30	TS-15	Plenary-7 Symposium: Interbasin water transfer - Bheri Babai Diversion Project Experience Sharing		
12:30 - 13:30	Lunch/Networking			
13:30 - 15:00	Closing Session			
17:00 onwards	Farewell Dinner			

Young Professionals Training Program

Tuesday, May 01, 2018			
Hall: Crystal, Yak & Yeti Hotel			
Time	**Session**	**Topic**	**Resource Person**
08:00 to 08:30	Registration, Networking and Tea/Coffee		
08:30 to 09:00	**Opening Program** Program Coordinator: Sanjeeb Baral, Project Director, WRPPF Chairman: Saroj Pandit, Director General, DoI (President NENCID) Chief Guest: Secretary, Ministry of Energy, Water Resources and Irrigation Guest: Madhav Belbase, Joint Secretary, WECS, VP ICID Guest: AB Pandya, Secretary General, ICID Guest: Arnaud Cauchaous, Principle Water Resources Specialist, ADB		
09:00 to 10:30	Session-1: Trainning	*Water Foot Print and Virtual Water Approach* as a tool for improved Water Use Efficiency : Water Foot Prints and Virtual Water	Dr K Yella Reddy, FIE Vice President, ICID Director, WALAMTARI Hyderabad, India
12:30 to 13:30	Lunch		
13:30 to 15:30	Session-2: Trainning	Basin planning, its implementation, and introduction on the basin planning tool: Basin Futures	Mr Andrew Johnson, Senior Policy advisor Dr. Dave Penton, Research Team Leader, Basin Processes, CSIRO Land and Waterand Basin Futures – Mr Amit Parashar, Principal Research Consultant, CSIRO Land and Water.
17:00 to 19:00	Networking Dinner		

Inaugural Ceremony

Date : 11:00-12:30 hours Chief Guest : Rt. Hon'ble BIDYA DEVI BHANDARI President, Federal Democratic Republic of Nepal	
Hall- Regal	
Time	**Activities**
08:00 - 10:30	Registration/Networking
11:00 - 12:30	Inauguration Ceremony
12:30 - 13:30	Lunch
Master of Ceremony (MC) SADIKSHA SHRESTHA	

Plenary- 1 Opening Session

Time: 13:30 – 15:00 hrs
Moderator: Dipak Gyawali; Chair, Technical Advisory Committee (TAC)

PART-1: KEYNOTES

Arnaud Cauchaous Senior Water Resources Specialist, Asian Development Bank
Carol Jenkins Head of SEED Office, USAID
Saroj Pandit Director General, Department of Irrigation, Government of Nepal
A. B. Pandya General Secretary, ICID
Ahmed Shawky Senior Water Resources Specialist, World Bank

PART-2: Release of Technical Report of ASRWG – WT titled "Contribution of Agriculture Water to the Rural Development in Asia"

PLENARY-2 SYMPOSIUM:

Modernization of Irrigation Systems [DoI/World Bank]

Day 1: Wednesday, May 02, 2018				
Hall: Regal 1				
Time: 15:30 PM - 18:15 PM Coordination by : Vinay Poudel and Samjhana Maharjan				
SN	**Facilator**	**Keynote Speaker**	**Panelists**	**Remarks**
1	Dr Guna Nidhi Poudyal	Dr Bart Schultz	Mr Arnaud Cauchaous	
2	Mr Sanjeeb Baral	Dr Ian Makin	Mr Ahmad Shawky	
		Mr Kyu Sung Choi	Dr Puspa Khanal	
			Dr Purna B Chhetri	
			Mr Bakhodir Mirzaev	

PLENARY-3 SYMPOSIUM:

Irrigation Ecosystem Services and aquatic biodiversity [PANI]

Day 2: Thursday, 03 May, 2018				
Hall: Regal 1				
Time: 09:00 AM to 12:30PM Coordination by: Basudev Timilsina and Deepika Sharma				
SN	**Facilator**	**Speakers**	**Panelists**	**Remarks**
1	Dr Allen Turner	Prof Jeff Opperman (Keynote)	Dr. Jeff Opperman	
2	Nilu Basnyat		Prof Mark Weinhold	
		Presentations	Prof Ashutosh Shukla	
		Dr Ram Devi Tachamo Shah	Mr Ashok Tharu	
		Mr Dibesh Karmacharya	Ms Madhu Ghimire	
		Mr Sanjeeb Baral		
		Dr Maheshwor Shrestha		

PLENARY-4 SYMPOSIUM:

Sustainable Irrigation [IWMI/ICIMOD]

Day 2: Thursday May 03, 2018				
Hall: Regal 2				
Time: 09:00 AM to 12:30 PM Coordination by: Mahesh Yadav and Gitanjali Acharya				
SN	**Facilator**	**Keynote Speaker**	**Panelists**	**Remarks**
	Dr Aditi Mukharjee	Prof Dr Mathias Becker	Hon Karlene Maywald	
	Dr Luna Bharati	Dr Alan Nicol	Dr Ian Makin	
		Dr Santosh Nepal	Mr Felix Reinders	
		Dr Cai Xueling	Dr David Molden	
		Dr Vadim Sokolov	Dr Alok Sikka	
			Mr Saumitra Neupane	

PLENARY-5 SYMPOSIUM:

Nexus Challenge to Irrigation Institutions

Day 2: Thursday, 03 May, 2018				
Hall: Regal 1				
Time: 13:30 PM - 17:00 PM Coordination by: Ashok Gautam and Maleena Shakya				
SN	**Facilator**	**Keynote Speaker**	**Panelists**	**Remarks**
1	Dr Prachand Pradhan	Prof Dr Asit Biswas - Video	Dr Hafied Gany	
		Dr Douglas Merrey	Mr Sushil Acharya	
		Mr Devesh Belbase	Prof Dr Masayoshi Satoh	
			Prof Dr Ding Kunlun	
			Mr A B Pandya	

PLENARY-6 SYMPOSIUM:

Climate Change & Adaptation/Mitigation to Floods/Droughts [ICEWaRM]

Day 2: Thursday, 03 May, 2018				
Hall: Regal 2				
Time: 13:30 PM - 17:00 PM Coordination by : Ravi Shakya and Manju Kawan				
SN	**Facilator**	**Keynote Speaker**	**Panelists**	**Remarks**
1	Hon Karlene Maywald	Dr David Molden	Dr David Molden	
			Dr Kaluvai Yella Reddy	
			Mr Dipak Gyawali	
			Mr Daniel Casement	
			Dr Luna Bharati	

PLENARY-7 SYMPOSIUM:

Interbasin water transfer - Bheri Babai Diversion Project Experience Sharing

Day 3: Friday, 04 May, 2018
Hall: Regal 2
Time: 11:00 AM - 12:30 PM Moderated by: Mr. S.K. Basnet

Technical Sessions

Technical Session -1 (TS01): Enabling small holders' capacity to obviate farmers' distress				
Chairperson: Dr Hafied Gany				
Coordinator/Rapporteur: Ajay Raj Adhikari, Susmita Dahal				
Date: Wednesday, May 02, 2018 [Room: Regal2]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
15:30-15:45	TS01-1	Ram C. Bastakoti [*Nepal*]	Dealing with variations in access to water: An assessment of challenges and coping strategies in Far-western Nepal	International Water Management Institute (IWMI), Lalitpur, Nepal
15:45-16:00	TS01-2	Krishna Pd. Rijal [*Nepal*]	Paradigm shift in hill irrigation systems: A case study of Dolkha District	Department of Irrigation, Gov. of Nepal
16:00-16:15	TS01-3	Alok Sikka [*India*]	Building capacity of smallholder farmers for enhanced adoption of drip irrigation: Lessons from Karnataka, India	International Water Management Institute (IWMI), India
16:15-16:30	TS01-4	Neelam Patel [*India*]	Impact assessment of water savings technologies in livelihood improvement of small and marginal farmers of India	Water Technology Center, ICAR-Indian Agricultural Research Institute, New Delhi
16:30-16:45	TS01-5	Teki Surayya [*India*]	Strategic role of drip irrigation in efficient management of water resources and enhancing livelihoods: Select case study –India	Adikavi Nannaya University, Rajahmundry, Andhra Pradesh
16:45-17:00	Q&A/Discussion			

Technical Session -2 (TS02): Modernising irrigation system for better services				
Chairperson: Dr Kaluvai Yella Reddy				
Coordinator/Rapporteur: Tika Ram Baral, Manisha Panthi				
Date: Wednesday, May 02, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
15:30-15:45	TS02-1	Manoj Pantha [*Nepal*]	Potential of using solar energy for irrigation in hilly region of Nepal	Non-Conventional Irrigation Technology Project, Department of Irrigation
15:45-16:00	TS02-2	Sungsoo Bang [*Korea*]	Application of the groundwater irrigation system using solar power generation as a Water-Energy-Food-Nexus model project	Overseas Project Office, Korea Rural Community Corporation, the Republic of Korea
16:00-16:15	TS02-3	Pratap Thapa [*Nepal*]	Opportunities and challenges faced by emerging renewable energy based lift-irrigation systems: A case study of hydro-powered irrigation pumps	aQysta Nepal
16:15-16:30	TS02-4	Aditi Mukherji [*Nepal*]	Solar powered irrigation pumps as a clean Eeergy solution for Nepal Terai	International Centre for Integrated Mountain Development (ICIMOD)
16:30-16:45	TS02-5	Rashmi Shrestha [*Nepal*]	Harnessing the hydropower boom: Enhancing water resources for farmer managed irrigation systems	Independent Researcher Kathmandu, Nepal
16:45-17:00	Q&A/Discussion			

Technical Session -3 (TS03): Enabling small holders' capacity to obviate farmers' distress				
Chairperson: Dr Alan Nicol				
Coordinator/Rapporteur: Bir Singh Dhami, Deepika Sharma				
Date: Wednesday, May 02, 2018 [Room: Crystal]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
15:30-15:45	TS03-1	Eric Schmidt [*Australia*]	Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plain	University of Southern Queensland, Toowoomba, Australia
15:45-16:00	TS03-2	Dilip Yewalekar [*India*]	Empowering small growers by gravity micro-irrigation technology	Jain Irrigation Systems Ltd, India
16:00-16:15	TS03-3	Sumit Pal [*India*]	Decentralized approach for waste water treatment and long term effect of treated and untreated waste water irrigation on crop and soil quality	Indian Agriculture Research Institute
16:15-16:30	TS03-4	Raj Kumar G.C. [*USA*]	Rural water systems for smallholder farmers in the Hills of Nepal - An unregonized irrigation service	School of Public and International Affairs, Virginia Tech., USA
16:30-16:45	TS03-5	Gitta Shrestha [*Nepal*]	Gender differences in water security and capabilities in Far-West Nepal	International Water Management Institute (IWMI), Lalitpur, Nepal
16:45-17:00	Q&A/Discussion			

Technical Session -4 (TS04): Coping with recurring droughts and floods in the context of climate change				
Chairperson: Mr Shital Babu Regmi				
Coordinator/Rapporteur: Mitra Baral, Gitanjali Acharya				
Date: Friday, May 04, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
09:00-09:15	TS04-1	Luna Bharati [*Nepal*]	Digo Jal Bikas	International Water Management Institute (IWMI), Kathmandu, Nepal
09:15-09:30	TS04-2	Sanita Dhaubanjar [*Nepal*]	Projected future climate for Western Nepal	International Water Management Institute (IWMI), Kathmandu, Nepal
09:30-09:45	TS04-3	Vishnu Prasad Pandey [*Nepal*]	Assessing spatio-temporal variation in water resources availability in Karnali-Mohana River Basin, Nepal	International Water Management Institute (IWMI), Kathmandu, Nepal
09:45-10:00	TS04-4	Manisha Maharjan [*Japan*]	Spatio-temporal disintegration of different droughts in Nepal	Department of Environmental Engineering, Kyoto University
10:00-10:15	TS04-5	Mohammad sanaulla K. Hudar [*India*]	A remote sensing and GIS approach to analyze agricultural drought trend, frequency and severity in Marathawada, Maharashtra, India	Agriculture and Soils Division, Indian Institute of Remote Sensing-ISRO, Dehradun
10:15-10:30	Q&A/Discussion			

Technical Session -5 (TS05): Enabling Water Users Institutions (WUIs) for sustainability of irrigation systems				
Chairperson: Dr Puspa Khanal				
Coordinator/Rapporteur: Tara Bhatta, Sabina Khatri				
Date: Thursday, May 03, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
09:00-09:15	TS05-1	Masayoshi Satoh [*Japan*]	Japanese model of participatory irrigation management and Its implications	University of Tsukuba, Japan
09:15-09:30	TS05-2	A. Hafied A. Gany [*Indonesia*]	Participatory irrigation development and management procedures and empirical processes under the small land holding condition: With special seference to Indonesian condition	Scientific Board of Indonesian National Committee of ICID; & VP Hon of ICID
09:30-09:45	TS05-3	Deepak Pandey [*Nepal*]	Farmers Managed Irrigation Systems of Nepal: Assessment of the elements contributing to their sustainable operation and maintenance	FMIST, Nepal
09:45-10:00	TS05-4	Navin Kumar [*India*]	Social complexity of participatory irrigation management	School of Human Ecology, Ambedkar University Delhi, India
10:00-10:15	TS05-5	Wooho Myoung [*Korea*]	Utilization of subsurface dams for agricultural water supply in S. Korea	KRC, South Korea
10:15-10:30	Q&A/Discussion			

Technical Session -6 (TS06): Coping with recurring droughts and floods in the context of climate change				
Chairperson: Prof Dr Ding Kunlun				
Coordinator/Rapporteur: Prem Lasiwa, Samjhana Maharjan				
Date: Thursday, May 03, 2018 [Room: Crystal]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
09:00-09:15	TS06-1	Rocky Talchabhadel [*Japan*]	Agro-Climatic atlas of Nepal: A tool for sharing climatic information for agricultural sector	Disaster Prevention Research Institute, Kyoto University
09:15-09:30	TS06-2	Md. Farid Hossain [*Bangladesh*]	Climate change and water management impact on crop production in Bangladesh	School of Agriculture and Rural Development, Bangladesh Open University
09:30-09:45	TS06-3	R.B. Singandhupe [*India*]	Crop water status, severity of soil moisture stress and climatic variables on seed cotton yield in Semi-Arid region of India: A case study of Gujarat and Maharastra	Principal Scientist, Central Institute for Cotton Research, Nagpur, Maharashtra
09:45-10:00	TS06-4	Jyoti Prakash Padhi [*India*]	Optimal cropping pattern for sustainable agriculture under drought condition	School of Civil Engineering, KIIT University, Bhubaneswar, Odisha
10:00-10:15	TS06-5			
10:15-10:30	Q&A/Discussion			

Technical Session -7 (TS07): Modernising irrigation system for better services				
Chairperson: Mr Ahmad Shawky				
Coordinator/Rapporteur: Ezee GC, Tilasmi Aryal				
Date: Thursday, May 03, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
11:00-11:15	TS07-1	Bir Singh Dhami [*Nepal*]	Irrigation development in Nepal: A comparative historical review and future orientation	Sr. Divisional Engineer, Department of Irrigation, Government of Nepal
11:15-11:30	TS07-2	Michael Scobie [*Australia*]	Development of smart apps for data collection and decision support in India and Nepal	University of Southern Queensland, Toowoomba, Australia
11:30-11:45	TS07-3	Otilija Miseckaite [*Lithuania*]	Sprinkler irrigation management in loam soil	Aleksandras Stulginskis University, Lithuania
11:45-12:00	TS07-4	Indra Lal Kalu [*Nepal*]	Intermediate reservoir in irrigation laterals for improving irrigation system operation through making it efficient and women friendly	Dy Team Leader & IWRM Planner, Bagmati River Basin Improvement Project (BRBIP)
12:00-12:15	TS07-5	Jin-Yong Choi *[Korea]*	Development of reservoir operation model using reinforcement learning	Department of Rural Systems Engineering, Agriculture and Life Sciences, Seoul National University, Seoul
12:15-12:30	Q&A/Discussion			

Technical Session -8 (TS08): Coping with recurring droughts and floods in the context of climate change				
Chairperson: Mr B K Pradhan				
Coordinator/Rapporteur: Shailesh Pokharel, Grishma Acharya				
Date: Thursday, May 03, 2018 [Room: Crystal]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
11:00-11:15	TS08-1	Zuhair Hasnain [*Pakistan*]	Calibration of an annual crop Growth Model in order to simulate growth and water use efficiency	Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan
11:15-11:30	TS08-2	Weng Ngai Chan [*Malaysia*]	Issues and challenges in implementing rainfall harvesting systems in Malaysia	Universiti Sains Malaysia
11:30-11:45	TS08-3	Michael Davidson [*USA*]	The role of irrigation efficiency as a tool for mitigating the impacts of climate change	Davidson Consultants (for World Bank, International Finance Corporation)
11:45-12:00	TS08-4	Pu-Reun Yoon [*Korea*]	Estimating paddy rice yield change considering climate change impact on cropping period	Department of Rural System Engineering, Seoul National University, Seoul
12:00-12:15	Q&A/Discussion			

Technical Session -9 (TS09): Coping with recurring droughts and floods in the context of climate change				
Chairperson: Dr Alok Sikka				
Coordinator/Rapporteur: D P Jaishy, Jayalaxmi Singh				
Date: Thursday, May 03, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
13:30-13:45	TS09-1	Abdul Latif Khan [*India*]	Management of water resources in Himalayan region for food security and rural development in context of climate change	Retired Superintending Engineer, U.P. Irrigation & Flood Control Dep., Lucknow, India
13:45-14:00	TS09-2	Qazi Tallat M. Siddiqui [*Pakistan*]	A foresight for flood disaster management in Pakistan	Pakistan National Committee of ICID (PANCID)
14:00-14:15	TS09-3	Ghulam Zakir Hassan [*Pakistan*]	Groundwater reservoir as a source of flood water storage - A case study from Punjab, Pakistan	Irrigation Research Institute (IRI), Irrigation Department, Government of the Punjab, Lahore, Pakistan
14:15-14:30	TS09-4	T. Janaki Meegastenna [*Sri Lanka*]	Coping with recurring floods and droughts in the context of climate change in Sri Lanka	Director, Irrigation Department of Sri Lanka
14:30-14:45	TS09-5	Otilija Miseckaite [*Lithuania*]	Climate and aridity change	Aleksandras Stulginskis University, Lithuania
14:45-15:00	Q&A/Discussion			

Technical Session -10 (TS10): Modernising irrigation system for better services				
Chairperson: Prof Bart Schultz				
Coordinator/Rapporteur: Dev Raj Niraula, Sanchita Kaduwal				
Date: Thursday, May 03, 2018 [Room: Crystal]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
13:30 -13:45	TS10-1	Xueliang Cai [*Netherlands*]	Irrigation modernization: Catching up with farmers' initiative - the case of Vietnam	IHE Delft, Delft Institute for Water Education
13:45 -14:00	TS10-2	Suman Sijapati [*Nepal*]	Irrigation modernization by enhancing water productivity through water accounting	INPIM Nepal
14:00 -14:15	TS10-3	Trevor Beaumont [*Germany*]	Irrigation Master Plan for Nepal through integrated river basin planning	Lahmeyer Consultants
14:15 -14:30	TS10-4	K. Yella Reddy [*India*]	Efficient water management as a key for sustainable development: Context of national water policy in India	Water and Land Management Training Research Institute, Hyderabad, India
14:30-14:45	TS10-5	Bhesh Raj Thapa [*Nepal*]	Comparative assessment of various water application methods for improving water productivity during dry season agriculture	International Water Management Institute (IWMI), Kathmandu, Nepal
14:45 -15:00	Q&A/Discussion			

Technical Session -11 (TS11): Modernising irrigation system for better services				
Chairperson: Dr Vadim Sokolov				
Coordinator/Rapporteur: Dinesh Rajouria, Kiran Karki				
Date: Thursday, May 03, 2018 [Room: Dynasty]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
15:30-15:45	TS11-1	T.B.S. Rajput [*India*]	Development of a Decision Support System for scheduling irrigations and fertigations in drip irrigated crops	Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India
15:45-16:00	TS11-2	Sugat Bajracharya [*Nepal*]	A review of agriculture water management technologies in a climate smart context	International Centre for Integrated Mountain Development (ICIMOD)
16:00-16:15	TS11-3	A.K. Randev [*India*]	Irrigation management under changing climatic scenario for evergreen revolution: Asian economic perspective	Dr. Y S Parmar University of Horticulture & Forestry, Nauni – Solan, Himachal Pradesh
16:15-16:30	TS11-4	Amit Prasad [*India*]	Water Requirement of Different Horticultural Crops under Drip Irrigation System in Tamagarda - Erani Inter basin	G B Pant University of Agriculture and Technology
16:30-16:45	TS11-5	A. R. Adhikari [*Nepal*]	Scenario of Interbasin Water Transfer Projects in Nepal: A Case Study from Bheri Babai Diversion Multipurpose Project	Bheri Babai Diversion Multipurpose Project, Department of Irrigation, Nepal
16:45-17:00	Q&A/Discussion			

Technical Session -12 (TS12): Enabling Water Users Institutions (WUIs) for sustainability of irrigation systems				
Chairperson: Mr Mahendra Nath Aryal				
Coordinator/Rapporteur: Dr Rajan Bhattarai, Anish Mahat				
Date: Thursday, May 03, 2018 [Room: Crystal]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
15:30-15:45	TS12-1	Mukhlis Zainol Abidin [*Malaysia*]	Rejuvenating Water User Group: The Malaysia Granary Area context	Sr. Irrigation and Drainage Engineer
15:45-16:00	TS12-2	Birendra Kumar Yadav [*Nepal*]	Improved water management in Kankai Irrigation System, Nepal	Kankai Irrigation Mgmt. Division, Department of Irrigation, Nepal
16:00-16:15	TS12-3	Khem Raj Sharma [*Nepal*]	Status and performance of irrigations projects: Case studies of selected projects in Nepal	Nepal Engineering College (NEC), Lalitpur
16:15-16:30	TS12-4	Sanjeev Kumar Mishra [*Nepal*]	Operation performance of a modernised irrigation system: A case study of Sitagunj Irrigation System in Sunsari Morang Irrigation Project, Nepal	Department of Irrigation, Nepal
16:30-16:45	TS12-5			
16:45-17:00	Q&A/Discussion			

Technical Session -13 (TS13): Modernising irrigation system for better services				
Chairperson: Mr S.N. Poudel				
Coordinator/Rapporteur: Suresh Sharma, Susmita Dahal				
Date: Friday, May 04, 2018 [Room: Regal 1]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
09:00-9:15	TS13-1	Suman Gyawali [*Nepal*]	Practices of irrigation and drainage management in terms of sustainability aspect: A case study of Chapagaun, Lalitpur, Nepal	School of Education & Development Studies, Kathmandu University
09:15-9:30	TS13-2	Md. Lutfor Rahman [*Bangladesh*]	Cultivable area recovered by using bamboo bandalling structures	Hydraulic Research Directorate, River Research Institute, Faridpur, Bangladesh
09:30-9:45	TS13-3	Shruti Jain [*India*]	Politics of 'clean green' technology of hydropower projects in Himalayas	Centre for Development Practice and Research, Tata Institute of Social Sciences, Patna
09:45-10:00	TS13-4	Jehong Bang [*Korea*]	A study of quality control on time series of water level in agricultural reservoir	Dept. of Rural Systems Engineering, Agriculture and Life Sciences, Seoul National University
10:00-10:15	TS13-5	Brian Bromwich [*England*]	Nepal - Challenges of sediment removal on Sunari Morang Irrigation proejct	Cambridge, England
10:15-10:30	Q&A/Discussion			

Technical Session -14 (TS14): Enabling Water Users Institutions (WUIs) for sustainability of irrigation systems				
Chairperson: Prof Dr Mayayoshi Satoh				
Coordinator/Rapporteur: Anubhav Chaudhary, Bishal KC				
Date: Friday, May 04, 2018 [Room: Regal2]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
09:00-9:15	TS14-1	Sushil Acharya [*Nepal*]	Reorganizing Water User Association from flood irrigation system to modernization of irrigation infrastructure: A case study of Rani, Jamara and Kulariya Irrigation System of Kailali district, Nepal	RJKIP, Project Director
09:15-9:30	TS14-2	Pranita Udas [*Nepal*]	Gendered need for irrigation development in changing climate context	ICIMOD
09:30-9:45	TS14-3	Chetman Budha [*Nepal*]	A Success Story of Irrigation Management Transfer Program in Nepal: A Case Study of Kankai Water Users' Association, Kankai Irrigation System, Jhapa, Nepal	Department of Irrigation, Nepal
09:45-10:00	TS14-4	Ram C. Bastakoti [*Nepal*]	Institutional preconditions for robustness and sustainability in Irrigation Management: Insights from Nepal and Thailand	International Water Management Institute (IWMI), Lalitpur, Nepal
10:00-10:15	Q&A/Discussion			

Technical Session -15 (TS15): Irrigation, ecosystem services and aquatic biodiversity				
Chairperson: Dr Aditi Mukherji				
Coordinator/Rapporteur: Pramila Shreshtha, Nabin Poudyal				
Date: Friday, May 04, 2018 [Room: Regal1]				
Time	**Paper ID**	**Presenter [Country]**	**Title**	**Affiliation**
11:00-11:15	TS15-1	Sanita Dhaubanjar [*Nepal*]	Sustaining spring sources through evidence based interventions to augment irrigation in Nepal middle hills	International Water Management Institute (IWMI), Kathmandu, Nepal
11:15-11:30	TS15-2	Bart Schultz [*New Zealand*]	Impacts of dairy farming systems on water quantity and quality in Brazil, Ethiopia, Nepal, New Zealand and USA	Aqualinc Research Limited, Christchurch, New Zealand
11:30-11:45	TS15-3	H.C. Sharma [*India*]	Pollution of groundwate due to extensive use of fertilizers	G.B. Pant University of Agriculture and Technology, Uttarakhand
11:45-12:00	TS15-4	Kwangsik Yoon [*Korea*]	Phosphorus concentrations in irrigation,flooding, and drainage water of paddy fields and their relationship	Department of Rural & Bio-systems Engineering, Chonnam National University, GwangJu, Korea
12:00-12:15	TS15-5	Mohammad Faiz Alam [*India*]	Prioritising land and water interventions for climate smart villages (CSVs)	International Water Management Institute, New Delhi, India
12:15-12:30	Q&A/Discussion			

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