Proceeding of the

13th ICID International Drainage Workshop

Ahwaz, Iran, 4 - 7 March 2017

Drainage and Environmental Sustainability

International Commission on Irrigation and Drainage
Iranian National Committee on Irrigation and Drainage

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Khuzestan Regional Committee on Irrigation & Drainage

Khuzestan Water and Power Authority

Iran water Resources Management Company

Islamic Republic of Iran Ministry of Energy

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Rahim Meydani
Deputy Minister of Energy for Water and Wastewater Affairs and Chairman of IRNCID

Dear Participants,

Having the honor to welcome all respectful delegates and accompanying persons from various countries around the world, I am very pleased to inform you that the 13th International Drainage Workshop (13th IDW) is currently being held in the beautiful city of Ahwaz, in Khuzestan Province as one of the main agricultural and economic hubs of Iran.

Indeed the event is a valuable opportunity for drainage scholars and experts from all over the world to bring together the technologies, experiences and the latest findings of drainage to be further investigated with the aim of coming up with new approaches and solutions towards better and efficient agriculture with due consideration to environmental aspects of drainage and promotion of drainage management for environmental sustainability

As we are all aware, the International Commission on Irrigation and Drainage (ICID) once every two years holds international drainage conferences in one of the member countries. The first International Drainage Conference (IDW) was held in Wageningen, The Netherlands in 1978, and the last one was held in St. Petersburg, Russia, June 2014. Now we are in the stage of hosting the 13th International Drainage Workshop in Ahvaz, with its pleasant weather at this time of the year. This event is organized by IRNCID and hosted by Khuzestan Water and Power Authority (KWPA).

Worth noting that, Khuzestan province is the birthplace of drainage in Iran. About 60 percent of drained area of the country is in Khuzestan. In addition, there are many ancient unique hydraulic structures in the region such as Chogha Zanbil Ziggurat, an ancient complex built around 1250 B.C. accompanied with water treatment facilities.

I hope the participants of the workshop will find the opportunity to visit modern drainage networks and enjoy the ancient hydraulic structures dating back to over 3000 years.

I would encourage your participation, appreciate your kind cooperation and look forward to reviewing the fruitful results of this fabulous event. Last but not least, I intend to submit the outcomes of this international event in the fourth coming official meetings I have with the Commission on Agriculture, Water and Environment of the Islamic Republic of Iran Parliament.

Wishing you a very pleasant and memorable stay.

M. R. Shamsaei
Chairman and Managing Director
Khuzestan Water and Power Authority

On behalf of the Khuzestan Water and Power Authority (KWPA), I have the pleasure to welcome all researchers, scholars and experts to participate in the 13th International Drainage Workshop (13IDW) which will be held in Ahwaz, Iran. Unique capacities in water, soil and climatic conditions has made Khuzestan plain an attractive place to different ethnic groups in years. Double cropping is possible here in Khuzestan province having two summers and mild winters, a unique characteristic throughout the country. Among other characteristics are salt affected heavy soils requiring drainage facilities. The Shavoor open drainage system was constructed back in 1956 followed by the development of sugarcane plantation covering 12,000 hectares of Haft Tappeh as the first subsurface drainage system in the 1970s. These developments shows the historic significant of the development of drainage systems in the south western Iran.

I am quite sure that being familiar with the technical tours in the province, along with the most interesting and tourist worthy cultural tours brings you unforgettable moments of your stay in Iran. During the workshop, you may enjoy visiting historical unique hydraulic structures in Khuzestan including Choqazanbil, the only remnant of an ancient city that was constructed approximately in 1300 BC. You should not miss the chance to visit Shushtar historical hydraulic system, a masterpiece of creative genius be traced back to Darius the Great in the 5th century B.C.

I hope that the workshop provides you with the chance to be familiar with KWPA's years of experience in irrigation and drainage network developments, adapting new design criteria, followed by finding the best practice managements in favor of the environment. We will do our best to take all the opportunities to provide all participants a memorable stay and a successful workshop.

Dr. Saeed Nairizi
President, ICID

Water and food security will continue to remain as the main global concerns for the years to come. The growing demand on food requires 60% increase in world food production by the year 2050 where this target would be achieved if such enhancement in developing countries doubles over the next 30 years. Irrigated agriculture is expected to play the major role in this ambitious goal and global endeavor. Higher yields and expansion of irrigated area supported by innovation in technology and irrigation revitalization appear to be the main potential options, particularly for developing countries, to meet their food security challenges.

However, irrigation development inhere adverse environmental consequences which should be managed appropriately. To minimize negative impacts of irrigation practices such as water logging and salinity and hence to maintain or improve the land productivity, drainage of agricultural land is essential and considered as a part of integrated land and water resources management approaches.

ICID through its Working Group on Sustainable Drainage and assisted by the Iranian National Committee on Irrigation and Drainage (IRNCID) and hosted by Khuzestan Water and Power Authority (KWPA) is organizing the 13th International Drainage Workshop, IDW 13, in Ahwaz, Iran 4-7 March 2017. Under the theme of "Drainage and Environmental Sustainability" the Workshop will focus on (i) Measures to lower volume of drainage water; (ii) Measures to improve drainage water quality; (iii) Adoption of new design criteria in favour of the environment; and (iv) Application of alternative drainage methods.

I am delighted to see the enthusiasm of the host to expect a large number of participants consisting of decision makers and officials, academician, scientists, and drainage system managers from different countries who are interested in sharing their experiences and being engaged in various technical deliberations.

The workshop program also consists of several side events and technical tours which definitely attract the participants with a variety of tastes. For instance two round tables on "Alternative Drainage Methods" and "Water Reuse" along with the second management board of ICID-International Research Program on Irrigation and Drainage (ICID-IRPID) - Iran Regional Node (IRPID- RN- I) and several side lectures in different universities such as "Role of Drainage in a Historical Perspective and Challenges for the Future" and many more are amongst the programs of this international event.

A fabulous exhibition is also being organized during these days with the attendance of around 25 companies demonstrating their products, activities and achievements in the field on Drainage.

I am quite confident that we will all benefit from the innovative methods and products presented in the exhibition.

I look forward to meeting you all in person during this important event.

International Drainage Workshop

The International Commission on Irrigation and Drainage has held technical and professional conventions on various topics related to irrigation and drainage during its active years.
The professional workshops includes, the International Drainage Workshop held in 1978, and ever since, it has taken place in one of the member countries. The upcoming convention is the 13th International Drainage Workshop, which will be held in Ahwaz, Iran, during the 4-7 March 2017.

Previous Workshops

12th IDW	St. Petersburg, Russia	June 2014 23-26
11th IDW	Cairo, Egypt	September 2012 23-27
10th IDW	Helsinki, Finland/ Tallinn, Estonia	July 2008 6-11
9th IDW	Utrecht, The Netherlands	September 2003 10-13
8th IDW	New Delhi, India	January - 4 February 2000 31
7th IDW	Penang, Malaysia	November 1997 21 – 17
6th IDW	Ljubljana, Slovenia	April 1996 23 – 21
5th IDW	Lahore, Pakistan	February 1992 15 – 8
4th IDW	Cairo, Egypt	February 1990 24 – 23
3rd IDW	Columbus, Ohio, USA	December 1987
2nd IDW	Washington, USA	December 1982 12 – 5
1st IDW	Wageningen, Netherlands	May 1978 17 – 16

Keynotes

VALUE ENGINEERING FOR UNBIASED DESIGN IN IRRIGATION AND DRAINAGE PROJECTS (CASE STUDY: RAMHORMOZ IRRIGATION AND DRAINAGE PROJECT IN IRAN)

Kamran Emami[1], Mojtaba Akram[2], Saeed Pourshahidi[3], Jafar Al-e-Tayeb[4]

Abstract

All designs are biased due to the expertise, experiences and orientations of the designers and clients. Value engineering is a proven technique for improving the value of projects, products and services. The value engineering methodology is based on the synergy and creativity of an independent team. The independence and outside perspective of the team would reduce and bias in the design and consequently would result in saving and enhanced benefits for the projects.

Value Engineering Change Proposals (VECP) are post-award value engineering proposals made by construction contractors during the course of construction under a value engineering clause in the contract. These proposals may improve the project's performance, value and/or quality, lower construction costs, or shorten the delivery time, while considering their impacts on the project's overall life-cycle cost and other applicable factors. The Ramhormoz project is medium size 5500 hectares on-farm project located in Khuzestan province in southwest of Iran. Value Engineering Change proposal submitted by the contractor in 2014 included 2 proposals on changing the orientation and geometry of drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project. This paper describes the procedure of the value engineering study and compares the benefits of the proposals to the base case specifications.

Introduction

Large and medium scale irrigation systems worldwide account for about 60 percent of the irrigated areas but are the ones that present the most severe gap between expected and actual performance. Efforts to improve the performance of these systems have been mixed because of a number of misconceptions of the problems. In this context, Value

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Engineering (VE), has proved to be an effective and efficient methodology for recognizing and removing unnecessary costs in larges projects. The results of application of VE in 6297 highway projects in U.S. are shown in table 1. The total estimated cost of the projects studied is very close to 400 Billion USD. Consequently, the saving of $ 25.4 which is equal to 6.22% of the total cost, clearly indicates that all projects have unnecessary costs and can be improved.

Table1. Summary of Past VE Saving Federal-Aid Highway Projects (1997-2014) in U.S.A

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Sum
Number of VE Studies	369	431	385	388	378	377	344	324	300	242	316	388	427	402	378	352	281	215	6297
Cost of VE Studies Plus Administrative Cost (Million $)	5	7	7	8	8	9	8	7	10	8	12	12	17	14	13	12	9.8	8.7	175.5
Estimated Costs of Projects Studied (Million $)	10093	17227	18837	16240	18882	20607	20480	18672	31576	21527	24810	29596	29160	34248	32257	30273	23000	2090	399575
Value of Approved Recommendations (Million $)	540	769	846	1128	865	1043	1016	1115	3180	1650	1970	2530	1700	1980	1010	1145	1150	1730	25367
Return on Investment	1:106	1:117	1:113	1:145	1:119	1:116	1:120	1:145	1:325	1:240	1:157	1:205	1:100	1:146	1:80	1:96	1:118	1:200	1:146
% of Project Costs Saved	8.35	4.47	4.49	6.94	4.58	5.06	5.42	5.97	10.09	8.29	7.95	8.53	5.84	5.79	3.12	3.78	5	8.32	6.22

The Reasons for unnecessary Costs in projects can be summarized as follows:

- ❑ Shortage of time
- ❑ Misleading information
- ❑ Ambiguous goals, objectives, scope etc.
- ❑ Hasty decisions based on false assumption
- ❑ Lack of ideas
- ❑ Lack of funds
- ❑ Resistance to Change
- ❑ Unrealistic temporary circumstances
- ❑ Politics
- ❑ Bad habits and attitudes, beliefs
- ❑ Over design & Unrealistic safety factors
- ❑ Continues changing in the owner requirements
- ❑ Lack of communication coordination
- ❑ Using unsuitable standards & specification
- ❑ No LCC estimate …… and more….

Many of the reasons presented are the results of biased thinking and design. All designs are biased due to the expertise, experiences and orientations of the designers and clients. The value engineering methodology is based on the synergy and creativity of an independent team. The independence and outside perspective of the team would reduce the bias in the design and consequently would result in saving and enhanced benefits for the projects. The main strengths of VE are shown in figure 1:

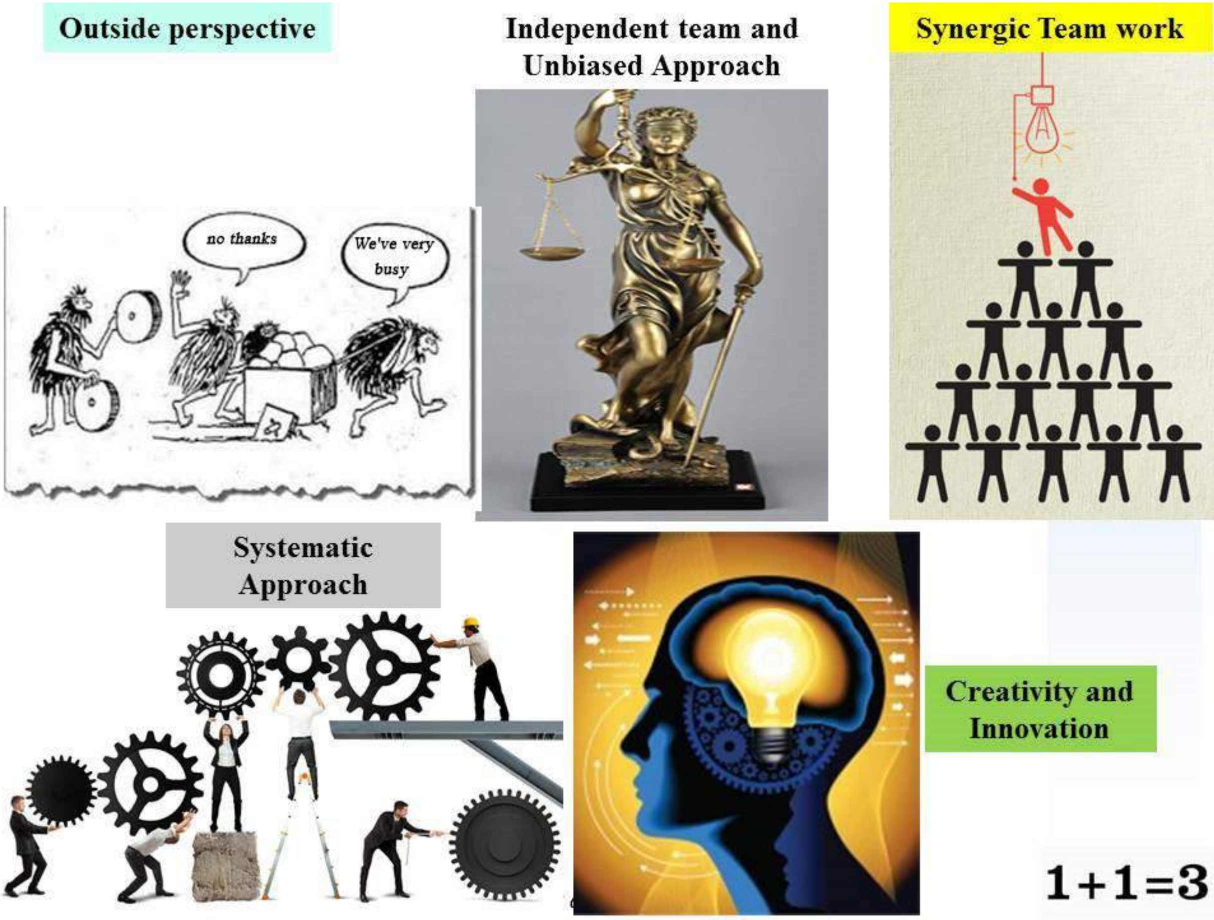

Figure 1. The main strengths of Value Engineering for removing unnecessary costs

In Bulletin 144 of ICOLD on “Cost Saving in dams”, the biased design and the role of VE to the address it have been discussed:

“There can be a tendency to copy previous designs or arrangements. From the perspective of the designer and owner, this can give the comfort of previous acceptable behavior. However, given the variety of such standardized arrangement it is highly unlikely that they are at present the most economical solution in each case. In some cases, designs may have been developed to fulfill a particular set of needs, some of which may not apply elsewhere. Similarly a new requirement may be needed in a particular case when it is not addressed to previous design. VE is a useful technique to address such issues.”

Consequently agencies adopted VE to:

- Save money and ensure cost-effectiveness,
- Improve quality,
- Eliminate unnecessary design elements, and
- Foster innovation and improve productivity

For example the U.S. Army Corps of Engineers have been using VE for more than 50 years and they have presented the main benefits of VE as follows:

- To shorten schedules significantly;
- To provide quality projects with reduced budgets;
- To ensure full project coordination with all stakeholders;
- To assist in preparing project scopes, negotiating environmental contracts, planning optimization, and project review;
- To provide planning assistance to states/communities;
- And to assist in program reviews.

Based on worldwide experiences, ICID has formed a Task Force on Application of Value Engineering for saving in Irrigation and Drainage Projects (TF-VE) to promote the application of Value Methodology (Value Engineering, Value Analysis, Value Planning, Value Management and Value Engineering Change Proposal (VECP)) in irrigation, drainage and flood management projects to increase benefits, reduce cost and ensure sustainable irrigated agriculture. A recent application of VE in Ramhormoz irrigation and drainage project in Iran is presented as a success story of VE in a drainage project.

Value Engineering study of irrigation and drainage project in Ramhormoz

The Ramhormoz project (third development block) is medium size 5500 hectares on-farm project located in Khuzestan province in southwest of Iran (Figure 2 and 3). The estimated cost of the project is approximately $10 m. To prepare Value Engineering Change proposal (VECP), a VE study was undertaken in 2014. Value Engineering Change proposal submitted by the contractor in 2014 included 2 proposals on changing the orientation and geometry of drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project.

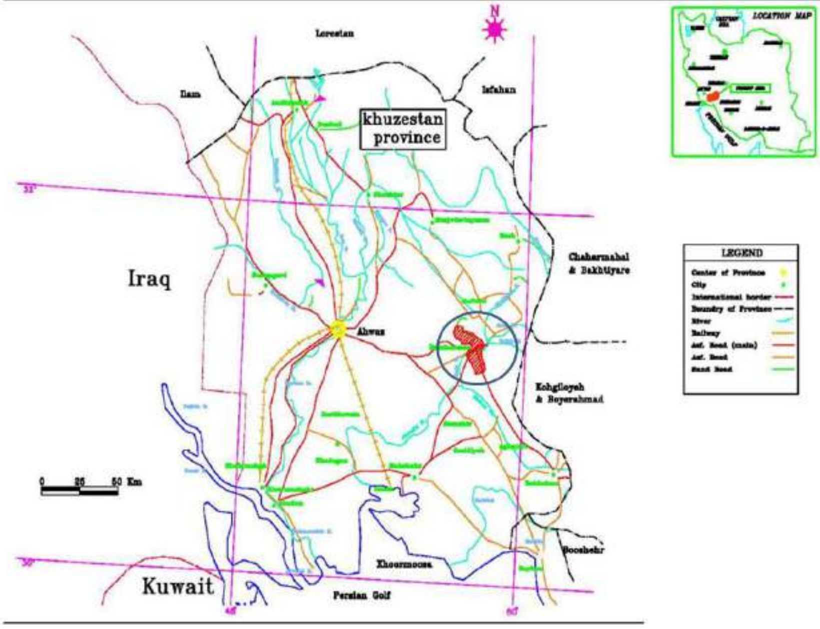

Figure 2. The location of Ramhormoz Project

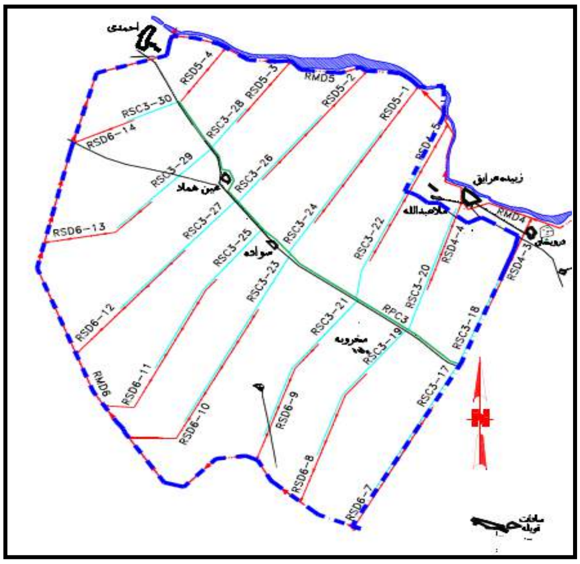

Figure 3. The general layout of Ramhormoz Project (third development block)

The members of the VE team were selected from Independent experts and engineers from the client, the consultant and the contractor. A few observers were also present in the workshops. The total professional experience of the team exceeded 400 years. The VE team is shown in Figure 4.

Figure 4. The VE Team of Ramhormoz Project ((Third development block)

The VE Job plan

The FHWA defines VE analysis as: A systematic process of review and analysis of a project, during the concept and design phases, by a multidiscipline team of persons not involved in the project. Simply stated, VE is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs in a project.

The "systematic application of recognized techniques," referred to in the above definition is embodied in the VE Job Plan. The Job Plan is a systematic and organized plan of action for conducting a VE analysis and assuring the implementation of the recommendations. The methodology utilized for any VE analysis shall follow widely recognized systematic problem-solving procedures that are used throughout private industry and governmental agencies.

The Job Plan contains seven phases. The first phase is completed prior to the commencement of the VE analysis, six of which are performed by the VE team and one that is conducted to "close out" the process. Each phase of the Job Plan includes several tasks. It is the melding of the various tasks and techniques, coupled with finesse in their application that makes the VE process work.

VE Job Plan consists of the following steps:

- Investigation (gathering of information)
- Function Analysis (analyzing functions, worth, cost, performance and quality)
- Creative (speculating using creative techniques to identify alternatives that can provide the required functions)
- Evaluation (evaluating the best and lowest life-cycle cost alternatives)

- Development (developing alternatives into fully supported recommendations)
- Presentation (presenting VE recommendations for review, approval, reporting and implementation)
- Close Out (Implementing and evaluating of the outcomes of the approved recommendations)

The 3-day workshop was conducted according to formal phases of the VE Job plan (above). After Information phase, the team prepared the FAST diagram shown in Fig 5. The diagram would improve creativity and help the team using Pareto principle (also known as the 80/20 rule or the law of the vital few) which help team to focus on the most important functions of the project.

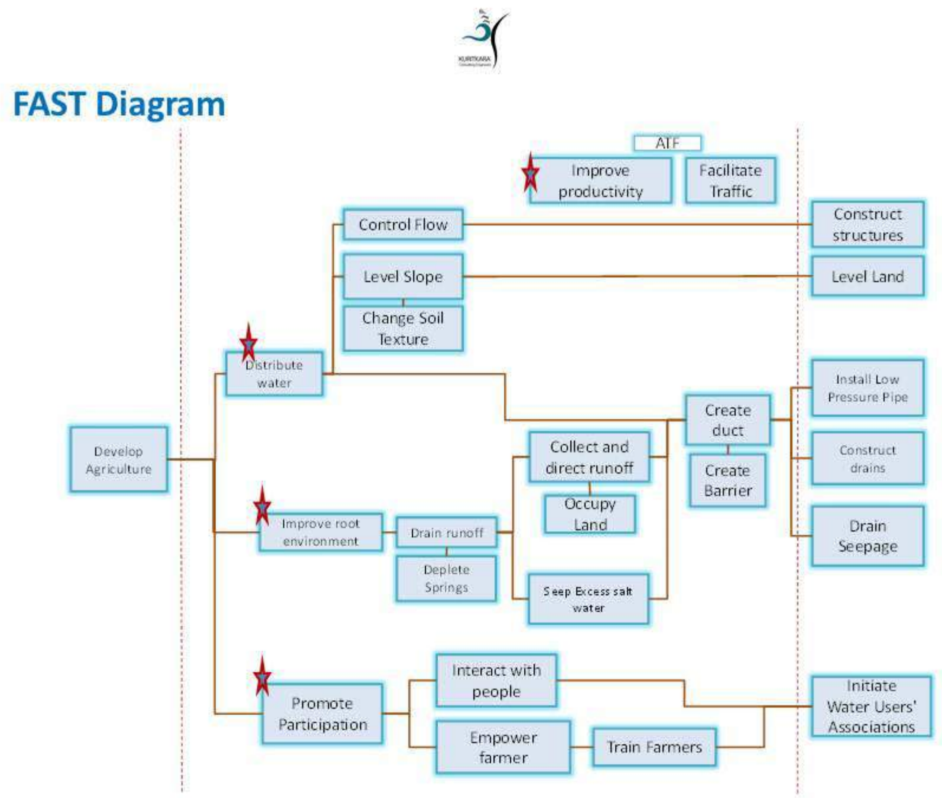

Figure 5. The Fast Diagram of Ramhormoz Project ((third development block)

Results and discussion

In Creative phase, the team generated ideas for improving the Value of the project. After screening the ideas, the selected ideas were developed and presented to the senior managers of the client. The approved proposals of the VE study are as follows:

1) Change in lateral alignment according to the natural slope

The base case is shown in figure 4.

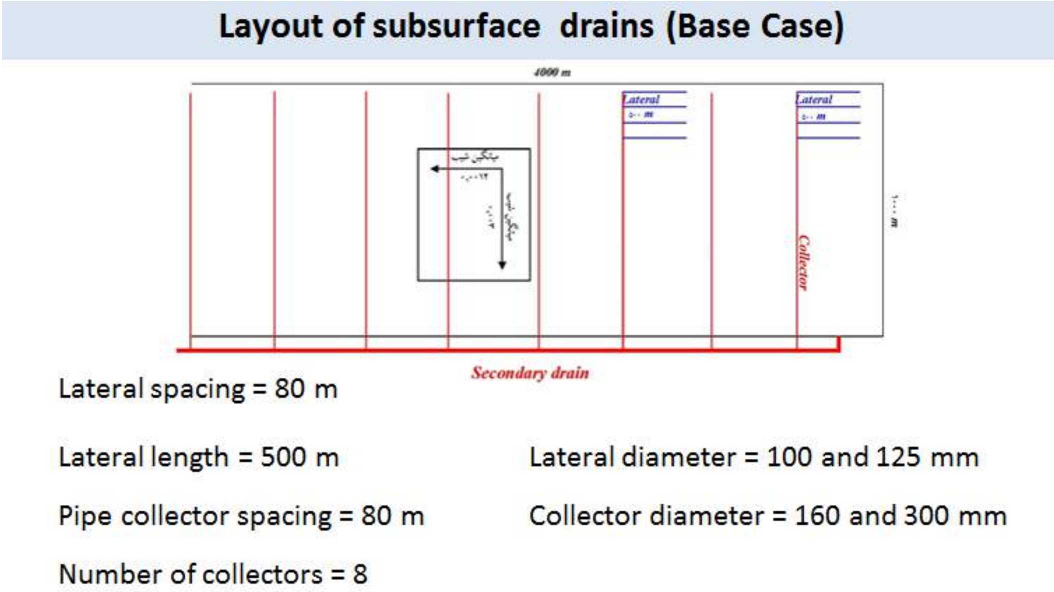

Figure 5. The base case for layout of subsurface drain

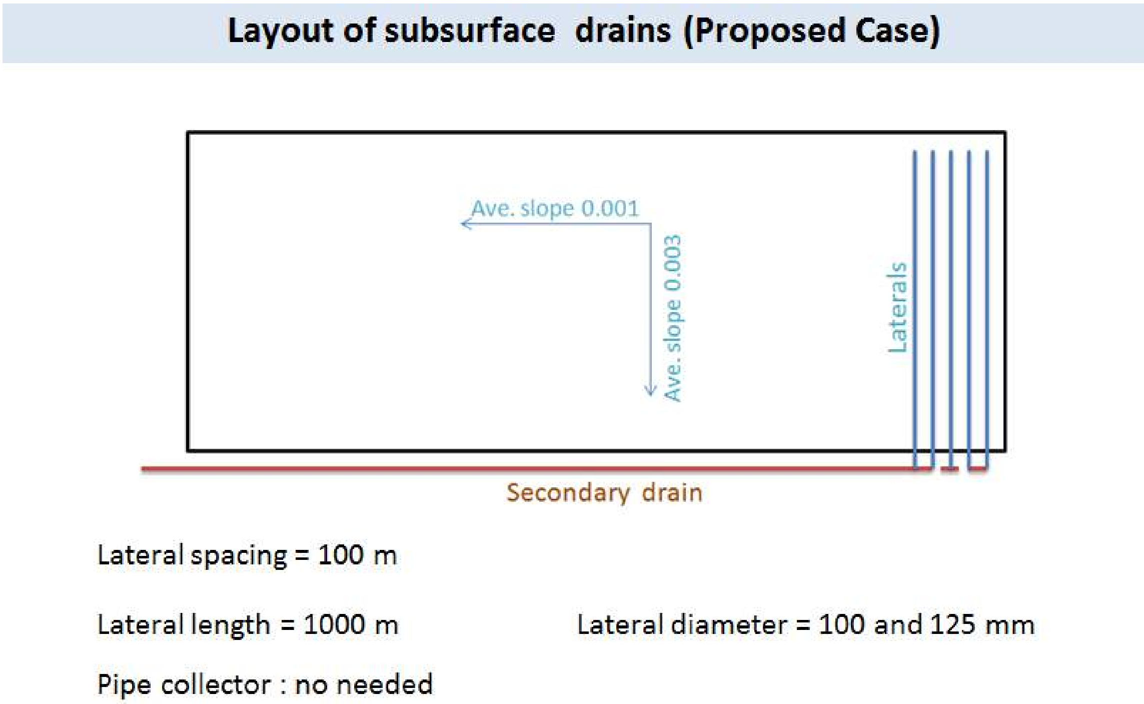

Figure 6. The VE proposal for Layout of subsurface drains

In original design, the laterals are connected to the collectors and the collectors to the secondary drain (Figure 5). In VE proposal, the laterals are directly connected to the secondary drain by the virtue of higher slopes. The seepage analysis has validated that the proposed design of the VE team was adequate for drainage purposes. Benefits of alteration of the direction of lateral drains were:

- Cost Saving equivalent to 0.9 million USD;
- No need for any type of collector drains;
- Constant depth of the laterals;
- Lower sedimentation risk in the drains because of higher water velocity; and
- Easier maintenance.

2) Change distance between the laterals and their depth

By changing the general layout of the laterals, the slope of the laterals would increase and consequently the distance between laterals can be increased. On the other hand, the depth of the laterals can be reduced by 20% considering the ground conditions and recommendations of drainage experts. Apart from cost saving equivalent to 2.3 million USD, these modifications would result in:

- Better adaptation to the natural slope;
- Constant drain depth along the lateral;
- Less sedimentation because of steeper slope;
- No need for any type of collectors;
- Less land loss in comparison to the base case.

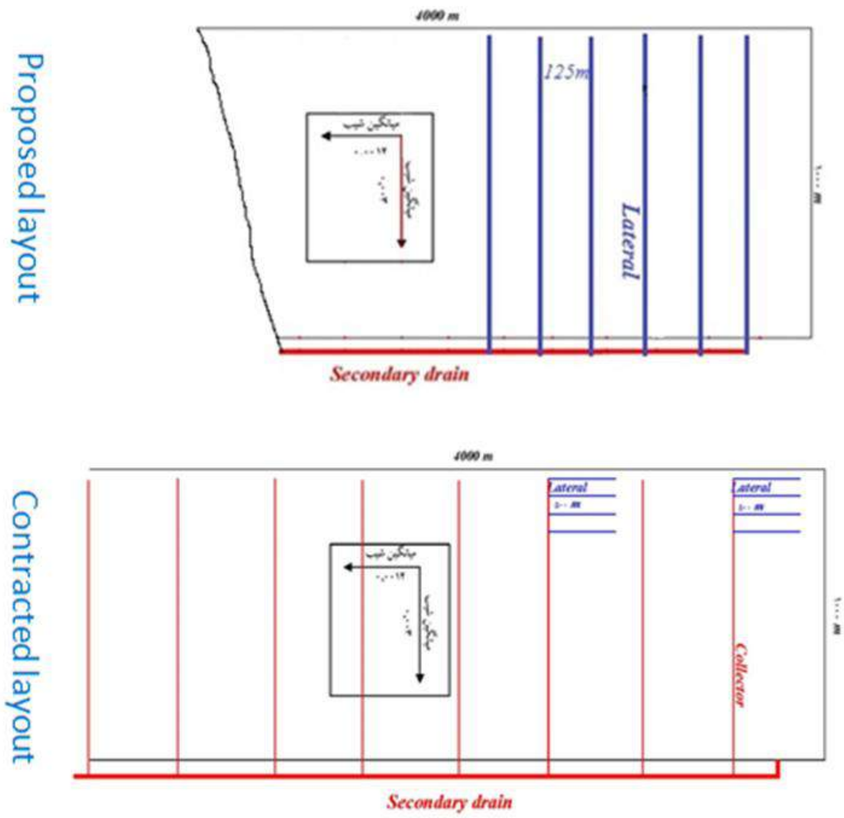

Figure 7

Conclusions

VE is a proven technique for improving the value of any projects especially larger ones. While "Food security" is one of the greatest challenges of 21st century, VE can have many benefits in large water projects:

- To shorten schedules significantly;
- To provide quality projects with reduced budgets;
- To ensure full project coordination with all stakeholders;
- To assist in preparing project scopes, negotiating environmental contracts, planning optimization, and project review;
- To provide planning assistance to states/communities;
- And to assist in project reviews.

The VE team of Ramhormoz project developed 2 proposals on changing the orientation and geometry of the drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project.

Acknowledgement

The authors wish to thank all the members of Ramhormoz VE team whose expertise, engineering ethics and synergy have improved the Value of Ramhormoz project drastically.

References

Brown James. 1992. Value Engineering, a blue print. Industrial Press, Inc.

Bytheway, Charles W. 2007. FAST Creativity & Innovation", Ross Publishing, Inc.

Dell'Isola, Alphonse.J. 1988. Value Engineering In the Construction Industry. Smith, Hinchman & Grylls, USA.

Emami, K. 2011. Value Engineering: An effective and efficient tool for irrigation and drainage projects. ICID 21st Congress. Tehran, Iran.

Federal Facilities Council Technical Report. 2001. Sustainable Federal Facilities. National Academy Press Washington, D.C., No 142

FWHA, 2014. Summary of Past VE Saving Federal-Aid Highway Projects (1997-2014) in U.S.A

ICOLD. 2013. Cost Saving in Dams. Bulletin 144. ICOLD.

Kurit Kara Engineers. 2014. The final report of Value Engineering study of Ramhormoz project.

Park, R. 1999. Value Engineering, a Plan for Invention. CRC Press.

U.S. Army Corps of Engineers. 2009. Value Engineering. U.S. Army Corps of Engineers.

USBR. 2008. Recalmation Value Engineering Handbook. 2008. USBR.

Wilson, David C. 2005. NCHRP Synthesis 352, Value Engineering Applications in Transportation", A Synthesis of Highway Practice, NCE Limited.

TRANSPORT OF VIRUSES AND COLLOIDS IN PARTIALLY-SATURATED SOIL AND GROUNDWATER

Seyed Majid Hassanizadeh[1,*], Gholamreza Sadeghi[2], Zhang Qiulan[3], Jack Schijven[4]

Abstract

Surface water is often used for the recharge of aquifers used in drinking-water production. Surface water is often contaminated with pathogenic micro-organisms and viruses. These pathogens have to be removed to produce safe drinking water. One effective way is the passage of surface water through soil, as is the case in bank filtration, dune recharge, and deep-well injection. Dune recharge is widely applied in The Netherlands, where surface water, after some pretreatment, is fed into canals in protected dune sands. Then, water is abstracted after 50 to 60m of passage through the soil. To assure production of safe drinking water from surface water, adequate travel times and travel distances are needed. In this regard, it is important to determine various factors that affect the rate of removal of pathogenic viruses during soil passage. These factors include hydraulic conditions (such as flow velocity and saturation) and geochemical conditions (pH, ionic strength, concentration of calcium, etc.).

In some parts of the world, use of grey water (e.g. kitchen/shower wastewater or treated wastewater) for agricultural purpose is practiced or is being considered. In such cases, it is essential to determine whether the infiltrating water will be droid pathogenic micro-organisms when it reaches groundwater.

In this lecture, we present results of a large number of laboratory and field experiments for the study of movement of bacteriophages (these are harmless viruses that are used as surrogates for pathogenic viruses) through soil and colloids through a micro-model (an artificial porous medium). Experiments are carried out under a variety of conditions: a range of pH values, a range of ionic strength values, different Ca concentrations, and

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[4] Professor of Quantitative Water Safety, National Institute of Public Health and Environment, The Netherlands

different water saturations; all under steady-state flow conditions. This data are used to derive (empirical) relationships between removal rate coefficients and geochemical conditions as well as soil moisture content. In the case of unsaturated flow, the role of air-water interfaces in the removal of viruses has been also investigated.

We have also performed experiments under transient flow conditions both in sand columns and in micro-models, where water content has been changed significantly. Our experiments as well as other researchers' results have shown that both drainage and imbibition fronts cause a remobilization of adsorbed viruses. We discuss the mechanisms behind this remobilization and provide evidence from pore-scale visualization experiments. Such a remobilization was also observed when the calcium concentration was changed significantly.

DRAINAGE MANAGEMENT FOR CROP PRODUCTION AND WATER QUALITY BENEFITS

Ali Madani[1]

Abstract

Nearly all agricultural soils require drainage. Artificial or improved drainage is essential to produce crops on most agricultural soils. Subsurface (tile) drainage systems are designed and installed to remove excess water from the soil profile to improve traffic ability and to facilitate timely seedbed preparation, planting, and harvesting. In dry regions, where irrigation is practiced, drainage systems may be required to maintain a suitable salinity level in the soil profile.

While some of the most productive agricultural soils are artificially drained, artificial drainage is blamed as a major contributor to water pollution. Results of numerous studies throughout the world have shown concentrations of agri-chemicals, pathogens, and other detrimental pollutants in subsurface water as well as groundwater.

Research has shown that management strategies can be used to reduce pollutant loads from agricultural drained lands. These strategies range from agricultural drainage water management to cultural and structural measures. A number of approaches have been identified as cultural and structural practices. These practices include routing of drainage water through constructed wetlands, precision agriculture, and nutrient management. This presentation will focus on these strategies as well as the use of simulation modeling on a watershed scale.

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IMPROVING IRRIGATION AND DRAINAGE EFFICIENCY USING EDDY COVARIANCE, SCINTILLOMETERY AND COSMOS TECHNOLOGIES

Ragab Ragab[1]

Abstract

In the context of increased pressure on water resources for food production, where globally some regions are already in water crisis, it is necessary to maximize yield for a given water resource. For irrigated crops, this means not only more efficient application of water, but also an improved understanding of crop water requirement.

Modern technologies to measure actual evapotranspiration (ETa) such as Large Aperture Scintillometer (LAS) and Eddy Covariance (EC) instruments can offer alternatives to the widely used potential evaporation equations such as those of FAO. Potential Evapotranspiration, ETp based on equations represent the atmospheric demand for water rather than the actual crop demand for water. Actual evaporation Eta represents the crop water requirement and is expected to be lower than the potential evapotranspiration, ETp.

The very recent field experiment results showed significant differences between actual evaporation values measured by the Eddy Covariance and Scintillometer when compared with the worldwide used potential reference evaporation, ETo, calculated from meteorological data using Penman-Monteith equation and the crop potential evaporation, ETc, which is based on the ETo and the crop coefficient, Kc. The ETc and ETo showed higher values than those of ETa obtained by Eddy and Scintillometer. On average the actual evaporation measured by Eddy Covariance and Scintillometers represented nearly 50% of the ETo. These are quite significant differences.

These results indicated that there is a potential for water saving in irrigation, should the crop water requirement be based on actual measured evapotranspiration rather than on the calculation based on the widely used Penman–Monteith equation and possibly other

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methods of calculating potential evaporation, not the actual evaporation. This proves that for realistic crop water requirement estimation, one should consider methods based on crop demand rather than the atmospheric demand for water.

The exact percentage of water saving by using these modern technologies, will differ between seasons and crops but will always be actual irrigation water requirement. Another benefit is that these modern technologies of measuring the actual evaporation do not need the crop coefficient Kc, which for many irrigation practitioners is difficult to obtain.

The field results showed that soil moisture obtained by COSMOS was comparable with those obtained for the top 50-60 cm soil layer soil moisture measured by sensors, soil cores and profile probes and simulated by the SALTMED model. This indicates that there is a possibility that COSMOS probe's effective depth could be within the top 50-60 cm of the irrigated lands particularly during the summer crop seasons. In such case, knowing that almost 80% of the crop root system is accommodated within the top 50-60 cm, the COSMOS measurement could be useful for monitoring the soil water status and subsequently soil moisture deficit in the root zone. The Cosmos results could be made operational for irrigation managers to determine when and how much to irrigate to avoid harmful water stress. The COSMOS technology is one step in the right direction as it provides continuous, integrated, area based values and solves the problem of spatial variability often found in point measurements in relation to the soil spatial heterogeneity. This method could also be used to determine the soil moisture deficit, hence determine when and how much to irrigate.

The above modern technologies, Eddy Covariance, Scintillometer and COSMOS proved their suitability for use in agricultural water management. They can improve water use efficiency, save water, reduce drainage volume, and reduce water logging and salinity.

AGRICULTURAL WATER MANAGEMENT AND FOOD SECURITY IN A SUSTAINABLE ENVIRONMENT

Bart Schultz[1]

Abstract

The Worlds' population is expected to grow from 7.4 billion at present to 10.0 billion by 2055. Combined with the expected rise of living standards, improvement in life expectancy, urbanisation and growing demands for animal feed and energy from crops this requires, among others, a substantial increase in cereal production to ensure food security. Overall, global cereal production meets the current demand and the global cereal stock is stable. Achieving the required increase in cereal production in a sustainable way seems to be possible.

In the framework of rural reconstruction irrigation and drainage will have to play a major role in achieving the required increase in cereal production, while most of the increase will have to be realised at already cultivated land and land reclamation can only result in a relatively small contribution. This implies a focus on approaches and solutions that on the one hand will result in the required increase and on the other hand are environmentally sustainable. In light of this upgrading, modernisation and expansion options for irrigation and drainage schemes will be presented with special attention to the role of drainage. This will be done with due attention for the Sustainable Development Goals (SDG) and the draft Action Plan 2030 of the International Commission on Irrigation and Drainage (ICID).

Introduction

The Worlds' population is expected to grow from 7.4 billion at present to 10.0 billion by 2055. Combined with the expected rise of living standards, improvement in life expectancy, urbanisation and growing demands for animal feed and energy from crops

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this requires, among others, a substantial increase in cereal production to ensure food security. In the framework of rural reconstruction irrigation and drainage will have to play a major role in achieving the required increase in cereal production. This implies a focus on approaches and solutions that on the one hand will result in the required increase in cereal production and on the other hand are environmentally sustainable. In light of this upgrading, modernisation and expansion options for irrigation and drainage schemes will be presented with special attention to the role of drainage in the arid and semi-arid zone. This will be done with due attention for the Sustainable Development Goals (SDG) and the draft *ICID Action Plan 2030* of the International Commission on Irrigation and Drainage (ICID).

Population, population growth and urbanisation

The World population is expected to grow from 7.4 billion at present to 10.0 billion by 2055, with thereafter a limited further growth till 11.2 billion by the end of the Century (Figure 1). The growth is especially expected in urban areas of countries with a low, medium and high Human Development Index (HDI) in Asia as well as in sub-Saharan Africa (Figure 2).[1] In addition the standard of living in countries with a medium and high HDI - almost 75% of the World population - is rapidly rising, among others resulting in changes in diets that require more and diversified food per person and in general more water to be produced. A third development is the significant improvement in life expectancy from 46 years in the 1950s to 71.4 years by 2015 (World Health Organisation (WHO), 2014 and 2017).

[1] Low Human Development Index. Most of the countries in Africa, five countries in Asia, one country in Central America and one in Oceania;
Medium and High Human Development Index. Most of the Eastern European countries (including Russia), most of the countries in Central and South America and in Asia (including China, India, Indonesia and Bangladesh) and several countries in Africa;
Very High Human Development Index. Most of the countries in Western and Central Europe, North America, several countries in Central and South America and in Asia, and the larger countries in Oceania.

World food situation and prospectives

Up to present cereal production has been in line with the increase in utilisation and the global cereal stock even increased in the past years (Figures 3 and 4).

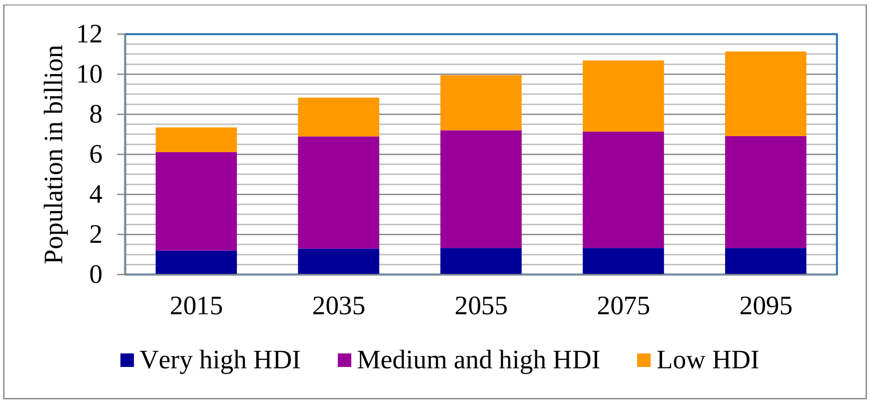
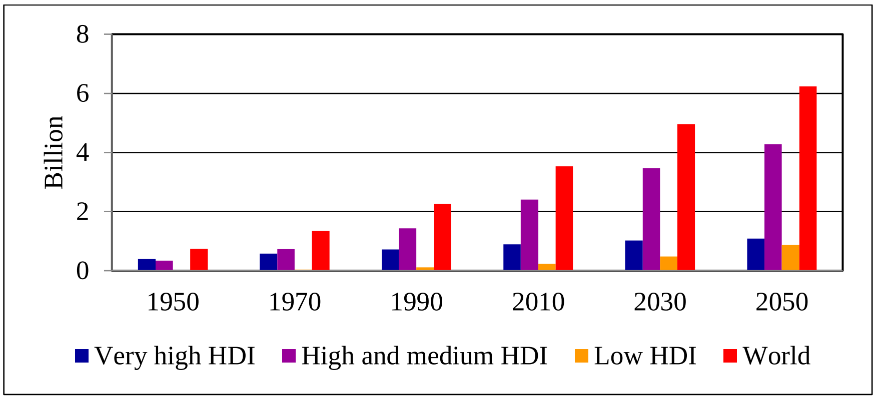
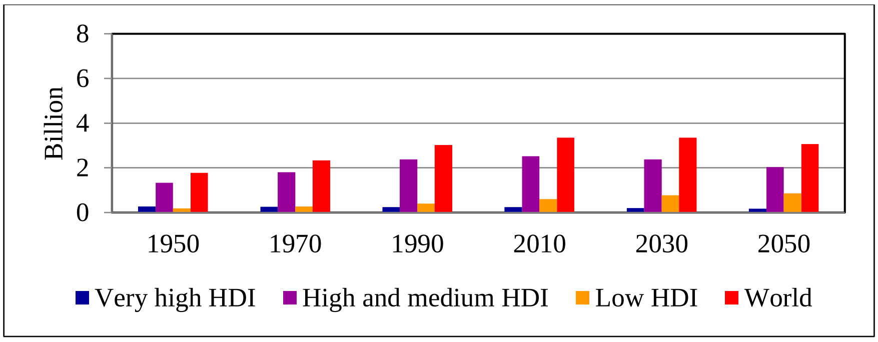


Figure 1. Population and population growth (updated after Schultz, 2012; based on data of the United Nations Department of Economic and Social Affairs, Population Division, 2015)



(a)



(b)

Figure 2. Development from 1950 - 2050 of urban (a) and rural (b) population in the three different groups of countries and at the global scale (updated after Schultz, 2012; UN Population Division, 2014)

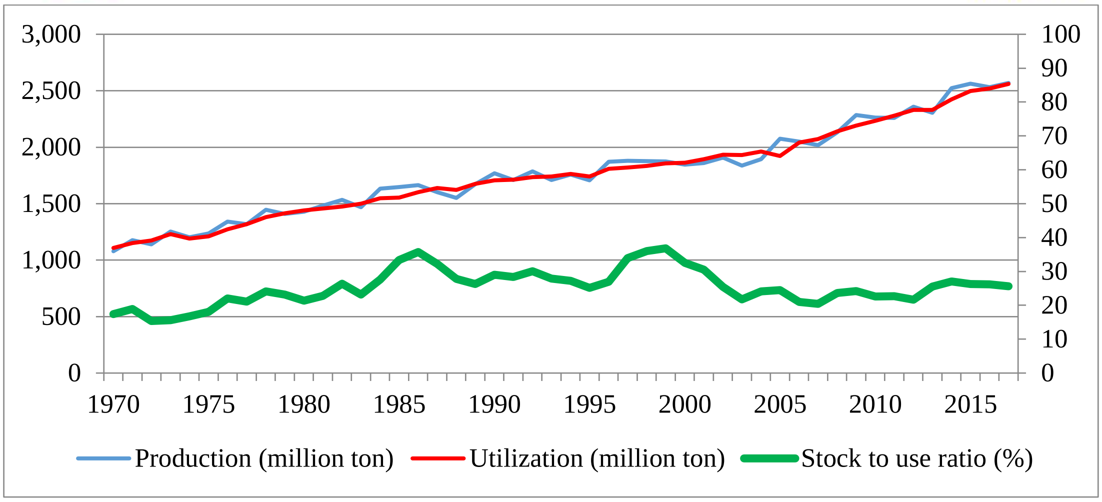


Figure 3. Development in World cereal supply and demand (Data Food and Agriculture Organisation of the United Nations (FAO), 2010 - 2016)

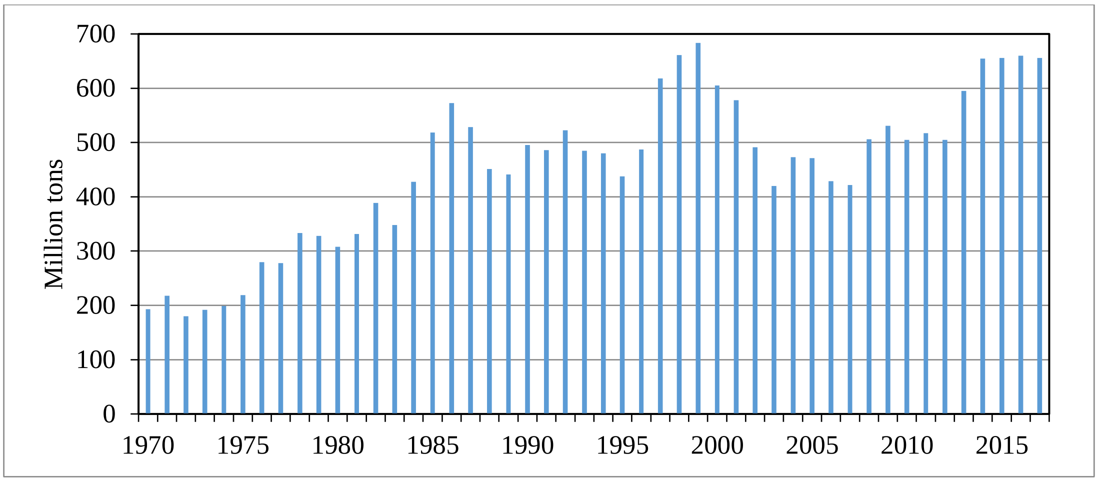


Figure 4. Development of the Global cereal stock since 1970, including forecast for 2017 (Data FAO, 2010 - 2016)

The long downward trend in cereal prices made a turnaround in the period 2000 - 2002 and prices rapidly increased in the period 2007 - 2008 (Figure 5). However, since 2008 prices did not show further increase and even went down for the most important cereals. With respect to farming the on-going urbanisation in countries with a medium and high HDI and to a certain extent in countries with a low HDI will have its impact. In countries with a very high HDI farming has gone through a significant up-scaling. For example in my country, the Netherlands, a farmer could have a living from 5 hectares at the beginning of the 20th century and from 50 hectares by the end. Similar processes can be observed in several countries with a medium and high HDI and to a certain extent already as well in some countries with a low HDI. In several other countries, especially in Africa, where despite rapid urbanisation the agricultural population is not decreasing and may even continue to increase, smallholder agriculture will retain an important place. However, the overall consequence will be that farmers will have to produce significantly more food for urban people in a competitive environment (Figure 6). This will require an increase in farm sizes, transfer to higher value crops and mechanisation. Especially in the countries with a low HDI it also implies that infrastructures have to be strengthened in order to secure the transport of food to the necessary places. Such trends will have to play an important role in measures with respect to food security at affordable prices.

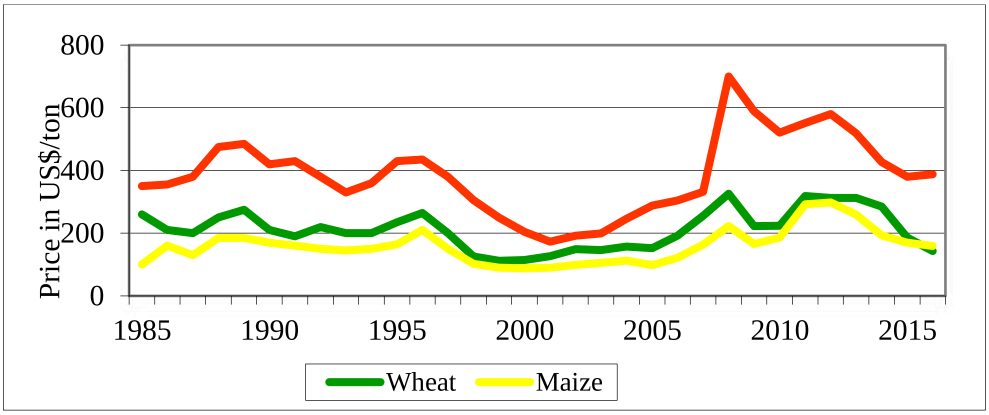


Figure 5. World market prices for wheat, maize and rice. Prices not corrected for inflation (data International Monetary Fund (IMF))

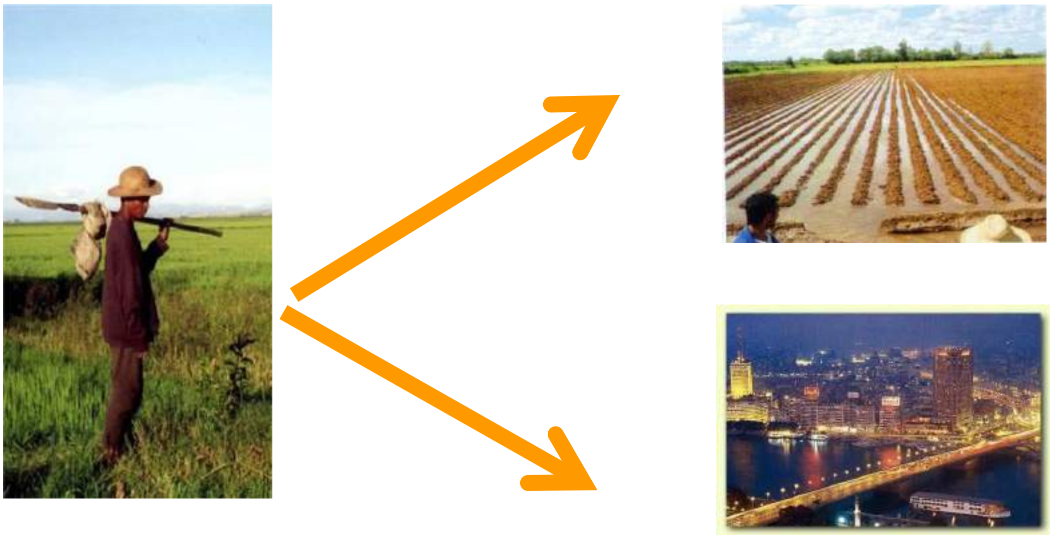


Figure 6. Increase in farm size to produce food for urban people at affordable prices (source: H. Tardieu)

There are different ways to achieve the required increase in cereal production. It can be increase in yield at the existing cultivated area, expansion of arable land, or increase in cropping intensity. There is a common understanding that 80 - 90% of the increase in production will have to be realised at the existing cultivated land and only 10 - 20% by expansion of agricultural land (FAO and ICID, 2014). This can, for example, for several regions be clarified by a study of FAO (2011) as shown in Figure 7.

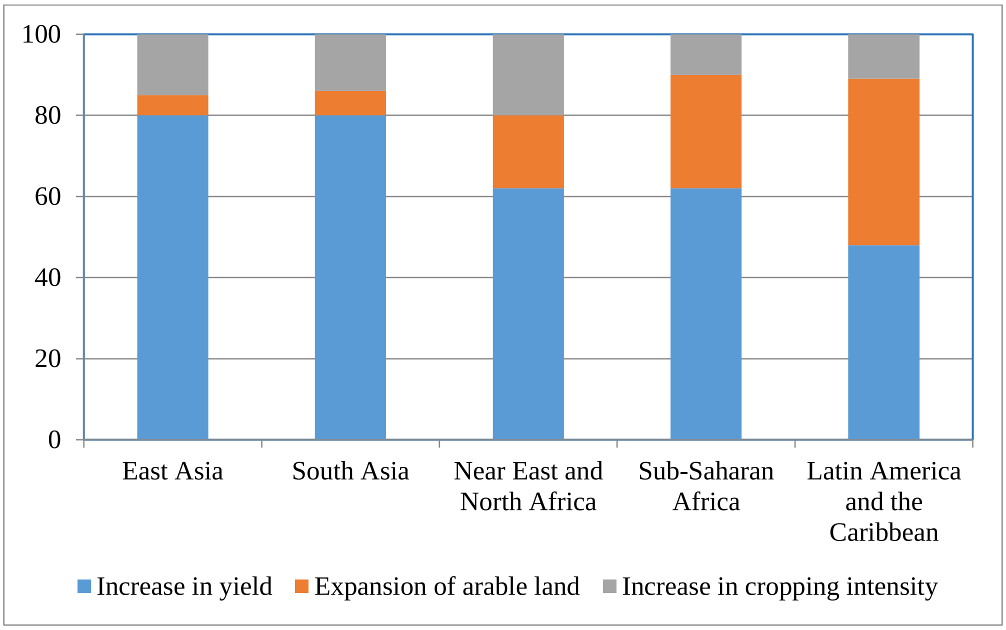


Figure 7. Anticipated sources of growth in crop production 1997 - 2030 (based on FAO, 2011)

Agricultural water management

In the last fifty years, agricultural water management has helped to meet the rapidly rising demand for food (Figures 3 and 4), and has contributed to the growth of farm profitability and poverty reduction as well as to regional development and environmental protection. The Green Revolution has enabled many countries with a medium and high HDI to transform from agrarian to industrializing economies. The technology of high inputs of nitrogen fertilizer, applied to responsive short-strawed, short-season varieties of rice and wheat, often required irrigation to realize its potential (FAO and ICID, 2014). In principle developments can be based on the various options of water management as shown in Figure 8.

When growing food crops, the timing and reliability of water supply and drainage is crucial. In the arid and semi-arid zone, as well as in the humid tropical zone irrigation allows cultivation of crops when rainfall is erratic or insufficient. In the temperate humid and the humid tropical zones drainage is generally required to prevent waterlogging during the winter or monsoon seasons. In the arid and semi-arid zone drainage may be required to prevent waterlogging and salinisation, especially in irrigated areas (Schultz, 1997). For the three groups of countries Table I shows the areas with and without a water management system. Table II shows these data for the different Continents. The data in the two Tables have been determined as good as possible, but have to be considered as rough estimates, while in quite some cases data are not available.

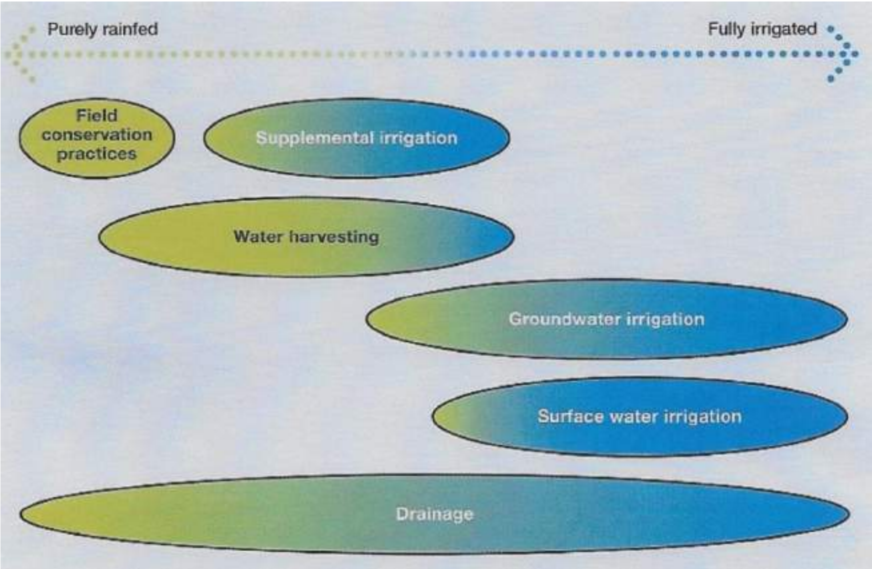


Figure 8. Diverse options for agricultural water management (International Water Management Institute (IWMI - CGIAR), 2007)

The irrigated area of the World increased significantly during the early and middle parts of the 20th century. Production and average yields of irrigated crops in these countries have responded to this demand by increasing two- to fourfold. Irrigated agriculture now provides approximately 45% of the Worlds' food, including most of its horticultural output, from an estimated 20% of the agricultural land. Irrigated agriculture accounts for about 70% (2,850 km^3 per year) of the freshwater withdrawals in the World, and up to 85% in countries with a low, medium and high HDI. In addition rainfed agriculture uses 6,400 km^3 per year. In the 20th century global water use has been growing at more than twice the rate of population increase (FAO and ICID, 2014).

Table I. Cultivated area with and without a water management system in the three groups of countries in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Countries with a very high HDI	436	33	23	56	99	10	109	271
Countries with a medium or high HDI	828	182	78	260	51	24	75	493
Countries with a low HDI	260	28	6	34	2	16	18	208
Total	1532	242	107	349	153	49	202	972

Table II. Cultivated area with and without a water management system in the different Continents in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Asia	530	184	79	262	68	31	69	199
Africa	239	12	3	14	1	4	5	220
Europe	303	18	3	21	54	3	57	225
Americas	400	27	22	48	57	11	68	284
Oceania	49	3	0	3	1	1	2	44
Total	1532	242	107	349	96	49	202	972

The challenge is how to meet the ever-rising demand for food in the context of the above mentioned processes and expected developments, while at the same time increasing farmer incomes, reducing poverty and protecting the environment (FAO and ICID, 2014). While the major part of the increase in food production will have to be achieved at the existing cultivated area the focus will have to be on a higher yield per hectare, and where possible on double or triple cropping. A significant part of the increase can already be achieved by improved operation and maintenance of existing schemes. As far as the contribution of improvement options of water management schemes is concerned the increase can be achieved by (Schultz *et al*., 2005 and 2009):

- modernization of existing irrigation and drainage systems;
- installation of drainage in irrigated areas;
- installation of irrigation in rainfed areas with drainage;
- installation of irrigation and/or drainage systems in areas without a system.

In light of this it is expected that the amount of water withdrawn by irrigated agriculture will have to be increased by 11% by 2050 (FAO, 2010; FAO and ICID, 2014). This will be a considerable challenge in water-constrained areas. An increasing number of regions are already reaching the limit at which reliable water services can be delivered (Figure 9). The situation will be exacerbated as demands of fast growing urban areas place increased pressure on the quality and quantity of local water and land resources.

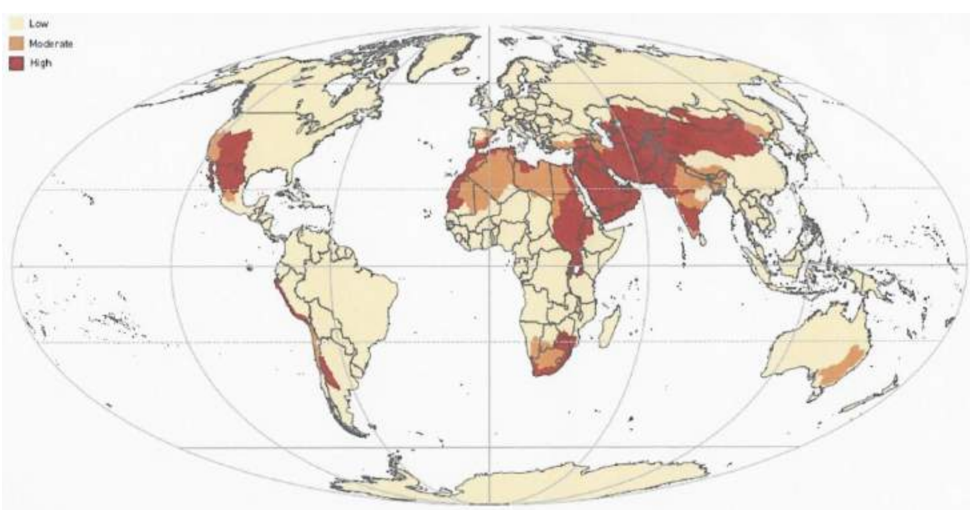


Figure 9. Global distribution of water scarcity by major river systems (FAO, 2011).

Another important point is who are really the actors in agricultural water management. This is shown in Figure 10. A distinction has been made in those who are responsible and those who are contributing. Key issue in this simple scheme is that when the three parties that are responsible have an agreement on their roles and responsibilities, the water management schemes will generally be operated and maintained in a proper way. If they cannot reach such an agreement there will generally be under performance of the water management scheme, resulting in lower yields.

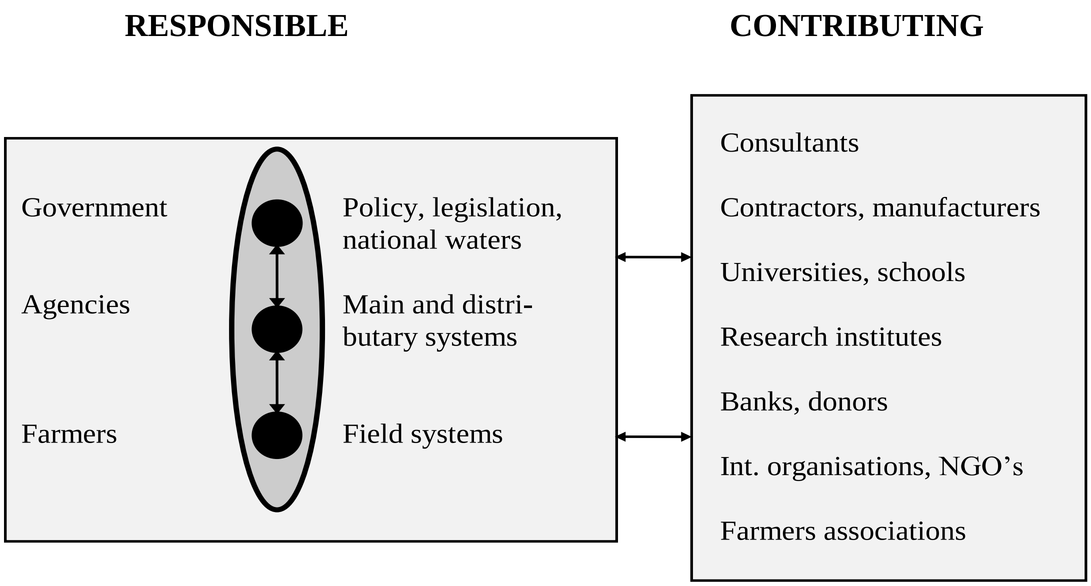


Figure 10. Actors in agricultural water management (Schultz, 2001)

With respect to modernisation of schemes in countries with a low, medium and high HDI it is important to point out that the Governments developed most schemes. These Governments can or will generally not continue to take full responsibility for operation and maintenance. Due to this transfer of responsibilities and/or of ownership of schemes to farmers, or companies is an on-going process. The sustainability of schemes through shared cost-recovery, for which the sustainability cost may be expected from the farmers, is essential (Tardieu, 2005). In parallel to such processes there will be an important role for innovation by better implementation of available research results in practice and by linking research projects and programmes to improved applications in practice. In addition to surface water also groundwater provides a resource and helps maintain the pace of, mostly private, irrigation expansion (Tables I and II). However, in many river basins groundwater is being mined and environmental stress is growing. In such cases measures will be required to assure sustainable exploitation of groundwater resources. An important issue in the arid and semi-arid zone is how to lessen the pressure on agricultural water by bringing in low quality water and reuse of wastewater in agriculture.

Role of drainage

The objective of drainage in agriculture is such that excess water, and may be salts will be removed from the fields in such a way that a good growth of the crops can be assured. With respect to the objectives of drainage different situations can be applicable:

- *prevention of waterlogging outside the main growing season*. Its effect on crops will be indirect. It is referred to as 'off-season drainage';
- *prevention of waterlogging during the main growing season.* This will have a direct effect on crop growth. It is referred to as 'crop-season drainage';
- *prevention of salinization of the soil by irrigation or by capillary rise of groundwater*. It is referred to as 'salt drainage'.

The drain depth and spacing determine the capacity of the system. The best capacity can be formulated in economic terms as that capacity where the net benefits of drainage are maximal. This economic criterion for design purposes is to be translated into hydrological criteria: the design discharge which is the quantity of water the system should be able to discharge during peak periods and the depth at which the groundwater table is to be controlled in those periods. The design discharge is commonly expressed as the required discharge rate in mm/day or l/s/ha. The criteria are different for: off season, crop season and salt drainage.

In many cases drainage systems are installed in lowland areas. This implies that the discharge of drainage water by outlet structures, or pumping stations and flood protection provisions may be of importance as well. In such cases the possible impacts of changes in land use, land subsidence and climate change will have to be taken into account (Schultz, 2000, 2008 and 2016).

As outlined above a significant part of the increase in cereal production has to be achieved at existing cultivated land. As described above this generally implies modernisation of existing irrigation and/or drainage systems, or installation of new systems. It may also apply to increased application of fertilisers and/or pesticides. Here is a very critical point with respect to environmental sustainability, while dependent on the application and the conditions a certain part of the fertilisers and/or pesticides cannot be absorbed by the plants, but will be discharged with the drainage water. In that case pollution of the receiving water body may become a problem. Therefore such applications have to be controlled in a strict way. A good example for this may be the development of environmental legislation in the European Union, among others by the European Water Framework Directive (European Commission, 2000). By this legislation the application by the farmers is being controlled in such a way that the discharge through the drains is at an acceptable level. In order to determine the criteria at several places research has been done. Figure 11 shows field research on the discharge of chemicals in relation to the application through drains under apple trees. Based on results of such researches quality criteria for surface waters have been developed that are applicable to all the member countries. These criteria are binding and have to be fulfilled when developing new projects.

Figure 11. Field research on the discharge of chemicals through subsurface drains under apple trees in relation to the application

Role of drainage in the arid and semi-arid zone

In quite some countries with a low, medium and high HDI drainage has been neglected in irrigated areas. This is especially the case in the arid and semi-arid zone, where the drains only may have a role in the control of waterlogging and salinity development. When in such regions irrigation systems are installed, sooner or later a certain amount of leaching will become required in order to prevent the development of waterlogging and salinity in the root zone. Generally in such cases subsurface drainage at a relatively deep level becomes required. There has been quite some discussion on the preferred depth of such drains. Smedema has made an analysis on the optimal depth that can well be used as a reference (Smedema, 2007). He found that in quite some cases the drains were located at a greater depth than required.

All in all agricultural water management has played and will play a central role in reducing the risk of food insecurity in countries with a Low, Medium and High HDI. To a large extent solutions to facilitate expansion of efficient irrigation and drainage through improved infrastructure and increased water productivity are known and available. Crucial question is what is best applicable under the local conditions (Figure 8).

Sustainable development goals and the draft icid action plan

In January 2016, the sustainable development goals (SDG) as adopted by the United Nations in September 2015 came into force. Six of the seventeen SDGs are of special importance for agricultural water management. These are:

- *Goal 1*. End poverty in all its forms everywhere;
- *Goal 2*. End hunger, achieve food security and improved nutrition and promote sustainable agriculture;
- *Goal 6*. Ensure access to water and sanitation for all;
- *Goal 12*. Ensure sustainable consumption and production patterns;
- *Goal 13*. Take urgent action to combat climate change and its impacts;
- *Goal 15*. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss;
- *Goal 17*. Revitalize the global partnership for sustainable development.

In this context, ICID is developing its *ICID Action Plan 2030.* The intention of the plan is to show the results of reviews and to propose planning principles, design criteria, operating rules, contingency plans and management policies for new water management systems.

Challenges

In the discussions on the draft *ICID Action Plan 2030* Prof. Daniele de Wrachien has formulated the following key challenges on agricultural water management (Editorial Board, 2016).

Despite the enormous advances in our ability to understand, interpret and ultimately manage the natural world we have reached the 21st century in awesome ignorance of what is likely to unfold in terms of both the natural changes and the human activities that affect the environment and the responses of the Earth to those stimuli. One certain fact is that the planet will be subjected to pressures hitherto unprecedented in its recent evolutionary history. The "tomorrow's world" will not simply be an inflated version of the "today's world", with more people, more energy consumption, more industry, rather it will be qualitatively different from today in at least three important respects:

- *first*, new technology will transform the relationship between man and the natural world. An example is the gradual transition from agriculture that is heavily dependent on chemicals to one that is essentially biologically intensive through the application of bio-technologies. Consequently, the release of bio-engineered organisms is likely to pose new kinds of risks if the development and use of such organisms are not carefully controlled.
- *second*, society will be moving beyond the era of localized environmental problems. What were once local incidents of natural resource impairment shared throughout a common watershed or basin, now involve many neighboring countries. What were once acute, short-lived episodes of reversible damage now affect many generations. What were once straightforward questions of conservation versus development now reflect more complex linkages;
- *third*, climate variations. It is nowadays widely accepted that the increasing concentration of the so-called greenhouse gases in the atmosphere is altering the Earth's radiation balance and causing the temperature to rise. This process in turn provides the context for a chain of events which leads to changes in the different components of the hydrological cycle, such as evapotranspiration rate, intensity and frequency of precipitation, river flows, soil moisture and groundwater recharge. Mankind is expected to respond to these effects by taking adaptive measures including changing patterns of land use, adopting new strategies for soil

and water management and looking for non-conventional water resources (e.g. saline/brackish waters, desalinated water, treated wastewater, hydroponics and aeroponics).

While the draft *ICID Action Plan 2030* is still under preparation input and comments have been requested from the ICID National Committees and Work Bodies. All this information is expected to be included in the revised Action Plan that will be presented, discussed and hopefully approved during the forthcoming ICID Congress in October this year in Mexico City. For the draft Action Plan six operational goals have been identified. These are:

- *Goal 1*. Enable higher crop productivity with less water and energy;
- *Goal 2*. Be a catalyst for change in policies and practices;
- *Goal 3*. Facilitate exchange of information, knowledge and technology;
- *Goal 4*. Enable cross disciplinary and inter-sectoral engagement;
- *Goal 5*. Encourage research and support development of tools to extend innovation into field practices;
- *Goal 6*. Facilitate capacity development.

These operational goals have been detailed in strategies, targets and indicators that will be further refined in the coming months.

Conclusion

Global food production is sufficient to feed the Worlds' population; shortages are of a regional and local nature. Although they may be caused by drought or other climatologic phenomena they can be prevented when sufficient action is being taken. First responsibility rests with the National and/or Regional Governments and the farmers or agricultural producers.

Over the past years an impressive increase in food production has been achieved. However, population growth and increase in standard of living, especially in countries with a medium and high HDI, require that food production will have to be doubled over the next 25 – 30 years. It is therefore required that governments have a clear policy on the level of food self sufficiency and on the measures that would be required to achieve this. In addition it will be of importance that they enable that the remaining food can be imported and sold at affordable prices. Based on the common understanding that 80 - 90% of to increase in food production will have to come from existing cultivated land and that the remaining has to come from land reclamation this will require a significant improvement in water management measures and their operation, maintenance and management. In principle this can be achieved.

The Sustainable Development Goals and the goals, strategies and activities as formulated in the draft *ICID Action Plan 2030* create a good frame in which the actual activities in the field of irrigation, drainage and flood control can be developed. However, we have to realise that the problems and activities will become more pronounced in the years to come, as society enters an era of increasingly complex paths towards the global economy. It will require wisdom, spirit, innovation and intense cooperation of all involved to achieve in the coming decades that agricultural water management will be further developed, operated and maintained to assure food security in a sustainable environment.

Acknowledgements

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References

Editorial Board (EB-JOUR), 2016. *Draft minutes of the meeting of 10 November 2016*. Chaing Mai, Thailand.

European Commission, 2000. EU Water Framework Directive, Directive 2000/60/EC, Brussels, Belgium

Food and Agriculture Organisation of the United Nations (FAO). 2010. *Climate change, water and food security*. Water reports, http://www.fao.org/docrep/014/i2096e/i2096e.pdf.

Food and Agriculture Organisation of the United Nations (FAO). 2010-2016. *Food outlook. Biannual reports on Global food markets*. Rome, Italy.

Food and Agriculture Organisation of the United Nations (FAO). 2011. *The state of the world's land and water resources for food and agriculture. Managing systems at risk*. FAO and Earthscan. Rome, Italy.

Food and Agriculture Organisation of the United Nations (FAO). 2014. *Food and Nutrition in numbers*. Rome, Italy.

Food and Agriculture Organisation of the United Nations (FAO). 2016. *The state of food insecurity in the World 2015. Strengthening the enabling environment to improve food security and nutrition.* Rome, Italy.

Food and Agriculture Organisation of the United Nations (FAO) and International Commission on Irrigation and Drainage (ICID), 2014. *Food Security by Optimal Use of Water. Synthesis of Theme 2.2 of the 6th World Water Forum.* Marseille, France, March 2012. Rome, Italy / New Delhi, India.

International Commission on Irrigation and Drainage (ICID). 2017. *World drained areas.* http://www.icid.org/world%20drained%20area.pdf.

International Monetary Fund (IMF). Statistical data. www.imf.org.

International Water Management Institute (IWMI - CGIAR). 2007. *Comprehensive assessment of water management in agriculture*. Earthscan. London, UK; Colombo, Sri Lanka, 645 p., http://www.iwmi.cgiar.org.

Irstea, 2015. Data on drainage. In: *World drained areas.*
http://www.icid.org/world%20drained%20area.pdf.

Schultz, B. 1997. *Drainage in the 21st century. Policy issues and strategies for emerging problems*. In: Proceedings of the 7th International Drainage Workshop. Volume 1. Penang, Malaysia, 17 - 21 November, 1997.

Schultz, B. 2000. *Integration of drainage, flood control and water management in deltaic and tidal zones*. Proceedings of the 8th International Drainage Workshop. New Delhi, India, 2000.

Schultz, B. 2001. *Irrigation, drainage and flood protection in a rapidly changing world*. Irrigation and Drainage, vol. 50, no. 4.

Schultz, B. *Extreme weather conditions, drainage, flood management and land use.* In: Proceedings of the 10th International Drainage Workshop, Helsinki, Finland and Tallinn, Estonia, 6 – 11 July 2008, Helsinki University of Technology, Helsinki, Finland.

Schultz B. 2012. *Land and water development. Finding a balance between planning, implementation, management and sustainability.* Valedictory address delivered on the occasion of the retirement from the Chair of Land and Water Development at UNESCO-IHE Institute for Water Education. Delft, the Netherlands, May 8, 2012.

Schultz, Bart. Impacts of man-induced changes in land use and climate change on living in coastal and deltaic areas. *Irrigation and Drainage.* DOI: 10.1002/ird.1969.

Schultz B., H. Tardieu and A. Vidal. 2009. Role of water management for global food production and poverty alleviation. *Irrigation and Drainage.* Volume 58 Issue S1, S3-S21. Supplement: Special Issue on Water for Food and Poverty Alleviation.

Schultz, B., C.D. Thatte and V.K. Labhsetwar, 2005. Irrigation and drainage. Main contributors to global food production. *Irrigation and Drainage.* Volume 54 Issue 3.

Smedema, L.K., 2007. Revisiting currently applied pipe drain depths for waterlogging and salinity control of irrigated land in the (semi) arid zone. Irrigation and Drainage. Volume 56, Issue 4.

Tardieu H. 2005. Irrigation and drainage services: some principles and issues towards sustainability. An ICID Position Paper. Irrigation and Drainage. Volume 54 Issue 3, 251–262.

United Nations, Department of Economic and Social Affairs, Population Division. 2014. *World Urbanisation Prospects*. The 2014 revision. New York, USA.

United Nations, Department of Economic and Social Affairs, Population Division. 2015. *World Population Prospects, medium prognosis. The 2015 revision.* New York, USA.

World Health Organisation (WHO), 2014. *WHO methods for life expectancy and healthy life expectancy*. Department of Health Statistics and Information Systems WHO, Geneva, Switzerland.

World Health Organisation (WHO), 2017. *Life expectancy.* 2014http://www.who.int/gho/ mortality_burden_disease/life_tables/situation_trends_text/en/

BEYOND MODERN LAND DRAINAGE

Willem F. Vlotman[1]

Abstract

Modern Land Drainage implies making drainage environmentally sustainable which includes enhanced water balance assessments at regional and field scale (incl. a detailed look at water movement on the root-zone), prevent excess water except for leaching salts, support ecological water requirements, and then if any access water remains design a drainage system. The less water is mobilised thorough our agricultural lands, the better the quality of water will remain. No matter how efficiently our crops are watered, sooner or later we need to have a well-functioning drainage system for complete in-field water management. Under natural conditions, i.e. in areas with rainfall surplus and no irrigation system, drainage is considered when causing waterlogging that restricts crop growth. Salinisation of the land, i.e. the accumulation of salts in the upper layers of the soil occurs naturally in coastal areas but can be a secondary effect of waterlogging. In all cases the absence of a sustained seasonal net downward water movement through the root-zone is generally the reason for salinisation. Beyond modern land drainage includes various approaches to assessment, prevention of waterlogging an salinity problems, considers the water-food-energy nexus approach and gives due attention to ecological considerations for more sustainable results. Theories of drainage design have been well developed and with powerful computing now available at the desktop at affordable prices, many solutions to a drainage issue can be considered that include controlling the amount of water drained, reuse and how best to control drainage water quality. Ready access to satellite imagery, new and enhanced existing computer models to simulate land inundation and the recent advance in the use of drones with cameras (quad copters and the like) provide an opportunity to enhance integrated water resource imbedded drainage design. Regardless of these technological advances nothing beats going out when it rains to assess what is really happening in the field. A holistic approach to drainage is describes that includes steps to successful stakeholder involvement from beginning to end, from farm to fork and from minister to manager.

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Introduction

Modern Land Drainage (MLD) is an extended approach to the traditional drainage design methods for rain fed agriculture in the humid temperate zone. It includes and extensive consideration of salinity control of irrigated land in (semi-) arid zones, drainage of rice land in the humid tropics and advocates controlled drainage in the framework of integrated water resources management (IWRM). Institutional, management and maintenance are included as well as the mitigation of adverse impacts of drainage interventions on the environment. Beyond Modern Land Drainage considers the Triple Bottom Line (TBL), the triangle that considers interactions between social, environmental (or ecological) and financial aspects and extents it to consideration of drainage within the Water-Food-Energy Nexus (Vlotman 2014).

At the ninth International Drainage Workshop (IDW9, 2003) in Utrecht, the Netherlands, drainage was placed firmly in the realm of Integrated Water Resources Management (IWRM). At IDW10 held in Finland and Latvia in 2008 it was mentioned that drainage is an important driver for sustainable outcomes and the three main areas of indicators for the need for drainage in the framework of sustainable IWRM were given as (Vlotman 2008):

1. an aging water supply system and infrastructure that supports economic development,
2. the perceived changes in regional climates (i.e. the Climate Change bandwagon), whether caused by anthropogenic influence or whether part of a natural cycle, and
3. the increased attention for sustainable physical environments.

At the 11th ICID International Drainage Workshop on Agricultural Drainage Needs and Future Priorities in Cairo, Egypt from September 23 to 27, 2012, the discussions centred around how to make agricultural production possible and more profitable. Agricultural drainage is part of integrated land and water resources management where environmental aspects play an important role; the impact of agricultural drainage on crop productivity and environmental aspects and advances to address these issue were elaborated (IDW11 2012).

The theme of the12th International Drainage Workshop (IDW), 23-26 June 2014, St. Petersburg, Russia was: Drainage on Waterlogged Agricultural Areas. Sub-topics were: (a) New equipment and modern technology drainage construction in wetlands; (b) Efficiency of the use of reclaimed land and socio-economic aspects of the use of reclaimed land; (c) Drainage design and methods of calculating; (d) Advanced training of specialists: constructors and engineers in the field of drainage systems management and operation; (e) An integrated approach to the management of drainage and environmental protection; (f) Using reclaimed land for agricultural purposes; and (g) History of the drainage system development. The proceedings do not contain a summary of the discussions of each section.

At IDW13, a new paradigm for sustainable, integrated, water resources management is presented that has been emerging from international conferences around the world. Its most succinct description is 'the water-food-energy nexus (WFEN) for a green economy'. The water, food and energy nexus aims at the most efficient, best practice principles applied throughout the full food supply chain. This includes consideration of reducing wastage of the food for various reasons in the supply chain. Food wastage equates on average to 243 litres of water a day/person in the food they throw away, which is 1.5 times the daily water use per person (Vlotman and Ballard, 2014). The concepts of virtual water and water footprint can help in identifying opportunities to save water by targeting reduction of wastage of food that has the highest virtual water content. Energy efficiency occurs when we consume where we grow, so do not transport food unnecessarily. Green economy aims at achieving the optimised supply chain objectives in a manner that espouses the sustainability principle, gives due attention to environmental concerns and helps with eradication of poverty and hunger.

Artificial and natural drainage systems are an essential part of the water management system; in fact many systems would not be sustainable without it. For instance, managing salinity and waterlogging requires artificial or natural drainage to be in place. However, it is probably needed only a few times per year if irrigation is applied efficiently resulting in minimum leaching requirements.

Over the years it has become clear from worldwide experiences that economics and technical expertise are not the only key drivers of drainage development and that care for the natural physical and social/cultural environment will enhance the likelihood of sustainable water management and sustainable drainage systems.

The drivers of sustainable environments are, amongst others, the Key Performance Indicators (KPIs) of Triple Bottom Line (TBL) frameworks that inform us how well we are doing. These KPIs are either oriented towards internal business performance or towards external impacts of water management organisations, incl. business by government departments. It is important to keep the internal and external KPIs separate such that mission, strategies and operational objectives of the organisation that is responsible for the drainage system are clear in the mind of all stakeholders. Drainage environmental KPIs are related to salinity, waterlogging and water quality while many others relate to the IWRM more generally.

The drainage system design process

The steps in traditional land drainage design are identification of the problem, reconnaissance or a pre-feasibility stage, then the actual feasibility stage followed by the detailed design stage (Smedema et al. 2004). Operation and Maintenance processes come into play after the construction and commissioning of the drainage system. Beyond modern land drainage design includes considerable stakeholder involvement right from inception to eventual ownership of the systems, and also includes remote sensing technologies in the early stages and post construction with due regard to economics and environmental/ecological considerations.

Beyond Modern Land Drainage starts with a process of stakeholder involvement. The process was elaborated in a background paper at the ICID meetings in Chiang Mia, Thailand and the following are suggested (after Ardakanian et al. 2016):

- Carry-out an assessment of existing institutional arrangements with all potential stakeholders of the area under consideration for water management interventions
- Ask stakeholders what needs to be established in order to become more involved (gap analysis)
- Identify the challenges & demands of the stakeholders
- Identify the need for continuity of participation and support capacity building keeping in mind the operation, management and maintenance needs of the future
- Identify the need for political commitment, innovation and advocacy for involvement.

Vlotman and Ballard (2014, 2016) included two more aspects:

- Energy efficiency. This includes considerations such as switching from high pressure sprinkler systems to low sprinkler pressures systems, gravity drainage instead of pumped drainage, consume food where it is produced, avoid growing food at location A, transport it to B for wholesale and then back again to A for retail; this will safe oil (truck and rail transport), gas (heating and cooling) and electricity (electric train transport, cooling needs), re-introduce seasonality in the availability of foods, and
- Reduce food wastage, i.e. reduce the loss of imbedded or virtual water. Do not buy more food than needed, recycle food via Foodshare (Foodbank, 2013), Fareshare (2013) and retail at farmer markets (Vlotman and Ballard 2014). This will use food more effectively and efficiently without wasting it and at the same time save virtual water which then allows it to be an actual water savings higher up in the food and water supply chains.

These latter two aspects were cast in the water-food energy nexus to assist the balancing of these elements in the triple bottom line framework with irrigation and drainage systems, Vlotman and Ballard (2014).

To achieve active stakeholder involvement a planned process will need to be executed (MDBA 2015):

- Assessment of state of institutional development at all levels;
- Needs assessment;
- Plan development reflecting:
    - Who you will engage with;
    - Why you will engage them;
    - Why they will want to engage with you;
    - How you will engage them;
    - When you will engage them, and how you will monitor and evaluate your engagement approach?

The key for involvement of stakeholders in irrigation and drainage system operation, management and maintenance (OMM) is the central question: what is in it for me? Incentives do not necessarily need to be economic in nature. They can be improvement in lifestyle, improvements in physical environment and in general improvement in social well-being. Hence, in order to involve stakeholders in water management, incl. irrigation, drainage and environmental watering, it is essential to find out first in what type of TBL environment they operate and what their needs are. It is not just involvement in water management but consideration of all aspects of being successful (i.e. all TBL elements and all water-food-energy nexus considerations, WFEN).

All stakeholders from farmer to system operator to top level regional and national government staff need to have a clear understanding of the potential benefits of being involved and they need assurance that those benefits are sustainable. Stakeholder engagement is a planned process with the specific purpose of working across organisations, stakeholders and communities to shape the decisions and actions of the members of the community, the stakeholders and the organisations involved. Typical questions to be asked in planning for the involvement of water managers at all levels, including foremost farmers, are:

- What issues do you face in being successful in your (water operation, management and maintenance) enterprise/organisation?
- Do you consider all TBL aspects for the design and future operations?

- Are you willing to share water with the environment/ecology?
- What additional knowledge, skills and information do you need to make an informed decision?

These questions will generate discussions, anger, trepidation, excitement and raise a range of socio-economic issues that should not be ignored and are essential to consider for successful involvement of stakeholders in the design process of drainage system and the eventual successful OMM of the system.

Design

Although traditionally drainage design evolves around rainfall intensities, in particularly in the temperate climate zones, this is not always the case and it is changing rapidly. In irrigated areas the efficiency of the water delivery system determines the need for drainage (Table 1). In drier climate zones flooding is caused by runoff from upstream areas congregating in the lower reaches of the catchment. The fact that the "problem" is caused upstream suggests a closer look at what is happening upstream. Should we re-forest certain areas, should we change land use (Baoa et al. 2017), should we built water and salt interception schemes? Fortunately recent advances in aerial photography with drones and advances in the use of satellite remote sensing applications will allow us to determine the need for drainage in more holistic ways than before. This will be described in further detail in the section on remote and robot reconnaissance.

Table 1 Efficiency of various irrigation methods

Method	Efficiency (%)	Remarks
Flood irrigation	50 - 85	New water management control technologies
Sprinkler irrigation	65 - 90	From high pressure to low pressure application
Trickle irrigation	75 - 95	Reliability, durability and water management
Sub-surface irrigation	50 - 95	Shallow soil management
Controlled drainage	50 - 85	Maintain and manage high water table as appropriate
State of the art water management	85 - 100	Soil moisture management and delivery system management combined

Traditionally (or, almost traditionally), design of drainage systems is supported by using a variety of water resource models (MIKE21, SWATRE, HEC-RAS, DUFLOW to name a few) and dedicated drainage models such as the various versions of DRAINMOD (Box 1), to investigate a variety of drainage rates under different weather and design arrangements (i.e. depth and spacing of drains). Modern Land Drainage (Smedema et al. 2004) gives a listing of websites to access these models which was current in 2003 and is a good starting point to investigate the latest in computer aided design. The models can include salinity levels and levels of other potentially toxic elements such as nitrogen, Biological and Chemical Oxygen Demand (BOD & COD), a variety of micro-organism, pesticides, etc. Many dedicated computer models exist for these situations.

Obtaining good topographical maps is essential for detailed design. A viable alternative during the reconnaissance stage of projects under consideration is the use of Google Earth, which now includes generation of surface elevations along selected lines, which could be proposed surface and sub-surface drains rather than the streams shown in Figure 1. Spatial software applications based on satellite imagery, aerial photography or drone imagery can also provide the exact extent of flooding, waterlogging (indirectly through observing the status of the vegetation) and salinity.

Box 1 Overview of the state of DRAINMOD models.

DRAINMOD based field and watershed scale models

http://www.bae.ncsu.edu/soil_water/drainmod/models.html accessed 5/11/16.

For details of references see the website.

The original DRAINMOD hydrology model has been modified to include sub-models on the fate and transport of nitrogen in the soil and salinity. The field hydrology and water quality models were also coupled with drainage network routing sub-models for watershed scale applications. Below are the models developed at the Biological and Agricultural Engineering Department at NCSU.

FLD&STRM (Konyha, 1989) - DRAINMOD based watershed scale Agricultural water management model.

DRAINLOB (McCarthy, 1990)- DRAINMOD based field scale forest hydrologic model.

DRAINMOD-S (Kandil, 1992)- DRAINMOD based field scale model for predicting salinity on arid/semi-arid lands.

DRAINWAT (Amatya, 1993) - DRAINLOB/FLD&STRM based watershed scale forest hydrologic model.

The FAO Irrigation and Drainage Paper no 62 (van der Molen et al. 2007) on guidelines and computer programs for the planning and design of land drainage system is one of the latest readily available publications on land drainage design but considers minimal attention to stakeholders (farmers only) and environment is described in an eleven line paragraph. For the latest in environmental design and for examples of the use of the web to view live river data see the Murray-Darling Basin Authority website (http://www.mdba.gov.au) and navigate to the “publications” and “live river data” sections (http://livedata.mdba.gov.au/system-view). For selected locations in the system overview data such as water levels, river and channel flows, reservoir storage levels and reservoir releases, rainfall, water temperature, dissolved oxygen levels and salinity levels are given. This type of information will be very helpful during the reconnaissance and OMM stages in the life cycle of drainage systems and how they interact in the broader integrated water resource management system.

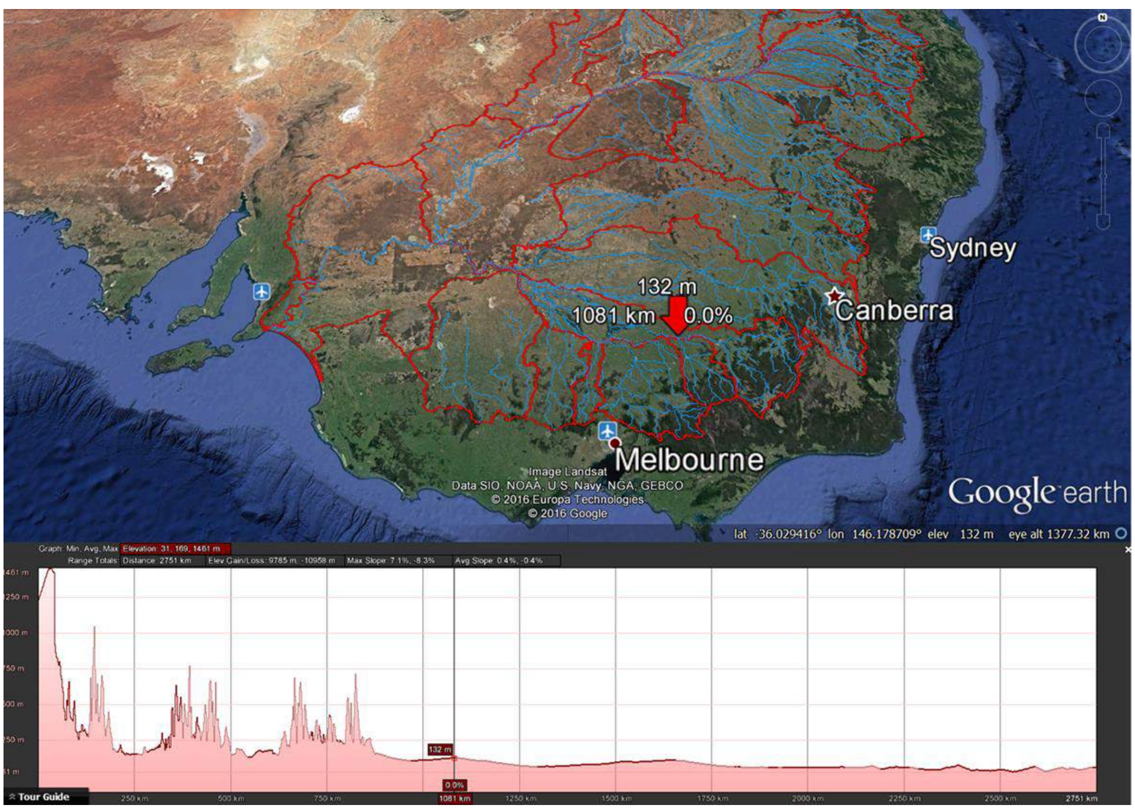

Figure 1 Screen dump of Google Earth map with basin regions boundaries (in red; i.e. catchment boundaries) and rivers in blue.

A right-hand click on top of a river line will produce an elevation profile as shown. Naturally the river will not go uphill as is shown in the profile here; this however is a scale and location of the line representing the stream on top of the Google Earth map which at this scale is highly inaccurate (accessed December 2016). The red arrow in the map will move along the river line when the vertical line in the elevation profile is moved. The elevation heights are in meter, but care should be taken to check the datum of the elevation used.

A rather interesting design process is proposed by Tuohy et al. 2016. The method is based on a new visual soil assessment method whereby an approximation of the permeability of specific soil horizons is made using seven indicators (water seepage, pan layers, texture, porosity, consistence, stone content and root development) to provide a basis for the design of a site-specific drainage system. The incentive was the ability to design a suitable system for each of the stakeholders at the lowest possible costs.

In the next section additional innovations are described that are considered beyond MLD in the reconnaissance, analysis, and design stages of drainage systems, including consideration of new materials and equipment available in today's environments and markets.

Remote and Robot Reconnaissance

Similar to involving stakeholders from the beginning to the end, a thorough technical analysis of the condition at, up and downstream of the intended drainage system is essential. The advances in remote sensing techniques and the availability of these services as well as the skills of our stakeholders allow a sophisticated process to be included in the reconnaissance stage of the design process. These processes may actually lead to the conclusion that drainage is not necessary if other, potential cheaper solutions high or lower in the water management system show promise that will negate the need for drainage, or, show means of controlling water quality at downstream locations.

The continued advances in remote sensing in the last couple of decades (Figure 2) have been significant and will continue to evolve at a rapid pace when more satellites are launched (Landsat, IKONOS, MODIS, SPOT, QuickBird, WorldView, RapidEye, etc.). Access to the raw outputs of Landsat imagery is easy via the web. More advanced outputs are commercially available and can include those from other platforms such as aerial photography and drones. Many government agencies and private companies are developing tools to help with accessing and assessing the data available via the web and internal computer network systems. This is a far cry from the good old days when draftsmen prepared drawings on tracing paper; then to be printed; the smells of ammonia filling your nose; something un-imaginable with today's attention to Occupation Health and Safety procedures (OHS).

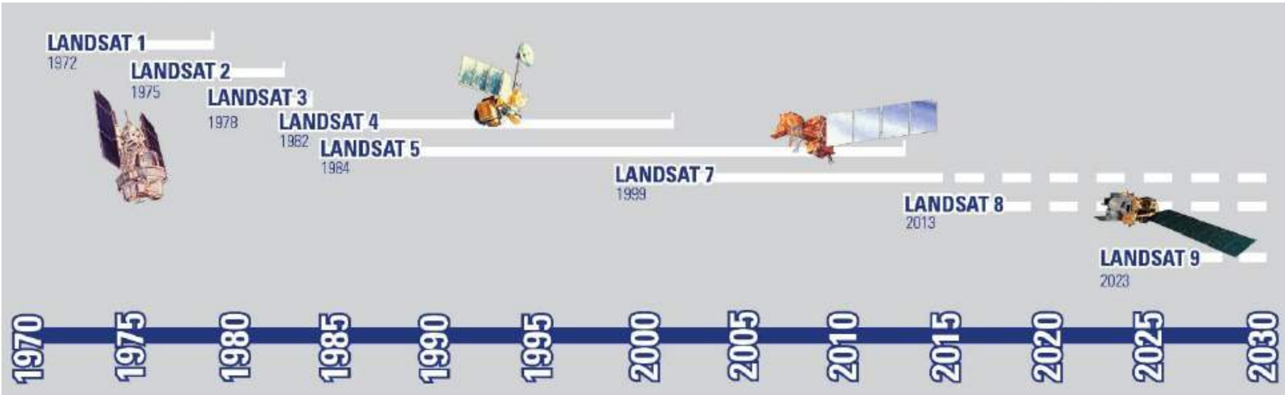

Figure 2 Overview of Landsat satellites past, present and future.

Agencies in the US and Australia now make water observation from space (WOfS) maps available (US Landsat web, http://landsat.usgs.gov, and WOfS web from Geoscience Australia, www.ga.gov.au). These maps are used to inform flood inundation modelling and mapping which allows us to assess the extent and duration of flooding at certain flow rates from low overbank flows (Figure 3) that occur on a regular basis (several times a year) to events that occur only 1 in 50 or 1 in 100 years. As Figure 2 shows the remote sensing information is readily available from 1972 and one will find that in these last 40 years there is a good likelihood that events that occur 1 in every 50 or more years are covered.

The emergence of drones with cameras at retail outlets, rather than the sophisticated multi-million dollar drones used by the military has opened a whole new avenue of reconnaissance. Combined with traditional aerial surveys, albeit with far more sophisticated equipment such as cameras used on satellites with various band widths that identify plant health and water in the landscape than in the past, we now can study flood events as they occur.

Reconnaissance during operation, management and maintenance (OMM) stage of the life cycle of a drainage system could be with the use of swarm farm robots for precision application and control of drainage water quality (Figure 4). The idea is that farmers instead of large tractors and sprayers use a swarm of autonomous, collision-avoiding robots that can spray with accuracy and in the right quantity when via GPS and satellite linkage other farm inputs such as soil type, moisture content, etc. are fed into the software controlling the swarm bots and adjusting the intensity and concentration of the spraying. Clearly a variety of sensors can be added or built-in the swarm bot and salinity (think of EM38 salinity survey technologies, Vlotman 2000), soil moisture, temperature of the soil and a variety of chemical assessments with probes drawn through the top layers of the root zone can be performed.

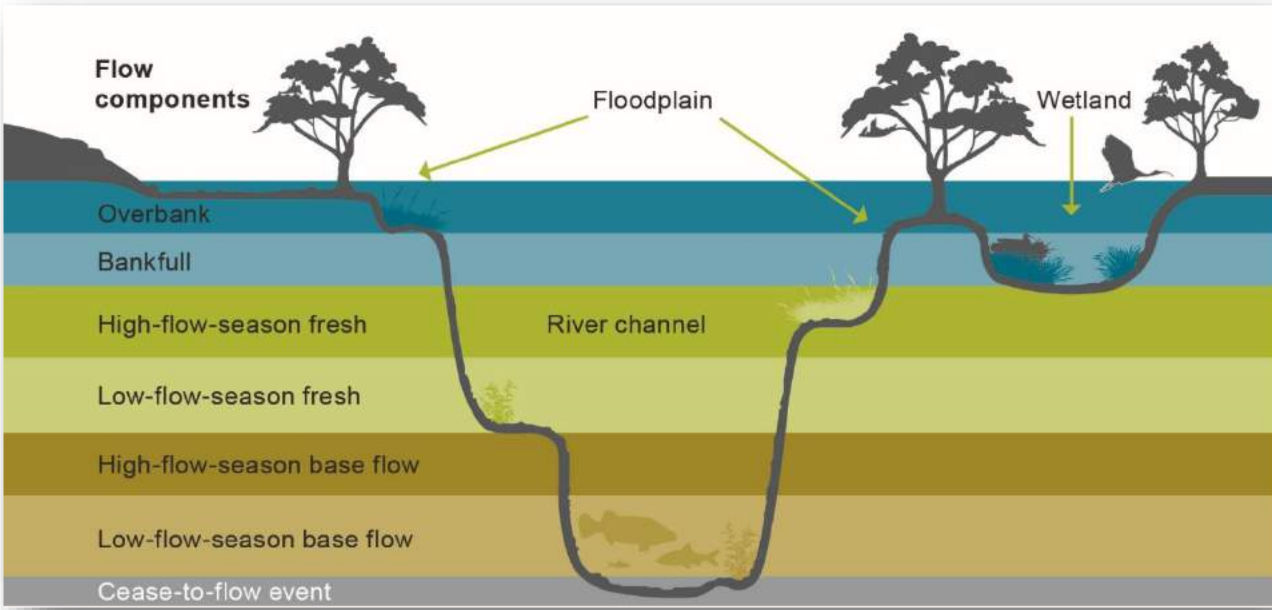

Figure 3 Schematic of flow types, incl. overbank flow (MDBA 2011)

Figure 4 Swarmfarm robots in action (www.swarmfarm.com).

Linking hydrological data with remote sensing data, whether flood extent, vegetation type or biological occurrence (bird surveys, fish numbers) can result in outputs such as shown in Figure 5 showing the area of flood plain grassland covered for a range of flow rates and Figure 6 showing aerial survey of the number of birds observed in various wetlands and the area of wetland at the time of fly-over. Data collected as shown in Figure 4 and 5 can be used in design and OMM processes to determine the amount of irrigation water needed, drainage water to be removed or localised leaching of salts to be planned. Bird breeding events can be analysed in more detail and may actually be planned by giving additional water to certain wetlands.

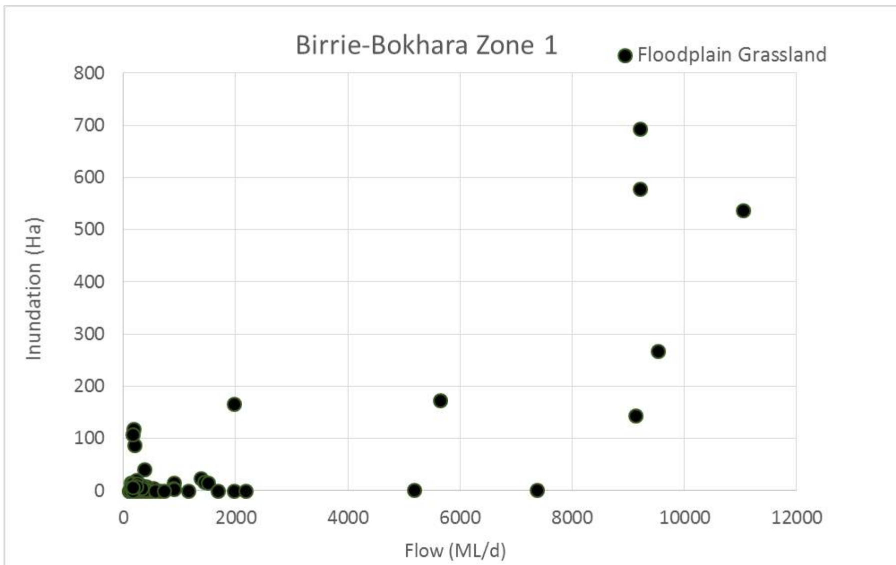

Figure 5 Example of relating a vegetation type to flood extent (Weldrake et al. 2016).

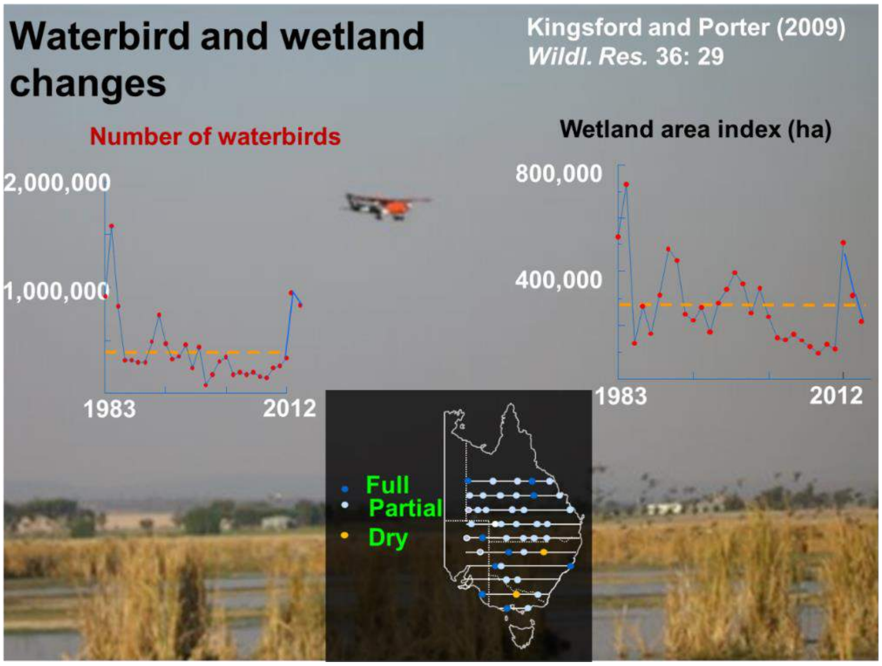

Figure 6 Number of Water birds and Wetland area index (Kingsford and Porter, 2009).

The applications of remote reconnaissance described above are only the tip of the proverbial iceberg of possibilities and opportunities to develop and advance these technologies further.

Final comments and conclusions

Beyond Modern Land Drainage espouses the use of new materials. For instance the Capiphone drain (www.greenability.com.au) uses the capillary action of the drain to both drain and supply water to the root zone; a new form of controlled drainage and irrigation. This type of drainage is also known as wick drainage although this is different in its applications and configurations (Koerner 1994, Vlotman et al. 2000).

For water quality control prevention is the best solution and precision agriculture, including the type of application such as advocated by swarm farm robots are exiting new developments.

For salinity control we need to become a bit more innovative and think out of the box. For instance the farmer which sees his land becoming increasing saline over time and looks at the government to provide him with solution can actually do something himself. By taking part of his farm out of production and assuming has access to the same an=mount of water as before, he can irrigate the remainder of his fields with adequate water, including meeting leaching requirements. It is important that in fields affected by salinity a net downward water movement through the root zone is maintained on seasonal basis! This assumes that the government cannot give him more water due to a number of constraints, and assumes that he can still make a living of the remainder of the farm. It may be that the farmer needs some financial support in the form of government guarantees of income, while he or she experiments with concentrating the water available to recover sections of the farm and make them salinity free.

Consider solutions that reduce the upward movement of water (and salts) in the root zone; can we cover the ground with plastic during part of the growing season and thus minimise direct soil water evaporation? Unfortunately in areas where plastic has been used in agriculture, the OMM is not very effective in removal of the plastic afterwards and severe visual and possibly ecological damage results.

A major change in paradigm in Modern Land Drainage design, construction and operation is that we not only concentrate on technical solutions, and not only consider the location of the problem, but take a much wider perspective in time, space, environment, ecology and stakeholder involvement. Look what can be done upstream of the location, look how a change in water management upstream can prevent the problem occurring downstream, look what alternatives there are for the farmer such as re-locate, train, re-skill and change job. If the solution is not found upstream look at minimising or eradicating the negative downstream impacts and turn them into opportunities to enhance water schemes elsewhere.

Finally, in the foregoing a number of solutions were described to use the advances in science and technology combined with active stakeholder involvement from top to bottom and from beginning to … no not the end, but to the stage of Operation, Management and Maintenance (OMM). This is intended to make drainage design more effective and sustainable in the long-term. It is suggested that prevention is the solution to many problems and that a holistic approach such as advocated by Vlotman and Ballard (2014) in describing the water-food-energy nexus for a green economy is necessary for a sustainable triple bottom line development. It is also imperative that the scale of intervention is extended beyond the mere location of the drainage system and that by considering carefully what is happening upstream and downstream of the location, it may be concluded that other solutions to the problem are more effective and guarantee long-term success. There are many opportunities to save water, energy and food beyond the realm of consideration of a drainage system in isolation. The involvement of stakeholders from beginning to end, from farm to fork, from minister to manager, and from preserving and maintaining ecological environments in conjunction with food production is essential in the success of any endeavour including modern land drainage design.

Beyond Modern Land Drainage design is using the latest science, technology and socio-economic insights and considering the interaction between water, food and energy for the best outcomes for all stakeholders in a green economy.

References

Ardakanian, R, Avellan, T, Ghany, H.A., Vlotman, W, Perret, S., Ragab, R. Zainal, H. and Im, S. 2016. Key Issues of Irrigation and Drainage in Balancing Water, Food Energy and Ecology. Background Paper, Second World Irrigation Forum, Nov 2016, Chiang Mai, Thailand, 11pp.

Baoa A, Huanga Y, Mab Y, Guoa H, Yongqin. 2017. Assessing the effect of EWDP on vegetation restoration by remote sensing in the lower reaches of Tarim River. Ecological Indicators. Volume 74, March 2017, Pages 261–275. http://dx.doi.org/10.1016/j.ecolind.2016.11.007.

Fareshare 2013. http://fareshare.net.au, Accessed May 2013.

Foodbank 2013. http://foodbankvictoria.org.au, Accessed May 2013.

MDBA, 2015, Tips for Developing an Engagement Plan. Murray-Darling Basin Authority (MDBA), Canberra, Aug 2015.

MDBA 2011. The proposed 'environmentally sustainable level of take' for surface water of the Murray-Darling Basin: Method and Outcomes. Murray-Darling Basin Authority (MDBA), Canberra, Nov 2011.

IDW11. 2012. Summary of the 11th ICID International Drainage Workshop, Agricultural Drainage Needs and Future Priorities. Downloaded 13 Nov 2016 from http://www.icid.org/summary_11idw.pdf.

Koerner, R.M. 1994. Designing with geosynthetics. 3rd edition, Prentice-Hall, Englewood Cliffs, New Jersey, USA, pp. 1 - 313, 783.

Kingsford, R. and Porter. 2009. Waterbird and wetland changes. Wildl. Res. 36: 29.

Schultz, B, Zimmer, D. and Vlotman, W.F. 2007, Drainage under Increasing and Changing Requirements. Irrig. and Drain. 56: S3 – S22.Wiley Interscience. DOI: 10.1002/ird372.

Smedema, L.K., Vlotman, W.F. and Rycroft D.W. 2004. Modern Land Drainage Design – Planning, design and Management of Agricultural Drainage systems. A.A. Balkema Publishers, Leiden, The Netherlands, 446 pp.

Tuohy, P, Humphreys, J, Holden N.M., O'Loughlin, J.O., Reidy, B. and Fenton, O. 2016. Visual Drainage Assessment: A standardised visual soil assessment method for use in land drainage design in Ireland. Irish Journal of Agriculture and Food Research. DOI: 10.1515/ijafr-2016-0003 IJAFR.55(1).2016.AOP.

van der Molen, W.H., J. Martínez Beltrán and W.J. Ochs. 2007. Guidelines and computer programs for the planning and design of land drainage systems. FOA Irrigation and Drainage Paper 62, Food and Agriculture Organization of the United Nations, Rome, Italy.

Vlotman, W.F. and Ballard, C. 2014. Water, Food and Energy Supply Chains for a Green Economy. Irrig. and Drain. Published online in Wiley Online Library (wileyonlinelibrary.com) Irrig. and Drain., 63: 232–240. doi: 10.1002/ird.1835.

Vlotman, W.F., L.S. Willardson and W. Dierickx 2000: Envelope design for subsurface drains. ILRI Pub. No 56, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 358 pp.

Vlotman, W.F. 2014, Water Management in the Murray-Darling Basin, OzWater Report, Water, Journal of the Australian Water Association, June 2014, pp 36- 38. Report on Special Stream on the Murray-Darling Basin as AWA Stream Champion, Chair AWA Rural Water Specialist Network. Assistant Director Hydrology & Modelling Coordination, Murray-Darling Basin Authority (MDBA), Canberra, ACT.

Vlotman, W.F. 2009. Sustainable Agricultural Drainage, Drivers, Benchmarking and KPI's as part of IWRM. Presented at Special Session on Drainage, 5th Asian Regional Conference on Improvement in Efficiency of Irrigation Projects through Technology "Upgradation" and Better Operation & Maintenance. New Delhi, India , 6 – 11 December 2009. 17pp.

Vlotman, W.F. 2008. Drainage, the driver of sustainable environments. Proceedings of the 10th International Drainage Workshop of ICID Working Group on Drainage, Helsinki/Tallinn 6-11. July 2008, pp 343 - 356. Helsinki University of Technology, Water Resources Publications, TKK-VTR-16, Espoo, 2008, ISBN 978-951-22-9469-5.

Vlotman, W.F. (Ed.) 2000: EM38 workshop proceedings, February 2000, New Delhi, India, Special Report. International Institute for Land reclamation and Improvement, Wageningen, The Netherlands.

Welke, R. 2016. Pump efficiency without testing pumps? The facts about kWh/ML/m. Irrigation Australia, Pump Feature, Spring 2016, p25-27.

Weldrake D., Kathleen McKenna, Joel Bailey & Paul Carlile. 2016. Floodplain and Vegetation Inundation using WOFS Satellite Imagery: Local and Reach-Scale Analysis. Internal report Murray-Darling Basin authority (MDBA).

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Topic 1:
Measures to Lower Volume of Drainage Water

EFFECTS OF AGRICULTURAL DRAIN WATER CONSUMPTION ON THE GROWTH OF JUVENILE DATE PALM

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Abstract

The efficient use of irrigation water is one of the important issues and programs of the agricultural sector in Iran. The purpose of this study is the exploring of the possibility of juvenile date palms irrigation utilizing agricultural drain water. This experiment was carried out using acomplete block design with three irrigation water salinities of 2.5, 8 and 12 dS m^{-1} in four replications. Saline water with 8 and 12 dS m^{-1} were obtained from a mix of agricultural drain water and water abstracted from the Karun River. The results show that the salinity of irrigation water had a significant effect on soil salinity, the number of leaves, leaf length, leaf width, number of leaflets and truck perimeter at 5% level of probability. The maximum and minimum of plant vegetative characteristics except for leaf chlorophyll and leaflet width were obtained from water with 2.5 dS m^{-1} and 12 dS m^{-1}, respectively. There was a significant difference between the water with 2.5 dS m^{-1} and 8 dS m^{-1} in terms of leaf number, leaf width, number of leaflets and truck perimeter. Therefore, saline water (EC $\geq$8 dS m^{-1}) cannot be used for irrigation of juvenile date palms.

KEY WORDS: Irrigation, Lysimeter, Saline water, Salt, Soil salinity.

Introduction

Water salinity is one of the most important problems in many countries in the world, especially in arid and semi-arid regions. The lack of fresh water resources has resulted into the use of non-conventional water resources such as brackish and saline water and has received greater attentions in the agriculture sector in recent years. Iran has large salt water sources that have different levels of salinity. These sources can have a great impact on the country's agricultural development (Shiati, 1998). The use of these resources requires special management practices for the reduction

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of their negative environmental impacts. The use of saline drainage waters, generated by irrigated agriculture, seems inevitable for plants irrigation (Qadir and Oster, 2004).

The Date palm is an important horticultural crop in Iran. According to the Food and Agriculture Organization of the United Nations (FAO) report in 2013, Iran with a harvested area of 163000 hectares and 1100000 tons production of date fruit is ranked third and second in the world, respectively. The salinity threshold in date palms, based on water salinity and soil saturated extract salinity are 2.7 dS m^{-1} and 4 dS m^{-1}, respectively. The reduction of 50% in fruit yield is at a water salinity of 12 dS m^{-1} and a soil salinity of 18 dS m^{-1} (Ayers and Westcot, 1994). The date palm cultivars have different tolerance levels to water and soil salinity.

Akhlas and *Ruzaiz* are two of the most common and well-known date varieties in the Al-Hassa oasis of Saudi Arabia. Abderrahman and Abdelhadi (1990) reported that the *Akhlas* variety has a low tolerance level while the *Ruzaiz* variety has a high tolerance level for soil salinity. Al-Rokibah et al. (1998) compared six months old seedlings growth of ten palm date cultivars. Irrigation water salinity of 12.9 dS m^{-1} reduced seedlings length and fresh weight rate to salinity 1.4 dS m^{-1} for most date cultivars. However, seedlings length and the fresh weight of one date cultivar increased with irrigation water salinity.

Aljuburi and Maroff (2007) investigated the effect of diluted sea water when used for irrigation on date palm seedlings. This study was carried out on four levels of sea water (SW) 0.0%, 20%, 40% and 60% on two year old uniform date palm seedlings of the *Hatamy* variety at the experimental station of the University of Qatar. Salinity treatments were imposed by irrigating each seedling once every 20 days with 300 ml of different concentrations of sea water. The number of roots and leaves per seedling significantly increased with the application of 40 or 60% sea water as compared to untreated control plants. Shoot dry weight matter percentages significantly increased with sea water. The Irrigation of *Hatamy* seedlings with sea water did not affect root dry matter percentage. The addition of 40 or 60% sea water to irrigation water significantly increased leaf Na concentrations, where as 20% sea water reduced leaf Na concentrations as compared to untreated seedlings. While, Leaf K^+ and Ca^{2+} concentrations significantly decreased with 60% sea water and different sea water concentrations, respectively.

Tripler et al. (2007) investigated the growth characteristics, transpiration and ion uptake in juvenile date palms (cv. *Medjool*) under conditions of increasing salinity and B concentrations. Irrigation water salinity levels included EC=0.5, 4, 8, and 12 dS m^{-1}. Boron concentrations in irrigation water were 0.028, 0.185, 0.4625, 1.850, and 3.700 mmol l^{-1}. The salinity levels were a result of additions of concentrations of NaCl and $CaCl_2$. The negative effects of salinity were evident as early as the first months of treatments, manifesting themselves as a drastic decrease in evapotranspiration which appeared during the 12 dS m^{-1} treatment. Elevated root concentrations of Cl and Na were found with increasing irrigation salinity. For salinity treatments of 4, 8 and 12 dS m^{-1}, root Na was two times greater than that in the leaves, while Cl was up to eight fold greater in roots than in leaves.

Four date palm varieties offshoots were irrigated with saline water commencing with 7.8 dS m^{-1} and slowly increasing the concentration of salt to 11.7, 15.6, 19.5, 23.4 and 27.3 dS m^{-1} at regular intervals of three months duration (Kurup et al., 2009). The varieties response was different to the increasing salt concentration. The plant height, collar girth and number of leaves of *Mesalli* and

Razez variety cultivars reduced with the increasing of water salinity from 7.8 to 27.3 dS m^{-1}, while water salinity increased vegetative growth of *Bugal White* and *Khashkar* cultivars.
The overall objective of this research was to evaluate the effect of irrigation water salinity on the survival and growth characters of Barhee juvenile date palms. The *Barhee* date palm is one of most important date palm cultivars in Iran.

Materials and Methods

This field study was conducted in the Date Palm and Tropical Fruits Research Center (N 31°15′ E 48°30′ and22.5 m a.s.l.) in the city of Ahwaz, Iran. The research was carried out as a randomized complete block design with three treatments and four replications on *Barhee* juvenile date palm. The treatments were:
WS1: Water salinity of 2.5 dS m^{-1} (Karoun River).
WS2: Water salinity of 8 dS m^{-1}.
WS3: Water salinity of 12 dS m^{-1}.
12 polyethylene drainage lysimeters of 0.6 m diameter and 0.9 m depth were installed for the performing of this experiment. The lysimeters were filled with sandy loam soil (Table 1).

Table 1. Composition of lysimeter soil.

Sand	Silt	Clay	Texture	EC (dS m^{-1})	SAR	pH	Na^+ (meq/lit)	Ca^{2+} (meq/lit)	Mg^{2+} (meq/lit)
69	17	14	Sandy loam	3.9	4.9	7.8	17.7	12.2	13.5

A *Barhee* juvenile date palm was planted in each lysimeter (February 2015). The juvenile date palms were irrigated via a bubbler system. The lysimeters soil surface was covered with date palm leaf particles (1 kg/m^2) as mulch (Hussain *et al*., 1986; Terasaki *et al*., 2009; He *et al*., 2009; Tishehzan *et al*., 2011).
After completing the plant establishment period ,the juvenile date palms were irrigated based on the salinity of the irrigation water (May 2015). The Karun River water and other irrigation water were stored in 1000 liters tanks that were connected to the irrigation system separately.
The mean salinity of the Karun river water salinity was 2.5 dS m^{-1} during the experiment and saline irrigation water was obtained by mixing the drainage runoff and stored irrigation water (Table 2).
Soil moisture was measured during the treatment of water salinity of 2.5 dS m^{-1} (Karun River) for determining irrigation interval. The net irrigation depth (d_n) was calculated for obtaining soil moisture deficiency:

$$d_n = (\theta_{fc} - \theta_i)\, Z \quad (1)$$

Where
θ_{fc} = Field capacity (m^3/m^3),
θ_i = Measured soil moisture (m^3/m^3),
Z = Root depth (mm).

The gross irrigation depth was determined based on leaching requirements (LR_t):

$$LR_t = EC_w / [2(EC_e)_{max}] \quad (2)$$

Where EC_w is the irrigation water electrical conductivity and $(EC_e)_{max}$ is the saturated extract electrical conductivity of the soil root zone for zero yield point which is 32 dS m^{-1} for the date palm (Ayers and Westcot, 1994).
The soil salinity was measured by sampling soil depths (0-25, 25-50, 50-75 cm) at the end of the experiment. The date plants growth characters such as number of leaves, leaf length, leaf width, leaf chlorophyll, number of leaflets, leaflet length, leaflet width, trunk perimeter were measured. Data was analyzed statistically using SPSS Statistics 19 software. the mean comparison was also performed using Duncan's Multiple Range test.

Results and discussion

ANOVA test of soil salinity in different layers (0-25, 25-50 and 50-75 cm) indicated that the effect of irrigation water salinity was significant at probability level 0.01. The highest soil salinity in 0-25 cm layer was obtained in water salinity of 12 dS/m (Table 3). There was a significant difference in soil salinity between water with 2.5 dS/m and 12 dS/m. Soil salinity for treatment of 12 dS/m (16.2 and 16.6 dS/m, respectively) was also more than other treatments in soil layers of 25-50 cm and 50-75 cm.

Table 2. Composition of irrigation water.

EC (dS m^{-1})	SAR	pH	Cation (meq/L)			Anion (meq/L)		
			Na^+	Mg^{2+}	Ca^{2+}	Cl^-	HCO_3^-	SO_4^{2-}
2.5	5.2	7.9	13.3	7.7	5.5	19.8	3.7	-
8.0	12.9	8.0	54.8	25.8	9.8	64.0	5.3	-
12.0	17.5	8.0	85.1	29.1	18.2	86.0	12.1	-

Table 3. Effect of water salinity on soil layers salinity*.

Treatment	0 - 25 cm	25 - 50 cm	50 - 75 cm	0 - 75 cm
WS_1	9.6 bc	8.5 c	8.1 c	8.7 bc
WS_2	11.2 ab	12.1 bc	12.2 b	11.8 b
WS_3	13.8 a	16.2 a	16.6 a	15.5 a

* Means followed by same letter in column are not significantly different at level 1%.

There was significant difference in soil salinity in this treatment with water of 2.5 dS/m and 8 dS/m.
The ANOVA test of soil salinity at different depths (0-75 cm) indicated that the effect of irrigation water salinity was significant at probability level 0.05. The mean of soil salinity (0-75 cm) is presented in Table 1. The highest soil salinity (15.5 dS/m) was obtained in water salinity of 12 dS/m. The results reported in Table 1 demonstrate clearly that soil salinity has a direct and significant connection with irrigation water salinity, as soil salinity in irrigation water of 12 dS/m was 1.8 and 1.3 times the irrigation water electrical conductivity levels of 2.5 and 8 dS/m, respectively. This condition is due to the increasing of total dissolved solids (TDS) of irrigation

water resulting into the enhancement of water electrical conductivity. The change process of soil salinity is according to other studies (Kamali *et al*. 2011; Salehi *et al*., 2011). This issue is important due to the salts effect on the physical and chemical characteristics of soil or growth location of the plant.

The survival rate of the juvenile date palms was 100 percent in all treatments. The date plants survival in the case of irrigation with saline water of 12 dS/m (soil salinity 15.5 dS/m) showed that the *Barhee* juvenile date palms tolerated irrigation water salinity. This result is similar to other research results. The survival of all *Barhee* juvenile date palms has been reported in the usage of saline water of 9 dS/m (Valizadeh *et al*., 2012) and in saline soil of 14.2 dS/m (Tishehzan *et al*., 2011).

The ANOVA test of juvenile date palms vegetative characters showed that the effect of irrigation water salinity was significant at probability levels of 0.05 on all vegetative characteristics except leaf chlorophyll and leaflet width. The highest and lowest plant vegetative characteristics except for leaflet width were formed in irrigation water of 2.5 dS/m and 12 dS/m, respectively (Tables 4 and 5). Duncan's test for comparison of the mean showed a significant difference in the number of leaves, leaf width, number of leaflets and trunk perimeter between water salinity treatments of 2.5 dS/m and 8dS/m. Saline water of 8 dS/m and 12 dS/m had a significant difference only in leaf width and trunk perimeter.

The evaluation of the effect of irrigation water salinity on the growth of 12 cultivars of United Arab Emirates date palm indicated that the number of leaves showed a significant reduction with the increasing of irrigation water salinity from 3000 to 6000 ppm (Alhammadi and Edward, 2009). Whatsmore, the growth response of date palm cultivars was significant in regards to irrigation water salinity. Irrigation with saline water of 11 dS/m reduced the leaf growth of two date cultivars *Sakkoti* and *Bartamoda* in Egypt significantly (Hussein *et al*., 1993). The salinity stress effect on the growth of three date varieties seedlings indicated that salinity of 4000 ppm NaCl created a significant increase in the growth of vegetative characteristics rate as compared to a salinity of 0.0 ppm, while salinities 8000 and 12000 ppm reduced the growth of vegetative characters significantly (El-Sharabasy *et al*., 2008).

Table 4. Effect of water salinity on date plants leaf characteristics*.

Treatment	Number of leaves	Leaf length (cm)	Leaf width (cm)	Leaf chlorophyll
WS_1	4.7^{a}	44.8^{a}	44.2^{a}	61.8^{a}
WS_2	2.0^{b}	39.8^{ab}	37.0^{b}	61.1^{a}
WS_3	2.0^{b}	34.8^{b}	33.2^{c}	59.9^{a}

* Means followed by same letter in column are not significantly different at level 5%.

Table 5. Effect of water salinity on leaflet and trunk characteristics*.

Treatment	Number of leaflets	Leaflet length (cm)	Leaflet width (cm)	Trunk perimeter (cm)
WS_1	375.0^{a}	25.4^{a}	1.83^{a}	13.8^{a}
WS_2	234.0^{b}	23.7^{ab}	1.94^{a}	9.8^{b}
WS_3	228.0^{b}	22.2^{b}	1.95^{a}	7.8^{c}

* Means followed by same letter in column are not significantly different at level 5%.

According to Ramoilya and Pandey (2003) the date palm is tolerant to salinity, because 50% *Rati* date seedlings grow in saline soil of 9 dS/m. The ability of date palm in osmotic pressure regulation rate in regards to Na^+ and Cl^- has been recognized as the reason for the tolerance of date palm to salinity (Al-Khayri, 2002). Kurup *et al*. (2009) reported that date palm response to salinity stress can be attributed to the availability, uptake and transport of elements within the plant. They state that irrigation water concentration of 7.8-12.5 dS/m is the salinity threshold for reducing date palm growth. Kafi *et al*. (2010) reported that plants are more sensitive to water and soil salinity in germination and the early stage of growth than other growth states.

Conclusion

The survival of all date plants even in saline water 12 dS/m indicates that juvenile date palm tolerate irrigation water salinity. This experiment shows that vegetative growth of *the Barhee* varety juvenile date palm in water salinity of 2.5 dS/m is more than saline water of 8 dS/m and 12 dS/m. The maximum and minimum of plant vegetative characteristics except leaf chlorophyll and leaflet width were obtained at water of 2.5 dS/m and 12 dS/m, respectively. There was a significant difference between water of 2.5 dS/m and 8 dS/m in terms of leaf number, leaf width, number of leaflets and truck perimeter. Therefore, saline waters (EC ≥8 dS/m) cannot be used for irrigation of the *Barhee* juvenile date palm variety.

References

Al-Khayri JM. 2002. Growth, proline accumulation and ion content in sodium chloride stressed callus of date palm. In Virto Cellular Developmental Biology-Plant, 38 (1): 79-82.

Al-Rokibah AA., MY. Abdalla and YM. Fakharani. 1998. Effect of water salinity on *Thielaviopsisparadoxa* of growth of date palm seedling. Journal of King Saud University, 10(1): 55-63.

Abderrahman WA. and YM. Abdelhadi. 1990. Effect of salt tolerance levels on farming of date palm varieties: a case study. Arid Soil Research and Rehabilitation, 4(4): 269-272.

Alhammadi MS. and GP. Edward. 2009. Effect of salinity on growth of twelve cultivars of the United Arab Emirates date palm. Communications in Soil Science and Plant Analysis, 40(15-16): 2372-2388.

Aljuburi HJ., Maroff A. and M. Wafi. 2007. The growth and mineral composition of Hatamy date palm seedlings as affected by sea water and growth regulators. Acta Hort. (ISHS) 736: 161-177.

Ayers RS. and DW. Westcot. 1994. Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Rome, Italy.

El-Sharabesy SF., Wanas WH. and AY. Al-Kerdany. 2008. Effect of salinity stress on some date palm cultivars during proliferation stage in vitro. Arab. Journal Biotech. 11(2): 273-280.
He C., Fukuhara T., Sun J. and W. Feng. 2009. Enhancement of soil moisture preservation by date palm mulch. Mem. Grad. Eng. Univ. Fukui., 57: 53-56.

Hussain G., Makki Y., Helweg O. and W. Alvarado. 1986. The effects of palm leaf mulch to conserve soil moisture. Proceedings of the Second Symposium on the Date Palm, Saudi Arabia: 359-364.

Hussein F., Khalifa AS. and KM. Abdalla. 1993. Effect of different salt concentration on growth and salt uptake of dry date palm. Proceeding of Third Symposium on the Date palm, King Faisal University, Saudi Arabia: 299-304.

Kamali E., Shahmohammadi Heydari Z., Heydari M. and M. Feyzi. 2011. Effects of Irrigation Water Salinity and Leaching Fraction on Soil Chemical Characteristic, Grain Yield, Yield Components and Cation Accumulation in Safflower in Esfehan. Iranian Journal of Field Crop Science, 42(1): 63-70.

Kafi M., Salehi M. and HR. Eshghizadeh. 2010. Biosaline agriculture: Plant, water and soil management approaches. Ferdowsi University of Mashhad, No. 573.

Kurap SS., Hedar YS., Al-Dhaheri MA., El-Heawiety AY., Aly MAM. and G. Alhadrami. 2009. Morpho-physiological evaluation and RAPD markers-assisted characterization of date palm (*Phoenix dactylifera* L.) varieties for salinity tolerance. Journal of Food, Agriculture & Environment, 7(3&4): 503-507.

Qadir M. and JD. Oster. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Science of the Total Environment, 232: 1-19.

Ramoilya PJ. and AN. Pandey. 2003. Soil salinity and water status effect growth of *Phoenix dactylifera* seedlings. New Zealand Journal of Crop and Horticultural Science, 31(4): 345-353.

Salehi M., Kafi M. and A. Kiani. 2011. Effect of salinity and water deficit stresses on biomass production ofKochia (*Kochiascoparia*) and trend of soil salinity. Seed and Plant Production Journal, 27(4): 417-433.

Terasaki H., Fukuhara T., Ito M. and C. He. 2009. Effects of gravel and date-palm mulch on heat moisture and salt movement in a desert soil. Advances in Water Resources and Hydraulic Engineering, Vol. 1: 320-325.

Tishehzan P., Naseri A., Hassanoghli A. and M. Meskarbashi. 2011. Effects of shallow saline water table management on the root zone salt balance and date palm growth in South-West Iran. Res. on Crops, 12 (3): 839-847.

Tripler E., Ben-Gal A. and U. Shani. 2007. Consequence of salinity and excess boron on growth evapotranspiration and ion uptake in date palm (Phoenix dactylifera L., cv. Medjool). Plant Soil, 297: 147-155.

Valizadeh M., Tishehzan P. and S. Boroomandnasab. 2012. Investigation of saline water irrigation on date palm seedlings growth (Cv. *Berhi* and *Dairi*). First National Congress on Date Palm and Food Security, Ahvaz, Iran: 78-84.

EFFECTS OF CLIMATE CHANGE ON SURFACE DRAINAGE (CASE STUDY: ILAM DAM WATERSHED)

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Abstract

Water is essential to human survival, and changes in its supply from overland flow can potentially have devastating implications, particularly in Iran, where much of the population relies on local rivers for water. Future climate change may pose one of the greatest threats to poverty eradication plans in this country, and related changes in surface water supply will exacerbate this threat. Climate change will alter the duration, intensity, type and timing of precipitation. This can cause unprecedented droughts and floods. Whatsmore, it changes the volume, timing, and duration of the runoff, leading to many changes and developments in the field of water resources management. Early spring runoff in snow-fed rivers will lead to increased flooding. In addition to the primary impact of floods on lives, crops, livestock, and property, they bring the threat of epidemics in their aftermath. Increased surface drainage capacity may be required to prevent crop damage or loss or even the threatening of haman and animal lives. Runoff and overland flow ultimately effect land erosion and sediment transport to surface drains. Sediment itself is a major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which in themselves affect the health of receiving open water bodies.

Ilam dam basin which is 471.6 km2 is located in western Iran. The basin consists of three rivers originating from three sub-basins joining at the dam site. Rain-fed cultivation is a prevailing type of agriculture in the aforementioned basin (about 80% of the total area of agricultural lands in the basin). Therefore Agriculture in this region depends critically on weather conditions so that every change in weather conditions can greatly affect the cropping pattern.

In this study, a commercial hydrological model (SWAT) with A2 and B1 emission scenarios predicted usingHadCM3 General Circulation Models (GCMs) in a future period (2046-2065) were applied to determine the total runoff volume and peak rate. By applying various climate change scenarios, the mean annual air temperature shows an increase from 1.47°C (B1) to 2.11°C (A2) in the future as compared to the baseline (1990-2010). The mean total annual precipitation also shows

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an increase from 35.4 mm (A2) to 63.8 mm (B1) in the same period. The results show that in the A2 scenario, the average annual discharge rate decreases by 24% in the future, while in the B1 scenario it increases up to 10% in the same period. According to the B1 scenario, an increase in total runoff is predicted. Although in the A2 scenario total runoff will decrease, the average number of days with heavy precipitation will increase. To cope with such changes, the drainage capacity must be increased. To reduce sediment transport and contaminants adhering to it, new approaches such as buffer strips should be considered. Finally, it is recommended that other scenarios that are more adaptable to the region's future conditions such as land use changes also be investigated.

KEY WORDS: Climate change, Surface drainage, SWAT Model, LARS-WG, Ilam dam watershed

Introduction

The growth of industries and factories since the industrial revolution and the consequential increased consumption of fossil fuels on the one hand and the destruction of forests and changes in agricultural land use, on the other hand, has resulted into increased emissions of greenhouse gasses, especially CO_2 in recent decades. The concentration of CO_2 has increased from 280 ppm in 1750 to 379 ppm in 2005 leading to global warming (IPCC 2007). The global air temperature has increased by 1.4-5.8°C as compared to the pre-industrial period (Houghton et al. 2001). Developing countries are more vulnerable to climate change since they have less social and financial resources and technologies for adaptation (UNFCCC 2007). Future climate change may pose one of the greatest threats to poverty eradication plans in such countries, and related changes in surface water supply will exacerbate this threat. Climate change alters the duration, intensity, form and timing of precipitation in different regions of the globe. This can cause unprecedented droughts and floods (Mendizabal et al. 2014). Whatsmore, it changes the volume, timing and duration of the runoff thus leading to many changes and developments in the field of agriculture and water resources management (Jothityangkoon et al. 2001; Leavesley 2002; Rudra et al. 2015). Surface drainage which requires the construction of small open ditches or waterways that take water away from fields to larger collection ditches or natural streams is directly affected by climate change. . Since surface drainage is highly dependent on the conditions of the hydrology of the basin such as changes in runoff, it can easily be affected by climate change (Skaggs et al., 1994).

In this study, the effects of climate change on the basin's total runoff has been investigated using a hydrological model (SWAT) with future climate change scenarios predicted by HadCM3 A2 and HadCM3 B1 model-scenarios (IPCC 2007). Runoff and overland flow ultimately effect land erosion and sediment transport to the surface drains. Sediment itself is the major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which affects the health of receiving open water bodies. Finally, the results obtained can be used to modify the capacity of the basin's surface drainage in the future.

Methods

In this study, a hydrological model (SWAT) for current and future climate change scenarios which were in themselves predicted by HadCM3 A2 and HadCM3 B1 model-scenarios was used. To predict the future temperature and precipitation, the fourth IPCC report (AR4) was used. The AOGCM model used in this study is HadCM3 and LARS-WG model has been used for downscaling the HadCM3 model outputs. After entering these values as SWAT model inputs, the future period's runoff is obtained Finally, a few strategies for surface drainage adaptation to climate change has been suggested. Figure 1 illustrates the procedure.

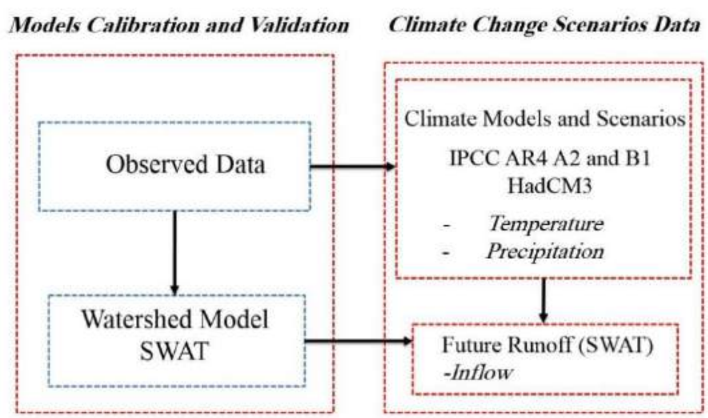

Figure 1. Schematic diagram of methodology used to simulate the future runoff of the basin

Study Area

The Ilam dam basin with a reservoir of 471.6 km2 is located in the West of Iran between 46° 20' 25" to 46° 36' 58" East longitude and 33° 23' 53" to 33° 38' 56" North latitude. The basin consists of three rivers originating from three sub-basins ithat is the Golgol, Chaviz and Ama rivers which convergeat the dam site (46° 40' E and 32° 48' N).

Rain-fed cultivation is a prevailing type of agriculture in the aforementioned catchment (about 80% of the total area of agricultural lands in the catchment). Therefore Agriculture in this region is critically dependent on weather conditions, so that every change in weather conditions can greatly affect the cropping pattern.

Data required to build the models used in this study has been collected from different organizations and companies. Figure 2 shows the geographic location of the basin and the location of the dam and the stations in the Ilam dam basin. Table 1 lists the stations used in each model.

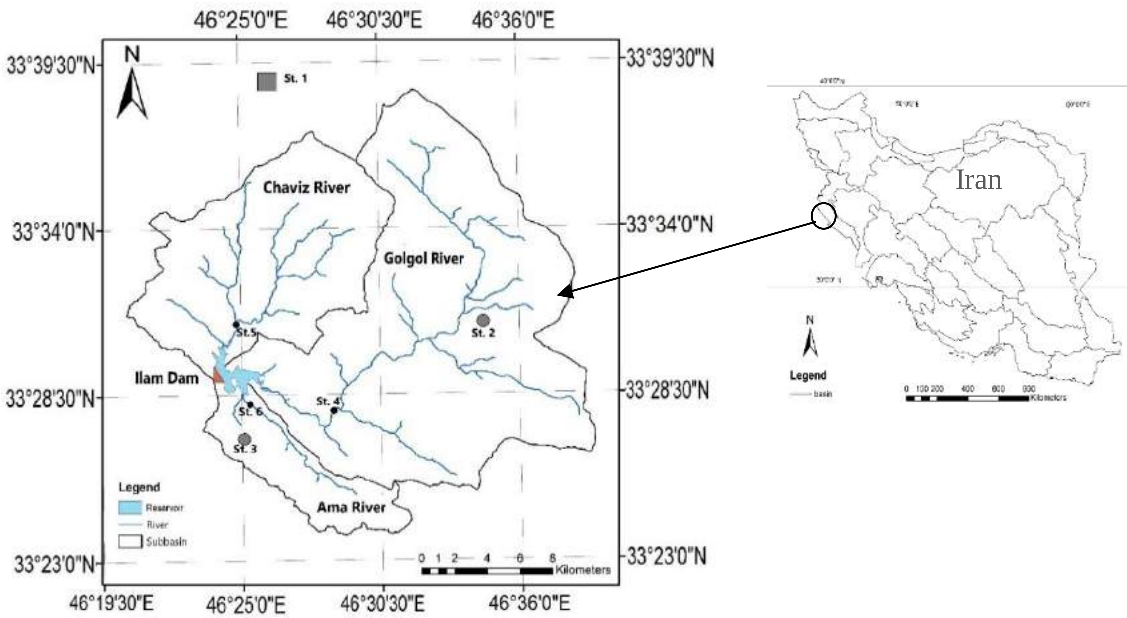

Figure 2. Location of Ilam basin and meteorological and hydrological stations

Table 1. Meteorological and hydrological stations data used in each model

Station No.	Station Type	Used in Model	Data Period	Latitude	Longitude	Elevation (m)
St. 1	Synoptic	LARS-WG SWAT	1987-2010	33° 38’	46° 26’	1337
St. 2	Rain Gauge	SWAT	1997-2007	33° 31’	46° 34’	1434
St. 3	Rain Gauge	SWAT	1999-2007	33° 26’	46° 25’	1360
St. 4	Hydrometric	SWAT	1998-2010	33° 27’	46° 28’	1100
St. 5	Hydrometric	SWAT	2003-2010	33° 30’	46° 24’	1067
St. 6	Hydrometric	SWAT	2003-2010	33° 28’	46° 25’	1032

General Circulation Models (GCMs) and their downscaling to suit the region

In the study, general circulation models (GCMs) were used to predict the thermal stratification in the reservoir. That is why two GCMs are reflected in the fourth report of IPCC (AR4) (Randall et al. 2007) Both were used to predict temperature and precipitation in the Ilam Dam basin in the middle of the current century (the horizon of 2055 or 2046-2065). In addition, GCMs were used to predict temperature and precipitation with greenhouse gas emissions scenarios (IPCC Special Report on Emission Scenarios or SRES 2000). In this study, B1 (lower) and A2 (higher) greenhouse gas emissions scenarios were used. GCMs are able to predict future situation on a global and continental scale but lack suitable accuracy in predicting climatic parameters on smaller scales because of the regional effects on the climate such as slope and aspect, elevation, proximity to the sea, etc. (Wigley et al. 1990). To use GCMs outputs, downscaling methods should be used. In this study, LARS-WG5.5 statistical model simulator was used for downscaling. In fact, LARS-WG is a model used for producing meteorological data. By Fitting a distribution function with 21 parameters on the measured data, it is able to reproduce the measured data. It can also generate future data in case a particular climate scenario for modeling is defined (Semenov and Barrow 2002).

Using measured data, LARS-WG model was calibrated in the Ilam Dam basin. Then, according to the median forecast of each GCM, future data was generated on a daily scale. To determine the quality of calibration results, the suitablity of fit (P-value) and correlation coefficients were used (Semenov and Barrow 2002). The results indicated an acceptable fitness at a confidence level of 95%. However, due to low precipitation levels in the summer, the calibration results in this season were weaker but still significant.

The Hydrological Simulator (SWAT)

The SWAT model is a comprehensive model on the basin scale provided by the U.S. Agricultural Research Service. It is a semi-distributed model utilized to predict the impact of different management methods on flow, sediment, nutrients and chemical balance in basins with different soils, land use and management conditions over long periods of time. The model includes hydrology, climate, erosion, plant growth, nutrients, pesticides, land management and flow routing. A more detailed description of the model has been given by Neitsch et al. (2002).

The following data for making hydrological model were obtained from a variety of sources:

Digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters (*http://www2.jpl.nasa.gov/srtm/*).

The land use map from Global Landuse /Landcover Characterization USGS with a spatial resolution of 1 km including 17 land use categories (*http://landcover.usgs.gov/glcc/*)

The soil map was obtained from the global soil map of the Food and Agriculture Organization of the United Nations (FAO) (FAO 1995), which provides data for 5000 soil types comprising two layers (0-30 cm and 30-100 cm depth) at a spatial resolution of 5 km (*http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/*).

Meteorological data (daily precipitation, maximum and minimum daily temperature and daily solar radiation) from St. 1, St. 2 and St. 3 were obtained from I.R. of IRAN Meteorological Organization.

The river flow in St. 4, St 5 and St 6 were obtained from Iran Water Resources Management Co.

At the end of the model making process, a model with 74 sub-basins and 274 HRUs was determined.

SWAT Calibration and Validation

In this study, SUFI-2 (Sequential Uncertainty Fitting) algorithm and SWAT-CUP program were used to calibrate and validate the model. SUFI-2 combines the calibration and uncertainty to find uncertainty parameters, so that the majority of measured data is in the estimation uncertainty range while creating the smallest band of estimation uncertainty. The uncertainty of the model output is calculated by uncertainty estimation at the level of 95% sampled from the domain at 2.5% and 97.5% of the cumulative distribution function of the output variable by the Latin hypercube method (Abbaspour et al. 1997, 2004).

Two indices are used to determine the performance of uncertainty; p-factor: the percentage of data that fall within the 95PPU (95 Percent Prediction Uncertainty) band (maximum 100%) and R-factor: the average thickness of the band divided by the standard deviation of the measured data. SUFI-2 assumes a large range of uncertainty for each parameter. Thus, the measurement data are initially at 95PPU level and this uncertainty is reduced in subsequent steps until two conditions are met: (1) the majority of the measured data is at 95PPU level (P-factor $\rightarrow$ 1), (2) the average distance between the upper and lower limits of 95% divided by the standard deviation of the measured data is as small as possible (R-factor $\rightarrow$ 0) (more details of SUFI-2 can be found in Abbaspour et al. 2007). NS factor was selected as the objective function. After sensitivity analysis of parameters in SUFI-2, 20 parameters were selected for the calibration and validation as shown in Table 2.

Table 2. Parameters used for calibration and validation of SWAT model

No	Variation	Parameter	Definition	Fitted value
1	Relative	CN2	Initial SCS runoff curve number for moisture (condition II)	0.07
2	Replace	USLE_P	Universal Soil Loss Equation coefficient	0.59
3	Replace	REVAPMN	Threshold depth of water in the shallow aquifer for "Revap" to occur (mm)	85.24
4	Replace	GW_REVAP	Groundwater "Revap" coefficient	0.13
5	Replace	ALPHA_BF	Baseflow alpha factor (days)	0.28
6	Relative	CH_K1	Effective hydraulic conductivity in tributary channel alluvium (mm/hr)	85.49
7	Replace	CH_COV1	Channel erodibility factor	0.42
8	Replace	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	114.19
9	Replace	CH_N2	Manning's "n" value for the main channel	0.026
10	Replace	ALPHA_BNK	Baseflow alpha factor for bank storage (days)	0.24
11	Replace	SURLAG	Surface runoff lag time (days)	11.52
12	Replace	SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover (mm H_2O)	194.51
13	Replace	SMFMX	Melt factor for snow on June 21 (mm H_2O/°C-day)	4.02
14	Replace	HRU_SLP	HRU slope (m/m)	0.36
15	Replace	EPCO	Plant uptake compensation factor	0.39
16	Replace	SLSUBBSN	Average slope length (m)	41.10
17	Replace	CANMX	Maximum canopy storage (mm H_2O)	60.86
18	Relative	SOL_Z	Depth from soil surface to bottom of layer (mm)	1780.87
19	Relative	SOL_K	Saturated hydraulic conductivity (mm/hr)	0.31
20	Relative	SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)	0.18

Out of a 23-year statistical period, 5 years (from 2006 to 2010) were used for calibration of the discharge in St. 5 and St. 6 hydrometric stations. Eight years from 2003 to 2010 were used for the calibration of the discharge in St. 4 hydrometric station. Data over three years (from 2003 to 20060 was used for THE validation of St. 5 and St. 6. Six years from 1998 to 2003 was used for The validation of St. 4. The period from 1987 to the end of 1989 was used to warm-up the model. To assess the ability of the SWAT model in river discharge simulation, P-factor, R-factor, R2 and Nash-Sutcliffe (NS) were used. Table 3 shows the simulation results separately for the calibration and validation periods. Figures 3 to 5 show the calibration and validation of the hydrometric stations.

Table 3. SWAT model calibration and validation result in hydrometric stations

Criteria	St. 4		St. 5		St. 6	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.71	0.77	0.79	0.56	0.79	0.79
E_{NS}	0.66	0.63	0.77	0.51	0.51	0.78
R-factor	1.07	0.77	1.16	0.58	1.47	0.74
P-factor	0.57	0.43	0.58	0.43	0.49	0.54

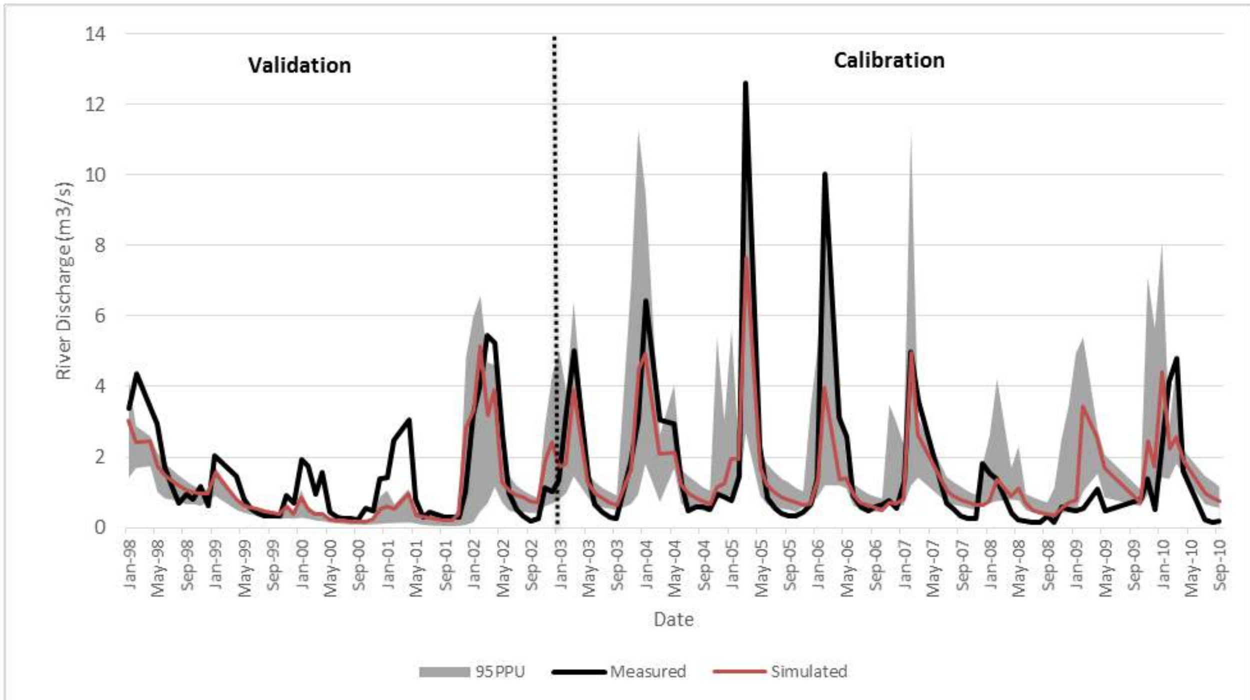

Figure 3. Result of SWAT calibration and validation for St. 4

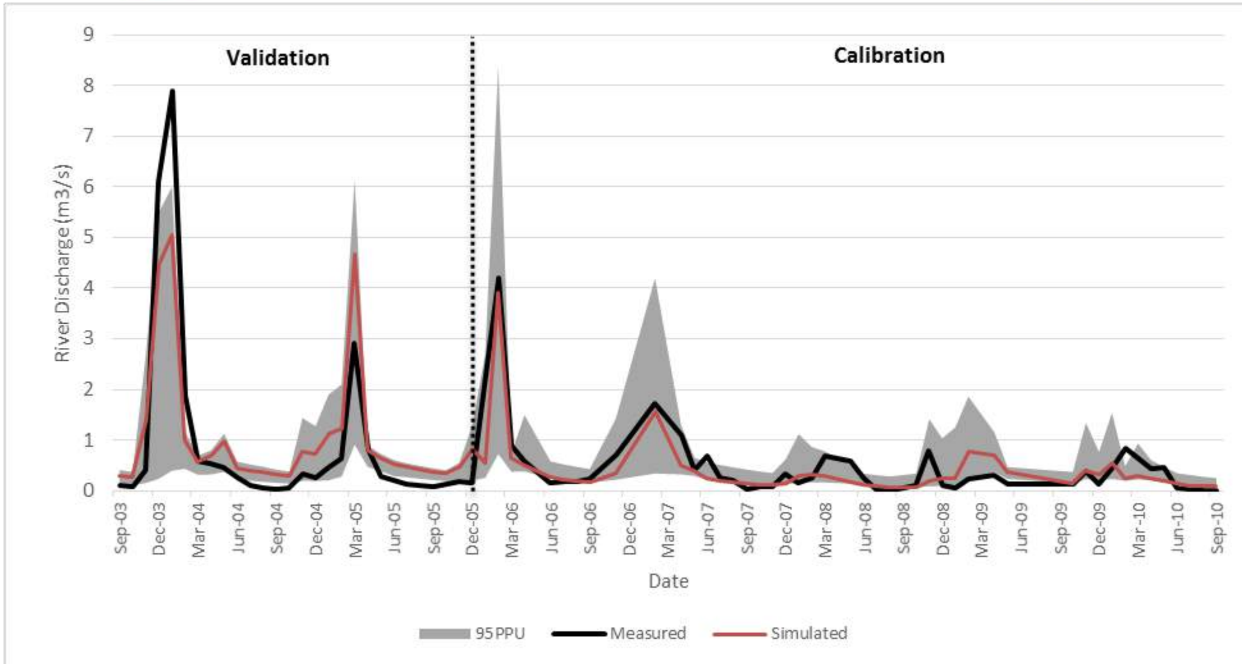

Figure 4. Result of SWAT calibration and validation for St. 5

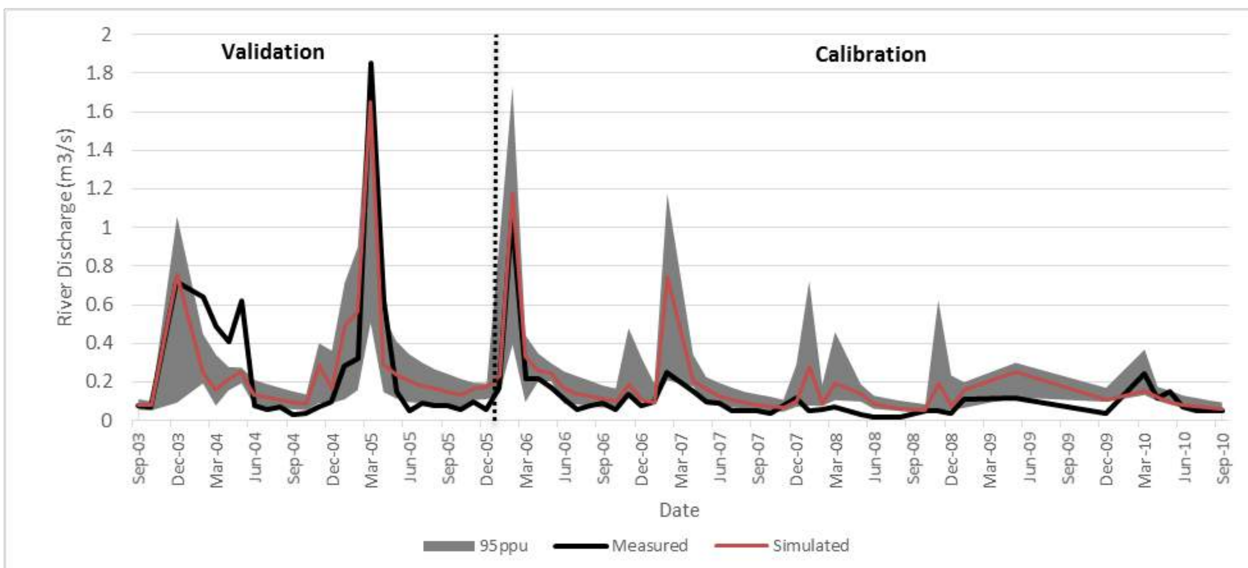

Figure 5. Result of SWAT calibration and validation for St. 6

Results and Discussion

Forecasting future temperature and precipitation by LARS-WG model

The downscaling results of the HadCM3model with a B1 and an A2 emission scenario for precipitation and temperature are shown in Figures 6 and 7. It should be noted that precipitation data is reported as the mean total monthly precipitation in mm and temperature is the mean monthly temperature in degrees Celsius.

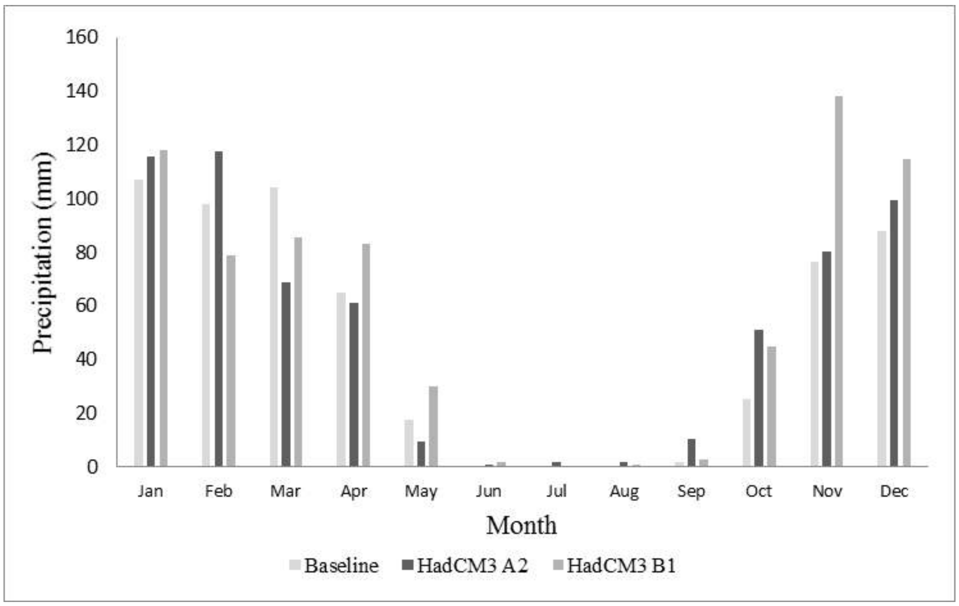

Figure 6. Mean total monthly Precipitation in baseline (1990-2010) and future (2046-2065) periods

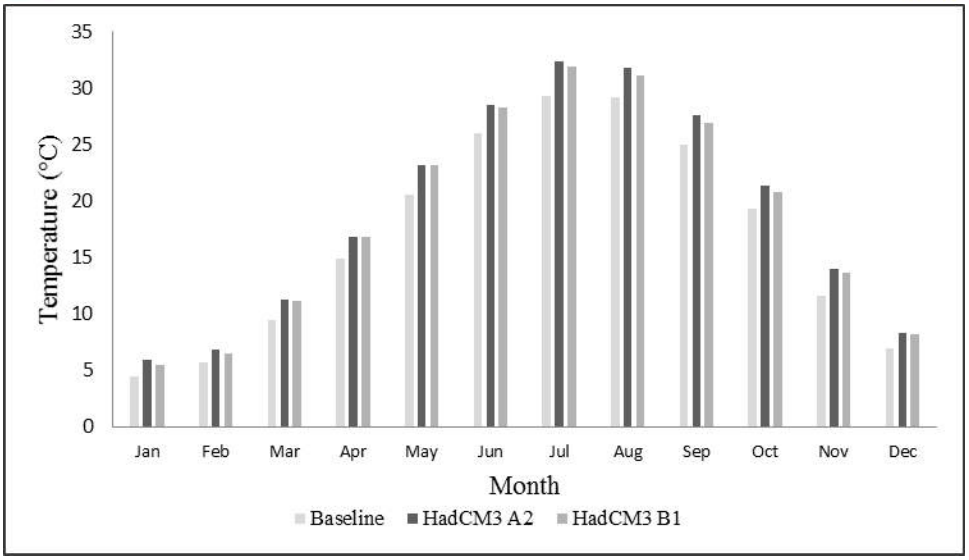

Figure 7. Mean monthly Temperature in baseline (1990-2010) and future (2046-2065) periods

Table 4. Mean annual temperature and annual precipitation values in the baseline (1990-2010) and future (2046-2065) periods

HadCM3		Observed	
B1	A2		Scenario
18.68	18.99	16.87	Mean Annual Temperature (°c)
647.5	619.1	583.7	Mean Annual Precipitation (mm)

Forecasting future runoff using the SWAT model

After downscaling the climatic data for future periods using the HadCM3 model with A2 and B1 scenarios, a 20-year time series data for the future period (2046-2065) was generated to be used in the SWAT model. Figure 8 shows the mean monthly discharge as it increases or decreases in the future period as the mean monthly discharge at hydrometric stations in the baseline and future periods.

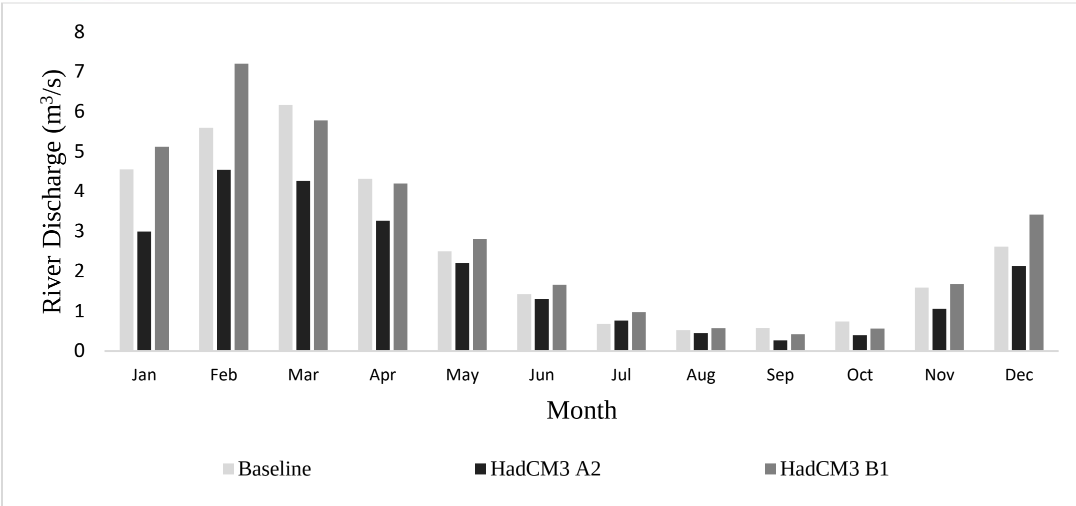

Figure 8. Sum of mean monthly discharge in Baseline (1990-2010) and future (2046-2065) periods in 3 hydrometric stations

As seen in Figure 8, the maximum average monthly discharge rate in the baseline period is seen in March, but in the future period Model-scenarios, it is observed to be in February. This change indicates that the time of occurrence of the maximum average monthly discharge rate has changed. In addition, future discharge rate change as compared to the baseline period. The results show that in the A2 scenario, the average annual discharge rate decreases by 24% in the future period, while in the B1 scenario it increases up to 10% in the same period.

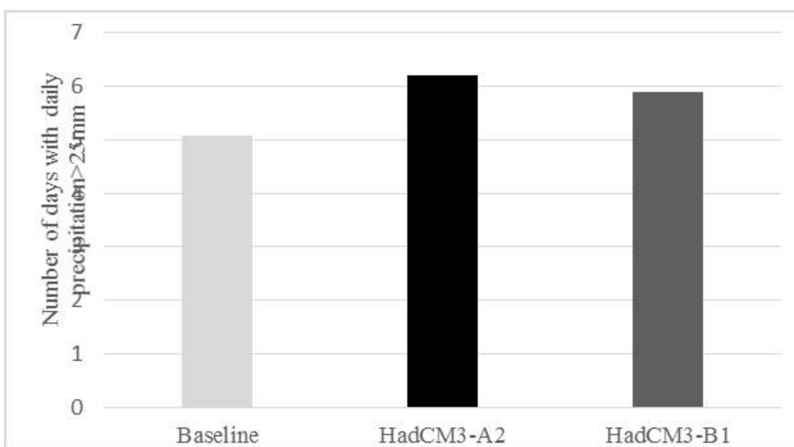

Figure 9. Comparison between number of days with extremely heavy precipitation between baseline and future periods

Figure 9 shows the average number of days with an amount of precipitation of more than 25mm in the baseline and future periods. According to the graph, in the future, approximately one day will be added to the number of days with heavy precipitation. Heavy precipitation refers to instances during which the amount of rain or snow experienced in a location substantially exceeds what is normal. What constitutes a period of heavy precipitation varies according to location and season. Climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation. For example, heavier rain and snow storms (Melillo et al., 2014). The potential impacts of heavy precipitation include crop damage, soil erosion, and an increase in flood risk due to heavy rains which in turn can lead to injuries, drownings, and other flooding-related effects on health (Bell et al., 2016). In addition, runoff from precipitation can impair water quality as pollutants deposited on land wash into water bodies. Heavy precipitation does not necessarily mean the total amount of precipitation at a location has increased just that precipitation is occurring in more intense events. However, changes in the intensity of precipitation, when combined with changes in the interval between precipitation events, can also lead to changes in overall precipitation totals.

Conclusion

According to literature, a basin's hydrology is extremel sensitive to climatic conditions and basins respond to the changes quickly. Hydrology is the primary factor in various processes in the basin. Climate change will alter the hydrology of the basin ,leading to changes in temperature and precipitation patterns. In this study, a hydrological model was developed to consider the potential effects of changing basin variables on the basin's runoff.

To explain the mechanism affecting runoff volume in a basin and its impact on water needed for agriculture and surface drainage system, the hydrology, and hydrological relationships were investigated and simulated using a hydrological model. In the climate change scenarios, the A2 and B1 scenarios respectively assumed mean annual temperature increase of 2.11 °C and 1.47 °C in the 2046-2065 period based on 1987-2010 data. Furthermore, the mean total annual precipitation in the 2046-2065 period increased by 35.4 and 63.8 mm according to the A2 and B1 scenarios and 1987-2010 data, respectively. Finally, the effects of changes in precipitation and temperature on increase or decrease of the discharge of rivers was studied. The simulation results of the A2 and B1 scenarios have been compared with the results of the baseline period. The results showed that the total runoff for the period 2046-2065 will decrease 24% according to the HadCM3 A2 model scenario and will increase 10% according to the HadCM3 B1 model-scenario based on 1987-2010 data. Runoff and overland flow essentially effect land erosion and sediment transport to the surface drains. Sediment itself is the major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which affects the health of receiving open water bodies. In order to adapt to such changes, it is necessary to modify the surface drainage system and use methods to reduce water pollution as briefly described in the following paragraphs.

Increasing the capacity of surface drainage systems:

Because of the changes in the pattern and amount of precipitation and surface runoff volume and more heavy precipitation in the future period and in order to adapt to these changes, it is necessary to increase the capacity of the surface drainage system in the basin. Surface drainage improvements may consist of land smoothing, grading, precision, and land forming and the establishing of a slight grade on the land surface. A network of field ditches, laterals, and main canals also may be an integral part of a surface drainage system.

Using Buffer Strips:

Numerous studies have shown that cultivating green stripes as a buffer between the edge of streams and rivers has a significant effect in preventing or diminishing water pollution. Creating green stripes is considered as being one of the good practices in reducing water pollution. For example, a green margin of 15 meters on both sides of the river prevents the transport of sediment and nutrients from farm sewage to the water resource. To determine the proper width, information about the intensity of water pollution, soil type, slope of the land, and type of ground cover is essential (Anonymous, 1994). To create a green margin, bushy shrubs and grass can be used. Surface runoff and farm's sewage passes through the green strips and plants obstruct the sediments and suspended solids which are then deposited and as a result relatively clear water flows into rivers. For example nitrate in the surface runoff can be absorbed by plant roots and finally, during the Denitrification procedure, Nitrogen gas is released into the air. Phosphorus which has been deposited along with sediment in buffer strips is used to produce chlorophyll, which is gradually used by plant roots and prevents its transformation into the waters (Anonymous, 1995).

Finally, it is recommended that other scenarios that are more adaptable to the region's future conditions such as land use changes be investigated.

References

Abbaspour, K.C., Vejdani, M., Haghighat, S. (2007). SWAT-CUP calibration and uncertainty programs for SWAT. In: Oxley, L., Kulasiri, D. (Eds.), Proc.Intl. Congress on Modelling and Simulation (MODSIM'07). Modeling and Simulation Society of Australia and New Zealand, Melbourne, Australia, pp. 1603-1609.

Abbaspour, K.C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., Srinivasan, R., Reichert, P. (2007). Modeling of hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. J. Hydrol. 333, 413-430.

Abbaspour, K.C., Johnson, A., van Genuchten, M.Th. (2004). Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone J. 3, 1340-1352.

Abbaspour, K.C., van Genuchten, M.Th., Schulin, R., Schlappi, E. (1997). A sequential uncertainty domain inverse procedure for estimating subsurface flow and transport parameters. Water Resour. Res. 33, 1879-1892.

Abbaspour, K.C., Faramarzi, M., Ghasemi, S.S., Yang, H. (2009). Assessing the impact of climate change on water resources in Iran, Water Resour. Res. 45, W10434.

Anonymous, 1994. Best management practices, water management. Agriculture Canada Pp. 93.

Anonymous, 1995. Managing nonpoint source pollution in agriculture. Deere & Company Technical Center. Moline, IL, 61265. Technical Report No. 272. Pp. 63.

Arhonditsis, G.B., Brett, M.T., DeGasperi, C.L., Schindler, D.E. (2004). Effects of climatic variability on the thermal properties of Lake Washington. Limnol Oceanogr. 49, 256–270

Baffaut, C., Farrand, T.D., Benson, V.W. (2005). Potential accuracy of water quality estimates based on noncalibrated SWAT simulations. 3rd International SWAT Conference, Zurich, Switzerland, pp. 301-309.

Bell, J.E., S.C. Herring, L. Jantarasami, C. Adrianopoli, K. Benedict, K. Conlon, V. Escobar, J. Hess, J. Luvall, C.P. Garcia-Pando, D. Quattrochi, J. Runkle, and C.J. Schreck, III. (2016). Chapter 4: Impacts of extreme events on human health. The impacts of climate change on human health in the United States: A scientific assessment. U.S. Global Change Research Program.

Cole, T.M., Wells, S.A. (2003). CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version 3.1. Instruction Report EL-03-1, US Army Engineering and Research Development Center, Vicksburg, MS.

Elshemy, M. (2013). Climate Change Impacts on Water Resources in SemiArid Regions: Case Study of Aswan High Dam Reservoir. Climate Change and Water Resources. T. Younos and A. C. Grady. Berlin, Heidelberg, Springer Berlin Heidelberg: 69-98.

Houghton, J.T., Ding, Y., Griggs, D.J., Noquer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. (2001). Climate change 2001: The scientific basis. Cambridge University Press, pp 881

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate change 2007: The physical science basis. Cambrige Univ. Press, New York

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, H.J.M., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Papper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., Dadi, Z. Nakicenovic, N., Swart, R., (Eds.). (2000). Special Report on Emissions Scenarios, IPCC, Cambridge University Press, Cambridge, UK, pp 570

Jones, P.D., Hulme, M. (1996). Calculating regional climatic times series for temperature and precipitation: methods and illustrations. Int. J. Climatol. 16, 361-377.

Jothityangkoon, C., Sivapalan, M., Farmer, D.L. (2001). Process controls of water balance variability in a large semi-arid catchment: a downward approach to hydrological model development. J. Hydrol. 254, 174-198

Leavesley, G.H., Markstrom, S.L., Restrepo, P.J., Viger, R.J. (2002). A modular approach to addressing model design, scale, and parameter estimation issues in distributed hydrological modeling. Hydrol. Process. 16, 173-187.

Liu, W., Bocaniov, S.A., Lamb, K.G., Smith, R.E.H. (2014). Three-dimensional modeling of the effects of changes in meteorological forcing on the thermal structure of Lake Erie. Journal of Great Lake Research. 40, 827-840.

Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). (2014). Climate change impacts in the United States: The third National Climate Assessment. U.S. Global Change Research Program.

Mendizabal, M., Sepúlveda, J., Torp, P. (2014). Climate Change Impacts on Flood Events and Its Consequences on Human in Deba River. International Journal of Environmental Research. 8, 221-230.

Mortsch, L.D., Quinn, F.H (1996). Climate change scenarios for Great Lakes Basin ecosystem studies. Limnol Oceanogr. 41, 903-911

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., King, K.W. (2002). Soil and water assessment tool: Theoretical documentation. Blackland Research Center, Texas Agricultural Experiment Station

Park, G.A., Ahn, S.R., Lee, Y.J., Shin, H.J., Park, M.J., Kim, S.J. (2009). Assessment of climate change impact on the inflow and outflow of two agricultural reservoirs in Korea. Trans ASABE. 52, 1869-1883

Randall, D.A., Wood, R.A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Kattsov, V., Pitman, A., Shukla, J., Srinivasan, J., Stouffer, R.J., Sumi, A., Taylor, K.E. (2007). Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. The contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Rudra, R.P., Dickinson, W.T., Ahmed, S.I., Patel, P., Zhou, J., Gharabaghi, B., Khan, A.A. (2015). Changes in Rainfall Extremes in Ontario. International Journal of Environmental Research 9, 1117-1126.

Salmaso, N., Morabito, G.G., Mosello, R. (2007). Trophic development of the deep lakes south of the Alps: a comparative analysis. Fundam. Appl. Limnol. 170, 177-196.

Schindler, D. (2009). Lakes as sentinels and integrators for the effects of climatic change on watersheds, airsheds, and landscapes. Limnol Oceanogr. 54, 2349-2358.

Schuol, J., Abbaspour, K.C., Srinivasan, R., Yang, H. (2006). Estimation of freshwater availability in the West African Sub-continent using the SWAT hydrologic model. J. Hydrol. 352, 30-49

Semenov, M.A., Barrow, E.M. (2002). LARS-WG. A stochastic weather generator for use in climate impact studies. User Manual. Rothamstead Research, Hertfordshire, 27 pp .

Shepherd, B., Harper, D., Millington, A. (1999). Modeling catchment-scale nutrient transport to watercourses in the U.K. Hydrobiologia. 395, 227-237

Skaggs, R. W., Brevé, M. A., & Gilliam, J. W. (1994): Hydrologic and water quality impacts of agricultural drainage, Critical Reviews in Environmental Science and Technology, 24:1, 1-32

Tolson, B.A., Shoemaker. C.A. (2004). Watershed modeling of the Cannonsville basin using SWAT2000: Model development, calibration, and validation for the prediction of flow, sediment and phosphorus transport to the Cannonsville reservoir. Technical Report, School of Civil and Environmental Engineering, Cornell Univ., Ithaca, N. Y

UNFCCC. (2007). Climate Change Impacts, Vulnerabilities, and Adaptation. Note by the secretariat. UNFCCC. Bonn, Germany. 68 pp. https://unfccc.int/resource/docs/publications/impacts.pdf

Wigley, T.M.L., Jones, P.D., Briffa, K.R., Smith, G. (1990). Obtaining sub-grid-scale information from coarse-resolution general circulation model output. J. Geophys. Res. 95, 1943-1953

Winchell, M., Srinivasan, R., Di luzio, M., Arnold, J. G. (2009). ArcSWAT 2.3 Interface for SWAT 2005, User's guide,

CONTROLLED SUB-SURFACE DRAINAGE AS A STRATEGY FOR IMPROVED WATER MANAGEMENT IN IRRIGATED AGRICULTURE OF UZBEKISTAN

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Abstract

An existing conventional subsurface drainage system (CVD) was modified to control the flow from the drainage lateral and to control the groundwater table depth in portion to the irrigated winter wheat field during the 2014-2015 crop growing season in the Fergana valley, Uzbekistan. Drainage outflow at the one out of two drainages was controlled (CTD) while the other was left free (CVD). Drainage water volumes and water quality were monitored from October 25, 2014 until June 15, 2015. The cumulative drainage water volume from the CVD treatment was 22% greater than the CTD treatment over this period. The flow weighted mean salt concentration of the drainage water was 7% lower at the CTD treatment (2.08 mS cm^{-1}) as compared the CVD treatment (2.24 mS cm^{-1}). In addition, the effect of CTD experiment on crop growth parameters as well as on grain yield was evaluated by comparing a ratio of the field level hydraulic parameters between transects #A and #B (1) vs. #B and an open collector (2) along the drainage course. The ratio of soil water content in the 1 m soil profile between (1) and (2) was 1.20 which indicated that the upper part of the field contained 20% greather soil moisture for the crop to utilize during the growing period as compared with the lower portion of the field. Conversely, the ratio of the water table depth between (1) and (2) was 0.78 indicating that the water table of the upper portion of the field was 47 cm (22%) shallower than the lower part. Thus, CTD increased the moisture storage of the soil layer at the upper part of the field as compared with the lower part. Managing the water table resulted in less water stress between irrigation events and increased grain yields in the area with shallowest groundwater. Introduction of the CTD at the farm level has the potential to improve the livelihoods of farmers by reducing costs associated with water application and maintaining agricultural production in water short years as well as reducing collector-drainage water outflow.

KEY WORDS: Controlled drainage, Groundwater table, Drainage outflow, Wheat yield.

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Introduction

Rapid expansion of irrigated lands during 1960-1980 in Uzbekistan is followed by installation of drainage systems in response to water logging and salinity problems. Currently, artificially drained area in Uzbekistan covers about 2.9 Mha, of which 19% (about 13% of country's irrigated land) constitutes subsurface drainage systems (Dukhovny et al, 2007). Depending on hydrological and economic conditions, the depth of subsurface drainage installation is usually 0.3-1.0 m deeper from the depth of active groundwater level (GWL) while space between two laterals is not less than 50 m (Dukhovny et al., 2005a;b; 2007). Peculiarity of drainage system in arid areas is that installation depth and the lateral spacing are nearly twice deeper and 4-5 times greater than those in humid areas, respectively (Ayars et al., 1996). However, the principal differences of subsurface drainage system design in arid areas compared to those in humid areas are grounded on peculiarity of natural-climatic condition (high evaporation intensity, moisture deficit, soil salinity etc.) that stipulated for deeper installation (2.5-3.5 m against 0.8-1.2 m), lesser intensity, considerably higher designed discharge and therefore deeper GWL and higher surface water application for agricultural crops. However, there is no need to drain soil much deeper than the root zone.
Another peculiarity of these drainage systems is their design that discharges water continuously, without regard to environmental consequences. Conventional agricultural land drainage systems are usually over designed to cope with worst-case situations in terms of crop rooting depths and drainage requirements, as well as the expected loss of performance as systems age. For many crops and for much of the time this results in more water being removed from the soil profile and passed to drains than is necessary to control water-logging or the buildup of salinity in the soil profile. Analysis of approximate water-salt balance at district level across provinces of Uzbekistan, demonstrated that the majority of drainage systems were over-draining, as they were removing 2.3 times more salt than was applied by irrigation water (Fig.1). In general, farmers frequently over-irrigate to compensate for rapid removal of water by drainage systems.
Negative environmental impacts caused by mismanagement, deterioration and aging of collector-drainage network is accompanied with lack of management of return water effluent into the main rivers, lakes and wetlands releasing salts and pollutants from different water economy sectors. Coupling with that the increase of water mineralization in Syrdarya and Amudarya rivers was observed in time and along the course since 1950-1970 (Kenjabaev, 2014). Moreover, existing irrigation system efficiency is low being 0.48-0.73 thus only 30–35% of water drawn from the source is used for irrigation of agricultural crops (Ikramov, 2007). Partially water losses return to the main stream as a return flow from collector-drainage systems. Hence, mean multiyear stocks of collector-drainage water (CDW) in Uzbekistan makes 21±2 $км^3$. About 95% out of total return CDW comes from irrigated lands and is almost 43±6% of total agricultural water withdrawal (CAWATERinfo, 2016).

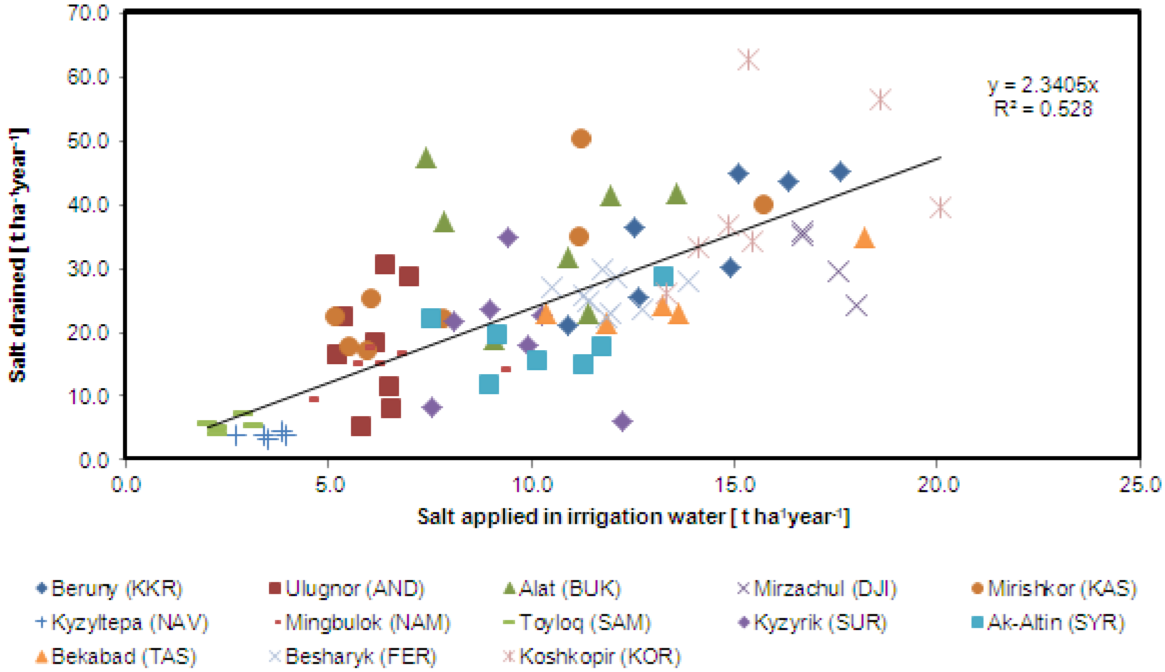

Figure 1. Salt loads in irrigation water and drainage water from various irrigation districts in Uzbekistan (based on data for 1995-2003 periods from the Ministry of Agriculture and Water Resources, the Republic of Uzbekistan)

Note: KKR: Karakalpakistan Republic, AND: Andijan, BUK: Bukhara, DJI: Djizakh, KAS: Kashkadarya, NAV: Navoi, NAM: Namangan, SAM: Samarkand, SUR: Surkhandarya, SYR: Syrdarya, TAS: TAshkent, FER: Fergana, KOR: Khorezm provinces.

One of the ways to solve the problem of further development of water management in agrarian sector is elaboration of large-scale measures to reduce collector-drainage runoff through reuse in place of its formation (Berdjansky & Zaks, 1996). Nowadays about 13% of total return water is re-used for irrigation purposes (Dukhovny et al., 2007), mainly in upper and middle course provinces of Uzbekistan. Although conventional drainage decreases soil salinity under leaching/irrigation mode, improves soil aeration, thereby machine trafficability and increases crop yields (Dukhovny et al., 1979; Madramootoo et al., 2007), it can also lead to soil water stress during the dry periods. As Ayars (1996) stated "in arid areas, subsurface drainage design is based on the concept of "dynamic equilibrium" which assumes that the range of the cyclic annual water table fluctuation is constant". Therefore, the mid-point water table height reaches the maximum height above the drains at the same time each year, generally by the end of the growing season. Moreover, the laterals in a subsurface drainage system design in arid areas have typically been laid to parallel the surface grade of the field being drained. Hence retrofitting an older system to include control structures may not be practical because the slope of the field and drain laterals may require many control structures in the field (Ayars & Shoneman, 2006). The challenge for the most effective water table management system is to find the drainage system, where the laterals having been installed perpendicular to the surface grade or to develop a new system design and installation which enables water table control over a large part of the field with a minimum number of control structures.

Coupling to that it needs a new approach to subsurface drainage that applies management to these drainage systems to reduce their downstream environmental impacts whilst maintaining agricultural production. Controlled drainage may be an option with an existing drainage system that contributes a reduced drainage flow and lower irrigation requirements. Hence it can help farmers to better manage the soil moisture by removing excess water in wet periods as well as to retain moisture in the field during dry periods through regulation of the drain outlets (Singh et al., 2014). In addition, in a controlled drainage system the water table is maintained at a shallower depth by a control structure which reduces deep percolation below the root zone by reducing hydraulic gradients and increases potential capillary upflow as evapotranspiration depletes soil water in the root zone. In addition, the flow lines, in controlled drainage implemented land area, are shallower than in the uncontrolled system and are more concentrated closer to the soil surface. In soil profiles with zones of lower soil salinity at the soil surface this will result in decreased drain water salinity compared to the uncontrolled system. The reduced drain flows and lower salinity result in much reduced salt loads; hence their downstream environmental impacts are minimized. However, it seems more local research will be required to reach to new standards and design criteria leading to optimize technical, economic and environmental issues. After carrying out researches, we would expect a reduction in drainage environmental problems by practicing alternative methods. Therefore, the aim of this study is to know how the management of the GWL by controlled subsurface drainage will provide the opportunity to increase in situ crop water use, which should result in improved irrigation efficiency, and reduced drainage outflow.

Materials and methods

Site description

The experimental site, so called "Azizbek" site (40°28'N; 71°32'E) is situated in the water users association "Oktepa Kyrgizobod ziloli" under the command area of "Naryn-Fergana" administrative irrigation system of Fergana province, Uzbekistan. Two fields at the experimental farm of SANIIRI's branch in Fergana were selected as research objects. The fields lie within the irrigation zone of Big Fergana Canal (BFC) at flat smooth proluvial plain that constitutes the peripheral part of the alluvial cone of the Margilansay, Shahimardansay, and Isfaramsay transboundary small rivers (Stulina et al., 2005). Slopes are northward and relatively plain, being 0.002 to 0.003 (Stulina et al., 2005; Dukhovny et al., 2005a). Water for irrigation is distributed to the fields through 4 km long concrete-flume canal "Pakhtakor-4" delivering water from the BFC. Hence the fields are suffering with frequent water shortages due to improper water management within the system as well as their location at the tile course of the canal. The field agronomical monitoring as well as research was conducted at two fields (contours: 13/14, 20.2 ha and 15/16, 16.3 ha), with total area of 36.5 ha (Fig.2).

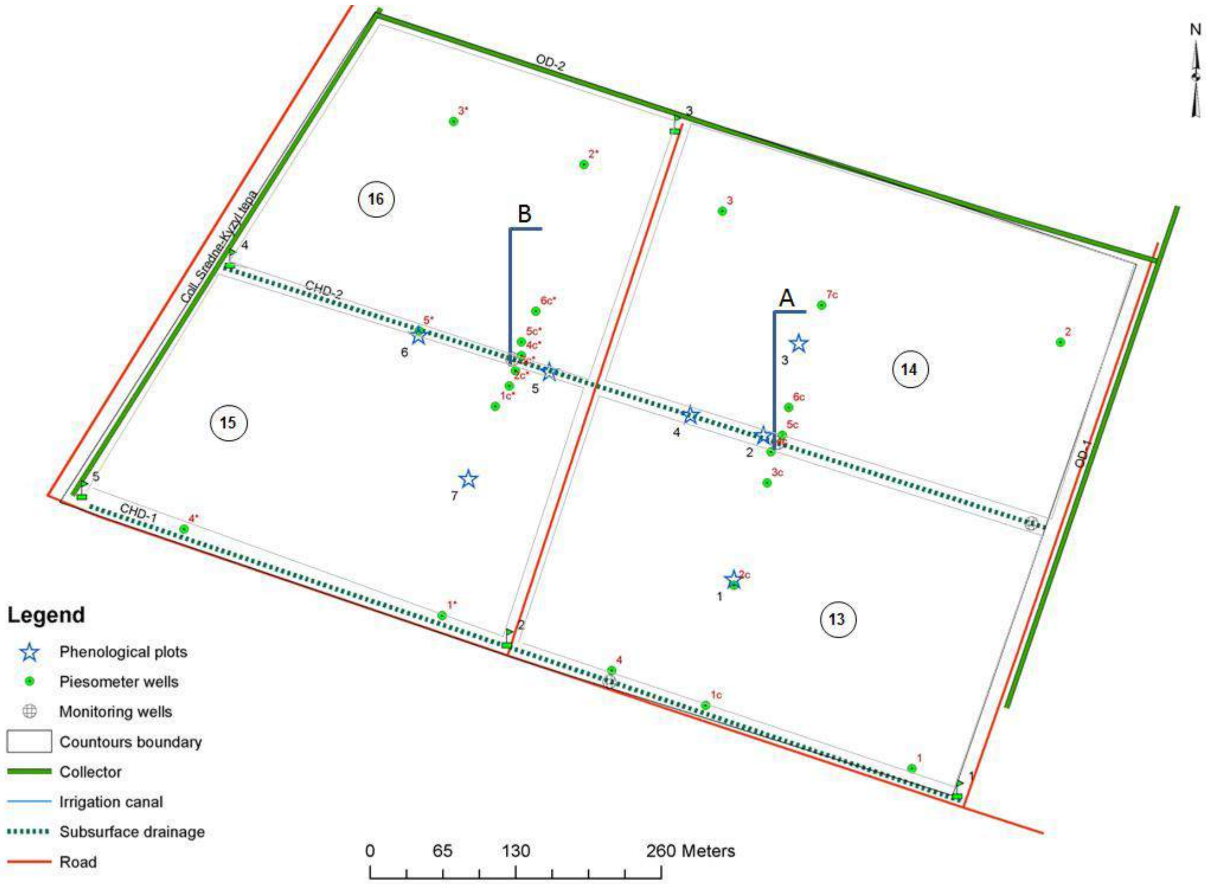

Figure 2. General overview of the experimental site

The study site belongs to the Central Climatic zone (Ц II) (FAO, 2003). The general climatic characteristic of the region according to Köppen-Geiger climate classification varies with typical continental, cold, arid, desert and steppe climate (BWk and BSk) (Kottek et al., 2006). The climatic condition of the study region is characterized by data from meteorological station "Fergana". There is a positive regime of temperature with mean annual air temperature during the period being +15.3 °C. Mean air temperature during vegetation (from April 1, 2015 to September 30, 2015) and non-vegetation period (from October 1, 2014 to March 31, 2015) was +23.7 and +5.9, respectively. Mean wind velocity during 2001-2015 was 1.2 with daily value fluctuating from 0 to 8.0 m s^{-1}. Mean relative humidity (RH) during 2001-2013 was 64%. The average daily RH during non-vegetation period (October, 2014-March, 2015) and vegetation period (April-September, 2015) was 78 and 55%, respectively. Mean daily sunshine duration hours during 2001-2015 was ranged from 3.3 to 8.0 hours with maximum being 13.8 hour per day. Precipitation data shows that there was relatively similar rainfall during the growing season in 2014 (68 mm) and 2015 (59 mm) compared the 13-yr average annual precipitation (67 mm). However, this amount is not evenly distributed throughout the year and about 64% of rainfall falls during non-growing period (October-March). Reference evapotranspiration (ETo) during 2001-2015 was fluctuated from 0.3 to 10.3 mm day^{-1} with mean value for the period – 3.2 mm day^{-1}. Total calculated ETo for vegetation period in 2014 and 2015 as well as non-vegetation period in 2014-2015 was 1100 and 850 mm and 215 mm, respectively.

Lithological structure is presented by melkozems and sandy stratum with lesser depth. According the Russian classification, soils are calcic sierozem and loams are less permeable (percolation rate 0.2 to 2.0 m day^{-1}). They are formed on alluvial-proluvial deposits of talus train. According to the FAO classification, soils are calcaric gleysols (Gc) (FAO, 2003) in which there is substantial secondary accumulation of lime and has a gleyic colour pattern. According to the World reference base for soil resources (WRB, 2006), common name for many Gleysols is gley and meadow soils. In terms of hydrology, the study site is located within the area of a shallow water table and groundwater discharge zone influenced by both groundwater and artesian water. Artesian water is exposed at a depth of 120-200 m and is related to sandy-gravel sediments of Golodnostepsky and Tashkent system. Groundwater fluctuation is 1.0-2.6 m (even shallower during irrigation events) and located within sandy loam and loam layers with salinity ranging from 2.9 to 4.6 g l^{-1}. Groundwater salinity is higher at deeper levels. Chemical composition of groundwater is sulphate-chloride and sulphate. Water table gradient is northwestward with a gradient of 0.002-0.0025 that indicates weak drainability.

Agronomical practices and phenological observation

Winter wheat (*Triticum aestivum* L.) variety "Tanya" was sown by broadcasting with a seeding rate of 240-260 kg ha^{-1}, under not yet harvested cotton on October 7-8, 2014 in C-13/14 and October 15, 2014 in C-15/16. One or two times cultivation was conducted in cotton fields before and after wheat has been sown in order to incorporate seeds into the soil. Plant density was ranged from 228 (plot #5) to 507 (plot #1) plants m^{-2}. Fertilization was carried out by tractor-broadcast (with aggregate NRU-0.5). The total amount of nitrogen (N) comprised 250-275 kg N ha^{-1} (in nutrient form) during the growing season of wheat. N was applied in three splits during the growing period. Six irrigations with gross amount of 530 and 550 mm have been carried out during wheat growth period at C-13/14 and C-15/16, respectively (Tab.1). The length of the total growing period (life cycle) of wheat ranged from 246 (C-15/16) to 250 (C-13/14) days. Phonological observations of wheat (plant height and root depth at bi-weekly interval and plant density at maturity and yield at harvest) were performed at 7 plots with plot size of 1 m^2 following the approach proposed by Dospekhov (1985). In addition, soil moisture, soil salinity and groundwater table (GWT) were measured routinely using state-of-the-art devices nearby phonological plots (see Fig.2). Installed state-of-the-art devices are described in following sections.

Table 1. Gross irrigation amount for winter wheat in fields C-13/14 and C-15/16

Irrigation No.	Date of Irrigation		Gross irrigation (mm)	
	C-13/14	C-15/16	C-13/14	C-15/16
1	13-14.10.2014	16-24.10.2014	125	75
2	20-26.01.2015	12-20.01.2015	119	129
3	18-23.03.2015	12-20.03.2015	109	83
4	23-28.04.2015	25-30.04.2015	61	87
5	10-19.05.2015	13-20.05.2015	92	133
6	29.05-06.06.2015	29.05-06.06.2015	27	40
Total			**533**	**547**

Design characteristics of the tile drainage system

The site is bordered with open drainages (OD-1 and OD-2) at the south and south-east, road at the west and collector "Srednekyzyltepa" at the north-west (see Fig.2). Two closed horizontal drainages (CHD) made out of asbestos-cement tubes perforated from bottom with 11 openings (Ø= 0.8 cm) at 1 m length and surrounded by sand-gravel as a filter (Shamsutdinov, 1966). The specific length of subsurface drainage is 25 m length per hectare. The drainages are operating since the last 55 years. Both drainages discharge their water into the collector "Srednekyzyltepa", which has a depth of 3.5-3.7 m, bottom width – 1-1.5 m and bank slope - 1:1.25-1-1.5. The designed parameters of the CHD are given in Tab.2. Two and three observation wells (inspection sump) made from reinforced concrete with depth and diameter -100x100 cm are installed with four sections at the CHD-1 and CHD-2, respectively (Fig.3A). However, one out of two observation wells was operating in CHD-1 before start of the design. Hence, the second well was cleaned as well in order to create a free water flow into the collector.

Table 2. Designed parameters of the subsurface horizontal drainages in experimental site

Sub-surface drains #	Service area (ha)	Depth (m)	Slope	Distance (m)	Length (m)	Inner diameter of pipe (mm)	Pipe type	Designed modulus ($ls^{-1}ha^{-1}$)
CHD-1	40	3.2	0.0025	250	1670	147	asbestos-cement	0.17
CHD-2	20		0.002		750			

Experimental design

Installation of control structure

Based on existing groundwater control construction techniques (Nyvall, 1998; Singh, 2013; Wesström et al., 2014), the polyvinyl chloride (PVC) risers on the drainage laterals to control drainage outlet used by Hornbuckle et al. (2005) seemed to be more practical and cost effective. Hence, a similar PVC riser was developed manually and entered into a drainage pipe outlet in the monitoring well (inspection sump) in order to grab free water flow. Sump sections are hermitically sealed with cement and further covered by bitumen in order to prevent raised water outflow from the sump. The 3rd and 4th sections of the inspection sump was marked with the red and blue color with 10 cm scale increments in order to easy eye monitor water level rise between the drainage pipe bottom and riser opening (Fig.3B).

In this experiment, the CHD-1 was leaved as free outlet drain due to difficulties in cleaning the drainage pipe. Therefore it operated on submerged mode during the observations and considered as a similar with controlled drainage. For controlled drainage, the CHD-2 was considered. Outlet was closed at two sections of the CHD-2 pipe line (e.g., at the inspection sump #A and B, see Fig.2). Water exited through outlet A, when the water table rose above the desired 90 cm level, was then captured at outlet B. Raised water table above the desired level at outlet B thereafter flowed freely into the open collector "Srednekyzyltepa".

Monitoring of drainage water flow volumes and salinity was undertaken at both drainage outlets (mouth). Drainage volume was measured in a 5-10 days interval (daily during irrigation events) with already installed weir "Chippoletti" with bottom width – 50 cm. Drainage salinity was measured in-situ using ES-2 sensor (Decagon Devices, Inc.) and ProCheck handheld reader (ICT International).

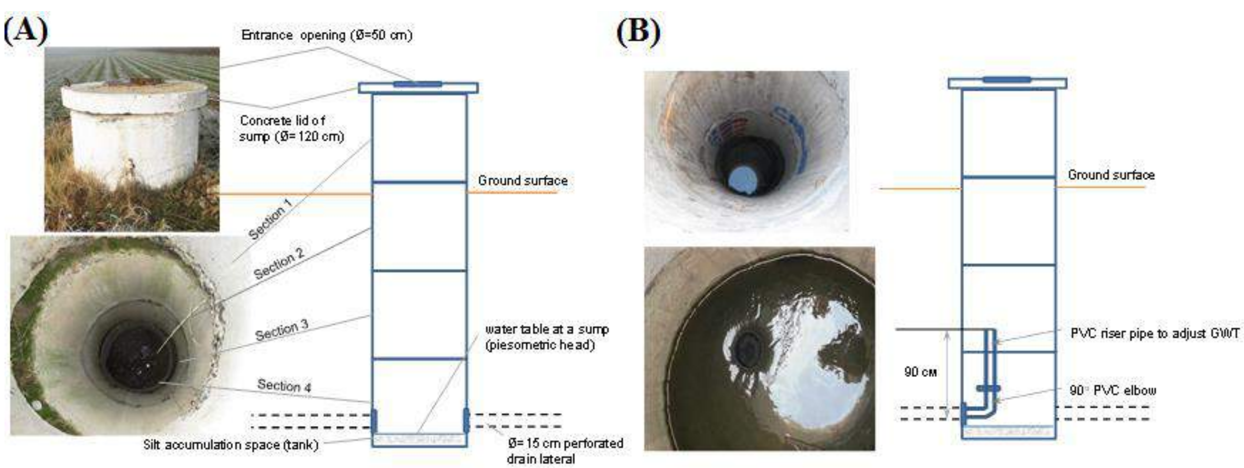

Figure 3. Cross-section of inspection sump (A) and raised water table after installation of pipe riser on lateral drain (B)

Installation of groundwater table monitoring piezometers

In total 22 piezometer wells were installed (see Fig.2 for location) using hand operated auger drill in the experimental site to study groundwater regime between subsurface drainages. Wells are made out of polyvinyl chloride (PVC) pipe (Ø 40 mm), with a length of ~ 3.33 m, perforated (Ø 3-4 mm) from the bottom depth of 1.2 m and covered by thin synthetic material (Ø 0.3 mm, approximately) as a filter to prevent silting. Man-made flap (*xlopushka*) and 3.5 m ruler type were used to measure GWT. Measurements are performed with frequency of 5-6 days during October 26, 2014 to June 15, 2015.

Installation of state-of-the-art devices

The following devices were installed near to the phenological plots:

Four 5TE sensors (Decagon devices, Inc.) with increments of depth 0-30, 30-60, 60-90 and 90-120 cm and one CTD-10 sensor (Decagon devices, Inc.) were installed nearby piezometer at the phenological plots #1, 2, 3 and 6. In addition five 5TE sensors with increments of depth 0-30, 30-60, 60-90, 90-120 and 120-150 cm were installed into phenological plot #5. All these sensors were wired into EM50G data loggers on March 3-4, 2015 and removed on June 14-15, 2015 before harvest of winter wheat. Measurements are done in an hourly basis.

Results and discussion

Crop growth

At sowing date till emergence (9-10 days), mean daily air temperature ranged from 12.5 to 15.6 ^{o}C. Prolonged periods below 5 ^{o}C (Nov. 26, 2014 - Feb. 22, 2015) caused dormancy in wheat. Optimum growth was started when mean daily temperature was between 15 and 23 ^{o}C. Grain filling was started on May 20-25, 2015 when mean daily temperature was ranged between 21-25 ^{o}C.

Fig.4 shows development of height and rooting depth at 7 phenological plots during main growing period of wheat. Based on this figure, it can be noted that plant height on May 30, 2015 (maturity stage) is relatively taller at plots ## 2, 4 and 5 (along the CHD-2), ranging from 79.5 to 104 cm, whereas plant root depth is shallower, e.g., 59-64 cm at these plots compared those at plot ## 1, 3 and 6 (74-77 cm and 59-71 cm). From these values, it is evident that root depth at the plots aside from the CHD-2 line is penetrated deeper due to increase in water table depth. In contrary, lower root depth of ## 2, 4 and 5 plots mainly resulted from the restriction of water table on the downward penetration of root system. Brisson et al. (2002) reported that root growth slowed down and stopped when oxygen concentration of the soil was below a critical value due to saturated soil moisture content. This indicates that shallower groundwater level increase plant root water uptake and thus reduces root development. These parameters at plot # 7 (in-between CHD-1 and CHD-2) are almost the same as observed at plot # 6.

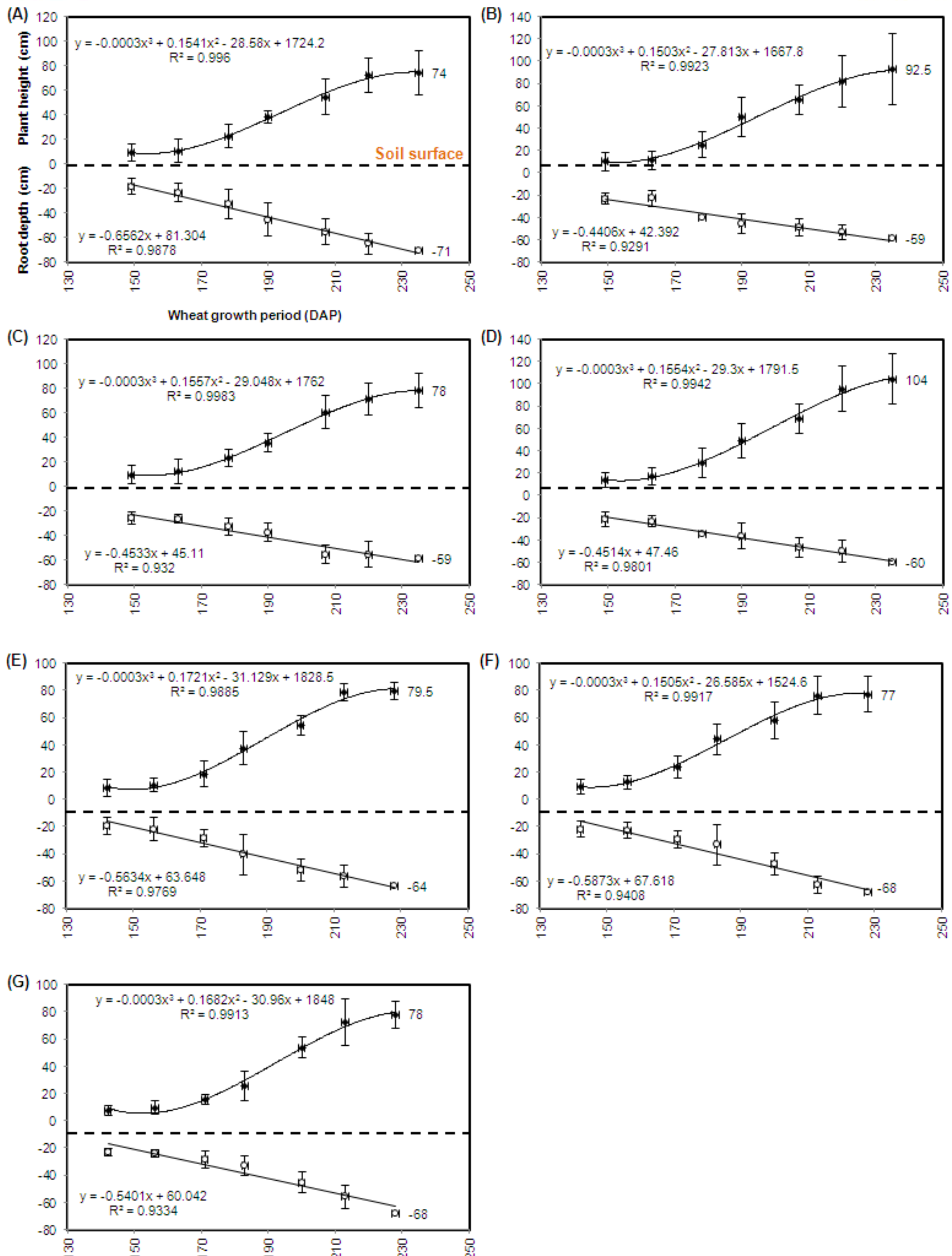

Figure 4. Dynamics of height and rooting depth of winter wheat during the growth period (day after planting, DAP) at Plot #1 (A), Plot #2 (B), Plot #3 (C), Plot #4 (D), Plot #5 (E), Plot #6 (F) and Plot #7 (G) (for plot location refer Fig.2)

Drainage control structure

The overflow level of the drainage monitoring well at the sections # A and B is presented in Fig.5. The overflow levels of the drain outlets were elevated for the first time in March 20, 2015 when

3rd vegetative irrigation was started in C-13/14 (during that time it was completed in field C-14/15). Although irrigation was started on March 18 at C-13/14, the initial overflow level was raised up to 45 and 70 cm above the drain outlet levels at monitoring wells # A and B, respectively. Due to finishing the 3rd irrigation at field contour C-15/16 on March 20, the maximum overflow level at well # B was smaller (111 cm) compared well # A (200 cm). Starting in third decade of April, when 4th vegetative irrigation was initiated, the overflow levels raised from 58 and 68 cm up to 158 and 148 cm in well # A and B, respectively. It should be noted that the control structure was not removed during the vegetation period of wheat. This is due to fact that existing open drainage (OD-2) and collector (Srednekyzyltepa) as well as existence of sand and sand-gravel layers at the depth of 1.5-1.75 m, apart 30-75 m from the tile drain CHD-2 line in the C-13/14 had a greatest impact on maintaining groundwater table. This enabled to maintain water table between 90-251 cm above drainage pipe level throughout 5th to 6th irrigations.

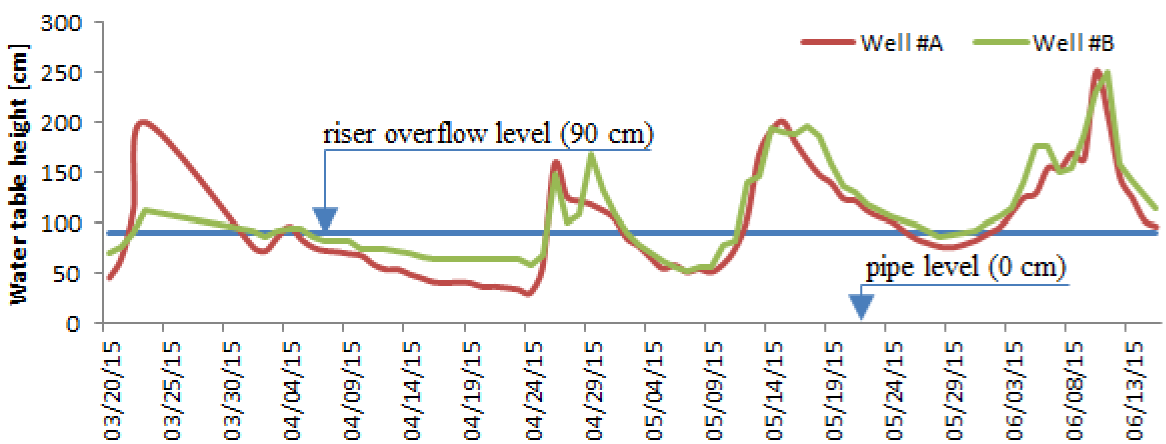

Figure 5. Relative water level (below fixed riser at 90 cm) and overflow level (above the fixed riser at 90 cm) from drainage installation depth at the drainage wells # A (C-13/14) and B (C-15/16)

Soil moisture

Soil moisture measured by 5TE sensor from March 4 to April 16 at Phenological plots ##1 (A), 2 (B) and 3 (C) (C-13/14) is given at Fig.6. Hence, the irrigation in each application is rotated within a field (e.g., 60-100 furrows simultaneously irrigated within a day then water is applied for the next 60-100 furrows following day and so on), the rise of soil moisture content (SMC) is concomitant to that point where irrigation water reaches (both vertical profile as well as spatial scale). This can be seen at Fig.6A, e.g., 3rd vegetative irrigation was started on March 18 while water reached the phenological plot #1 on March 20 at 3:30 PM (e.g., after two days) increasing SMC from 18.8 to 20.0 %vol at 30 cm depth soil profile with maximum - 34.5 %vol at 12:00 AM on March 21. Thereby SMC rise at the vertical profiles delays from upper soil (3:30 PM for 30 cm) to lower soil (6:30 PM for 120 cm). Consequently applied irrigation water reach phenological plot #2 and plot #3 on March 22 (4:30 PM, Fig.6B) and on March 24 (1:30 AM, Fig.6C), respectively.

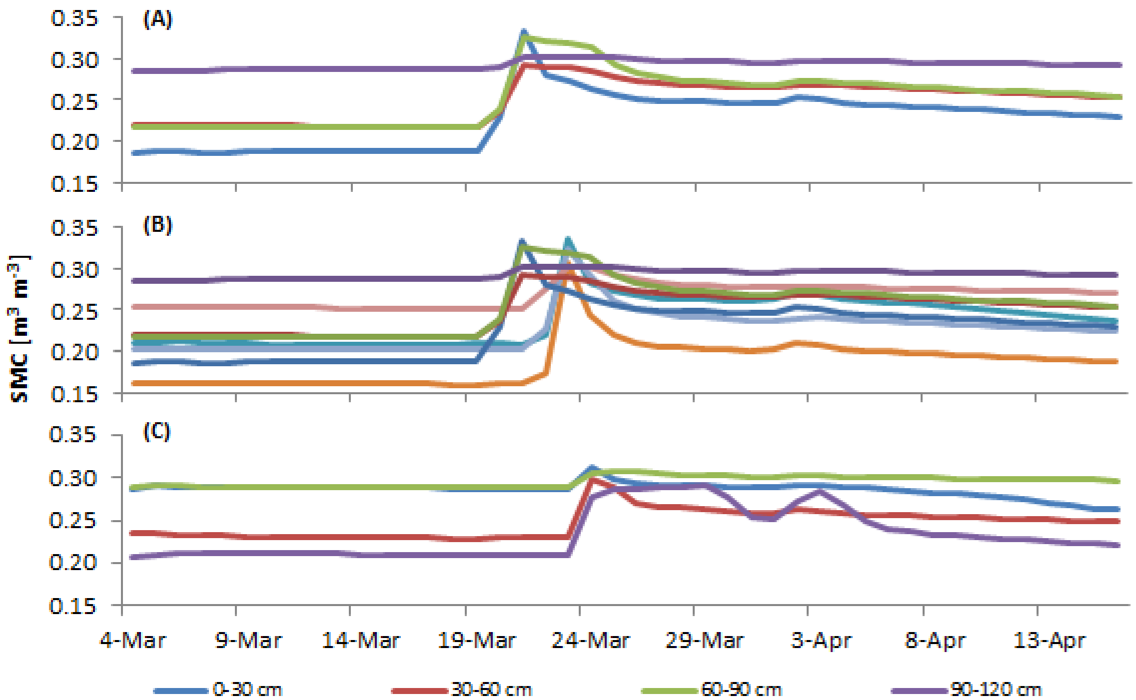

Figure 6. Dynamics of soil moisture content (m^3 m^{-3}) during 2nd irrigation of winter wheat at phenological plots # 1 (A), 2 (B) and 3 (C) in field C-13/14

Groundwater table

Groundwater table (GWT) measured by CTD-10 sensor during 3rd irrigation of wheat is given at Fig.7. The graph shows that water levels tend to increase gradually, indicating delayed response to the input of irrigation water from phonological plots #1 to 3. In fact, the maximum rise of the GWL (even though irrigation was started 1-3 days before) was concomitant with irrigation of the part of the field where the piezometers are located. During the third irrigation of wheat, in phenological plot # 1 located mid-point of drainages CHD-1 and CHD-2, the duration to rise GWL from 180 cm up to 20 cm was 1.5 days (excluding irrigation start of 3 days), while it took 11 days to drop down to the initial level (180 cm) (Fig.7). Similarly the third irrigation of wheat in phenological plot # 3 located mid-point of drainage such as CHD-2 as well as open drainage OD-2, the duration to rise GWL from 180 cm up to 25 cm was 1 day (excluding irrigation start of 3 days), while it took 6.5 days to drop down to the initial level (180 cm). In general, in the part of the plots (## 1&3) located at the drain mid-spacing, the lagging of GWL lowering is higher, i.e. this process is slower. Whereas, it took 1.4 days (excluding irrigation duration - 3 days) to raise the GWL from 180 cm up to 3 cm and 6.2 days to drop down till 180 cm, i.e. the rate of drop is 4-fold longer of that of rise.

It can be concluded that close up of the regulation structure during irrigation in observation well # A at CHD-2 prolonged GWT drop down on 11 days at the mid-space of CHD-1&2 thus maintain soil moisture for the longer periods. This duration should be longer at phenological plot #5 in C-15/16 due to its location from closed drain outflow at observation well #B.

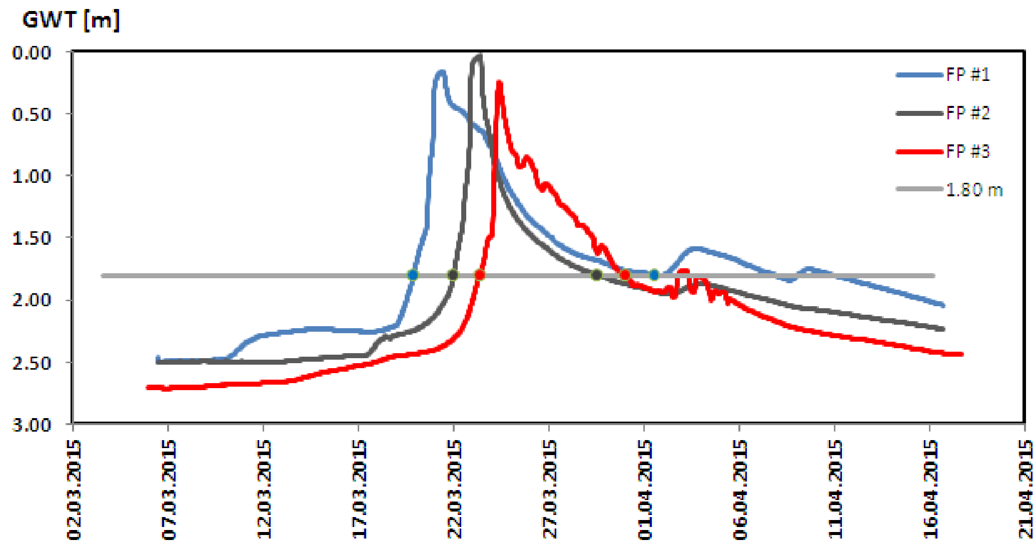

Figure 7. Accession and recession of the GWT during the second irrigation of winter wheat in C-13/14 measured using CTD-10 (30-min interval) at phonological plots ## 1-3 in 2015 (straight horizontal line is given for comparison purpose)

Mean water tables manually measured from 22 wells in total at C-13/14 and C-15/16 for the wheat growing period is presented in Fig.8. The rise of GWT in the hydrograph indicate that all irrigations (including charging irrigation during October 25-November 11, 2014, not shown) at the both fields were concomitant with application dates (refer to Tab.1). In addition, it can be seen from the hydrographs that two fields showed some delay of water table peak during periods of high recharge (during irrigation events).

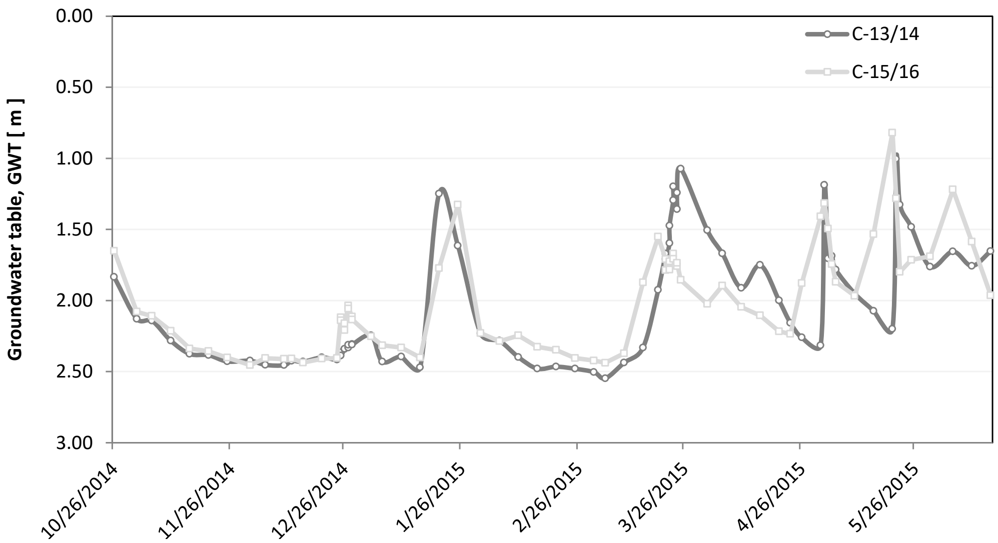

Figure 8. Dynamics of GWT (averaged from 11 wells in each field)

Water fluxes

The effect of controlled drainage experiment was evaluated by comparing a ratio of the field parameters between transects #A and #B (1) vs. #B and collector "Srednekyzyltepa" (2) along the CHD-2 (Tab.3). The ratio of soil water content in the 1.2 m soil profile between (1) and (2) was 1.20 which suggested that the upper part of the field contained more soil moisture for the crop to utilize during the growing period compared with the lower portion of the field. Conversely, the ratio of the water table depth between (1) and (2) was 0.78 indicating that the water table of the upper portion of the field was 47 cm (22%) shallower than the lower part (Tab.3). Thus, subsurface irrigation increased the moisture storage of the soil layer at the upper part of the field compared with the lower part.

The most important quantitative hydrological monitoring results are summarized in Fig. 9. This graph presents the irrigation and precipitation amount, soil moisture content, groundwater levels and drainage amount at 5 phenological plots during March 3, 2015 to June 15, 2015. Although the 3rd vegetation period irrigation was started on March 18, 2015, applied water is reached to phenological point #1 after 3 days, hence average weighted soil moisture at 1 m soil profile and GWT are raised from 22 %vol to 32 %vol and from 220 cm up to 27 cm, respectively (Fig. 9A). Based on this graph it can be noted that soil moisture at the phenological plot #5 (Fig. 9D, between transects A and B) is fluctuated lesser compared other plots due to closed drainage outflow during the period. The average soil moisture content during the study period (i.e. ≈0.31 m^3m^{-3}) at maximum root zone distributions (90 cm) in phenological plot # 5 (Fig. 9D) were not much different from the average field capacity values (i.e. ≈0.30 m^3m^{-3}). As expected, the average root zone soil moisture content under plot ## 3 and 5 (0.27-0.30 m^3m^{-3}) was greater than those observed at plot ## 1 and 6 (0.24-0.25 m^3m^{-3}), because closed outflow of the tile drainage CHD-2.

Table 3. Average values of field parameters and its ratio between upper part of the drainage field (transects A and B) and lower part (transect B and collector) measured during March 3-June 15, 2015

Parameters	Statistics	Transects A and B (1)	Transect B and collector (2)	Ratio (1)/(2)
Soil water content at 0-120 cm soil profile	Minimum (mm)	220.3	117.4	1.88
	Maximum (mm)	354.7	355.8	1.00
	Mean (mm)	298.6	248.1	1.20
	Standard deviation (mm)	29.9	45.5	
	Coefficient of variation (%)	10.0	18.3	
GWT	Minimum (cm)	64.0	86.3	0.74
	Maximum (cm)	242.0	249.6	0.97
	Mean (cm)	163.5	210.4	0.78
	Standard deviation (cm)	38.0	35.7	
	Coefficient of variation (%)	23.3	17.0	

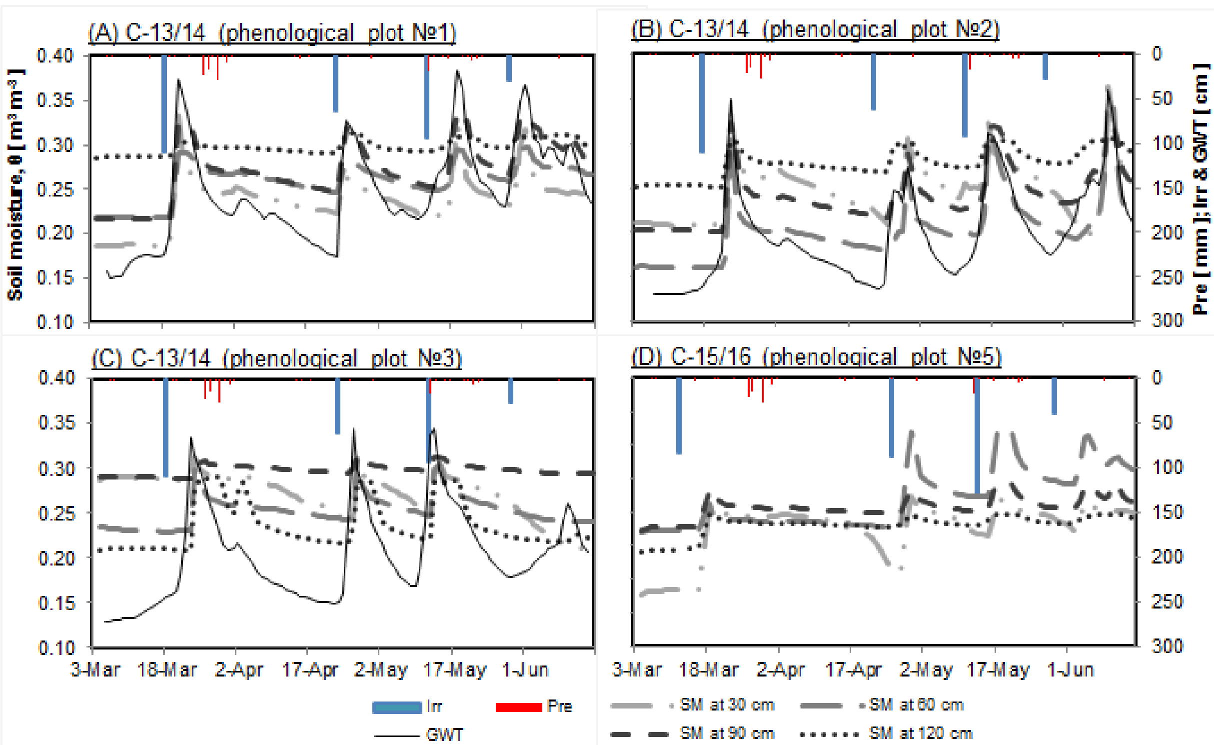

Figure 9. Combined results of hydrological measurements (Irr: irrigation, cm; Pre: precipitation, mm; GWT: groundwater table, cm; soil moisture, m^3 m^{-3}) at phenological plots #1 (A); #2 (B); #3 (C); #4 (D)

Crop yield

The yields and its components under different soil moisture conditions and groundwater table were presented in Tab.4. The results suggested that, soil moisture content had notable effect on the yield of winter wheat (Fig.10A). However, shallow GWT was negatively affected to grain yield (Fig.10B). It was consistent with the finding in other studies which were under the irrigation condition (Karimov et al., 2014). The maximum yields were 429 and 506 g m^{-2} in phenological plots # 2 (average soil moisture content ≈0.24 m^3m^{-3}) and # 4 (0.34 m^3m^{-3}), respectively. The root zone moisture content in phenological plots # 1 (≈0.26 m^3m^{-3}) and # 3 (≈0.27 m^3m^{-3}) produced lower yield (Tab.4).

Table 4. Wheat yields under mean soil moisture content and groundwater table from March 3 to June 15, 2015

Parameters	Phenological plots ##						
	1	2	3	4	5	6	7
Grain yield (g m^{-2})	276	429	298	506	434	465	356
Soil moisture content (m^3 m^{-3})	0.26	0.29	0.27	0.34	0.30	0.28	0.31
GWT (cm)	154	201	197		163	210	157

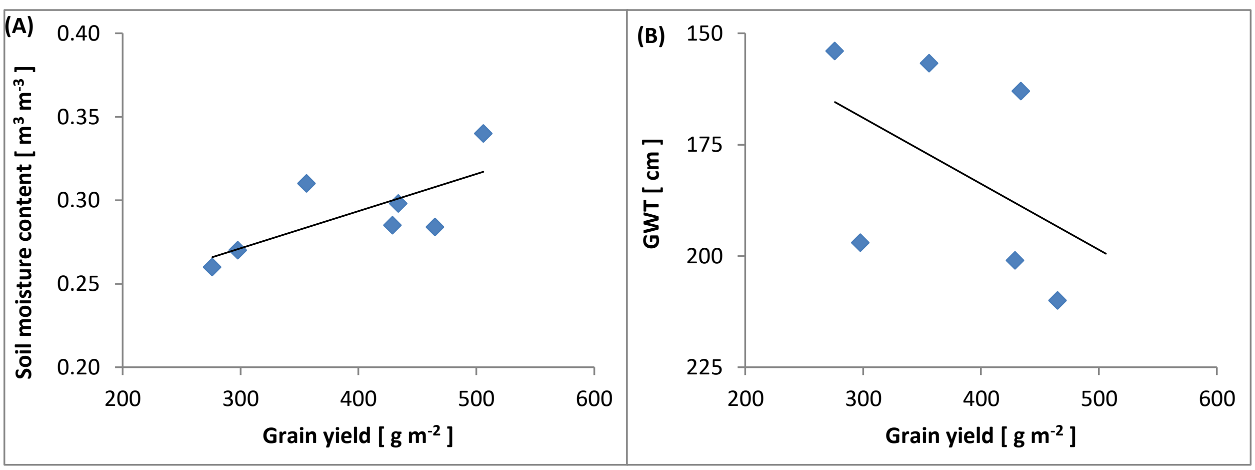

Figure 10. Wheat yield trend at the 7 phenological plots under average soil moisture content (A) and GWT (B) levels

Conclusion

Our experimental setup produced valuable insights in the hydrological effects of controlled drainage. The introduction of controlled structure on tile drainage at the monitoring well increased the soil moisture storage in the studied field-site.

Studies suggests, that it is possible to control the water table depth at monitoring wells. However, it is difficult to manage irrigation and drainage system at the larger fields to control groundwater table and assess its impact on maximizing crop yield. Nevertheless, this study is helpful to manage irrigation and control shallow water tables and the results of the study can support the first view of controlled drainage studies that provide good short-term returns in the form of higher crop yields due to reduced water deficiency stress.

Based on the findings from this experiment, the following recommendations can be highlighted:

- a new approach, e.g., integrated irrigation and drainage water management system is needed in order to apply controlled drainage management. This implies interactivity between the operation of the irrigation system and the management of the drainage system. In this instance, the drainage system will be managed to control the flow and water table depth in the course of time in response to the irrigation management and deep percolation;
- control of the water table at the inspection sump is possible using manually developed PVC riser, but is only feasible in flat lands because of the alignment of the subsurface drains relative to the grade of the field surface. However, careful selection of proper drainage site is needed. For controlled drainage to be effective, soil texture under the site selected, has to be more or less homogeneous with less or no sand and sand-gravel layer near the control structure. In addition, one has to be sure that tile drainage pipe has no perforations near to control structure in the monitoring sump. These implies consideration of structures in future for the control of the water table position in new tile drainage system design;
- careful monitoring of all water balance components and irrigation water management will be required when implementing controlled drainage.

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References

Ayars, J.E., 1996. Managing irrigation and drainage systems in arid areas in the presence of shallow groundwater: case studies. Irrig. Drain. Syst. 10, pp. 227–244

Ayars, J.E., Schoneman, R.A., 2006. Irrigating field crops in the presence of saline groundwater. Irrig. Drain. 55, pp. 265-279.

Berdjansky V., Zaks I., 1996. Environmental benefits of reducing collector-drain runoff and ways to improve irrigation water quality in the rivers of the Aral Sea basin, in: The Inter-Relationship between Irrigation, Drainage and the Environment in the Aral Sea Basin. Springer, pp. 21–26.

Brisson N., Rebisre B., Zimmer D., Renault P., 2002. Response of the root system of a winter wheat crop to waterlogging. Plant Soil 243, pp. 43-55.

CAWATERinfo, 2016. Regional Information System on Water and Land Resources in the Aral Sea Basin (CAREWIB). Scientific Information Centre of ICWC, Tashkent. http://www.cawater-info.net (last cited 27.10.2016).

Dospekhov B.A. 1985. Methodology of field experiments. Moscow, Agropromizdat. p.351. (in Russian).

Dukhovny V.A., Baklushin M.B., Tomin E.D., Serebrennikov F.V., 1979. Horizontal drainage in irrigated lands. Moscow, Kolos, p. 255 (in Russian).

Dukhovny V., Umarov P., Yakubov H., Madramootoo C., 2007. Drainage in the Aral Sea Basin. Irrigation and Drainage 56, pp. S91-S100.

Dukhovny V., Yakubov Kh. Umarov P., 2005b. Relationship between irrigation and drainage. In: Pereira et al. (Eds.) Irrigation management for combating desertification in the Aral Sea basin. Assessment and tools. INCO-Copernicus, Vita Color, Tashkent, pp. 271-285.

Dukhovny V., Yakubov Kh., Umarov P., 2005a. Drainage and salinity control: review of related problems in Central Asia. In: Pereira et al. (Eds.) Irrigation management for combating desertification in the Aral Sea basin. Assessment and tools. INCO-Copernicus, Vita Color, Tashkent, pp. 249-270.

FAO, 2003. Fertilizer use by crop in Uzbekistan. Food and Agriculture Organization of the United Nations, Rome, Italy, p. 41.

Hornbuckle J.W., Christen E.W., Ayars J.E., Faulkner R. D., 2005. Controlled water table management as a strategy for reducing salt loads from subsurface drainage under perennial agriculture in semi-arid Australia. Irrigation and Drainage Systems 19, pp. 145-159.

Hutmacher, R.B., Ayars, J.E., Vail, S.S., Bravo, A.D., Dettinger, D., Schoneman, R.A., 1996. Uptake of shallow groundwater by cotton: growth stage, groundwater salinity effects in column lysimeters. Agric. Water Manag. 31, pp. 205-223.

Ikramov R., 2007. Underground and surface water resources of Central Asia, and impact of irrigation on their balance and quality. In: Lal R. et al. (Eds.) Climate change and terrestrial carbon sequestration in Central Asia. Taylor & Francis Group, London, UK, pp. 97-107

Karimov A., Simunek J., Hanjra M., Avliyakulov M., Forkutsa I., 2014. Effects of the shallow water table on water use of winter wheat andecosystem health: Implications for unlocking the potential ofgroundwater in the Fergana Valley (Central Asia). Agricultural Water Management 131, pp. 57-69.

Kenjabaev Sh.M., 2014. Ecohydrology in a Changing Environment. PhD Dissertation. Cuvillier Verlag, Gottingen, Germany, p. 191 (ISBN 978-3-95404-865-6).

Kottek M., Grieser J., Beck Ch., Rudolf B., Rubel F., 2006. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, Vol. 15, No. 3, 259-263.

Madramootoo C. A., Johnston W. R., Ayars J. E., Evans R. O., Fausey N. R., 2007. Agricultural drainage management, quality, and disposal issues in North America. Irrigation and Drainage 56 (S1), S35-S45.

Nyvall J., 1998. Controlled Drainage/Subirrigation. Drainage factsheets, Order No. 564.000-1, Ministry of Agriculture and Food, British Columbia, p. 10.

Shamsutdinov E.Sh., 1966. Experience to use closed drainage in Central Fergana (Opyt primeneniya zakrytogo drenaja v Centralnoy Fergany), Fan, Tashkent, p. 30.

Singh A. K., 2013. Water and nitrogen use efficiency of corn (Zea mays L.) under water table management. PhD Dissertation. Department of Bioresource Engineering, McGill University, Montreal, Canada, p. 169.

Singh A. K., Madramootoo C. A., Smith D. L., 2014. Impact of different water management scenarios on corn water use efficiency. Transactions of the ASABE 57(5), pp. 1319-1328.

Stulina G., Cameira M., Pereira L., 2005. Using RZWQM to search improved practices for irrigated maize in Fergana, Uzbekistan. Agricultural Water Management 77, pp. 263-281.

Wesström I., Joel A., Messing I., 2014. Controlled drainage and subirrigation - A water management option to reduce non-point source pollution from agricultural land. Agriculture, Ecosystems and Environment 198, pp. 74-82.

WRB, 2006. World reference base for soil resources 2006. A framework for international classification, correlation and communication. IUSS Working Group, World Soil Resources Reports No. 103. FAO, Rome, p. 145.

DRAINAGE WATER MANAGEMENT BY FUZZY ANALYTICAL HIERARCHY PROCESS MODEL FOR THE DECLINE OF DRAINAGE WATER VOLUME

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Abstract

In the past decade, major changes in water management in arid and semi-arid areas have emerged. Previously, the focus was on the design and management of irrigation systems and subsurface drainage to compensate for shortcomings. A result of the previous design was high deep percolation losses which led to greater than necessary drainage. The selecting of the depth of drains in the past resulted into large spacing between the drainage pipe and saved costs. These systems reduced cumulative salt in the root zone, causing the low quality water to flow into groundwater sources. To minimize the short-term and long-term detrimental effects of drainage water on the environment, plant products, soil fertility and water quality, in addition to paying attention to the decline of drainage water volume issues is important. Hence, the aim of the present study is to prioritize and assess influencing factors in prioritizing the preference of drainage water management specialist using fuzzy AHP.

Analytical hierarchy process (AHP), multi-attribute utility theory, outranking theory and goal programming are among the most common used multi-criteria methods. Although AHP has had a great potential in the evaluation of multi criteria options, it is not compatible with existing uncertainties in paired comparisons and their effect in the selection process. Therefore, in recent years, the application of of Multi-criteria decision-making methods has been expanded. Fuzzy multi-criteria decision making methods are combined with fuzzy logic and multi-criteria decision processes. The numbers used in this procedure are fuzzy triangular numbers.

In this study, water conservation, Drainage water reuse, drainage water disposal and drainage water purification were reviewed. The model includes the steps of problem definition, calculation, and ranking of drainage water management options and fuzzy hierarchical structures that

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encompass three targets, in addition to the main criteria and sub criteria. In order to select the criteria, sub criteria and factors and determine the relative importance of each of them, researchers and experts' opinions, as well as a summarizing of the results of the questionnaire were used. In the next step, using Chang's extent analysis, various water management options based on the criteria and sub criteria and selected factors were evaluated. The results show that water conservation is the most important option in drainage water management. Among the sub criteria water conservation, and source reduction are the highest priority. Among the main criteria of drainage water management the second priority is placed on the reuse of water. Among its sub criteria wildlife and wetland criteria, with a weight factor of 0.260 is the most important. Sequential use of drainage water criterion of with a weight factor of 0.248 is the second priority .

The treatment and disposal of drainage water are the third and fourth priorities respectively. Among the disposal of drainage water sub criteria, draining into oceans and salt lakes are the best options. The physical – chemical index among drainage water treatment options with a weight factor of 0.605 has a higher priority than the biological index.

KEY WORDS**:** Drainage water management, Fuzzy hierarchical analysis, Resource conservation, Reuse of drainage water, Sequential use of drainage water.

Introduction

In the past decade, major changes in water management in arid and semi-arid areas have emerged. Previously, focus was on Design and management of irrigation systems and subsurface drainage to fix shortcomings. A result of the previous design was High deep percolation losses which led to high draining. Selecting depth of drains in the past caused the large distances between the drainage pipe and save the costs. These systems are to reduce Cumulative salt in the root zone, causing the low quality water flow into groundwater (Chang et al., 2014).

After the World Summit in 1992, the International Committee on Irrigation and Drainage focused his full attention on the management of drainage water. So not only need for drainage as Critical Supplements for irrigation development in arid and semiarid areas was emphasized , but also simultaneously emphasis was placed on the conservation and reuse of fresh water resources in concept of Integrated Resource Management .

For the present drainage system, a number of available options of drainage water management for achieve the goals of development is available. These options can be divided into four major groups "water conservation, reuse of drainage water, the disposal of drainage water and drainage water treatment". Each of these options has certain potential effects on Hydrology and Water Quality of region. Thus, planners, decision makers and engineers for choosing among different options and to assess the impact and contribution of each for achieving the development goals, need certain framework. Furthermore, in order to achieve a superior selection from value of effect of distinctive options, technical expertise's opinion and guidelines for each of the options are needed.

Analytical hierarchy process (AHP), multi-attribute utility theory, outranking theory and goal programming are among the most common used multi-criteria methods. AHP is broadly applied in preference analysis of complex and multi-attribute issues (Varis 1989). By its flexibility in setting the objectives ,AHP can proportionate the qualitative and quantitative decision attributes (Kangas, 1993). According to Alphonce (1997), AHP can eliminate certain decision problems in agriculture.

Although AHP has great potential in the evaluation of multi criteria options, but is not able to impose on existing Uncertainties in paired comparisons and their effect in the selection process (Hajeeh, 2010). Therefore, in recent years, using of Multi-criteria decision-making methods has been expanded. Fuzzy multi-criteria decision making methods are combined of fuzzy logic and multi-criteria decision processes (Chang, 1996). Chang in 1992 provided a very simple way to expansion of AHP to fuzzy space. The numbers used in this procedure are fuzzy triangular numbers. This method is based on the *arithmetic mean,* expert's opinion and Saaty's *normalization* method (Chang, 1996).

From conducted researches with fuzzy AHP in irrigation systems and water resources can be mentioned the fuzzy hierarchical model for the assessment of global water partnership (GWP) Irrigation and Drainage Networks .Montazar and Zadbagher (2010) developed an analytical hierarchy model for assessing the Global Water Productivity (GWP) status of irrigation networks. For this purpose 14 criteria, affecting water productivity, and 14 major modern irrigation networks of Iran are analyzed. Dez and Saveh irrigation networks, with the relative weights of 0.112 and 0.045, show the highest and lowest GWP, respectively. The results obtained by AHP model are in good agreement with the results determined from the field survey.

Srdjevic and Medeiros (2008) introduced a fuzzy AHP methodology for solving fully structured decision problems with criteria, sub-criteria and alternatives. The introduced methodology was applied for the evaluation of water management plans in part of the Paraguacu River Basin in Brazil.

In other research, irrigation networks by Montazar et al (2013) are investigated. four irrigation projects is applied in this research and the results is showed that the managerial criterion has the greatest impact on the assessment process .The technical, social, economical, and environmental criteria rank next in effectiveness, respectively .Hence, in order to improve irrigation system performance, all rehabilitation tasks should focus more on the managerial issues.

Fuzzy hierarchy process is applied to improve irrigation project. The results is showed that irrigation professionals give the first priority to water delivery services project-wide and they consider that irrigation hardware of primary canals is more important than that of secondary canals(Okada, 2008).

Since achieving a superior choice among the effect of distinctive options, needs technical expertise and Instructions for each of the options. The aim of this study is to propose an appropriate priority for various metrics of agricultural drainage water Management Using hierarchical fuzzy model.

Materials and Methods

The purpose of this study is to identify and set priorities infrastructures of agricultural drainage water Management with fuzzy AHP approach. Based on algorithm research, first, Determining criteria Priority, and infrastructures of agricultural drainage water management will be discussed. For setting priorities in agricultural drainage water management AHP technique with fuzzy approach is used. *Analysis of* data was performed in Excel software environment and Coding was done in Visual Basic.

To determine the priority of the performance factors technique of fuzzy analytic hierarchy process (FAHP) is applied. The analysis is as follows :

1- Paired comparisons on the main criteria based on the purpose and determine weight of main criteria

2- Paired comparison on sub criteria of each criterion, and determining the weight of each sub criteria cluster

3- Weight of sub criteria multiplied by the weight of relevant criteria to determine the final weight of sub criteria

The first step of this study was to Set Priorities of criteria and sub criteria of agricultural drainage water Management. Basic infrastructures for the management of agricultural drainage waters in this study include water conservation, reuse of drainage, effluent disposal and effluent treatment. For each of these criteria, indices have been considered. So in total 24 the sub criteria have been chosen. Also criteria and sub criteria in table 1 are named with a numeric index in order to track and study easily. Pattern of network of the relationship between variables is presented in Figure 1. Paired comparison of elements has been done by Saaty's 1-9 Scale .Saaty's 1-9 Scale was presented by Thomas L. saaty theoretician of the Analytic Hierarchy Process (AHP). Also in this study, fuzzy approach was used to quantify the values. Therefore, the fuzzy domain has been used (table 2).

For mentioned analysis in first step the main criteria were compared in pairs based on goal. Paired comparison is very simple and all the elements of each cluster must be mutually compared. So if there is n elements in a cluster $\frac{n(n-1)}{2}$ comparisons will be made. Because there are four criteria so numbers of made comparisons is :

$$\frac{n(n-1)}{2} = \frac{4(4-1)}{2} = 6 \qquad (1)$$

After forming matrix the paired comparisons, Eigenvector is calculated. First of all fuzzy summation of each row is calculated .

$$\sum_{j=1}^{n} M_{g_1}^{j} \quad (2)$$

Then fuzzy summation of the preferences column set is calculated as :

$$\sum_{i=1}^{n}\sum_{j=1}^{n} M_g^j \quad (3)$$

For normalize preferences for each criterion, the total value must be divided by the sum of all preferences (elements of columns). Since values are fuzzy therefore, the fuzzy summation of each row multiplies by inverse of the sum. Inverse of the summation is calculated as:

$F_1^{-1} = (1/u_1, 1/m_1, 1/l_1)$ (4)

$$P_k =* \left(\sum_{i=1}^{n}\sum_{j=1}^{n} M_g^j\right)^{-1} \quad (5)$$

Each of the obtained values of fuzzy weights and normalized are related to the main criteria. For defuzzification of obtained Values there are a variety of methods. One of the methods used for the defuzzification is calculation of degree of preference, and also Crisp number. In this study, Preference degrees are calculated.

Calculation of Degree of Preference

Calculation of degree of preference (Possibility Degree) P is a fuzzy number fuzzy number that is larger than k .

P_i; i=1,2,…,k

$V(P_i \geq P_k)$

$V(P_i \geq P_k)$

$$V(S_i \geq S_k \begin{cases} 1 \quad \text{if}(m_i \geq m_k) \\ \frac{l_k - u_i}{(m_i - u_i)-(m_k - l_k)} \quad \text{else} \end{cases}$$

V(C1>Pk)=1.000; V(C2>Pk)=0.682; V(C3>Pk)=0.462; V(C4>Pk)=0.056; V(P5>Pk)=0.043

If it is assumed that d'(Ci)=minV(Pi≥Pk then the weight vector follows as:

W' = (d'(C1)… d'(Cn))

It calculated weights are defuzzification but should be normal .

To determine the final priority of water management by FAHP techniques weights of the main criteria (W1) and the weight of indices based on each criterion (W2) must be available. The results of sub criteria comparison their corresponding weights forms make up matrix W2. To determine the final priority of indexes with AHP technique, Indices weight based on each criterion (W2) must multiply by the weight of the main criteria (W1). Each of these matrices is calculated in the previous steps. With inserting CRISP values in superdecision software, by using this software the final priority of indices are calculated.

Results and Discussion

Paired comparison has been done by team approach of ten experts. Expert's opinion was quantified by fuzzy scale. Gathering the views of experts was done Saaty's 1-9 Scale. By fuzzy mean the views of experts, paired comparison matrix is shown in Table 3.
The final weight for each option which in fact calculated from *linear* combination of options, criteria and sub criteria is shown in Figure2.
Accordingly, Eigen vector of preference of criteria is W1.

$$W_1 = \begin{pmatrix} 0.444 \\ 0.350 \\ 0.106 \\ 0.099 \end{pmatrix}$$

According to obtained eigenvector water conservation with normal weight of 0.444 has the highest priority. Reuse of effluent with normal weight of 0.35 is the second priority; effluent disposal with normal weight of 0.106 is the third and eventually last priority is effluent treatment. Inconsistency rate over comparisons is 0.059 which is smaller than 0.1 and therefore regarding to comparisons the disposal of drainage water can considered as the first option among the criteria. Among the research which done in the field of water conservation conducted experiments by Hanson and may (2004) can be pointed out. Experiments were conducted in three tomato farms under subsurface drip irrigation and sprinkler irrigation with saline water and shallow groundwater conditions has been performed. Results have shown that subsurface drip irrigation compared to sprinkler irrigation under conditions of salinity and shallow groundwater is largely beneficial for reduce of produce of drain water.
In the second step of the FAHP technique related sub criteria of each class are compared.

Sub criteria of water conservation priority

Sub criteria of water conservation are Source Reduction, shallow water table management and fallow land. Fuzzy values of mean of expert's opinion to priority of water conservation sub criteria are presented in Table 4. Due to the use of four indices of water conservation, six paired comparisons have been made.
Each of obtained value fuzzy weight and normalized in Table 4, are related to the main criteria. For defuzzification of values calculations of preference degree were used.

According to table 6 Eigen vector of water conservation criteria priority is WC1.

$$W_{C1}=\begin{pmatrix} 0.383 \\ 0.244 \\ 0.244 \\ 0.129 \end{pmatrix}$$

According to obtained eigenvector source reduction with0.383 weight has the highest priority. Water table management and the management of the shallow groundwater with the same weight of 0.244 are central priorities. Finally, fallow land is the last priority. Inconsistency rate is obtained 0.02, which is smaller than 0.1. Thus, comparisons are trusted. The conventional approach to subsurface drain design was to install the drain laterals as deep as was practical which would result in the biggest spacing and minimize the installation cost. These depths of installation were also thought to be needed to reduce salinity accumulation in the root zone by upward flow from saline groundwater (Ayars, 1993). This study shows that resource reduction is an important factor in Drainage Flow reduction.

Priority of sub criteria of reuse of drainage waters

Reuse of drainage water for irrigation is known as a viable means of reducing the amount of saline-sodic spent water that will finally need treatment or disposal in the western San Joaquin Valley (SJVDP, 1990).

Sub criteria of reuse of drainage include using in saline land, wildlife and wetlands, agriculture, sequential use of drainage and soil amendment. Figure 4 shows related priorities of each sub criteria of drainage reuse. According to eigenvector of setting priority wildlife and wetland with Weight of 0.260 is the most important. A criterion of sequential use of drainage with weight of 0.248 is the second priority. Saline soil amendment with weight of 0.213 is the central priority. Agricultural index with weight of 0.124 is the last priority. Inconsistency rate is obtained 08/0 which is smaller than 0.1. Therefore, using of conducted comparisons of drainage reuse in the process of decision making is permitted. In a research presented by Ayars and Sope (2014) Drainage water from irrigated areas with fresh water and sensitive plants field, were used for halophytes .The results shows that the sequential use of drainage water is a temporary solution for replacing with Disposal of drainage water until a stable system can be developed. Díaz et al (2013) With the use of six halophyte species use drainage water in growing they concluded that drainage water can be used to produce these species for producing livestock forage, but their use is not recommended for long-term because level of sodium, chlorine, Boron, selenium and nitrate in leaf tissue of halophytes is dangerously and critically collected.

Priority of sub criteria drainage water

In this study criterion of drainage water disposal consist of four sub criteria of river, evaporation ponds, oceans, salt lakes and grouting into soil. According eigenvector prioritization and Figure 5, it is clear that the index of oceans and salt lakes with weight of 0.341 is the most important. Evaporation ponds with weight of 0.327 are the central priority and the rivers with weight of 0.134 is the last priority. Inconsistency rate is obtained about 0.018 so obtained judgments are consistent and using of them in selection process, is permitted.

Priority of sub criterion of drainage water treatment

In this study, criterion of drainage water treatment consists of two sub criteria Physical - chemical and biological. The fuzzified values of expert opinion mean for determining the priority of sub criteria of drainage water treatment is presented in Figure 6. It is clear that, the physical – chemical index with weight of 0.605 has higher priority than the biological index. Also, because there are only two sub criteria and a comparison inconsistency rate is zero.

Sub criterion of Physical - chemical is composed of five sub indices. These indices include sedimentation, adsorption, ion exchange, reverse osmosis, precipitation. Also the sub criterion of biological is composed of five sub indices Rehabilitation / oxidation, uptake plant, evaporation, artificial wetlands. According to calculations the final weight of these indices are shown in Figures7 and 8. As it seen in Figure 7, among the options for physical – chemical treatment uptake with weight of 0.282 has the highest priority. After that reverse osmosis with weight of 0.221 is selected as the next appropriate option. Sequestration, with weight about 0.136 is the next priority which is chosen the last option in sub criterion of water drainage treatment. Prioritizing of sub criteria related to Physical - chemical treatment presented in Figure 8. As it can be seen the use of plants and special algae for water drainage treatment should be the first priority of biological treatment. The weight of this criterion is obtained 0.282. Other sub criteria Rehabilitation, evaporation and artificial wetlands are next priorities respectively.

(C4)

The results of calculation and the weights of indices are given in Figure 9. As the graph in Figure 9 shows source reduction with final weight of 0.17 options is the best option. However, the other options such as drainage management which is consist of shallow water table management, underground water management, wildlife and wetlands, sequential useof drainage water, saline soil amendment, physical - chemical treatment, fallow land, use in saline soil lands, agricultural, biological treatment, evaporation ponds, rivers, oceans and lakes, salts and grouting deep into the soil are 2 to 16 priorities.

Conclusions

The present study reviews and prioritizes influencing factors on water drainage management expert's preference using fuzzy AHP. Examined options in this study include water conservation, reuse of drainage water, drainage water disposal and drainage water treatment.

The results show that water conservation is the most important option in the drainage water management. Among sub criteria water conservation, source reduction are the highest priority. Among main criteria of drainage water management the second priority place on reuse of water. Among its sub criteria wildlife and wetland criteria, with weight of 0.260 is the most important. Sequential use of drainage water criterion of with weight of 0.248 is the second priority .

Treatment and disposal of drainage water management are the third and fourth priorities respectively. Among disposal of drainage water sub criteria, draining into oceans and salt lakes are the best options. Physical – chemical index among drainage water treatment options with weight of 0.605 has higher priority than the biological index.

References

Hajeeh M A, (2010). Water desalination plants performance using fuzzy multi-criteria decision making. WSEAS TRANSACTIONS on SYSTEMS, 9(4):422-431.

Chang D Y, (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 95(3):649-655.

Chang D Y, (1992). Extent analysis and synthetic decision. Optimization Techniques and Applications, 1:352.

Chang, Andrew C, Brawer Silva, Deborah (Eds.), (2014). Salinity and Drainage in San Joaquin Valley, California. Science, Technology, and Policy Series. Vol. 5.

Montazar A, Omid N G, and Richard L Snyder, 2013. "A fuzzy analytical hierarchy methodology for the performance assessment of irrigation projects." Agricultural Water Management 121: 113-123.

Okada H, S W Styles, and M E Grismer, (2008). "Application of the Analytic Hierarchy Process to irrigation project improvement: Part II. How professionals evaluate an irrigation project for its improvement." Agricultural water management 95.3: 205-210.

Hanson B R, & May, D. M, (2004). Effect of subsurface drip irrigation on processing tomato yield, water table depth, soil salinity, and profitability. Agricultural Water Management, 68,1–17.

Montazar A, Zadbagher E, (2010). An Analytical Hierarchy Model for Assessing Global Water Productivity of Irrigation Networks in Iran. Water Resources Management 24, 2817–2832.

Saaty T L, (1977). A scaling method for priorities in hierarchical structure. Journal of Mathematical Psychology 15, 228–234.

Ayars James E, and Richard WO Soppe. (2014). "INTEGRATED ON-FARM DRAINAGE MANAGEMENT FOR DRAINAGE WATER DISPOSAL." Irrigation and Drainage 63.1: 102-111.

Díaz F J, Benes S E, & Grattan S R, (2013). Field performance of halophytic species under irrigation with saline drainage water in the San Joaquin Valley of California. Agricultural Water Management, 118, 59-69.

Ayars J E, Hutmacher R B, Schoneman R A, Vail S S, & Pflaum T, (1993). Long term use of saline water for irrigation.Irrigation Science, 14, 27–34.

SJVDP (San Joaquin Valley Drainage Program), (1990). A management plan for agricultural subsurface drainage and related problems on the Westside San Joaquin Valley (Final report of the San Joaquin Valley Drainage Program, 183pp.). Sacramento: U.S. Dept. Interior and Calif. Resources Agency.

Srdjevic B, Medeiros YDP, (2008). Fuzzy AHP assessment of water management plans. Water Resour Manage 22:877–894.

Varis O, (1989). The analysis of preferences in complex environmental judgements, a focus on the analytic hierarchy process. Environ Manage 28:283–294.

Alphonce CB, (1997). Application of the analytical hierarchy process in agriculture in developing countries. Agric Syst 53(1):97–112.

Srdjevic B, Medeiros YDP, (2008). Fuzzy AHP assessment of water management plans. Water Resour Manage 22:877–894.

Lee, A. H., Chen, W. C., & Chang, C. J. (2008). A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. Expert systems with applications, 34(1), 96-107.

THE TENDENCY OF DRAINAGE RUNOFF IN CLIMATE CHANGE CONTEXT

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Abstract

The present article analyzes the change of climatic conditions in the Central Lithuania. Meteorological conditions in 1969–2009 were studied while analysing changes in seasonal distribution of the average air temperature and precipitation amount in Central Lithuania during the period of four decades, meanwhile complete studied period was divided each ten years. The activity of drainage during various seasons and the impact of meteorological conditions on drainage runoff in different seasons (winter, spring, summer and autumn) are reviewed.

KEY WORDS: Drainage, Runoff, Precipitation, Temperature, Climate.

Introduction

Global increase of precipitation is forecasted under changing climatic conditions; however, its extremes will also increase (Climate…, 2007). Simulating the impact of climate change on runoff has been realized in recent years. By applying projected climate scenarios into a validated hydrological model, hydrologists could assess potential variation tendencies of flow components in the future (Bastola *et al*., 2011; Bergstrom *et al*., 2001; Harding *et al*., 2012; Raghavan *et al*., 2014). Hydrology plays a key role for productivity of different biomes, including agriculturally used land. Therefore understanding relevant influences on hydrological processes is fundamental for ecosystem management (Yu *et al*., 2016). Land use and climate are two main factors that affect watershed hydrologic processes (Brath *et al*., 2006; Chien *et al*., 2013; Wu *et al*., 2012). Drainage of agricultural fields is not only a modern tool for removal of excess water, but also a great component of water balance of open water ponds. Runoff is a key water loss component with strong impact on crop production, vegetation restoration and ecosystem services such as water resource conservation (Gyssels *et al*., 2005; Valentin *et al*., 2005). When analysing the elution of biogenesis from soil through drainage, much research have been carried out (Sileika, Guzys, 2003; McDowell *et al*., 2001; David *et al*., 2008; Tan *et al*., 2008). (Malisauskas, Kutra, 2008) determined that the highest trend of increase of nitrates in drainage water is in May, and the

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concentration of nitrates in drainage water was characterized by the lowest increase in October. 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 (Soussana, Luscher, 2006). The major factor, which leads to the pollution, diffused by biogenesis N and P through drainage runoff and how the pollution occurs under various natural and agricultural conditions. The most important is the size of drainage runoff (Saulys, Bastiene, 2008).

Materials and methods

Experimental site layout

The field study was carried out in the southern part of Kaunas district, in the territory of training farm of Aleksandras Stulginskis University, Lithuanian (54.879485, 23.861525). Drain depth of 0.8, 1.10, 1.40 m, the drainage distance - 12, 18 m. Average surface test object slope - 0.008. The test site soil according to FAO: calcar - HypogleyicLuvisol, texture - light loam, dripping down on medium loam. Topsoil layer thickness is 0.2 to 0.25 Arable layer of filtration rate - 1.0 to 2.0 m / day, the lower layers of soil - from 0.01 to 0.004 m / day. The meteorological parameters (precipitation and average air temperature) of 1969–2009 were analysed in this article meanwhile data was obtained from Kaunas Meteorological Station, which is the nearest to the analyzed object (at the distance of 0.5 km Summarize the five long-term drainage systems (area 0.44 ha, 0.45 ha, 0.44 ha, 0.44 ha, 0.45 ha) of drainage studies, the data.

Results and discussion

One of the key factors in determining the size of runoff is precipitation. In the researched object the doughtiest year was 2010, the moistest – 1992. The integral curves of average precipitation height deviation from the average show the trends of precipitation height change: the linear trend, defining the trend of chronological sequence change, is positive (Figure 1).

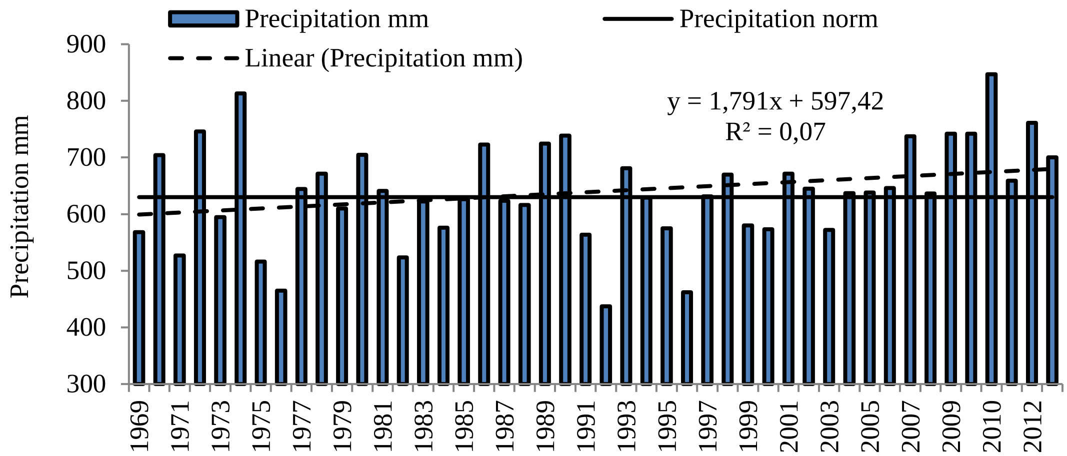

Figure 1. Dynamics of annual precipitation amount and their linear fluctuation trend

While analyzing the annual air temperature for the period of 1969–2013, it is seen that the highest average temperature was in 2008, and the lowest - in 1993. The linear trend, defining the trend of chronological sequence change, is positive (Figure 2).

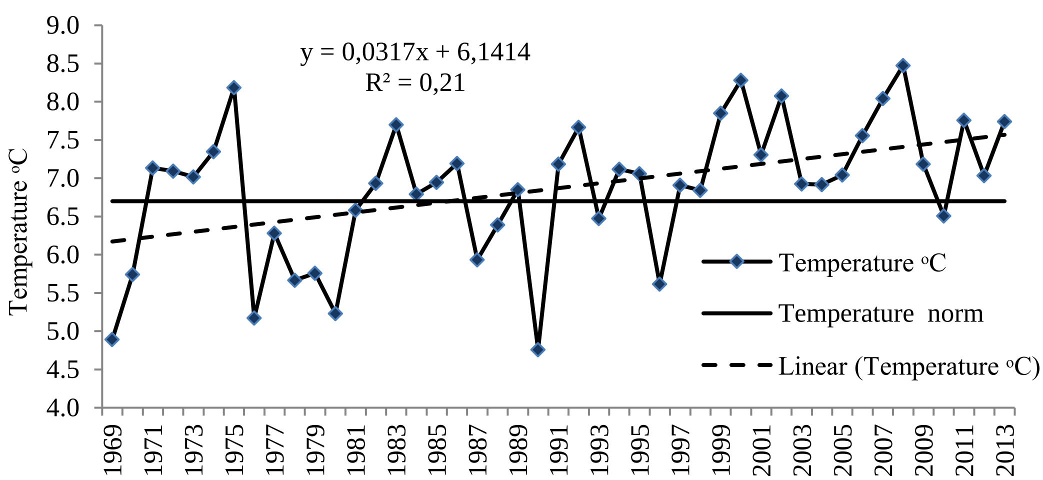

Figure 2. Annual temperature and they linear fluctuation trend

Meteorological conditions in 1970–2009 were studied while analysing changes in seasonal distribution of the average air temperature and precipitation amount in Central Lithuania during the period of four decades (1970–2009), meanwhile complete studied period was divided each ten years. In the recent decade (2000-2009) the average winder air temperature in Kaunas was 0.71°C warmer in compare with average temperature of the four decades (1970–2009), and amount of precipitation increased only in 0.7 mm in compare with average of 40 years period (Figure 3).

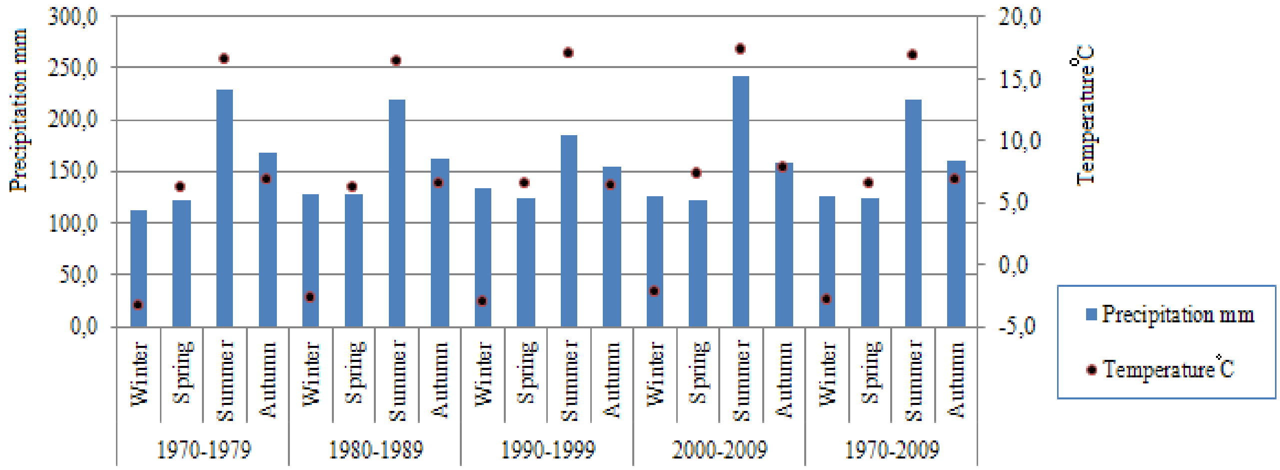

Figure 3. Perennial (of 1970–2009 period) and four decades (1970–1979, 1980–1989, 1990-1999, 2000–2009) average air temperature and precipitation amount of different seasons

During analysis of the temperature in decades it was revealed that in the spring it was always increasing and during the past decade (2000–2009) was 1.13°C warmer in compare with average temperature of year 1970–2009. Average sum of precipitation amount in spring (124.0 mm) and winter (125.1 mm) is very similar, and during the past decade average precipitation amount had decreased only in 1 mm in compare with the average precipitation amount of the complete period. Temperature in the summer was also increasing, and in 1970-1979 it was insignificantly (0.1°C) higher than in 1980-1989, and in the last decade (2000–2009) the summer temperature was in 0.5°C higher than the average temperature in 1970-2009 (Figure 3). The biggest amount of precipitation is in summer months. In the June-August of the last decade amount of precipitation increased in 33.3 mm in compare with the average of complete period, and when comparing with decade of 1990-1999 – amount increased even 56.6 mm. In the last decade (2000-2009) autumn in the region of Central Lithuania was warmer in 0.9°C, although during analysis of the last four decades data in decades, decrease of average temperature was observed (in 1980-1989 and 1990-1999). Autumn season is also characterized by plenty of precipitation, although in the last two decades insignificant decrease in precipitation amount was observed (in 1990-1999 – 6.2 mm, in 2000-2009 – 0.7mm.) in compare with average precipitation amount of the studied period. Analysis of air temperature and precipitation amount change during four decades of 1969–2009 had shown that the average air temperature of 2000–2009 was the highest, and the lowest average temperature was observed in 1970–1979 (Figure 4). The smallest amount of precipitation was in 1990-1999, and the largest amount – in 2000-2009, although it was only in 5.2 mm more than before three decades (in 1970-1979). During analysis of the drainage runoff dynamics it can be seen that the largest runoff was in 1980-1989, and the smallest, the same as in the case of precipitation amount – in 1990-1999.

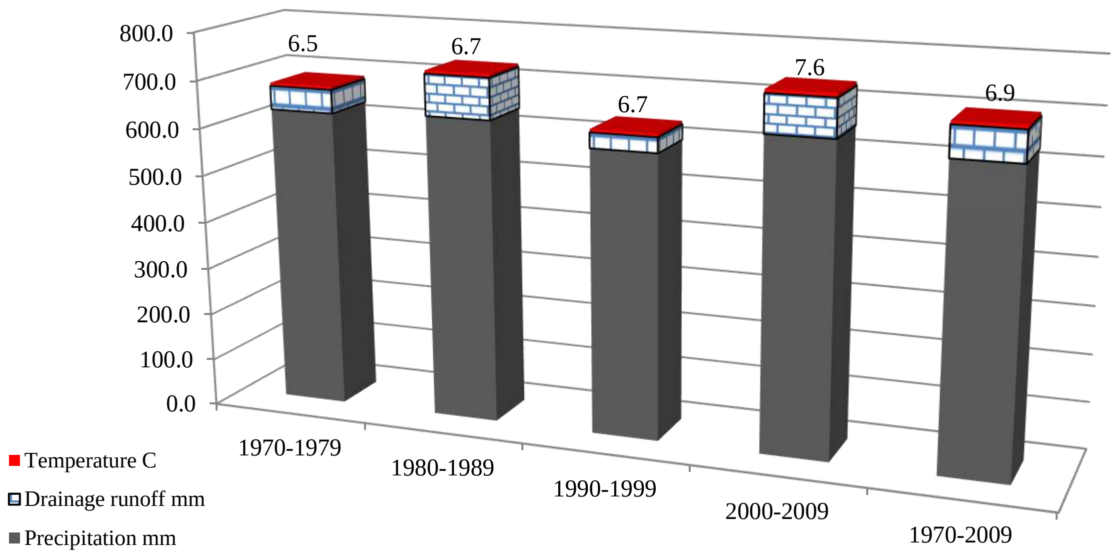

Figure 4. Perennial (of 1970–2009 period) and four decades (in 1970–1979, 1980–1989, 1990-1999, 2000–2009) average air temperature, amount of precipitation, drainage runoff and precipitation amount of different seasons

When studying seasonal distribution of the drainage runoff in decades, the summer season should be distinguished as constantly decreasing, meanwhile the average drainage runoff of the other seasons during decades is fluctuating. Although in the last decade the winter season had distinguished itself – the average runoff height was 32.4 mm (average of the four decades is 17.2 mm). When analysing data of 1970-2009 in the studied territory it was determined, that the smallest precipitation amount is in spring (19.7 %), in winter – very similarly (19.9 %), and the largest precipitation amount is in summer (even 34.8 %) and in autumn. Analysing distribution of the percent amounts of the average precipitation and drainage runoff in 1970–2009 according to the seasons, the highest drainage runoff is namely in spring (48.7 %), and the lowest – in summer (4.9 %), meanwhile the highest precipitation - in summer (34.8 %), and the lowest – in spring and summer (about 20 %, Figure 5).

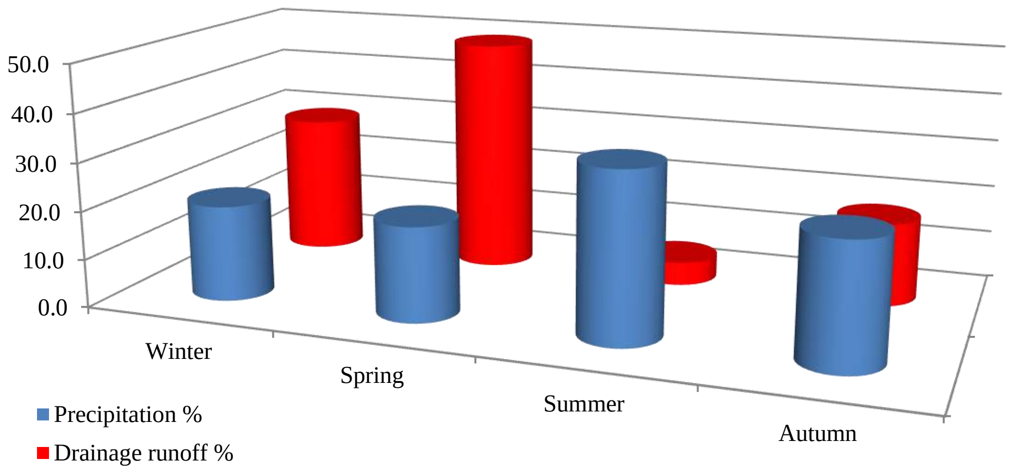

Figure 5. Distribution of the percent amounts of the average precipitation and drainage runoff

After performance of correlation-regression analysis of the study data it was revealed that relation between drainage runoff and precipitation amount during different seasons was weak (in spring (r=0.3) and in summer (r=0.33) or average (in winter (r=0.41) and autumn (r=0.40, Figure 6).

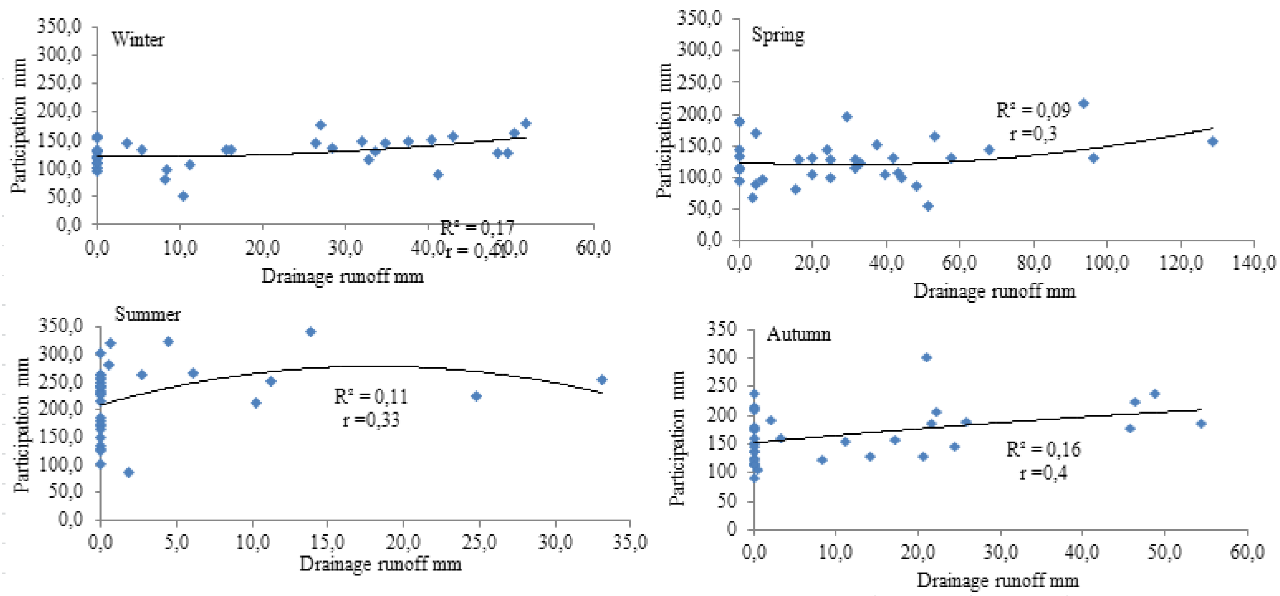

Figure 6. Dependence of the monthly drainage runoff from the average precipitation amount in different seasons (r_w – winter, r_{sp} – spring, r_{su}- summer, r_a – autumn).

When studying relations between drainage runoff and average air temperature in different seasons it was determined that in winter there was an average link (r=0.55), and in other seasons – the inter-relation was very weak (in spring (r=0.17), in summer (r=0.17) and in autumn (r=0.14, Figure 7).

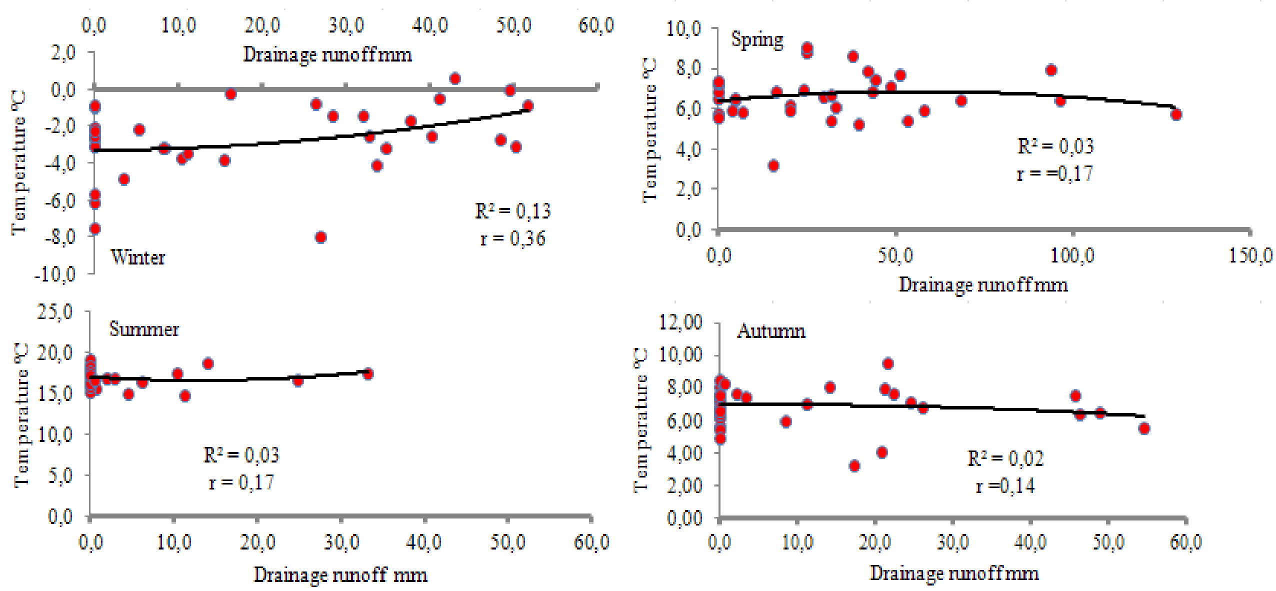

Figure7. Dependence of the monthly drainage runoff from the average air temperature in different seasons (r_w – winter, r_{sp} – spring, r_{su}- summer, r_a – autumn).

Table 1 presents the aggregate statistics of significant trends (5% significance level) of researched runoff characteristics, determined by Mann-Kendall test. It is obvious that in spring, summer and autumn (1969-2009) negative trends, i.e., the reduction of runoff, are determined, and runoff increases in winter (29%), and the change of total annual runoff has a plus. The sequences of multi-year air temperatures have already shown the increase of temperature of year and all seasons, except autumn (Rimkus *et al*. 2007). The depth, duration and temperature of frozen ground of soil depends on winter duration and air temperature, thickness of snow layer, vegetation layer, thermal characteristics and humidity, texture of soil, depth of ground water. Since the middle of twentieth century the duration of frozen ground has shortened by approximately two weeks, moreover, the probability of its total thaw and repeated freezing has increased. An increased incidence of thaw of frozen ground demonstrates that water infiltration conditions of cold season must have changed. Water, present in thinner capillaries of clay and loam soil, freezes at lower temperature. On the other hand, wet soil freezes less, since during water freezing heat of water crystallization is released, which slows down the further drop of soil temperature. Snow layer and vegetation also protect soil from deep freeze.

Table 1. Mann-Kendall test results

Month	Sum of year	MK-Stat	p-value
1	29	2.89	0.01
2	29	3.59	0.01
3	29	2.66	0.01
4	29	-0.36	0.72
5	29	0.21	0.84
6	29	-1.53	0.13
7	29	-1.13	0.26
8	29	-0.06	0.95
9	29	1.39	0.17
10	29	1.10	0.27
11	29	1.18	0.24
12	29	2.17	0.03

Conclusion

After performing the analysis of annual drainage runoff change during the period of 1969-2009, the significant one-trend change was not determined; however, the insignificant statistical linear trend is noticed. An important factor for runoff formation is precipitation intensity and duration, since intensive short rain forms a larger surface runoff, while the rain of lower intensity and longer duration better infiltrates into soil and evaporates from ground surface. After correlation-regression analysis of the study data it was revealed that relation between drainage runoff and precipitation amount during different seasons was weak (in spring and in summer), and average in winter and autumn. The analysis of runoff observation data revealed that seasonality, typical for run-off change, remains, however, the drainage runoff during winter season has increased significantly over the past four decades. Mann-Kendall test showed the significant increase of winter runoff during the analysed period. It was also influenced by growth of multi-year temperatures of all seasons, except autumn: the frozen soil is characterized by low water permeability, irrespective of its content. Significant decrease of drainage runoff is observed in

July and August. It is related with redistribution of precipitation amount, which increased in winter and decreased in summer.

References

Bastola S., Murphy C., Sweeney J. 2011. The role of hydrological modelling uncertainties in climate change impact assessments of Irish river catchments. Adv. Water Resour 34 (5): 562-576.

Bergstrom S., Carlsson B., Gardelin M., Lindstrom G., Pettersson A., Rummukainen M. 2001. Climate change impacts on runoff in Sweden-assessments by global climate models, dynamical downscaling and hydrological modelling. Climate Resource 16 (2): 101-112.

Brath A., Montanari A., Moretti G. 2006. Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). J. Hydrology 324: 141-153.

Chien H., Yeh PJF., Knouft JH. 2013. Modeling the potential impacts of climate change on streamflow in agricultural watersheds of the Midwestern United States. Journal of Hydrology 491: 73-88.

Climate Change 2007: The Physical science basis. 2007. IPCC / In: Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K. B., Tignor M., Miller H. L. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

David MB., Noah NR., Dorcas HF., Matthew HP., James TGJ. 2008. Runoff water quality from manured riparian grasslands with contrasting drainage and simulated grazing pressure. Agriculture, Ecosystems and Environment 126: 250-260.

Gyssels G., Poesen J., Bochet E., Li Y., 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog. Phys. Geog 29: 189–217.

Harding BL., Wood A.W., Prairie JR. 2012. The implications of climate change scenario selection for future streamflow projection in the Upper Colorado River Basin. Hydrology Earth Syst. Sci. Discuss 9 (1): 847-894.

Libiseller C., Grimvall A. 2002. Perfomance of partial Mann-Kendall test for trend detection in the presence of covariates. Environmetrics 1(13): 71–84.

Malisauskas A. P., Kutra S. 2008. Nitrate variation in drainage water under degradation of peat soils. Ekologija 54(4): 239-244.

McDowell RW., Sharpley AN. 2001. Approximating Phosphorus Release from Soils to Surface Runoff and Subsurface Drainage. Journal of Environmental Quality 30: 508-520.

Raghavan SV., Vu MT., Liong S. 2012. Assessment of future stream flow over the Sesan catchment of the Lower Mekong Basin in Vietnam. Hydrol. Process 26 (24): 3661-3668.

Rimkus E., Kazys J., Juneviciutė J., Stonevicius E. 2007. The forecast of Lithuanian climate change in the twenty-first century (in Lithuanian). Geografija 43(2): 37-47.

Saulys V., Bastiene N. The impact of lime on water quality when draining clay soils. Ekologija 54(1): 22-28.

Sileika AS., Guzys S. 2003. Drainage runoff and migration of mineral elements in organic and conventional cropping systems. Agronomic 23: 633-641.

Soussana J. F., Luscher A. 2006. Temperate grasslands and global atmospheric change. Grassland Science in Europe 11: 739-748.

Tan CS., Drury CF., Gaynor JD., Welacky TW., Reynolds WD. 2008. Effect of tillage and water table control on evapotranspiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil. Agricultural Water Management 54 (3, 2): 73-188.

Valentin C., Poesen J., Li Y., 2005. Gully erosion: impacts, factors and control. Catena 63: 132-153.

Wu Y., Liu S., Gallant A.L. 2012. Predicting impacts of increased CO2 and climate change on the water cycle and water quality in the semiarid James River Basin of the Midwestern USA. Sci. Total Environ 430: 150-160.

Yu Y., Loiskandl W., Kaul H., Himmelbauer M., Wei W., Chen L., Bodner G. Estimation of runoff mitigation by morphologically different cover crop root systems Journal of Hydrology 538: 667-676

THE EFFECT OF CLIMATE CHANGE ON THE QUANTITY AND QUALITY OF AGRICULTURAL RUNOFF (CASE STUDY: GOLGOL RIVER BASIN)

Bahman Moshtaghi[1,*], Sepehr Dalilsafaee[2], Mohammad Hossein Niksokhan[3]

Abstract

Nowadays, the effects of climate change due to global warming and changes in precipitation patterns is quite evident. The increase of greenhouse gases has had an extensive negative effect on almost all regions of the Earth and on different systems, such as water resources, the environment, agriculture, industry, and health. Climate change and global warming have caused an intense deficiency of available potable water. This deficiency can decrease the quality of water as well. One of the prominant effects of climate change is on agriculture and water. Changes in demand for agricultural products can affect water resource management seriously. The reuse of agricultural runoff in areas facing water deficiency is important. A study was carried out in the Golgol River Basin. This river is one the main sources of the Ilam reservoir dam. Nearly 27 percent of the total basin area is under irrigated and rain-fed cultivation. In the case of rain-fed cultivation, wheat and barley are dominant crops. In this basin, wheat and corn are often grown under irrigated cultivation. Using fertilizers, which may have a significant impact on the quality of runoff. In order to predict temperature and precipitation under the effect of climate change, using the output of a HadCM3 model under the A2 emission scenario for two future periods (2046-2065 and 2080-2099) were used. The scenario of high population growth and a lesser dependency on economic development has been used on a regional scale in order to determine the amount of greenhouse gases. The LARS-WG model was used for downscaling. The results show that the temperature increases during the two periods and also changes in precipitation is observed. In order to simulate the runoff, an organic nitrogen and nitrate hydrological model (SWAT) and for calibration, SWAT-Cup and Sufi2 method were applied. Introducing downscaled results of AOGCM models to the hydrological model and assuming similar regional conditions including fertilizer and land use, changes in runoff and pollutants in the future were also simulated. It was observed that during 2046-2065, the average monthly Runoff, Nitrate and Organic nitrogen loads would decrease by

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27, 18, 13.5 percent. 2080-2099 period when compared to the present, show that the average monthly Runoff, Nitrate and Organic nitrogen loads would decrease by 45, 33, 35 percent. To prevent economic and agricultural losses and concerns about the decrease in the quality of water resources, runoff management might be required in the future.
KEY WORDS: Climate change, River water quality, Agricultural runoff, SWAT, LARS-WG.

Introduction

Climate change, particularly changes in temperature and precipitation are the most important issue in the field of environmental sciences (IPCC, 2007), but it does not only involve an increase in average temperature, it also results in changes to natural phenomena such as extreme temperatures, wind, snowfall, rainfall, and an increase in sea level that directly and indirectly affect human life (Kang et al., 2016). Although various economic sectors including agriculture, forestry, water, industry, tourism and energy affected by climate change but agriculture is the most dependent part to climate (Kemfert, 2008). Several studies have been conducted on the potential impacts of climate change on water resources, including the impact on water quantity, hydrology and water demand (Jung and Chang, 2011). Access to water, plays a key role in development. It sustains human life, both through direct consumption and use in agriculture and industrial activities (Melese, 2016). The effects of climate change on water resources and hydrological cycle is a global concern and has long been considered by the international community (Arnell, 1999; Barnett et al., 2005; Piao et al., 2010). Water resources management and planning around the world have become a challenging task due to climate change uncertainties (Ficklin et al., 2013). Agriculture has always been the dominant end-use of diverted water; this will only intensify with increasing needs for irrigation brought on by higher temperatures and reduced precipitation, coupled with increasing populations (Melese, 2016). climate change is expected to affect the agricultural water cycle, the agricultural water demand, potential for drought and surface runoff, and agricultural production (Tao et al., 2003). Global climate change include changes in patterns of rainfall and temperature may have significant effects on the watershed water quality and quantity and fresh water sources used for drinking, health, agriculture and industry (Tu, 2009; USEPA, 2014). Weather temperature increased has caused an increase in the biological interactions and consequently has altered the nutrients cycle, increased eutrophication and decreased water quality (Bouraoui et al., 2004; Chiew and McMahon, 2002; Fan and Shibata, 2015; Jha et al., 2004; Wilby and Harris, 2006). In addition, the decrease in water resources may increase the concentration of pollutants and nutrients and thus it is possible that water quality faces by further reducing. Weather temperature rise due to increased primary production, decomposition of organic matter and nutrients flow rates in rivers and lakes leads to lower dissolved oxygen levels affecting water quality. Climate change decreases quality and quantity of irrigation water and agricultural runoff. As runoff moves, it picks up and carries pollution, which it can deposit into ponds, lakes, coastal waters, and underground sources of drinking water. So, agricultural runoff management means controlling the quantity and quality of produced runoff which will be used in agriculture.

The confrontation with climate change is also inevitable in Iran and given that Iran is located in arid and semiarid region and faced by the water shortage problem, thus, the effects of climate change and global warming could aggravate the shortage of potable available water. In this study, Golgol River basin in Ilam province is considered as study area. Given the importance of climate change and its impact on runoff quantity and quality from Agricultural lands, in this study we emphasize applying a model that is able to simulate the runoff and nutrients. One of the appropriate tools for the relation between meteorological data (for example, temperature and precipitation) and basin-scale water cycle and nutrients is Soil and Water Assessment Tool (SWAT) (Gassman et al., 2007). Therefore, SWAT (Arnold et al., 1998) model is used to simulate river basin in this study. This model is one of the best options available for the comprehensive and specialized review of the watershed. According to past studies, this model has a proper performance and efficiency in the simulation of runoff and nutrient load in the different basins (Abbaspour et al., 2007b; Alansi et al., 2009; Singh et al., 2005; Tripathi et al., 2003; Wu and Chen, 2015; Xu et al., 2009). In order to predict temperature and precipitation influenced by climate change, the outputs of atmosphere-ocean general circulation model HadCM3 have been used under the emission scenario A2 in two periods 2046-2065 and 2080-2099. To apply the large-scale outputs of atmospheric general circulation models we need a model to downscale these data and use the downscaled data to study the effects of climate change. In this study, statistical models have been used to downscale general circulation models among which LARS-WG model was chosen as selected model.

Material and methods

Study area and Data

The study area in this research is Golgol River watershed (Figure 1). The length of the main branch of this river to the Ilam dam is 35.2 km and its catchment area is 279.52 km2 (46° 24’ 30” to 46° 38’ 00” east longitude and 33° 25’ 30” to 33° 38’ 30” north latitude)

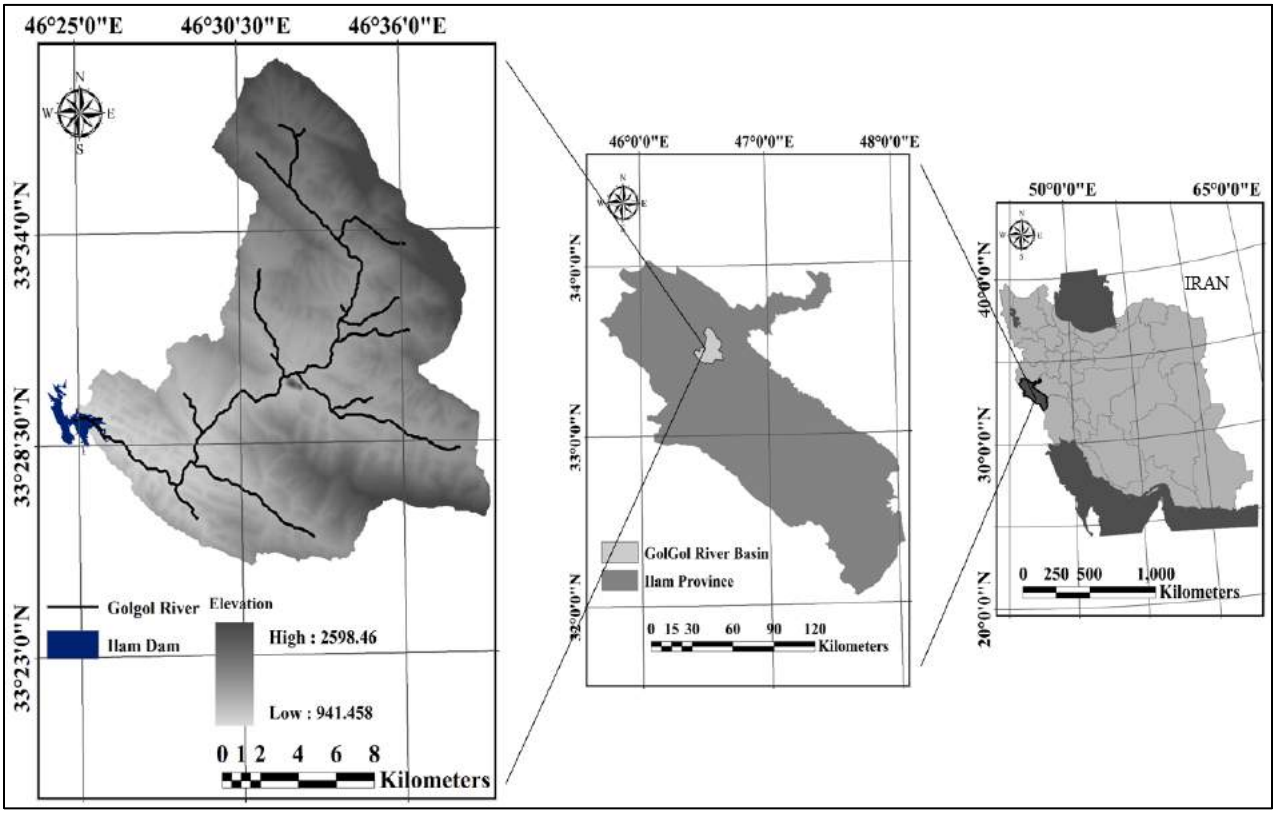

Figure 1: Gogol river basin in Iran

Ilam synoptic station data are used to examine the meteorological status of the Golgol river watershed. The most important sources of pollutants in this watershed are agriculture and grazing as non-point sources of pollutants. The dominant crop rotation in this area is both irrigated and rain-fed agriculture. The following data (Table 1) has been used to progress the research.

Table 1: Data description and sources used in project

Data type	Source
Digital elevation model (DEM)	Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters (http://www2.jpl.nasa.gov/srtm/).
soil	the Food and Agriculture Organization of the United Nations (FAO) spatial resolution of 5 km (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/).
Landuse	Global Landuse /Land cover Characterization USGS with a spatial resolution of 1 km (http://landcover.usgs.gov/glcc/)
Climate	I.R. of IRAN Meteorological Organization.
River discharge	Iran Water Resources Management Co.
Nitrate and organic nitrogen loads	Consulting Engineers Co. Mahab
Agricultural management and water resources (Planting,harvesting, fertilization)	Agriculture Organization of Ilam (http://www.jkoi.ir/)

As shown in Figure 2, 23% of landuse in the Golgol river basin is rain-fed cultivation and 4% of it is irrigated cultivation. it means that 85% of cultivated lands is rain-fed and other 15% is irrigated.

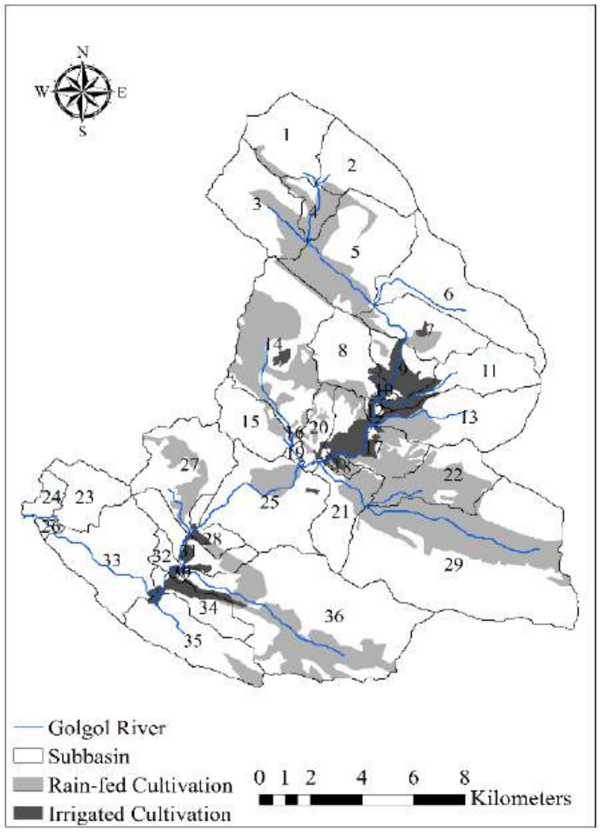

Figure 2 : rain-fed and irrigated cultivation in golgol river basin

Climate change model

IPCC[1] determines the values of climatic parameters change on the basis of scenarios in which predicts the general policy of the world of population growth, economy, environmental sustainability and type of consumption energy points of view. These policies are presented numerically using integrated assessment models which their outputs will be the final result of scenarios families for each policy. Currently the most reliable tool to develop climatic scenarios is AOGCM[2](Mitchell, 2003; Wilby and Harris, 2006). It should be noted that the information derived from the general circulation models are not possible to use unprocessed for local predictions they should be downscaled in the study area (Diaz-Nieto and Wilby, 2005). There are generally two ways for downscaling: statistical downscaling and dynamical downscaling methods (Arabi et al., 2008; Fakhri et al., 2013; Wilby and Harris, 2006). LARS-WG is synthetic generator of weather data which could be applied to simulate the meteorological data in an individual location under present and future climatic conditions. Data are created in daily time series for a series of appropriate climatic variables such as precipitation, minimum and maximum temperatures and radiation. Currently, the outputs of global climate models have limited spatial

[1] Intergovernmental Panel on Climate Change
[2] Atmospheric-Ocean General Circulation Models

and temporal accuracy. A synthetic generator model for weather data can be used as an inexpensive calculating tool in the production of multi-year scenarios of climate change in the daily time scale (Racsko et al., 1991; Semenov and Barrow., 1997). In this study, outputs of atmosphere-ocean general circulation model is used to predict temperature and precipitation under the effects of climate change. HadCM3 model used under emission scenario A2 in two periods 2046-2065 and 2080-2099. According to researches were done in this basin HadCM3-A2 is the most critical scenario model (Dalilsafaee et al., 2015 ; Moshtaghi et al., 2015).

SWAT model

SWAT model is a comprehensive model to simulate different processes within the watershed and has been developed for the US Department of Agriculture (Arnold et al., 1993).This model is composed of eight important parts: agricultural management, crop growth, hydrology, nutrients, pesticides, sediment, soil temperature and weather (El-Khoury et al., 2015). This semi-distributive model is continuous in time and watershed scale (Arnold et al., 2012; Gassman et al., 2007; Neitsch et al., 2005) and is developed to predict the effect of land use management on water, sediment and agricultural chemical products in large and complex watersheds with different soil, land use and management conditions in long-term periods (Abbaspour et al., 2015).

SWAT model setup

The first step in configuring the watershed is entering the DEM of the area into the model. In order to draw sub-basins and waterways using DEM, considered sub-basin definition threshold as equal to 500 hectares. Considering location of hydrometric and qualitative stations, 36 sub-basins were considered for this watershed. The next step of modeling is introducing the information layers required for the formation of hydrological response units into the model. In this study, hydrological response units were evaluated in different conditions in order to determine the number of HRUs. The multiple HRU and taking into account the 15% sub-basin area threshold for land use, soil and slope is used in this study. Thus, 174 hydrological response units in 36 sub-basins of the watershed were formed.

SWAT has allowed the user to enter the crop pattern and also the type of fertilizer used in the area to the model so that the pollution from these sources of contaminants to be considered in the model (Neitsch et al., 2005). In this regard, crop pattern and amount of fertilizer consumption per dominant crop of the area were obtained according to data from Agriculture Jihad Department of Ilam Province. In the case of rain-fed cultivation, wheat and barley are dominant crops. In this basin, often wheat and corn are grown under irrigated cultivation. The level and type of fertilizer consumed for any of these crops were determined using the data from the Agriculture Jihad Department of Ilam province. In addition, cultivation date and other agricultural practices such as tillage, fertilizing and harvesting were considered according to local climate and experts. Also the pattern and type of cultivation were considered fixed during the simulation as the assumptions of this investigation.

SWAT calibration and validation

In this study, the calibration has been done using SUFI-2 algorithm (Abbaspour et al., 2007b). This algorithm has been used in SWAT-CUP software format(Abbaspour et al., 2009, 2007a). The error criterion function used in this study is Nash–Sutcliffe Equation (NSE) (Nash and Sutcliffe, 1970). The uncertainty is calculated by two evaluation criteria P-FACTOR and R-FACTOR. In order to evaluate the model efficiency, Correlation coefficients (Equation 1) and Nash-Sutcliffe (Equation 2) coefficient of efficiency were used.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i^{sim} - X_i^{simav})(X_i^{obs} - X_i^{obsav})^2\right]}{\sum_{i=1}^{n}(X_i^{sim} - X_i^{simav})^2(X_i^{obs} - X_i^{obsav})^2} \quad (1)$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(X_i^{sim} - X_i^{obs})^2}{\sum_{i=1}^{n}(X_i^{obs} - X_i^{obsav})^2} \quad (2)$$

The simulation in SWAT model has performed from 1988 to 2010 that is during the entire statistical period of which first three years have been used for Warm up period of the model. From 2001 to 2010 and from 1998 to 2000 periods were selected as river discharge calibration and validation period, respectively. In the case of sediment calibration, two periods, from 2001 to 2009 and from 1998 to 2000 were chosen for calibration and validation, respectively. In this regard, in order to simulate the nutrient load, the data relating to the first half of 2010 was used for calibration and the data from second half of 2009 was used to validate; this model time step is on a daily basis.

Results and discussion

Downscaling results

According to the average prediction GCM model, the data of daily minimum and maximum temperature and precipitation for the period 2046 to 2065 and 2080 to 2099 were produced under HADCM3-A2 for Ilam station. The results are presented the following. In the case of precipitation values on average, total precipitation in mm per month and on average in °C per month are presented during the statistical period.

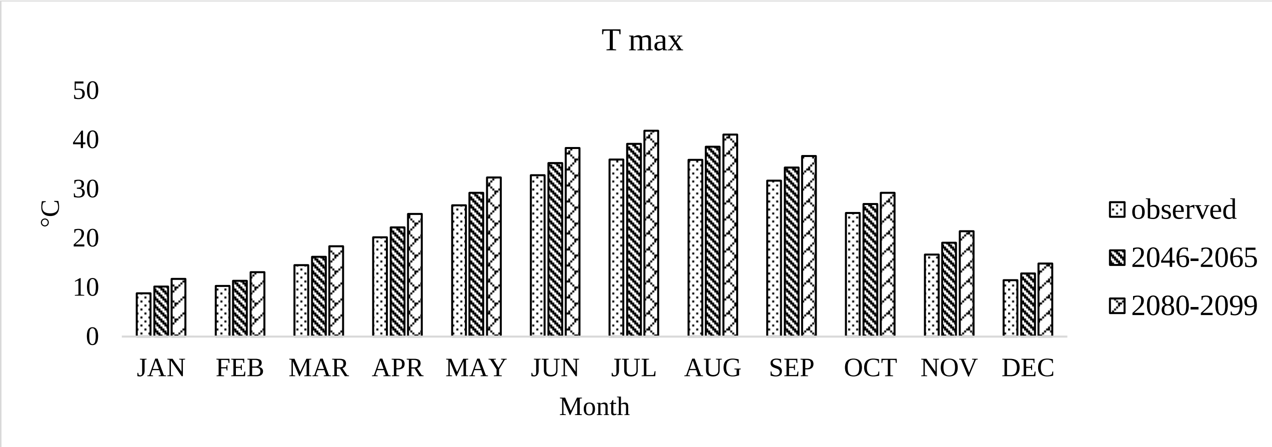

Figure 3: Compare average observed maximum temperature in each month with model- scenario in two periods

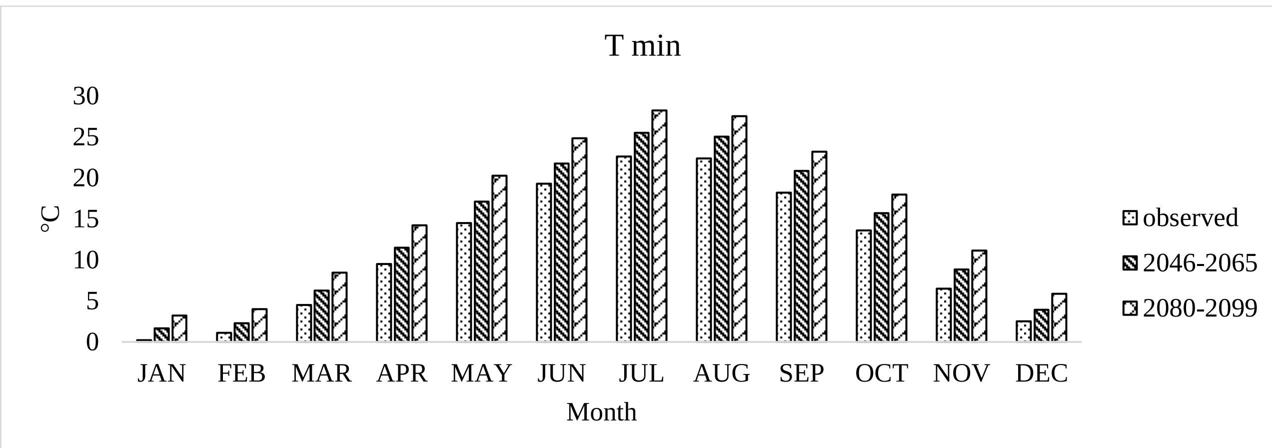

Figure 4: Compare average observed Minimum temperature in each month with model- scenario in two periods

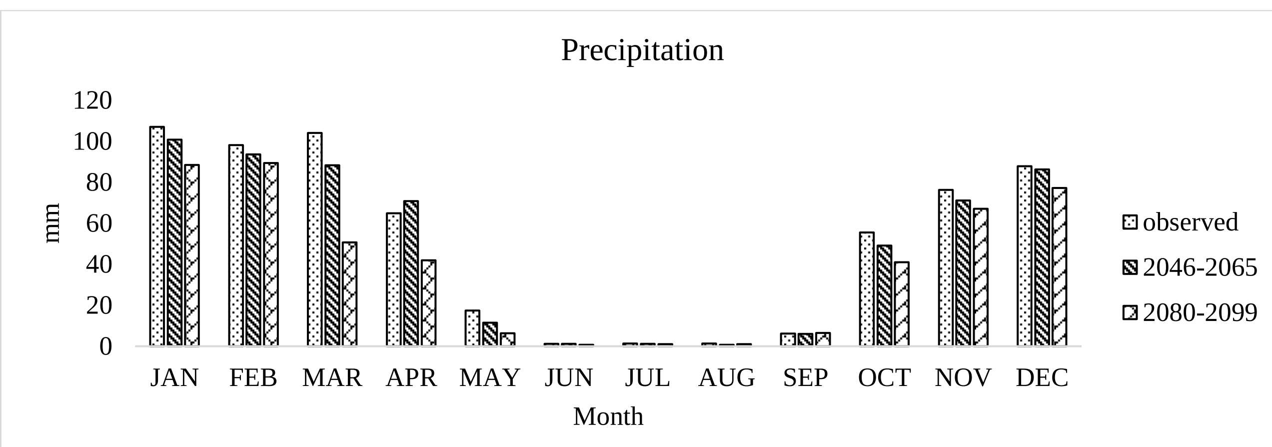

Figure 5: Compare average observed precipitation in each month with model- scenario in two periods

Table 2: summary of results from the impact of climate change

Period	Observed	HadCM3-A2	
		2046-2065	2080-2099
Mean Monthly Max Temperature (°c)	22.52	24.61	27
Mean Monthly Min Temperature (°c)	11.24	13.37	15.75
Mean Monthly Precipitation (mm)	51.7	48.39	39.26

SWAT Calibration and verification results

Selected final parameters and their variation range are shown in the Table 3. These values have been determined according to the results suggested by SWAT-CUP model as well as engineering judgment and taking into consideration the allowed range for each parameter.

Table 3: List of some SWAT's parameters that were fitted and their final calibrated values

Parameter	Parameter description	Final parameter value
v_SFTMP.bsn	Snowfall temperature (°C)	-3.13
v_SURLAG.bsn	Surface runoff lag coefficient	4.712
v_SNO_SUB.sub	Initial snow water content (mm H2O)	119.09
v_EPCO.hru	Plant evaporation compensation factor	0.841
v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur (mm H2O)	93.443
v_SLSUBBSN.hru	Average slope length (m)	22.81
v_SMTMP.bsn	Snowmelt base temperature (°C)	2.535
r_SOL_BD.sol	Moist bulk density(Mg/m3 or g/m3)	0.145
r_SOL_K.sol	Saturated hydraulic conductivity (mm H2O/ h1)	-0.064
r_SOL_AWC.sol	Available water capacity of the soil layer (mm H2O/mm soil)	-0.02
v_CH_K2.rte	Effective channel hydraulic conductivity (mm/hr)	59.046
v_CH_N2.rte	Manning's n value for the main channel	0.119
v_USLE_P.mgt	support practice factor	0.653
v_ESCO.hru	Soil evaporation compensation factor	0.95
v_GW_REVAP.gw	Groundwater 'revap' coefficient	0.068
v_ALPHA_BNK.rte	Baseflow alpha factor (days)	0.199
v_CANMX.hru	Maximum canopy storage(mm H2O)	38.265
r_CN2.mgt	SCS runoff curve number for moisture condition II	0.004
v_ALPHA_BF.gw	Baseflow alpha factor (days)	0.629
v_GW_DELAY.gw	Groundwater delay (days)	57.27
v_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H2O)	0.409
v_PRF.bsn	Peak rate adjustment factor for Sediment routing in main channels	1.145
v_SPCON.bsn	Channel re-entrained linear parameter	0.0011
v_SPEXP.bsn	Channel re-entrained exponent parameter	1.16
v_CH_ERODMO.rte	Channel erodability factor	0.909

v_RCN.bsn	Concentration of nitrogen in rain (mg N/L)	8.399
v_NPERCO.bsn	Nitrate percolation coefficient	0.015
v_CDN.bsn	Denitrification exponential rate coefficient	0.023
v_SDNCO.bsn	Denitrification threshold water content	0.096
v_AI1.wwq	Fraction of algal biomass that is nitrogen (mg N/mg alg)	0.385
v_SOL_NO3.chm	Initial NO3 concentration in the soil layer (mg N/ kg soil or ppm)	0.075
v_SOL_ORGN.chm	Initial organic N oncentration in the soil layer (mg N/ kg soil or ppm)	10.15
v_ERORGN.hru	Organic N enrichment for loading with sediment	0.981

To evaluate the performance of SWAT model to simulate variables in the calibration and validation period, the accuracy evaluation indicators of the simulation are shown in figures below.

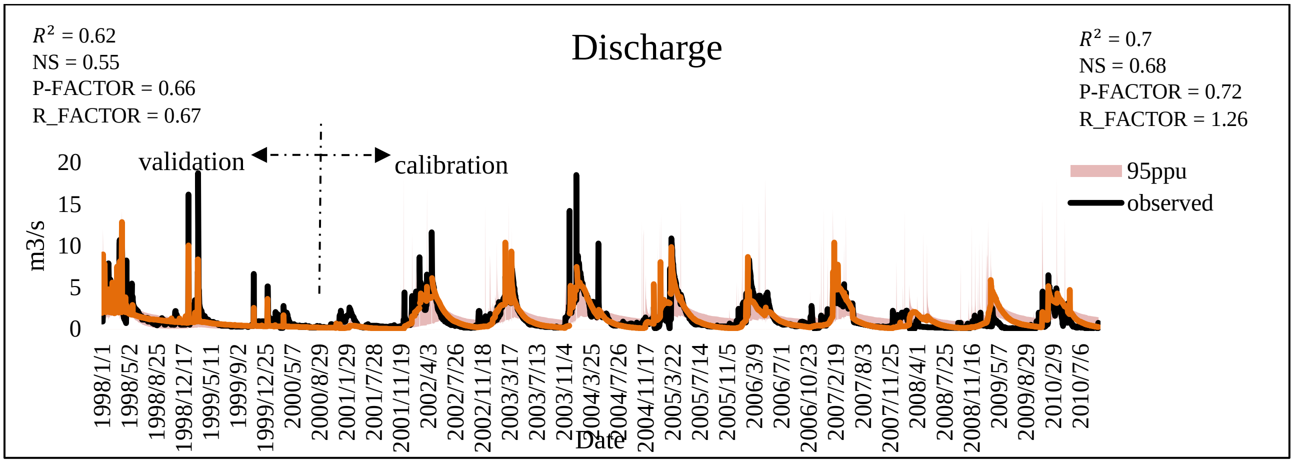

Figure 6: Results of Swat calibration and validation for daily river discharge

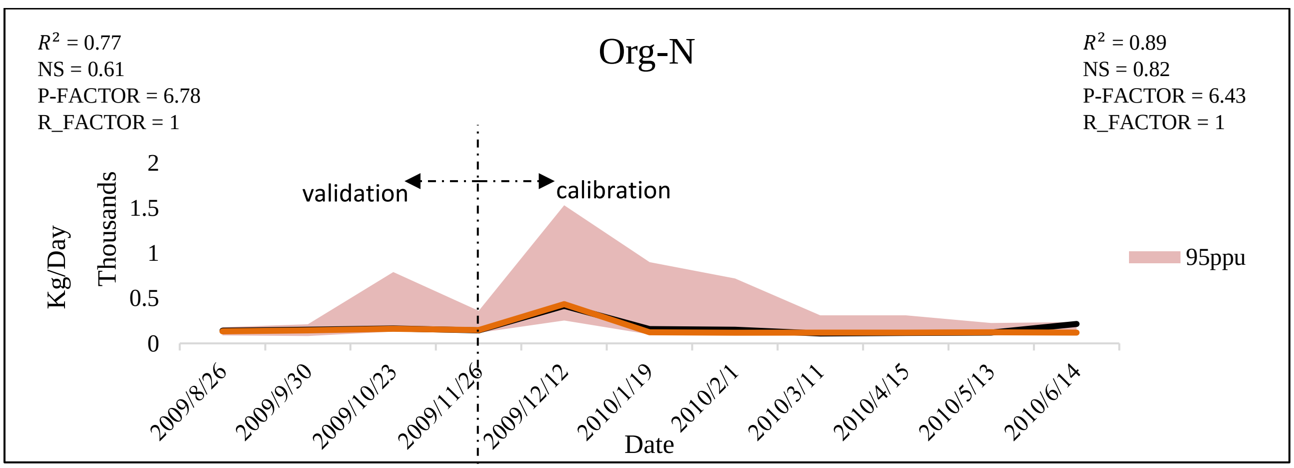

Figure 7: Results of Swat calibration and validation for daily Org-N loads

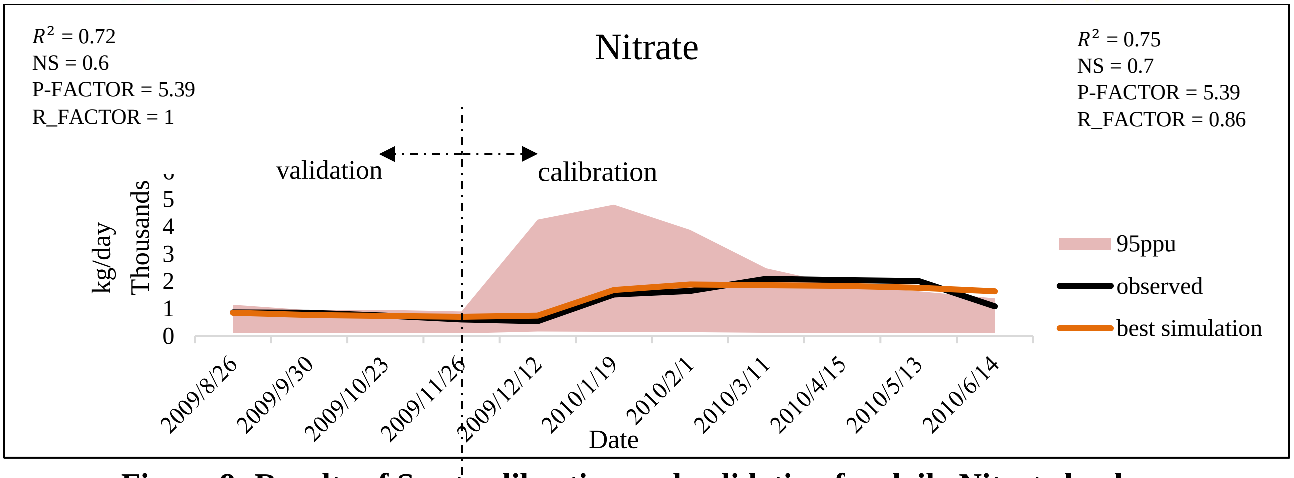

Figure 8: Results of Swat calibration and validation for daily Nitrate loads

46 initial parameters have been entered to model previously which were declined to 33 final parameters after calibration and removing parameters with less sensitivity to the model variables. CN2 had the most sensitivity compared to other parameters. Correlation coefficients, Nash-Sutcliffe coefficient, P-FACTOR and R-FACTOR for the variables of interest during the calibration and verification indicate the success of the model using the optimized parameters given daily step to simulate river discharge (Figure 6) and nutrients (Figure 7 and Figure 8) in Golgol Watershed.

Impact of climate change on Runoff, Nitrate Load and Org-N Load

The results from climate change was calculated as long-term average of each month in future period and baseline period assuming no change in land use and stability of the cropping pattern in the area; the results are displayed in the following graphs.

Irrigated cultivation

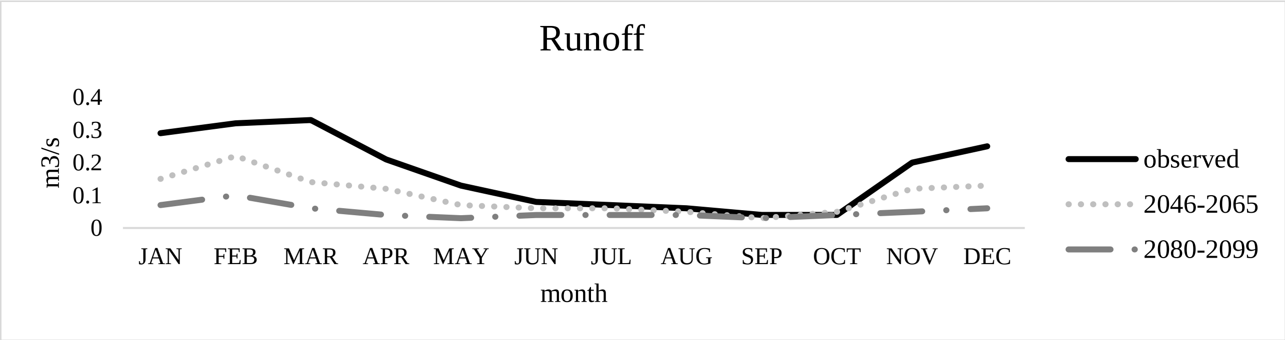

Figure 9: Comparison of average monthly Runoff from Irrigated cultivation in two periods relative to baseline period

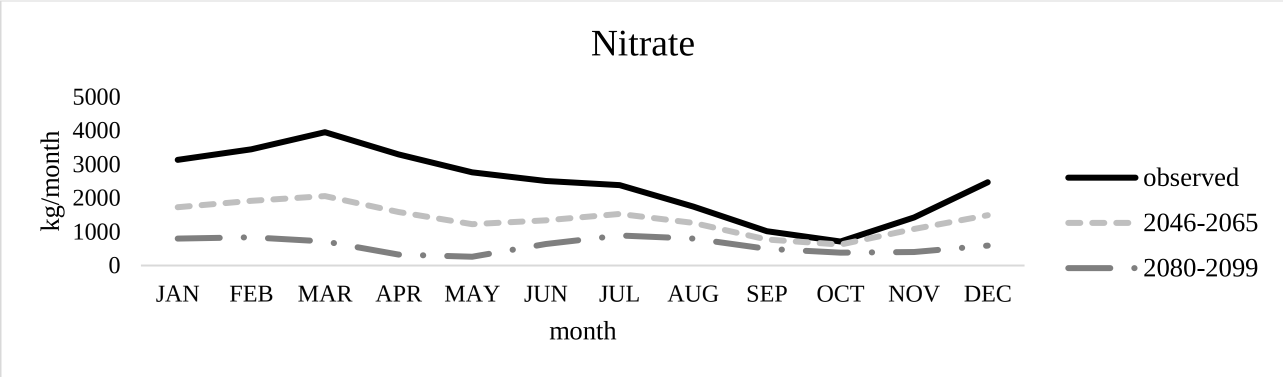

Figure 10: Comparison of average monthly Nitrate loads from Irrigated cultivation in two periods relative to baseline period

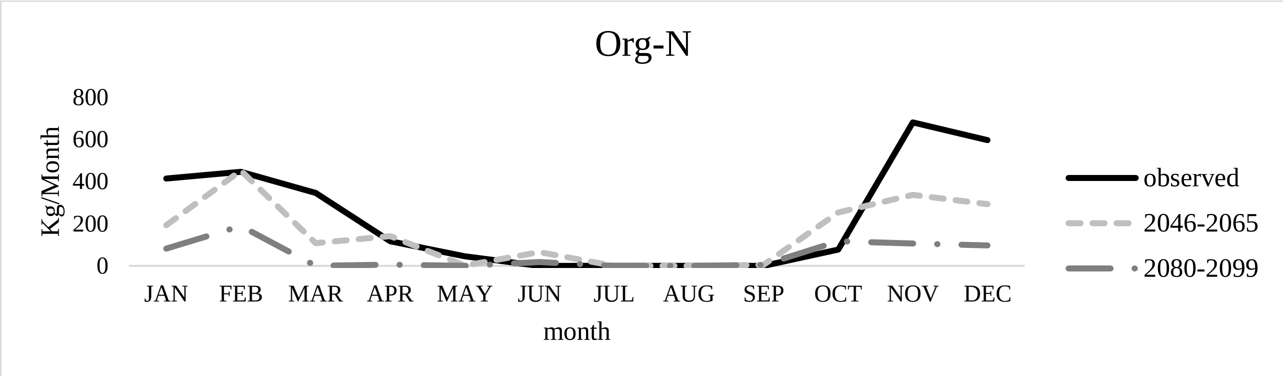

Figure 11: Comparison of average monthly Org-n loads from Irrigated cultivation in two periods relative to baseline period

Rain-fed cultivation

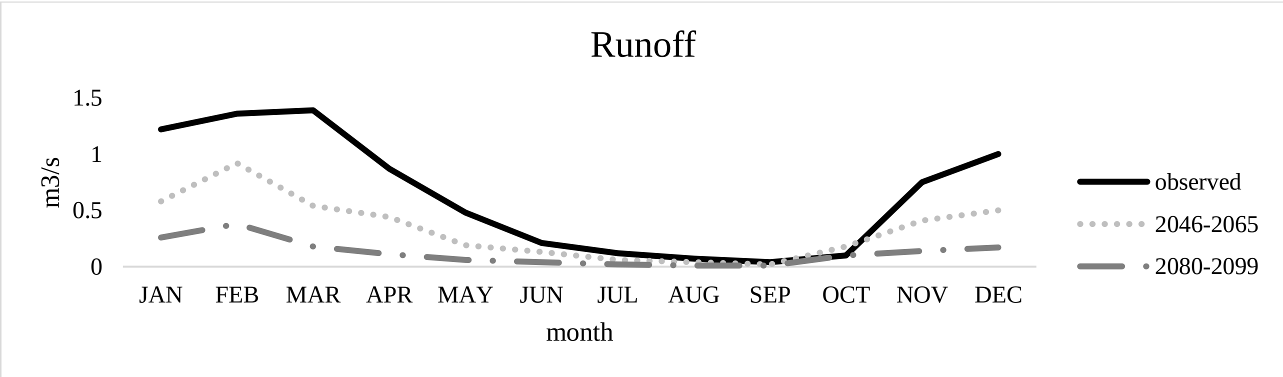

Figure 12: Comparison of average monthly Runoff from Rain-fed cultivation in two periods relative to baseline period

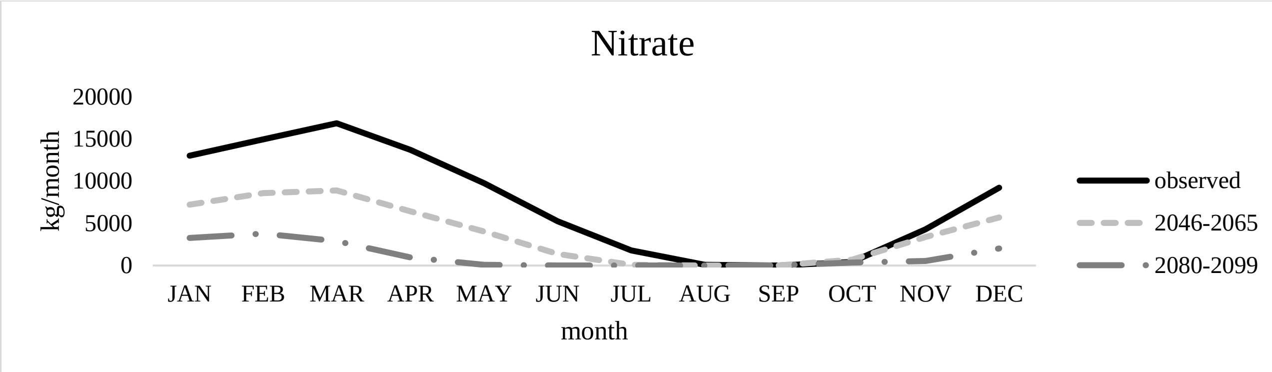

Figure 13: Comparison of average monthly Nitrate loads from Rain-fed cultivation in two periods relative to baseline period

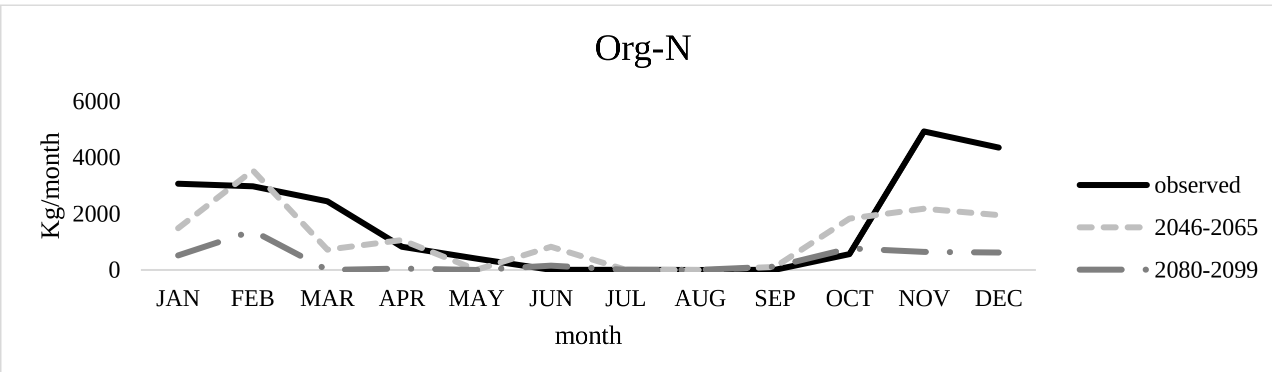

Figure 14: Comparison of average monthly Org-N loads from Rain-fed cultivation in two periods relative to baseline period

According to Figure 9 the amount of runoff from Irrigated cultivation of two periods are lower than the observed discharge in most months of the year indicating the impact of climate change on the area. The average monthly runoff is decreased from 0.17 M3/s to 0.13 in 2046 and to 0.1 in 2080 so decreasing from 23 to 41 % has been observed. according to Figure 12 Rain-fed cultivation runoff decreased from 0.46 in observation period to 0.31 in 2046 and to 0.23 in 2080. and this means 33 to 50% decrease. by comparing this two periods it is obvious that the runoff decrease about 20% in Irrigated cultivation and about 25% in Rain-fed cultivation.

According to Figure 10 the amount of Nitrate load in Irrigated cultivation from 2402.6 to 1984 kg/month in 2046 and to 1593.2 kg/month in 2090. according to Figure 13 in Rain-fed cultivation this amount decreased from 7443.9 to 6063 kg/month in 2046 and to 4916.2 in 2080 kg/month. Also by comparing two periods is found that annual nitrate load decreased 20% in Irrigated cultivation and 18% in Rain-fed cultivation.

The average of monthly Org-N load decreased from 227 kg/month in observation period to 193.6 kg/month in 2046 and to 151.2 kg/month in 2080 in Irrigated cultivation (Figure 11). according to Figure 14 the amount of nitrogen load in Rain-fed cultivation decrease from 1629.1 in observation period to 1403.7 in 2046 and to 1055.3 in 2080. In Irrigated cultivation the annual Org-N load decrease from 22% in 2080 compared to 2046 and in Rain-fed cultivation, 25%.

Conclusion

The aim of this study was to investigate the impact of climate change on the quantity and quality of agricultural runoff of Golgol River basin in which the SWAT model was used to simulate three water quality and quantity parameters and the LARS-WG model was applied for downscaling the atmosphere-ocean general circulation model. The temperatures increase in all model-scenarios. Precipitation also faced with both decrease and increase which the latter has no effect on the river discharge, therefore, it can be concluded that these increases are due to higher intensity of rainfall which may lead to floods and also Raising the temperature give rise to surface evaporation which paves the way for decresing river discharge. In two periods runoff and nutrient loads from agriculture lands have been reduced. But reducing the nutrients load associated with a sharp reduction in runoff so we face increasing in Concentrations of pollutants. Since iran is located in Arid and semi-arid regions, reusing the runoff is a good way to decrease water shortage. Another point is that some villages are located in Golgol glen. When runoff enter the river, this villages face water quality degradation. So according to runoff quality degradation, actions must be taken to reduce pollutants. There are many ways that agricultural operations can reduce nutrient pollution, including:

- Watershed efforts: The collaboration of a wide range of people and organizations often across an entire watershed is vital to reducing nutrient pollution. State governments, farm organizations, conservation groups, educational institutions, non-profit organizations, and community groups all play a part in successful efforts to improve water quality.
- Nutrient management: Applying fertilizers in the proper amount, at the right time of year and with the right method can significantly reduce the potential for pollution.
- Cover crops: Planting certain grasses, grains or clovers can help keep nutrients out of the water by recycling excess nitrogen and reducing soil erosion.
- Buffers: Planting trees, shrubs and grass around fields, especially those that border water bodies, can help by absorbing or filtering out nutrients before they reach a water body.
- Conservation tillage: Reducing how often fields are tilled reduces erosion and soil compaction, builds soil organic matter, and reduces runoff.
- Managing livestock waste: Keeping animals and their waste out of streams, rivers and lakes keeps nitrogen and phosphorus out of the water and restores stream banks.
- Drainage water management: Reducing nutrient loadings that drain from agricultural fields helps prevent degradation of the water in local streams and lakes.(USEPA, 2016)

Adapting to climate change should include reducing the multiple pressures on freshwater resources (such as water quality degrading and excessive exploitation) as well as improving drinking water and sanitation and providing management solutions.

References

Abbaspour, k. C., Faramarzi, M., Ghasemi, S.S., Yang, H., 2009. Assessing the impact of climate change on water resources in Iran. Water Resour. Res. 45, n/a–n/a. doi:10.1029/2008WR007615

Abbaspour, k. C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., Kløve, B., 2015. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. J. Hydrol. 524, 733–752. doi:10.1016/j.jhydrol.2015.03.027

Abbaspour, k. C., Vejdani, M., Haghighat, S., Yang, J., 2007a. SWAT-CUP Calibration and Uncertainty Programs for SWAT. fourth Int. SWAT Conf. 1596–1602. doi:10.1007/s00402-009-1032-4

Abbaspour, k. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., Srinivasan, R., 2007b. Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. J. Hydrol. 333, 413–430. doi:10.1016/j.jhydrol.2006.09.014

Alansi, A.W., Amin, M.S.M., Abdul Halim, G., Shafri, H.Z.M., Aimrun, W., 2009. Validation of SWAT model for stream flow simulation and forecasting in Upper Bernam humid tropical river basin, Malaysia. Hydrol. Earth Syst. Sci. Discuss. 6, 7581–7609. doi:10.5194/hessd-6-7581-2009

Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold, J.G., 2008. Representation of agricultural conservation practices with SWAT. Hydrol. Process. 22, 3042–3055. doi:10.1002/hyp.6890

Arnell, N.W., 1999. Climate change and global water resources. Glob. Environ. Chang. 9, S31–S49. doi:10.1016/S0959-3780(99)00017-5

Arnold, J.G., Allen, P.M., Bernhardt, G., 1993. A comprehensive surface-groundwater flow model. J. Hydrol. 142, 47–69. doi:10.1016/0022-1694(93)90004-S

Arnold, J.G., D. N. Moriasi, D.N., P. W. Gassman, P.W., K. C. Abbaspour, K.C., M. J. White, M.J., R. Srinivasan, R., C. Santhi, C., R. D. Harmel, R.D., A. van Griensven, A. van, M. W. Van Liew, M.W. Van, N. Kannan, N., M. K. Jha, M.K., 2012. SWAT: Model Use, Calibration, and Validation. Trans. ASABE 55, 1491–1508. doi:10.13031/2013.42256

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. J. Am. Water Resour. Assoc. 34, 73–89. doi:10.1111/j.1752-1688.1998.tb05961.x

Barnett, T.P., Adam, J.C., Lettenmaier, D.P., 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438, 303–309. doi:10.1038/nature04141

Bouraoui, F., Grizzetti, B., Granlund, K., Rekolainen, S., Bidoglio, G., 2004. Impact of Climate Change on the Water Cycle and Nutrient Losses in a Finnish Catchment. Clim. Change 66, 109–126. doi:10.1023/B:CLIM.0000043147.09365.e3

Chiew, F.H.S., McMahon, T.A., 2002. Modelling the impacts of climate change on Australian streamflow. Hydrol. Process. 16, 1235–1245. doi:10.1002/hyp.1059

Dalilsafaee, S., Niksokhan, M.H. & Moshtaghi, B., 2015 Investigation of the effect of climate change on temperature and precipitation in Ilam province using LARS-WG5.5 and Mann-Kendall (MK) test. Irrigation and Drainage's first National Congress, Mashhad, Iran.

Diaz-Nieto, J., Wilby, R.L., 2005. A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. Clim. Change 69, 245–268. doi:10.1007/s10584-005-1157-6

El-Khoury, A., Seidou, O., Lapen, D.R., Que, Z., Mohammadian, M., Sunohara, M., Bahram, D., 2015. Combined impacts of future climate and land use changes on discharge, nitrogen and phosphorus loads for a Canadian river basin. J. Environ. Manage. 151, 76–86. doi:10.1016/j.jenvman.2014.12.012

Fakhri, M., Farzaneh, M.R., Eslamian, S., Khordadi, M.J., 2013. Confidence Interval Assessment to Estimate Dry and Wet Spells under Climate Change in Shahrekord Station, Iran. J. Hydrol. Eng. 18, 911–918. doi:10.1061/(ASCE)HE.1943-5584.0000688

Fan, M., Shibata, H., 2015. Simulation of watershed hydrology and stream water quality under land use and climate change scenarios in Teshio River watershed, northern Japan. Ecol. Indic. 50, 79–89. doi:10.1016/j.ecolind.2014.11.003

Ficklin, D.L., Luo, Y., Zhang, M., 2013. Climate change sensitivity assessment of streamflow and agricultural pollutant transport in California's Central Valley using Latin hypercube sampling. Hydrol. Process. 27, 2666–2675. doi:10.1002/hyp.9386

Gassman, P.W., Reyes, M.R., Green, C.H., Arnold, J.G., 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Trans. ASABE 50, 1211–1250. doi:10.13031/2013.23637

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change[Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jha, M., Pan, Z., Takle, E.S., Gu, R., 2004. Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective. J. Geophys. Res. 109, D09105. doi:10.1029/2003JD003686

Jung, I.-W., Chang, H., 2011. Assessment of future runoff trends under multiple climate change scenarios in the Willamette River Basin, Oregon, USA. Hydrol. Process. 25, 258–277. doi:10.1002/hyp.7842

Kang, N., Kim, S., Kim, Y., Noh, H., Hong, S., Kim, H., 2016. Urban Drainage System Improvement for Climate Change Adaptation. Water 8, 268. doi:10.3390/w8070268

Kemfert, C., 2008. Climate Protection Requirements –the Economic Impact of Climate Change, in: Handbook Utility Management. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 725–739. doi:10.1007/978-3-540-79349-6_42

Melese, S.M., 2016. Effect of Climate Change on Water Resources. J. Water Resour. Ocean Sci. i, 14–21. doi:10.11648/j.wros.20160501.12

Mitchell, T.D., 2003. Pattern Scaling: An Examination of the Accuracy of the Technique for Describing Future Climates. Clim. Change 60, 217–242. doi:10.1023/A:1026035305597

Moshtaghi, B, Niksokhan, M H , Dalilsafaee, D., 2015 Effects of climate change on temperature and precipitation and Ilam drought forecasting. Conference on environmental science, engineering and technologies, ceset 2015. http://www.civilica.com/Paper-CESET01-CESET01_381.html

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I — A discussion of principles. J. Hydrol. 10, 282–290. doi:10.1016/0022-1694(70)90255-6

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams., J.R., 2005. Soil and Water Assessment Tool Theoretical Documentation Version 2005. Black. Res. Center, Texas Agric. Exp. Stn. 10, 10, 494.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., Zhou, L., Liu, H., Ma, Y., Ding, Y., Friedlingstein, P., Liu, C., Tan, K., Yu, Y., Zhang, T., Fang, J., 2010. The impacts of climate change on water resources and agriculture in China. Nature 467, 43–51. doi:10.1038/nature09364

Racsko, P., Szeidl, L., Semenov, M., 1991. A serial approach to local stochastic weather models. Ecol. Modell. 57, 27–41. doi:10.1016/0304-3800(91)90053-4

Semenov, M.A., Barrow., B.E., 1997. Use of a stochastic weather generator in the development of climate change scenarios. Clim. Change 35, 397–414. doi:10.1023/A:1005342632279

Singh, J., Knapp, H.V., Arnold, J.G., Demissie, M., 2005. Hydrological modeling of the Iroquois River watershed using HSPF and SWAT. J. Am. Water Resour. Assoc. 41, 343–360. doi:10.1111/j.1752-1688.2005.tb03740.x

Tao, F., Yokozawa, M., Hayashi, Y., Lin, E., 2003. Future climate change, the agricultural water cycle, and agricultural production in China. Agric. Ecosyst. Environ. 95, 203–215. doi:10.1016/S0167-8809(02)00093-2

Tripathi, M.P., Panda, R.K., Raghuwanshi, N.S., 2003. Identification and Prioritisation of Critical Sub-watersheds for Soil Conservation Management using the SWAT Model. Biosyst. Eng. 85, 365–379. doi:10.1016/S1537-5110(03)00066-7

Tu, J., 2009. Combined impact of climate and land use changes on streamflow and water quality in eastern Massachusetts, USA. J. Hydrol. 379, 268–283. doi:10.1016/j.jhydrol.2009.10.009

USEPA, 2016. The Sources and Solutions: Agriculture (online) https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

USEPA, 2014. Climate change Site (Online) http://www.epa.gov/climatechange/.

Wilby, R.L., Harris, I., 2006. A framework for assessing uncertainties in climate change impacts: Low-flow scenarios for the River Thames, UK. Water Resour. Res. 42, n/a–n/a. doi:10.1029/2005WR004065

Wu, H., Chen, B., 2015. Evaluating uncertainty estimates in distributed hydrological modeling for the Wenjing River watershed in China by GLUE, SUFI-2, and ParaSol methods. Ecol. Eng. 76, 110–121. doi:10.1016/j.ecoleng.2014.05.014

Xu, Z.X., Pang, J.P., Liu, C.M., Li, J.Y., 2009. Assessment of runoff and sediment yield in the Miyun Reservoir catchment by using SWAT model. Hydrol. Process. 23, 3619–3630. doi:10.1002/hyp.7475

2

Topic 2:
Measures to Improve Drainage Water Quality

MODELING NITRATE-N LEACHING IN NO-TILL FIELDS WITH DRAINMOD-N II

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Abstract

Conservation agriculture, especially no-tillage, has proven to result into sustainable farming in many agricultural environments globally. In spite of some advantages of no-till systems, this practice may increase infiltration into the soil and leaching to groundwater. This method can also enhance the movement of mobile nutrients and some pesticides to subsurface drains and to deeper groundwater along preferential pathways in the soil profile. In this study, DRAINMOD-N II was utilized for the simulation of nitrate-nitrogen (NO3-N) concentration in till drainage water outflows in no-till filed of Truro, Nova Scotia, Canada from2003-2006. The model performance was evaluated first by comparing the observed and simulated drain outflow data that is an essential prerequisite for the model to obtain a proper prediction of NO3-N movement, and then by comparing the observed and simulated NO3-N concentration in no-till fields using three statistical indices, relative root mean square error (RRMSE), average absolute deviation (AAD) and the correlation coefficient (R^2). The RMSE, AAD and R^2 for validation period were determined to be 1.09 mm, 1.85 mm and 0.83 for drain outflow, and 1.43 mg/l, 0.51 mg/l and 0.79 for NO3-N concentration respectively. The results showed that DRAINMOD-N II predicted reasonably well NO3-N leaching in drainage outflow of no-till fields over the whole years.

KEY WORDS: No-till, DRAINMOD-N II, Nitrate, Leaching.

Introduction

No-till farming has been recognized as an efficient practice to conserve soil and water, and to improve soil quality and to ensure food security (Lal 2004). No-till, also known as direct drilling or zero tillage (conservation tillage in the USA and Australia), means sowing directly into the residue of the previous crop without any prior topsoil loosening. Under such practices, a 30% or greater cover of residue from the previous crop is left on the soil surface. For example, a 60%

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reduction in surface runoff was reported for no-till corn in Quebec when compared with conventional tillage (McRae et al. 2000). The adoption of conservation tillage practices has resulted into lesser periods when soils are left bare and exposed to erosion. It reduced the number of bare soil days per hectare per year in Canada around 20% in 1981 to 1996 (McRae et al. 2000).

No-till generally increases the macro porosity of the soil since reduced tillage allows increased aggregation. Changes in pore size generally allow for enhanced infiltration but can cause an increase in bulk density in high-traffic areas (although no-till often can increase bulk density). The results of different studies showed that tillage and cropping have more effects on preferential flow through macro pores and solute transport (Kamau et al. 1996, Rasse and Smucker 1999).

Although minimum-tillage may reduce losses of water and the intrusion of some pollutants into surface drainage, this practice may increase infiltration into the soil and leaching to groundwater. This can enhance the movement of mobile nutrients and some pesticides to subsurface drains and to deeper groundwater along preferential pathways (e.g., cracks and worm holes) in the soil profile (Drury et al. 1996, Gaynor et al. 2002).

Rasse and Smucker (1999) and Ogden et al. (1999) found that no-till increased the flow volume as compared to conventional-till. In both studies, the amount of solute loss, whether nitrate-nitrogen or bromide, was essentially the same, even though flow was greater under no-till.

In Nova Scotia, Canada, the use of no-till increased from 4% of the total area prepared for seeding in 1991 to 14% in 2006 (Hofmann 2008). Many soils in Nova Scotia have poor drainage capabilities and receive an annual precipitation that exceeds potential evapotranspiration (Carter et al. 1996). Hence, the use of subsurface drainage systems is necessary to improve internal soil drainage for ensuring better crop growth.

The performance of the DRAINMOD model in colder regions has been evaluated in previous researches. Luo et al. (2001) used DRAINMOD ,version 5.1, to simulate water table and subsurface drainage for three fileds in Carsamba, Turkey; Truro, Canada; and Lamberton, Minnesota .This model gave reasonable predictions of field hydrology. Dayyani et al., (2009) assessed the hydrological performance of DRAINMOD 5.1 for Southern Quebec region with due consideration tofreezing/thawing conditions. The result showed that the DRAINMOD 5.1 performed well in simulating the hydrology of a cold region.

DRAINMOD−N II is a field−scale, process−based model that was developed to simulate nitrogen dynamics and turnover in the soil−water−plant system under different management practices and soil and environmental conditions. Youssef et al (2005) show that the model is capable of simulating N dynamics under different management practices and environmental and soil conditions. It operates in three modes with different levels of complexity, so it can be adapted to the system being simulated.

It is necessary to look for a model that can accurately predict Nitrate-N leaching in no-till fields. Therefore, the goal of this study was to evaluate the capacity of DRAINMOD-N II to simulate subsurface Nitrate-N leaching in no-till fields throughout the year in a cold climate, such as Truro, Nova Scotia.

Materials and methods

Site Description

A subsurface drainage system was installed in a six ha field in Truro, Nova Scotia, Canada in 1995 (45o 22' N, 63o 16o' W). The system had previously been used to compare the effects of composted poultry manure and fresh manure on water quality (Thiagarajan et al. 2007). The plot was divided into 10 plots (36 m × 72 m) with each plot isolated hydrologically by buffer drains. These plots consist of five conventional tillage (CT) and five zero tillage (ZT) systems. The plot layout, drainage and treatment details are illustrated in Figure 1. Since plot 6 (no-till plot) had a complete dataset, the data for this plot was used to evaluate the model. Perforated drainage conduits (100 mm in diameter) are located at an average depth of 80 cm with 12 m spacing. The drainage system information is given in Table 1. Soil in plot 6 wass imperfectly drained and was classified as Pagwash 52. Soils of the Pagwash group develop in coarse loamy till which is derived from sandstone of the carboniferous period. Pagwash 52 soils have 50 to 80 cm of friable, coarse loamy solum over firm, coarse loam, lower soil material (Webb 1991). Soil water characteristic of this soil were obtained using the standard pressure plate method. Saturated conductivities were determined by adjusting the values from the core method with the field effective soil hydraulic conductivities (Madani and Brenton 1995, Madani et al. 1997).

The cropping system was a wheat-soybean rotation from 2003 to 2006, respectively. Spring Wheat (var. Belvedere) and Soybeans (var. DKB 00/99) were planted using a no-till planter for all plots during the spring.

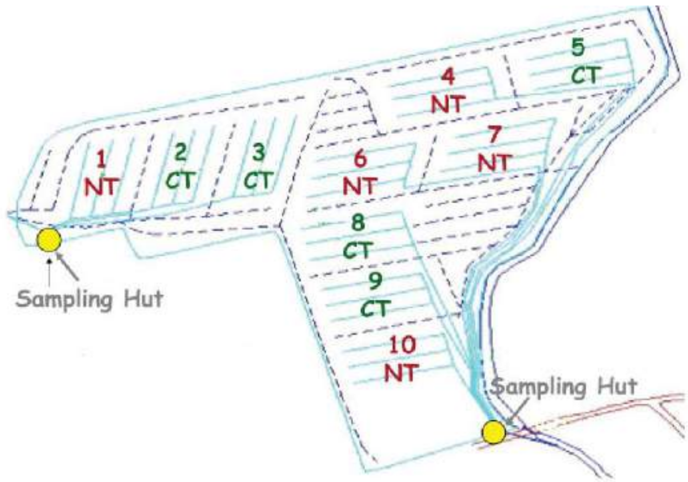

Figure1. Experimental field plot layout (CT: Conventional tillage, ZT: zero tillage)

Table 1. DRAINMOD input parameters

Parameters	Values
Drainage System	
Drain depth (cm)	80
Drain spacing (cm)	1200
Effective radius of drain (cm)	5
Actual distance to impermeable layer (cm)	100
Drainage coefficient (cm d^{-1})	2
Maximum surface storage (cm)	0.5
Kirkham's depth for flow to drains (cm)	0.5
Lateral saturated hydraulic conductivity of 4 layers (cm h^{-1})	11, 4.75, 5.3, 2.2
Soil Temperature	
Thermal conductivity function coefficient (W $m^{-1o}C^{-1}$)	a=0.55, b=1.96
Phase lag for daily air temperature sine wave (h)	9
Rain/snow dividing temperature (°C)	-2
Snowmelt base temperature (°C)	-3
Snowmelt coefficient (mm °C d^{-1})	2
Critical ice content (cm^3 cm^3)	0.2
ET monthly factors	
Jun.= 1.1, Feb.= 1.15, Mar.= 1.1, Apr.= 1.1, May= 1.1, June= 0.9, July = 0.4, Agu.= 0.5, Sep.= 0.7, Oct.= 0.7, Nov.= 0.9, Dec.= 1.1	

The liquid dairy manure application rate was based on the crop N requirement and on the assumption of 50% N availability from the manure applied during the current years (Tortora et al. 2007), in addition to soil nutrient status and any nutrient credits from previous manure applications. Then 40 and 25 ton/ha liquid dairy manure for wheat and soybean were used, respectively. Liquid dairy manure samples were collected each year from the manure storage pit prior to application and analyzed for nutrient content by the Nova Scotia Department of Agriculture and Fisheries Laboratory, Truro, Nova Scotia.

Data Measurements

Water samples were collected from the drainage water discharging into the tipping buckets in capped 50 mL centrifuge tubes for NO3--N. From Jun 2003 to July 2003, the nutrient was gathered manually. From August 2003 onwards, sampling data was gathered using Isco model 6700 auto samplers (Isco, Lincoln, NE). The frequency of sample collection was based on the duration of each flow event following the storm. Water samples were stored at 4oC until analyses were performed.

Shallow groundwater samples were collected every two weeks or one day after a significant rainfall event (greater than 13 mm), whichever occurred first. All samples were transported in coolers the same day they were collected and stored at 4°C until analyzed, usually within a week.

Model Inputs

DRAINMOD inputs include climate data (daily max/min temperature and hourly precipitation), soil properties, drainage volume-water table depth relationship, upward flux, infiltration parameters, crop parameters, and drainage system parameters (Skaggs 1980, Workman and Skaggs 1994). The drainage volume, upward flux and infiltration parameters were calculated by an internal DRINMOD subroutine, which used the soil water properties of each layer of the soil to produce values of volume drained for water table positions ranging from the surface to the bottom of the soil profile (Skaggs 1980). Climate data includes hourly rainfall and daily max/min temperature that were collected at the Truro station and used in the DRAINMOD model. Potential evapotranspiration was calculated during simulation using the Thornthwaite equation.

Model Calibration

The objective of the calibration process was to minimize the difference between measured and simulated data. DRAINMOD-N II was manually calibrated using monthly drainage outflow and nitrate concentration of 2003-2004, while the monthly drainage outflow and nitrate outflow data in 2005-2006 were used for model validation.

The simulated monthly drainage outflow and nitrate concentration outflows were compared with the observed data for both model calibration and validation. Monthly observed and simulated drain outflow and concentration were compared using statistical parameters including: average absolute deviation (AAD), relative root mean square error (RMER), coefficient of determination (R^2).

The AAD value shows the overall magnitude of deviation of simulated values from observed ones as given by Janssen and Heuberger (1995):

$$AAD = \frac{\sum_{i=1}^{n} |O_i - P_i|}{n} \quad (1)$$

where Oi is the i_{th} observed values, P_i is the i_{th} predict value, for a total number of events "n".

The Relative root mean square error is suggested by El-Sadek et al. (2001).

$$RRMSE = \frac{\sqrt{\sum_{i=1}^{n} (O_i - P_i)^2}}{O_{avg}} \quad (2)$$

Where O_{avg} is the mean observed value.

R^2 is also used to compare observed and predicted values (El-Sadek et al. 2001, Fernandez et al. 2006) and it is expressed as:

$$R^2 = \frac{\left(\sum_{i=1}^{n} (O_i - O_{avg})(P_i - P_{avg}) \right)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2 \sum_{i=1}^{n} (P_i - P_{avg})^2} \quad (3)$$

Where P_{avg} is the mean predicted value.

Results and discussion

Hydrology

DRAINMOD was manually calibrated by comparing observed and simulated drainage outflows. During the calibration process, and in order to obtain the optimal agreement between the predicted and observed system variables, the model input parameters were changed. Calibration parameters were selected based on previously cited literature and adjusted on a trial-and-error basis using daily and monthly drain flow.

The calibration parameters consisted of soil hydraulic parameters (saturated hydraulic conductivity, lateral saturated hydraulic conductivity (cm h-1) and factor α (cm-1)), monthly ET adjustment factors, drainage coefficient, and maximum surface storage (He et al. 2002, Singh et al. 2006, Wang et al. 2006).

Simulated and observed subsurface flows for monthly hydrographs during the calibration period (2002-2003) are shown in Figure 2. As shown in this figure, DRAINMOD simulations are closely matched with observed monthly drain outflow. The statistical indices calculated from the simulated and observed monthly outflow for the calibration period were 0.71 mm, 1.08 mm and 0.92 for AAD, RRMSE and R^2, respectively. The statistic values showed a good agreement between observed and simulated monthly drain outflows.

Monthly drain outflow data of 2005-2006 were used to validate the DRAINMOD model hydrology. To validate the calibrated model, the monthly predicted and observed drain outflow during the period of 2005-2006 were compared (Figure 3). The overall RRMSE in the predicted monthly drain outflow was 1.09 mm and the monthly values of R^2 and AAD were 0.83 and 1.85 mm, respectively, showing a close agreement between predicted and observed drain outflows during the validation years.

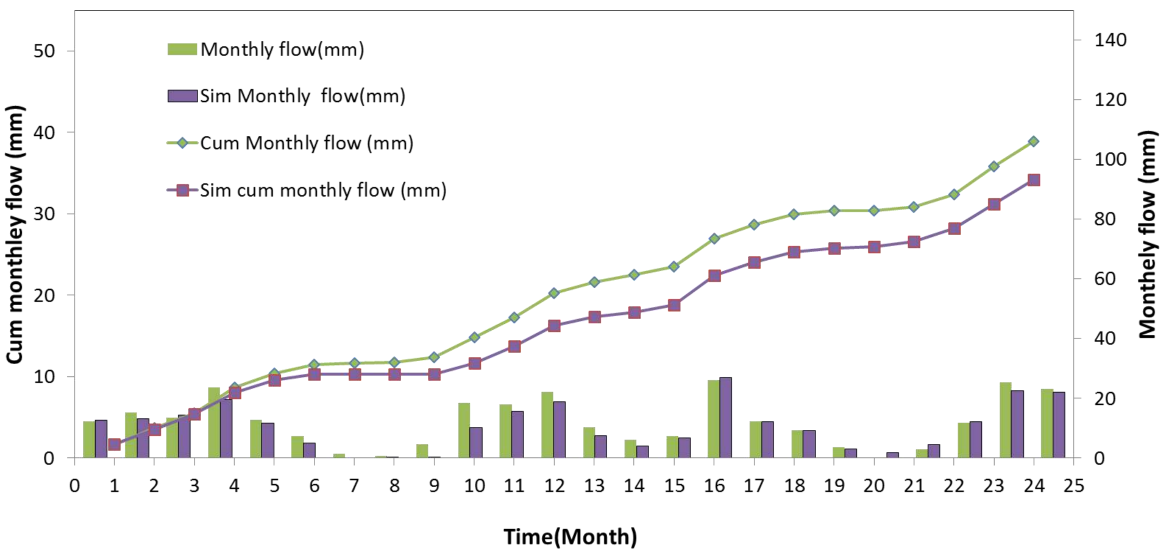

Figure 2. Simulated vs. observed daily drain outflow for calibration years (2003-2004)

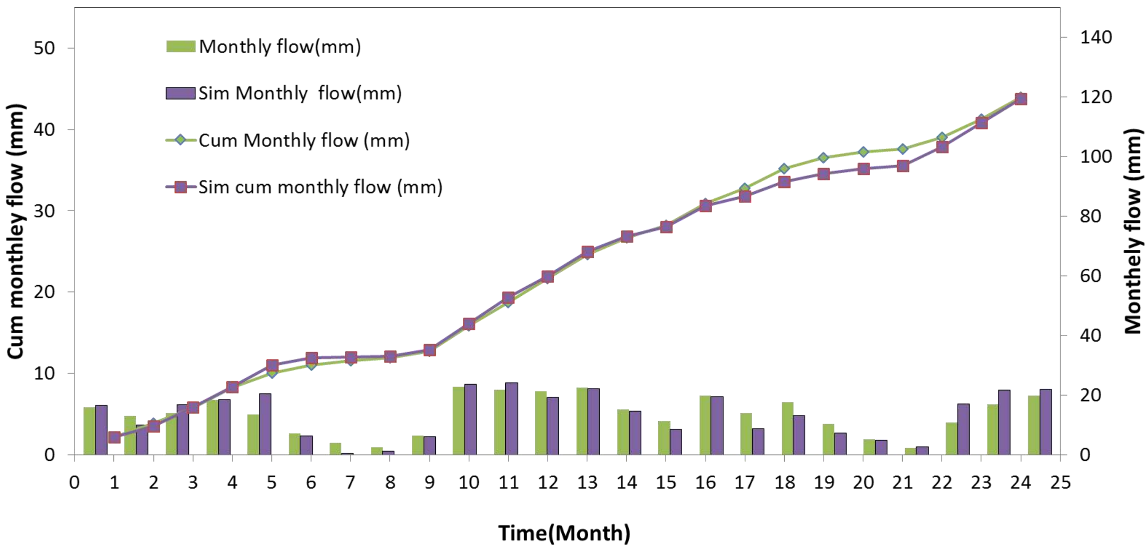

Figure 3. Simulated vs. observed daily drain outflow for validation years (2005-2006)

Nitrate

Several Nitrogen-related parameters are required for the DRAINMOD-N II simulation including crop management, N transport and transformation, and organic matter parameters. After calibrating the hydrological portion of the model, the nitrogen component was calibrated. The calibration process consisted of a trial and error testing of input values that resulted in the best agreement between simulated and observed monthly nitrate losses from the tile systems in the field. The range of parameters tested was taken from values found in the literature (Breve et al. 1997, Breve et al. 1997) and are summarized in tables 2, 3 and 4.

The DRAINMOD-N II was calibrated using the field measurements monthly drainage nitrate concentration taken during the study period. The Calibrated parameters and their ranges were selected based on a previously conducted calibration for DRAINMOD-N II (R.W. Skaggs, M.A. Youssef, G.M. Chescheir, DRAINMOD: model use, calibration and validation Trans. ASABE. Am. Soc. Agric. Biol. Eng., 55 (4) (2012), pp. 1509–1522 ISSN 2151-0032)). In order to measure the efficiency of the calibration, statistical measures were calculated using the calibration result data versus observed data. The RMSE and AAD value of the monthly NO3-N losses for the years f 2003 and 2004 were 1.42 and 0.46 mm, respectively, and R^2 for this period was 0.92. The low values of RMSE and AAD and high R^2 for all the calibration cases indicate a good fit between the simulation results and field observations.

Table 2. Initial transport parameters and NH4+ distribution coefficient used in DRAINMOD-N II.

Input parameter	Value
Longitude dispersivity (cm)	5
Tortuosity	0.5
Tolerance	10−4
Minimum time step (day)	0.001
Concentration in rainfall (mg l^{-1})	
NO_3–N	0.45
NH_4–N	0.55
NH_3–N concentration in air (mg l^{-1})	0
NO_3–N initial concentration in soil (mg l^{-1})	
0–100 cm	8
NH_4–N initial concentration in soil (mg l^{-1})	
0–100 cm	0

Table 3. Initial transformation parameters used in DRAINMOD–N II.

Input parameter	Nitrification	De-nitrification
Michaelis–Menten parameters		
Vmax (μg N g^{-1} soil day^{-1})	30	2
Km	10	40
Optimum temperature (°C)	20	35
Threshold water-filled pore space	–	0.77
Optimum water-filled pore space range	0.5–0.6	–

Table 4. Initial organic matter parameters used in DRAINMOD–N II.

Input parameter	Kdec (day^{-1})	C/N ratio (day^{-1})
Litter pool		
Surface structural	1.06849×10^{-2}	150
Surface metabolic	4.05479×10^{-2}	15
Surface microbes	1.64384×10^{-2}	8
Below-ground structural	1.34247×10^{-2}	150
Below-ground metabolic	5.06849×10^{-2}	15
SOM pools		
Active	$2.0000 \times 10_{-2}$	15
Slow	$5.4795 \times 10_{-4}$	20
Passive	$1.2329 \times 10_{-5}$	10

According to figure 4, the monthly simulated NO3–N losses portray a good agreement with the field measurements. The results show that NO3–N losses were strongly dependent on outflow rates following the typical behavior. As shown in figure 4, the accumulated model results tend to be slightly higher than field observations during wheat season. During soybean season, the highest monthly NO3–N drainage losses occurred during November and December.

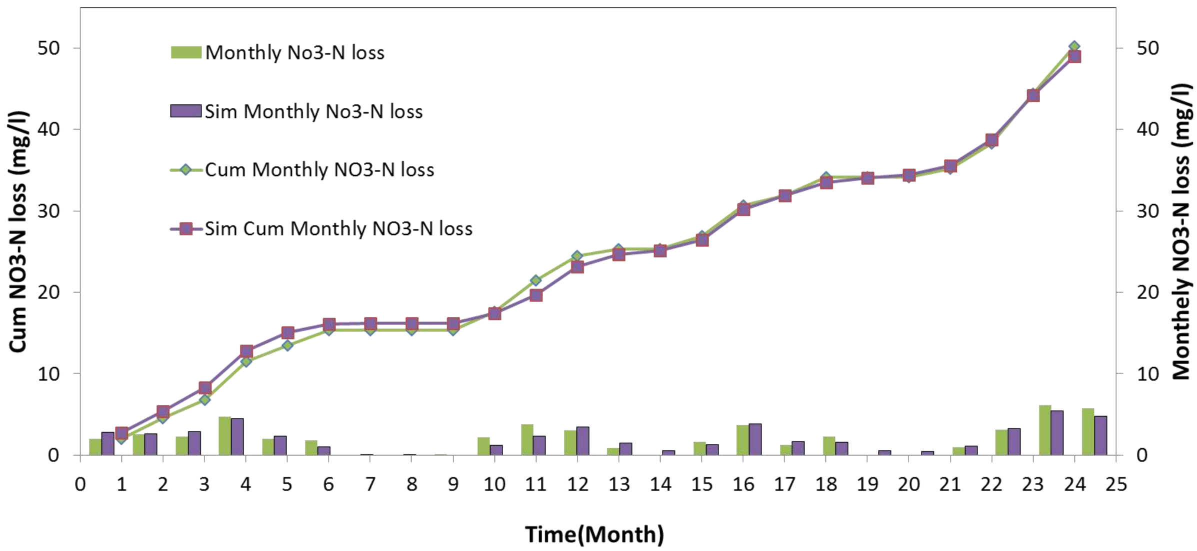

Figure 4. Observed and simulated monthly and cumulative NO3–N losses in subsurface drains for calibration period (2003-2004)

DRAINMOD-N II model was validated using the data obtained from the experimental years of 2005-2006 for this plot. According to figure 5, the results visually show a good agreement between the field measurements and the simulated results for monthly and cumulative NO3-N loss. The statistical analyses for NO3-N concentration in both years was reliable. The RRMSE, AAD, R^2 value of the monthly NO3-N losses for years 2005 and 2006 were 1.43 mm, 0.51 mm and 0.79, respectively. High R^2 values and low RRMSE and AAD showed that DRAINMOD-N II could be used successfully in simulating nitrogen-N concentration in a no-till area. Low RRMSE values indicated that the differences between the observed and simulated nitrate-N concentrations in no-till field was found to be small in both years. According to figure 5, the monthly DRANMOD-N II model results tended to be higher than field observations during wheat season and lower during the soybean season.

The results of this study demonstrated the potential of DRAINMOD-N II for simulating N dynamics in no-till fields. However, more rigorous testing of the model should be conducted before its extensive use.

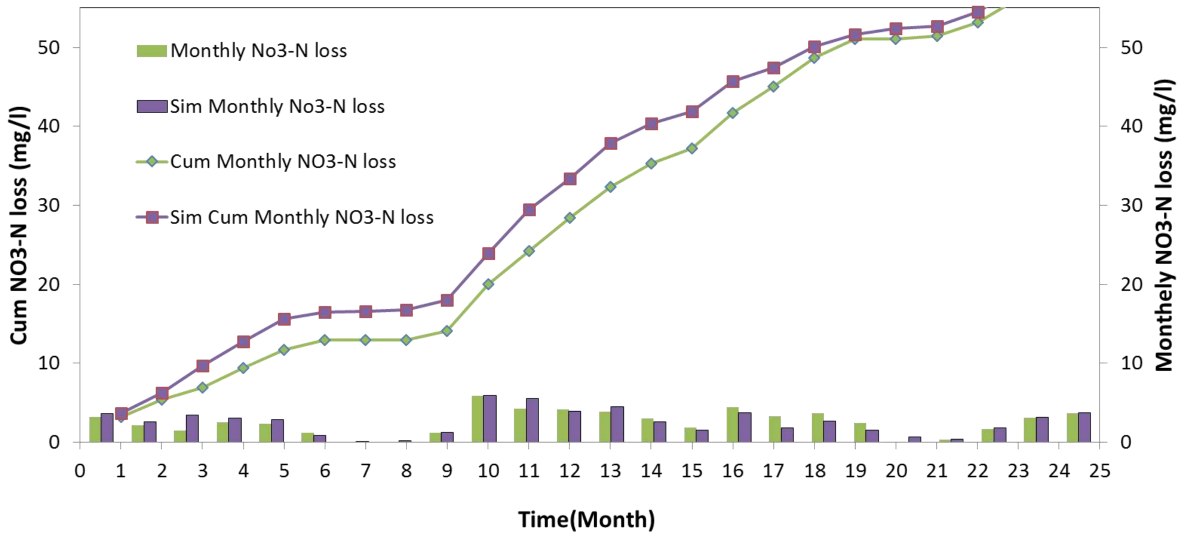

Figure 5. Observed and simulated monthly and cumulative NO3–N losses in subsurface drains for validation period (2005-2006)

Conclusion

The nitrogen simulation model, DRAINMOD-N II, was field-tested using four years of data from an experimental no-till field located in Truro, Nova Scotia, Canada, from 2003-2006. The test site was a no-till field with artificially drained agriculture and very poorly drained soil under natural conditions. In this study, the field was planted on the basis of awheat-soybean rotation and managed using free drainage, . DRAINMOD-N II model was successfully tuned up during calibration using data sets for cultivation periods between 2003 and 2004. Subsequently, the verification of the model shows a good agreement between the observed and simulated data. The statistical goodness-of-fit measures represented by the average absolute deviation (AAD), relative root mean square error (RMER), coefficient of determination (R^2) for the DRAINMOD-N II verify the good match between the model results and field observations. The consequences of this study demonstrate the capability of the DRAINMOD-N II to simulate drainage rate and nitrogen losses from no-till fields.

References

Breve, M., R. Skaggs, J. Parsons and J. Gilliam (1997). "DRAINMOD-N, a nitrogen model for artificially drained soil." Transactions of the ASAE 40(4): 1067-1075.

Breve, M. A., R. W. Skaggs, J. W. Gilliam, J. E. Parsons, A. T. Mohammad, G. M. Chescheir and R. O. Evans (1997). "Field testing of DRAINMOD-N." Transactions of the ASAE 40(4): 1077-1085.

Carter, M., D. Holmstrom, L. Cochrane, P. Brenton, W. Thomas, J. v. Roestel and D. Langille (1996). "Persistence of deep loosening of naturally compacted subsoils in Nova Scotia." Canadian journal of soil science 76(4): 541-547.

Dayyani, S., C. A. Madramootoo, P. Enright, G. Simard, A. Gullamudi, S. O. Prasher and A. Madani (2009). Field Evaluation of DRAINMOD 5.1 Under a Cold Climate: Simulation of Daily Midspan Water Table Depths and Drain Outflows1, Wiley Online Library.

Drury, C., C. Tan, J. Gaynor, T. Oloya and T. Welacky (1996). "Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss." Journal of Environmental Quality 25(2): 317-324.

El-Sadek, A., M. Radwan, J. Feyen and J. Berlamont (2001). Use of the DRAINMOD and MIKE 11 Models in Combination with GIS for Simulating at Catchment Scale the Nitrate Load. Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges, ASCE.

Fernandez, G., G. Chescheir, R. Skaggs and D. Amatya (2006). "DRAINMOD-GIS: a lumped parameter watershed scale drainage and water quality model." Agricultural Water Management 81(1): 77-97.

Gaynor, J., C. Tan, C. Drury, T. Welacky, H. Ng and W. Reynolds (2002). "Runoff and drainage losses of atrazine, metribuzin, and metolachlor in three water management systems." Journal of environmental quality 31(1): 300-308.

He, X., M. Vepraskas, R. Skaggs and D. Lindbo (2002). "Adapting a drainage model to simulate water table levels in coastal plain soils." Soil Science Society of America Journal 66(5): 1722-1731.

Hofmann, N. (2008). "Conventional tillage: How conventional is it?".

Janssen, P. and P. Heuberger (1995). "Calibration of process-oriented models." Ecological Modelling 83(1): 55-66.

Kamau, P., T. Ellsworth, C. Boast and F. Simmons (1996). "TILLAGE AND CROPPING EFFECTS ON PREFERENTIAL FLOW AND SOLUTE TRANSPORT." Soil science 161(9): 549-561.

Lal, R. (2004). "Soil carbon sequestration impacts on global climate change and food security." science 304(5677): 1623-1627.

Luo, W., R. W. Skaggs, A. Madani, S. Cizikci and A. Mavi (2001). "Predicting field hydrology in cold conditions with DRAINMOD." Transactions of the ASAE 44(4): 825-834.

Madani, A. and P. Brenton (1995). "Effect of drain spacing on subsurface drainage performance in a shallow, slowly permeable soil." Canadian Agricultural Engineering 37(1): 9-12.

Madani, A., S. Welling and P. Havard (1997). "A comparison of performance of 50 mm and 100 mm subsurface drain tiles in Atlantic Canada." Paper - American Society of Agricultural Engineers(972135): 23 pp.

McRae, T., C. Smith and L. Gregorich (2000). "Environmental sustainability of Canadian agriculture." Report of the Agri-Environmental Indicators Project. Ottawa ON: Agriculture and Agri-Food Canada.

Ogden, C. B., H. M. van Es, R. J. Wagenet and T. S. Steenhuis (1999). "Spatial—Temporal Variability of Preferential Flow in a Clay Soil under No-Till and Plow-Till." Journal of Environmental Quality 28(4): 1264-1273.

Rasse, D. P. and A. J. Smucker (1999). "Tillage effects on soil nitrogen and plant biomass in a corn-alfalfa rotation." Journal of Environmental Quality 28(3): 873-880.

Singh, R., M. Helmers and Z. Qi (2006). "Calibration and validation of DRAINMOD to design subsurface drainage systems for Iowa's tile landscapes." Agricultural Water Management 85(3): 221-232.

Skaggs, R. (1980). "Drainmod." Reference report. Methods for design and evaluation of drainage-water management systems for soils with high water tables. USDA-SCS, South National Technical Center, Fort Worth, TX, USA.

Thiagarajan, A., R. Gordon, A. Madani and G. Stratton (2007). "Discharge of Escherichia coli from agricultural surface and subsurface drainage water: tillage effects." Water, air, and soil pollution 182(1-4): 3-12.

Tortora, G., B. Funke and C. Case (2007). "The Prokaryotes: Domains Bacteria and Archaea." Microbiology an introduction.(9th edn), Pearson International Edition, Bejamin Cummings.

Wang, X., J. R. Frankenberger and E. J. Kladivko (2006). "Uncertainties in DRAINMOD predictions of subsurface drain flow for an Indiana silt loam using the GLUE methodology." Hydrological Processes 20(14): 3069-3084.

Webb, K. T. (1991). "Soils of Colchester County, Nova Scotia." 201p.

Workman, S. and R. Skaggs (1994). "Sensitivity of water management models to approaches for determining soil hydraulic properties." Transactions of the ASAE 37(1): 95-102.

Youssef, M., R. Skaggs, G. Chescheir and J. Gilliam (2005). "The nitrogen simulation model, DRAINMOD-N II." Transactions of the ASAE 48(2): 611-626.

IMPACT OF DRAINAGE EFFLUENTS ON GROUNDWATER QUALITY-A CASE STUDY FROM LAHORE PAKISTAN

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Abstract:

In Pakistan, approximately 80% the population in large cities do not have access to clean water. Lahore the provincial capital is the second largest populated city of Pakistan with an estimated population of 10 million people and an area of 1014 km^2. It is located on the alluvial plain of the Indus Basin on the left bank of the Ravi River. The Water and Sanitation Agency (WASA) is pumping groundwater at a rate of 1400 MCM per annum to meet the domestic needs of the city. Different drains are discharging domestic, industrial and agricultural effluents in the River and polluted water of the River is leached to underground reservoirs. To evaluate the impact of this pollution on underlying groundwater, an experimental setup has been developed in 2010 along the River. Fifty piezometers in the shape of three batteries perpendicular to the River, one just on the River edge, the 2nd at a distance of 500 ft. and the 3rd at a distance of about 1500 ft from the River bank have been installed on both sides of the River at three sites, covering a length of about 60 km of the River. Each battery consists of three piezometers at 50ft, 100ft and 150ft depth below ground level. The four dimensional (along the river, across the river, vertically downward and with respect to time) trends of groundwater levels and quality are being monitored and evaluated. The analysis of data observed so far indicates that groundwater quality is deteriorating with the passage of time especially at the Shahdra Bridge site (near Lahore). It has been further observed that pollution in the River Ravi is contributing to the deterioration of groundwater quality. Fluctuation of groundwater levels measured using a river gauge indicates that the River is hydraulically connected with the aquifer and is recharging it. Groundwater levels in the aquifer of Lahore are falling at an average rate of 2.5 ft. per year mainly due to excessive pumpage and less recharge due to urbanization. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near the city and improves at the depth below the natural surface. Sub-soil strata at most of the sites are generally sandy except a thin layer of clay/silt in the upper layer at 50 ft. The slope of groundwater seepage line at Shahdra on the left side of the River is steeper as compared to the right side due to excessive pumpage of groundwater in the city area. Keeping in view the current situation some possible measures for the management of groundwater have been recommended in the current study.

KEY WORDS: Groundwater, Piezometers, Effluents, Ravi River, Artificial recharge, Lahore.

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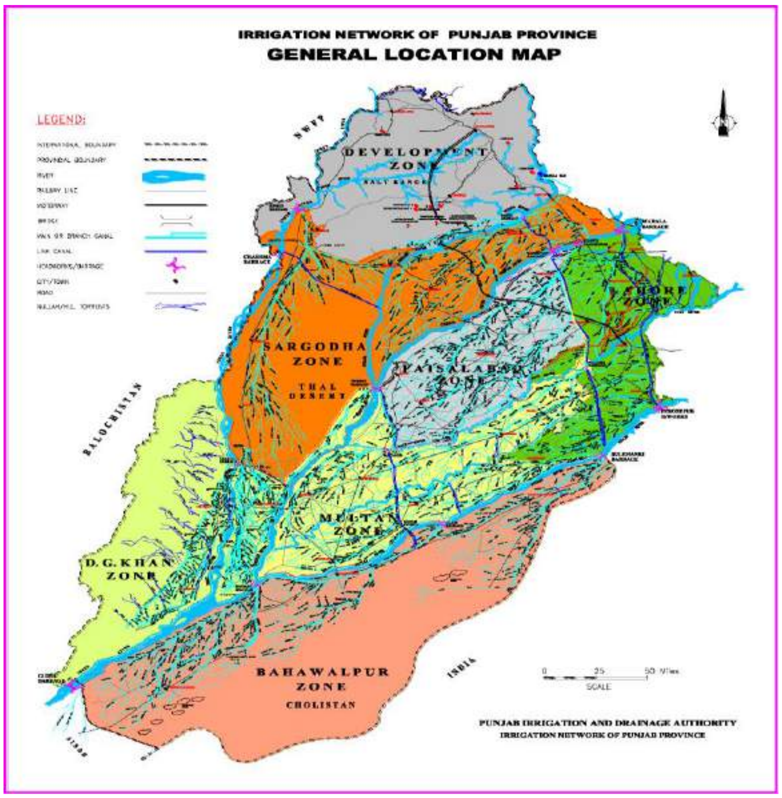
Introduction
Background of Irrigation and Drainage Network

Pakistan is bestowed with a largest contiguous irrigation canal network, major part of which lies in Punjab Province. This network (Figure 1) was started to be constructed by British during early nineteen 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).



Headworks/Barrages	13
Main Canals	24
Length of Main Canals and Branches	3993 Miles
Length of Distributaries and Minors	19191 Miles
Length of Inter River Link Canals	528 Miles
Off-take capacity of Main Canals	1.2 Lac Cs
Off-take Capacity of Link Canals	1.1 Lac Cs
Total Outlets	58000
GCA	23.35 m.a
CCA	20.78 m.a

Figure1: Irrigation network in the Punjab province

Table 1: Salient features of SCARPs

Province	Project area in M. Acres	Surface Drains in Km.	Tile Drain Km
Punjab	9.141	2956	800
Sindh	5.306	7187	976
NWFP	0.603	773	5781
Baluchistan	0.177	322	-

This situation created the need of drainage of agricultural lands in the country. Although some drainage was installed before World War II, little attention was paid to the growing waterlogging and salinity problems. To alleviate the twin menace of waterlogging and salinity, Water and Power Development Authority (WAPDA) was established in 1958 and Salinity Control and Reclamation Program

was conceived, planned and implemented by adopting surface as well as subsurface drainage projects in the country. First Salinity Control and Reclamation Project (SCARP-I) was implemented in 1960-63. Almost 61 such projects have been completed and salient features of SCARPs (Table 1).

In addition WAPDA also replaced 1472 tubewells and developed about 5363 private tubewells for groundwater development in Punjab. Parallel to subsurface drainage program a large network of surface drain of about 10,000 Km has led in the province to carryout surface and surface effluents. Surface drainage network of Punjab (Figure 2).

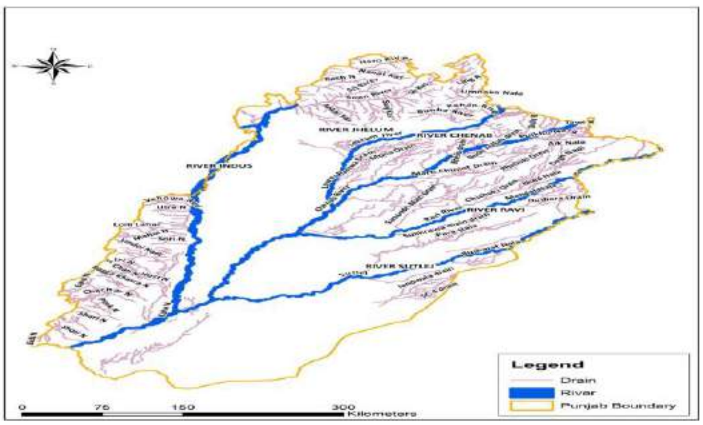


Figure 2: Drainage Network of Punjab

Table 2: Drainage Network of Punjab

Sr. No.	Name of Irrigation Zone	Number of Drains	Total Length of Drains (Km)
1	Lahore	277	2108
2	Faisalabad	222	2420
3	Multan	44	1351
4	Sargodha	383	3087
5	DG Khan	61	677
6	Bahalwalpur	20	340

Keeping in view the importance of irrigation and drainage projects in Pakistan, Asian Development Bank (ADB) in 2004 has classified these projects under the subsector agricultural and natural resources under their sector and thematic classification system which were previously clustered with rural development projects (ADB, 2008).

When this system of canal irrigation was put in operation, the problems of waterlogging become the major challenge which led to the parallel system of drainage network. During pre-irrigation era, watertable in different doabs (the land between two rivers) in Punjab province (Figure 3) was very deep at about 160 m (Ahmed. N, 1995). Seepage from the irrigation system and percolation from irrigated fields caused the watertable to rise continuously, reaching critical conditions for a substantial area especially in the Punjab province. This led to the dual menace of waterlogging and salinity and crops were seriously affected over a wide area.

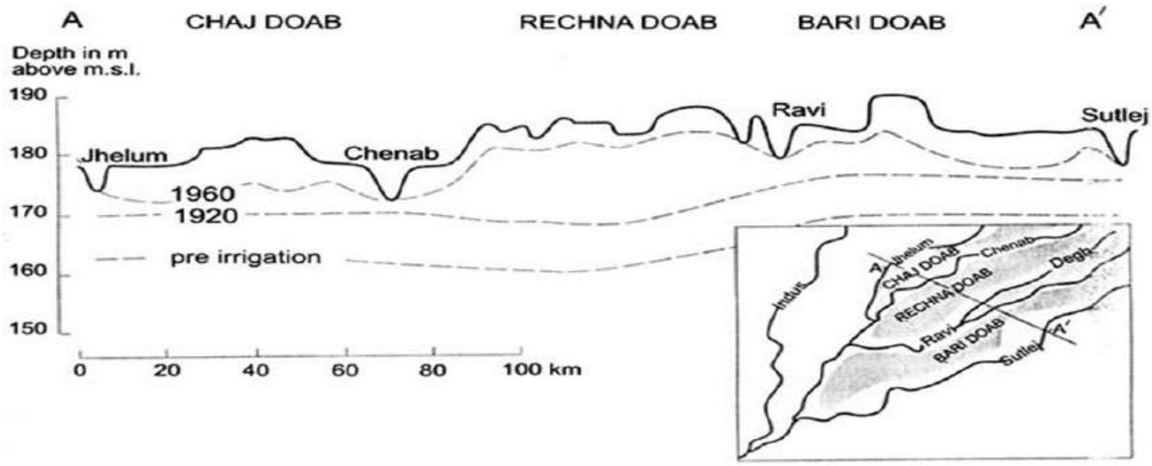


Figure 3: Groundwater table rise in Punjab along section AA/ (Ahmed N. 1995))

Issues of Drainage in Rural Areas

Increasing demands of food and fiber resulted in extensive use of fertilizers, insecticides, herbicides and other chemicals which ultimately wither leach down directly to groundwater or flow into surface drains. These agricultural runoff carry out salts and other hazardous materials to the drainage network where a major part is leached down to the groundwater. Area Treated with Pesticides (Figure 4). The 2nd largest issue of groundwater is its continuously deteriorating quality which is of more concern as it deals directly with human health.

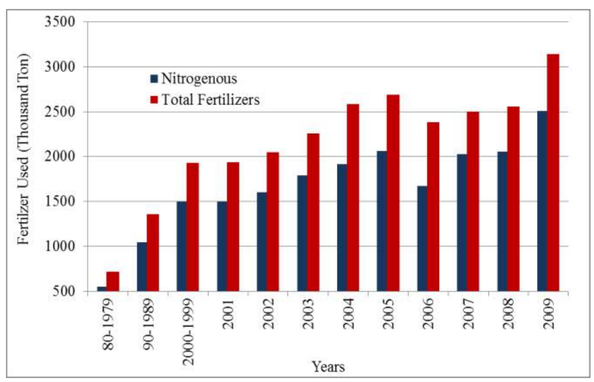


Figure 4: Area Treated with Pesticides

Sources of groundwater pollution normally are manmade intervention on earth surface and in certain cases the salts in bed rocks. Most of the pollutants effluents like industrial, agricultural, municipal etc. are in liquid forms which leach down to groundwater. Some other are in solid form like solid waste heaps through which pollutant leach down to subsurface soil and then to groundwater. Some pollutants are in gaseous form like vehicular and industrial emissions, which return back to soil surface in drains via acidic rains and percolate down to groundwater through unsaturated zone. Use of Fertilizers in Punjab (Figure 5).

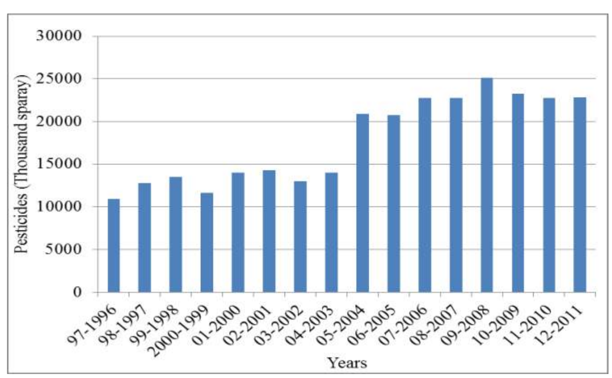


Figure 5: Use of Fertilizers in Punjab

Industrial effluents supplement the pollution load in these drains as most of the industries are throwing their waste waters into drains or even in some cases to canals directly without any treatment as two examples of industrial effluents (Figure 6).


Figure 6: Un-treated industrial Effluents

(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 drains and other potential threats for groundwater. Wherein it was observed that surface water bodies especially drains are playing a vital role in contamination of groundwater. (IRI, 2012) conducted a groundwater investigation study in Faisalabad area using MODFLOW (flow and solute transport) 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. Well-field for supply of drinking water to Faisalabad city was proposed accordingly near the River away from the area of influence of industrial drainage network.

In 1959 a salinity control and reclamation project (SCARP) was started in a limited area, based on public tube wells, to draw down the watertable and leach out accumulated salts near the surface, using groundwater for irrigation. Different projects were executed to install various types of drains like surface drains, subsurface drains/tiles drains, vertical drainage (tubewells) to mitigate the hazards of waterlogging and salinity. By the early 1980s, some thirty such projects were started to control the menace of waterlogging and salinity in the country. By 1993 the government had installed around 15,000 tube wells. Private farmers, however, had installed over 200,000 mostly small tube wells, mainly for irrigation purposes but also to lower the watertable.

Issues of Drainage in Urban Areas

In urban localities, inefficient sewerage system and lack of waste water treatment plants has resulted the discharge of waste water directly into drainage system/surface water bodies. Unfortunately, this drainage system articulates with the rivers-canal system and consequently becoming the main source of surface and ground water pollution. The consequences of shrinking good quality irrigation water resources have forced the farmers to use drainage water for irrigation. As such use of drainage water is augmenting environmental and health implications in addition to groundwater and surface water pollution (Hamid et al., 2013). More than 200 million people in the world are using different forms of wastewater (treated, partially treated, untreated) for irrigation purposes (Raschid-Sally and Jayakody, 2009). According to another estimate, 10% of the total world's food production is based on wastewater irrigation (Corcoran, 2010). A survey conducted by International Water Management Institute (IWMI) revealed that in Pakistan 32,500 hectares of land are directly irrigated with wastewater i.e. 26% of crops especially vegetables are being produced from wastewater (Baig et al., 2011).

The mobilization of heavy metals in soil through ground water and surface water is known to have potential toxic impact on environmental quality and human health as well (Iqbal et al, 2016). Moreover, the presence of heavy metals in soil and water beyond the permissible limits may render soil non- productive and may cause bio-accumulation of heavy metals in human beings (Singh et al., 2006). It may lead to a significant accumulation of heavy metals, thus influencing the food quality and safety through their ultimate entry in the food chain via plants and aquatic life (Muchuweti et al. 2006). Groundwater quality in the aquifer 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).

Material and methods

Description of Study Area

Lahore city, is the capital of Punjab province, has a population of about 7.2 million and plays an important role in the country's economy being hub of industrial activities. Major source of water supply in Lahore for domestic as well industrial uses is groundwater. Due to tremendous urbanization and industrialization in the city, pressure on groundwater has increased manifolds. The city is situated on the bank of Ravi River. Flows in the river have decreased continuously since 1960. A number of drains carrying domestic and industrial effluents are entering into the river. A reach of about 60 km of the river has been selected to investigate the impact of various effluents in drains and river on groundwater. Map of study area (Figure 7).

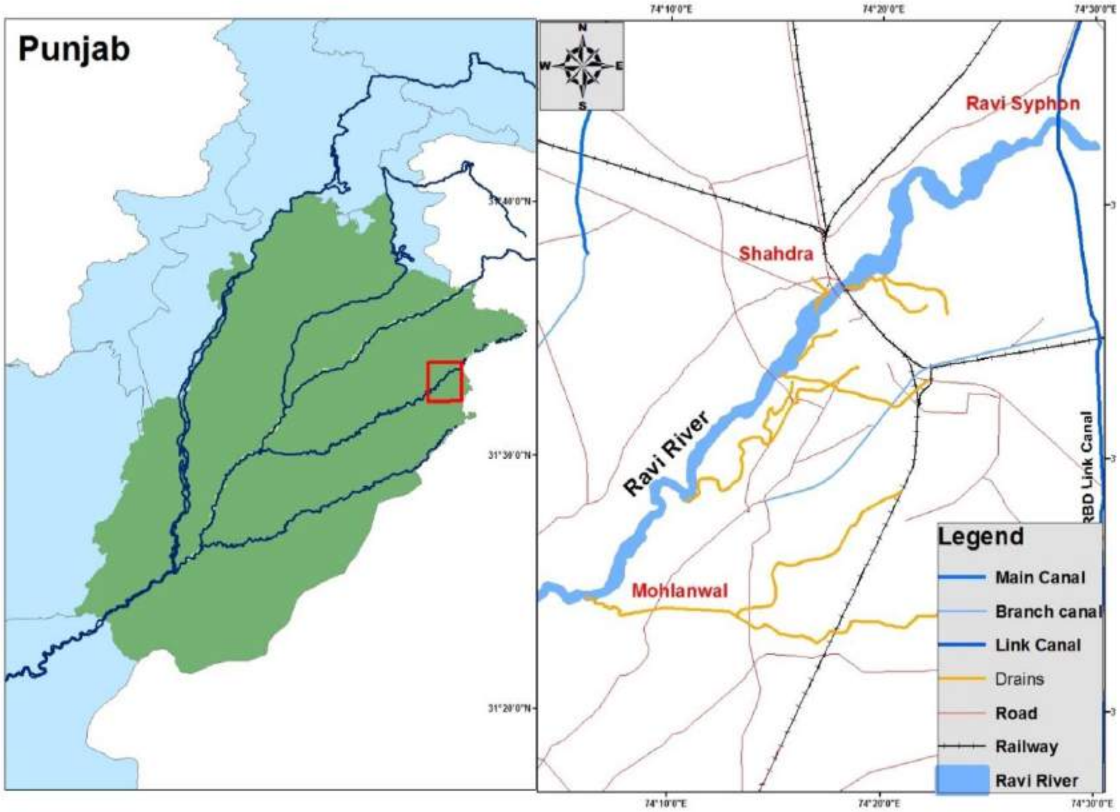


Figure 7: Map of study area

Population growth has a direct impact on depletion of groundwater resources. Abstraction of groundwater increases as population grows and over-exploitation of aquifer results in decline of groundwater levels. Temporal trends of depth to watertable and population growth in Lahore (Figure 8). Major consumers of groundwater in Lahore (Figure 9).

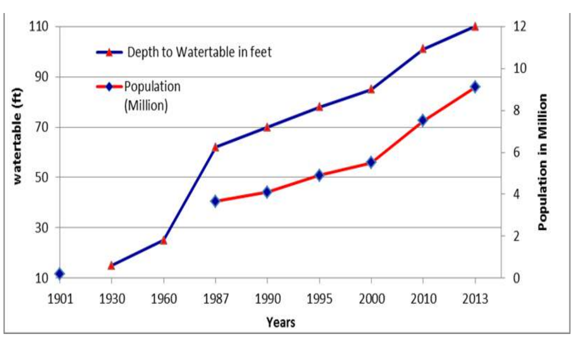


Figure 8: Trends of Population and Watertable Depth in Lahore

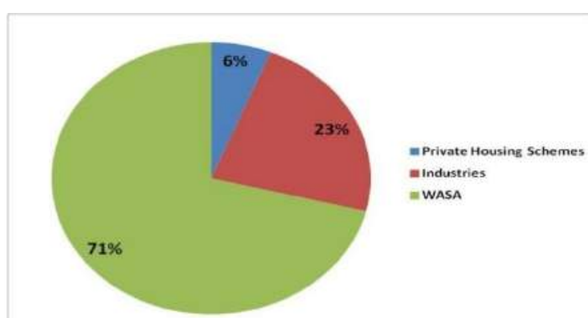


Figure 9: Major Groundwater Consumers in Lahore

An important aspect of the research study is to develop a link between quality of surface water bodies (Ravi River & drains) and its impacts on groundwater quality in the underlying aquifer. Ravi River has been polluted and is being polluted due to indiscriminate discharge of untreated municipal waste water and industrial effluent into it. Historic Ravi River discharge at Shahdra Bridge (Figure 10) and waste water effluents being thrown in the River (Figure 11).

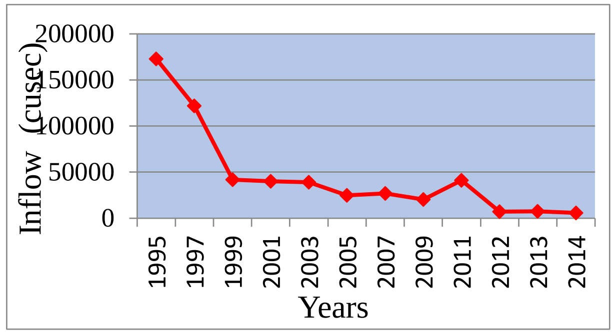


Figure 10: Discharge reduction in Ravi River

Figure 11: Waste water effluents in the Ravi River

Low flows in Ravi River have resulted in lowering in groundwater level in Lahore and it adjoining area. On one side recharge to the aquifer has decreased tremendously and on the other side the ecosystem in the river has suffered badly and river has become a "sludge carrier". (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 throwing it into the river.

Water and sanitation agency (WASA), Lahore has installed 480 tubewells of different capacities at a depth of ranging from 150 to 200 m for supplying water to the citizens of Lahore which are extracting about 1170 cusec of groundwater per day for drinking purpose. In addition to WASA tubewells, a large number of private tubewells installed in housing schemes are roughly pumping

100 cusec water daily. Water is also being pumped by industries at the rate of approximately 375 cusec (Hussain & Sultan, 2013). In this way total extraction of groundwater in Lahore becomes 1645 cusecs. Over exploitation of groundwater causes many serious environmental concerns like salt water intrusion, increase in pumping cost, increase in installation cost of tubewells, land subsidence, land sliding, development of sinkholes etc.

Urban population in the Lahore is increasing at an alarming rate of 4% per year which is leading towards a continuous increase in domestic sewage. This sewage coupled with street runoff is a severe threat to groundwater as a part of it ultimately leaches down to groundwater. It was estimated that discharge of waste water of Lahore city into Ravi River was about 990 cusecs in year 2006 (Saeed and Bahzad, 2006) and now has crossed to 3,304 cusecs through drains and various pumping stations (Figure 12) without proper treatment (Hussain & Sultan, 2013).

A survey of drains entering into the River has been carried out which has revealed that six (06) main drains are entering into the River which are throwing about 3304 cfs of wastewater in the River.

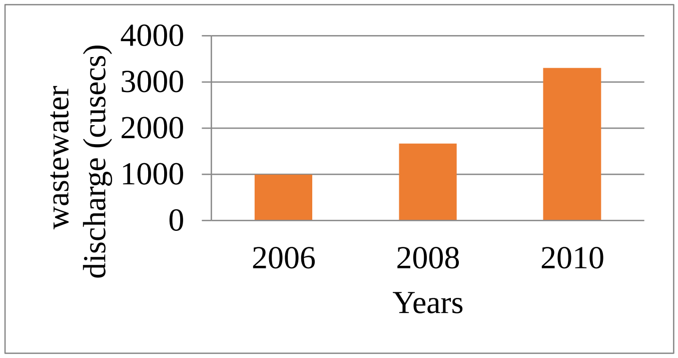


Figure 12: Effluents being thrown into the Ravi River

Monitoring Network and Survey

Three sites along Ravi River namely Ravi Syphon, Shahdra Bridge and Mohlanwal has been selected for installation of piezometers keeping in view the different factors including but not limited to distance from the River, availability of bench mark, safety of the piezometers, site approach, willingness of farmers and protection of piezometers from rainfall and irrigation water etc. Fifty piezometers along the River on both sides in the shape of triangular battery of three piezometers (9 on each side of the River at) at three selected locations were installed. In each battery, three piezometers were installed up to a depth of 150, 100 and 50 ft. respectively. Schematic layout of the piezometers installed three at sites (Figure 13). Three batteries of piezometers perpendicular to the River have been installed on one side of the River at all three sites. First battery has been installed on the edge of river bank, 2nd battery at a distance of about 500 ft. away from the river edge and 3rd battery at a distance of about 1000 to 1500 ft. from the River edge. A complete network of piezometers has been installed to monitor the 4th dimensional trend of changes in groundwater levels and quality, which are along the river, away from the river, below the natural surface level (NSL), and with respect to time. Monitoring network along the River has been laid on permanent basis which is to be used for long-term observation of changes in groundwater levels and quality and impact of pollution in River on groundwater.

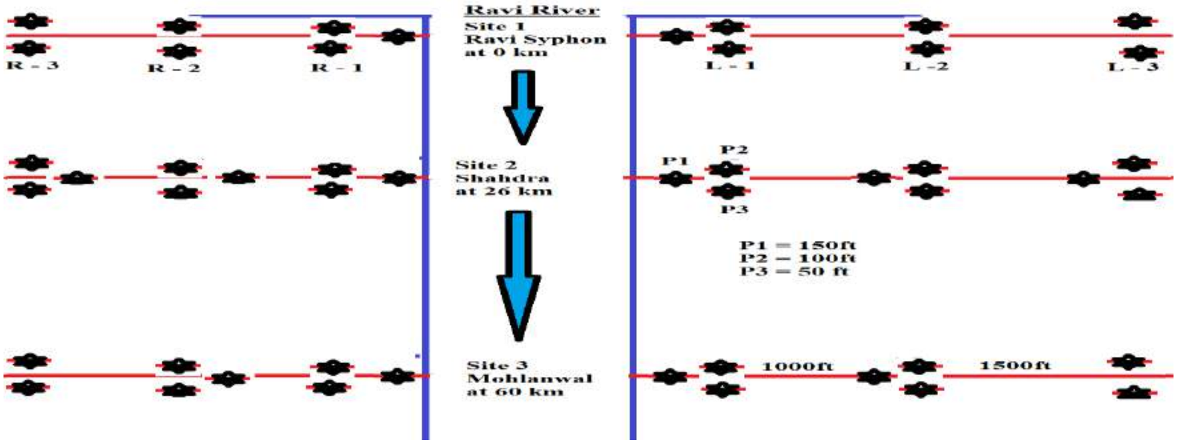


Figure 13: Layout of Ravi River Showing Locations of Piezometers

As mentioned already, Lahore has become hub of industrial activities in the country. A large number of industries are discharging wastewater into sewerage system and surface drains without treatment. 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). The environmental profile of Pakistan indicates that about 40% of deaths are related to waterborne diseases spread by water pollution, mainly due to the sewage and industrial wastewater contamination to drinking water distribution systems. Map of major drains entering into the Ravi River and schematic layout these drains are shown in Figures 14 and 15 respectively.

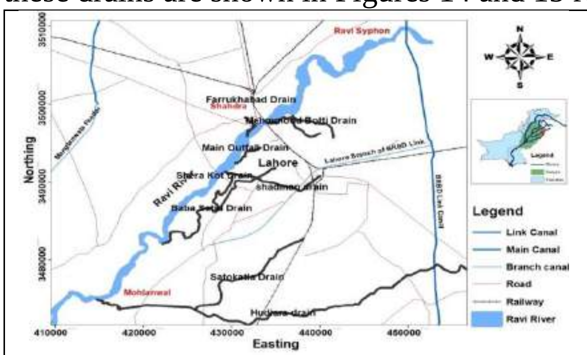


Figure 14: Map of Major Drains entering the Ravi River

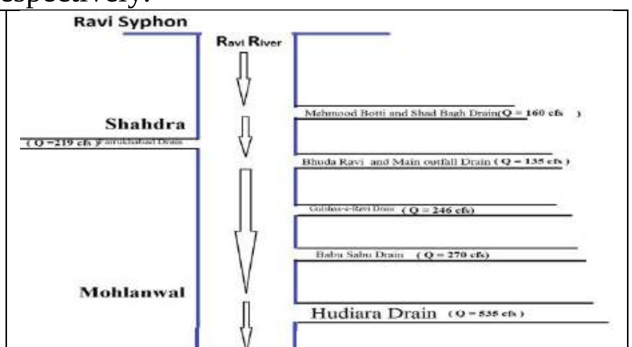


Figure 15: Schematic Layout of Major Drains entering into the Ravi River.

Results and Discussions

Major target of the study is to monitor and evaluate the impact of pollution in Ravi River due to surface drains on groundwater in the underlying aquifer. For this purpose a network of piezometers was installed along the River. Samples of water from following different sources have been collected and analyzed to arrive at conclusions.

i) Wastewater (drains entering the rivers)
ii) Groundwater at different depths/locations (from piezometers)
iii) Surface water (River water)

Waste Water Quality (Drains)

Water samples from these drains were collected and analyzed. Effluents of these drains are deteriorating the quality of groundwater along the River. The water quality determined from the drain samples (Table 2). More value of EC (2440 µs) from Farrukhabad Drain has been observed during 2012 that is adding polluted load into the River. The results represented indicate that pollution load in drains are increasing with the passage of time and enhancing pollution in the river and groundwater. A network of surface drains in Lahore city carries wastewater from various sources and ultimately enters the Ravi River. These are earthen channels which cause the leaching of various pollutants directly to groundwater. (Hassan et al, 2013).

Municipal Solid Waste (MSW) consists of household waste, commercial waste and institutional waste. Unscientific dumping of solid waste always poses serious environmental problems on groundwater. Leachate produced at landfill contains thousands of complex components and it becomes part of groundwater after infiltration. Lahore city, three sites have selected for dumping of solid waste. Groundwater is suspected to be contaminated due to unscientific, unsafe, unplanned and traditional selection of these sites. At least three-quarters of the total waste generated (3800 tons/day) in Lahore is dumped at these sites without proper treatment. According to a previous study, it was found that most of groundwater samples collected from nearby these landfill sites contain pollutants and their concentration level in groundwater is higher than prescribed by Pakistan Standards and Quality Control Authority (PSQCA) and concentration of Arsenic in drinking water is higher than WHO criteria (Akhtar & Zhonghua, 2013). It was reported in the Daily newspaper (20 May, 2008),that according to United Nations Environmental Program (UNEP)'s data about 47% drinking water in Lahore city was contaminated due to presence of various hazardous toxic elements (Manan, 2008).

Excessive and uncontrolled use of chemical fertilizers, pesticides and herbicides promotes contaminated agricultural run-off. This not only pollutes the surface drains but the water trickling down to lower layers of soil causes a severe contamination of the natural aquifer in surrounding areas of Lahore. Over abstraction of groundwater prompts recharge from the surface water drains, which themselves are severely contaminated. Chemical analysis of drain water samples 2016 (Table 3).

Table 3: Quality of Drainage Water entering the Ravi River

Sr. No.	Name of Drains	EC (µs) (2011)	EC (µs) (2016)	Increase in EC (%)
1	Mehmood Botti Drain	1550	1700	10
2	Farrukhabad Drain	2176	2290	5
3	Main Outfall Drain	2012	2100	4
4	Gulshan-e-Ravi Drain	1794	1850	3
5	Babu Sabu Drain	1520	1600	5
6	Hudiara Drain	2394	2460	4

Groundwater Quality

Groundwater quality at downstream from Ravi Syphon to Lahore city has deteriorated. It has been observed that the color of groundwater near Lahore city has varied from colorless to yellowish and its odor is now to objectionable with turbidity ranging from 2 to 4 NTU. Heavy metals have also been found in the groundwater samples and the concentration of lead (Pub), Nickel (Ni) and number of E. coli levels exceeded the permissible limits of drinking water quality (Ayesha, 2010). Municipal landfills are considered another sources which have a serious threat to urban environments and a great source of pollution especially groundwater (Akhtar and Zhonghua, 2014).

To develop the link between wastewater in river and groundwater in the underlying aquifer, water samples from all 50 piezometers installed along the river, away from the river and at different depth were taken through a specially designed sampler. The samples were analyzed. Electrical Conductivity (EC) of groundwater at all sites has been adopted as a parameter to compare the results. The results are graphically plotted in Figures 16-21.

Results indicate that groundwater quality at Ravi Syphon on both sides of the River at all depths (P1=50 ft., P2=100 ft. and P=150 ft.) is good and is not deteriorating with time. This indicates that groundwater quality perpendicular to the river from Left side (L_1, L_2, L3) or right side (R_1, R_2, R_3) is good and can be used as bench mark for comparison of groundwater quality.

The data analysis at Shahdra site (near the city) reveals that EC values at 50 ft. depth are more while the value at 150 ft. depth is lesser on both sides of the River which indicate groundwater improves vertically downward. Groundwater quality at 50 ft. depth at R_3P_3 and L_3P_3 is deteriorating.

At Mohlanwal site, EC values of piezometer installed at 50 ft. depth are more as compared to those at 100 ft. and 150 ft. depth on left side while lesser on right side of the river.

Results indicate that quality of groundwater at 50 ft. depth is deteriorating with the passage of time at Shahdra. Overall results of analysis of groundwater samples along Ravi River indicate that the quality of water is deteriorating, moving downstream from Ravi Syphon to Lahore.

Result of analysis indicates that groundwater quality is deteriorating more at Shahdra (as compared to that of Ravi Syphon and Mohlanwal) due to entrance of effluents through different drains into the river. The data at Shahdra site along both sides of the river indicate that quality of shallow water at depth of 50ft at R3 and L3 is deteriorating more with the passage of time.

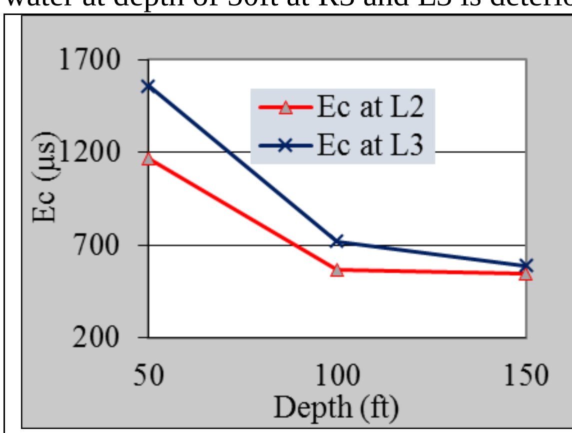


Figure 16: Ec (µs) at Shahdra site vertically downward for the year (2016)

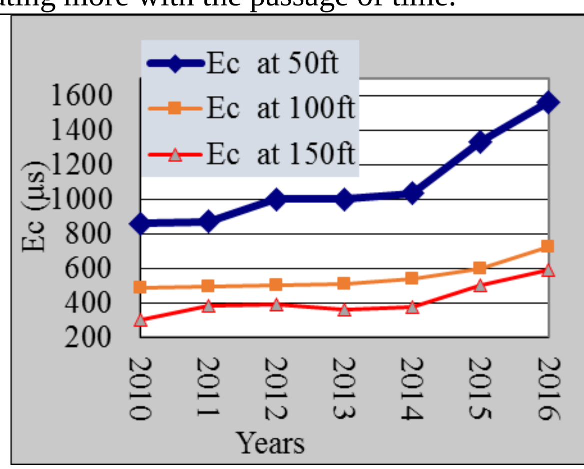


Figure 17: Ec (µs) at L3 Shahdra site w.r.t to Time

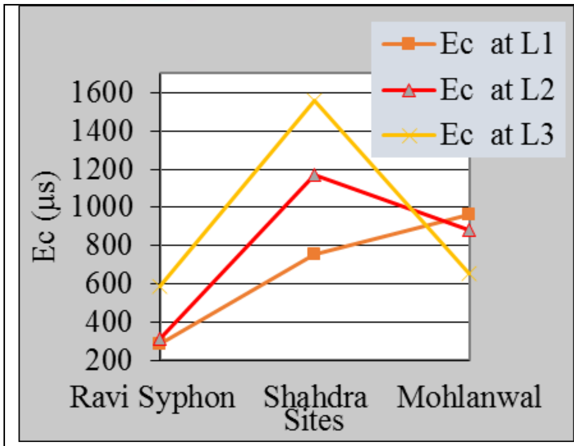


Figure 18: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

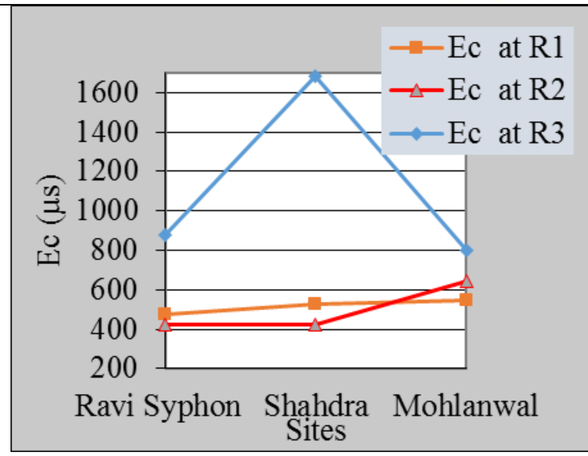


Figure 19: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

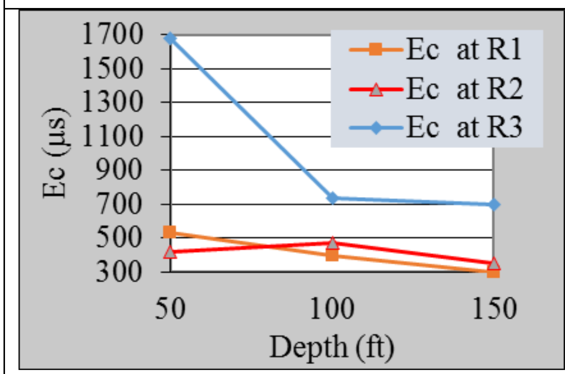


Figure 20: Ec (µs) at Shahdra site vertically 2016 downward for the year (2016)

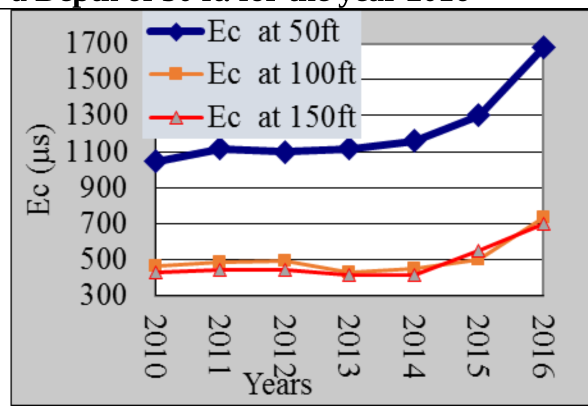


Figure 21: Ec (µs) at R3 shahdra site w.r.t to Time

Broadly speaking these all are the surface pollutants and flood waters can play a significant role in washing away and diluting these hazardous materials. Flood water contributes significantly towards recharging the aquifer and washing the pollutants. For example during flood 2014 average rise in watertable observed in Rechna doab was 2.57 ft. (IRI, 2015).

Conclusions

i. Pollution entering the Ravi River is ultimately affecting adversely the quality of underlying groundwater and the River has become a source of pollution for groundwater reservoir (due to low flows and throwing of untreated effluents in it).

ii. It is found that there is rise of about 3 -10% in EC value over a period of 5 years.

iii. Quality of drains water entering the River is deteriorating with the passage of time and consequently similar trends have been observed in River water quality

iv. Groundwater quality in the aquifer is deteriorating with the passage of time and sweet water is becoming rare and out of reach and quality improves with the depth below land surface.

v. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near Shahdra (near the city)

vi. Ravi River is contributing towards recharging the aquifer as groundwater levels fluctuate with the river gauge.
vii. Quality of effluents in drains entering the River is deteriorating with the passage of time.
viii. There is lack of communication/coordination among different Government Departments/ agencies and the various stakeholders/consumers

Recommendations

- Production of all pollutants should be reduced or minimized at source through scientific research and tools.
- Education, awareness and motivation campaigns for all stakeholders can play a vital role
- Formulation of long term policy framework/ legal framework and comprehensive master planning to guard against fast polluting groundwater reservoir.
- Treatment of industrial and municipal effluents before throwing into the River
- Harvesting of rainfall in separation from industrial and domestic wastes
- To strengthen the monitoring network for drainage system to evaluate their impacts
- Installation of treatment/recycling plants for sewerage and industrial effluents as well as for solid waste in the city at appropriate locations.
- Artificial recharge through rainfall-runoff modeling at identified potential sites and to explore feasible sites in parks, playgrounds and other natural depressions.
- To maintain minimum flow in Ravi River for dilution of pollutants and enable it to act as source of recharge.
- Industrialists should be provided with scientific solution to recycle or treat the effluents at source instead of throwing it into nearby water body or injecting directly to groundwater which off-course is not less than a crime.
- Sever steps are required to be taken for control/mitigation of gaseous emissions.
- Regarding solid waste management we can go for use of geo-synthetic materials at landfill sites to avoid leaching of pollutants.
- Solid waste can also be used to obtain bio-energy.
- Treatment plants should be adopted to make the industrial, municipal, and agricultural waste waters useable some purposes like industries, irrigation etc.
- Farmers must be educated to use less toxic and in limited/required quantity fertilizers, pesticides, weedicides etc.

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References

Ahmed Nawaz. 1995. Groundwater Resources of Pakistan. (revised and enlarged edition), Published by Shahzad Nazir: 61- B/2 Gulberg III, Lahore, Pakistan

Akhtar. M. M. and Zhonghua. T. 2013. A Study to Estimate Overall Environmental Pollution Potential in the Second Biggest City of Pakistan. European International Journal of Science and Technology

Akhtar. M. M., Zhonghua. T. 2013. Municipal Solid Waste and its Relation with Groundwater Contamination in Lahore, Pakistan. Research Journal of Applied Sciences, Engineering and Technology, 7(8): 1551-1560, 2014

Asian Development Bank. 2008. Best Practices in Irrigation and Drainage-Learning from successful Projects: A case study from the 2006 evaluation review.

Ayesha. A. (2010). Shallow Groundwater Quality of Lahore City along the Ravi River. Paper No. 704, Volume 71, Part-2, Pakistan Engineering Congress, Lahore, Proceedings -2006-2011.

Baig, I. A., Ashfaq, M., Hassan, I., Javed, M. I Khurshid, W and Ali, A. 2011. Economic Impacts of Wastewater Irrigation in Punjab. J. Agric. Res., 2011, 49(2)

Corcoran, E. 2010. Sick Water: The Central Role of Wastewater Management in Sustainable Development: a rapid response assessment. UNEP/Earth print.

Environmental Protection Department (EPD). 2008. Environmental Monitoring of Ravi River: Study carried out under Annual Development Scheme Monitoring of Surface Water Bodies in Punjab. EPA Laboratories, National Hockey Stadium, Lahore.

Hamid, A., Zeb, M., Mehmood, A., Akhtar, A and Saif, S. 2013. Assessment of Wastewater Quality of Drains for Irrigation. Journal of Environmental Protection, Vol. 4 No. 9, pp. 937-945. doi: 10.4236/jep.2013.49108.

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 (2016), ISSN 2518-4261 (print), ISSN 2518-427X (Online)

Hussain. F., Sultan. A. 2013. Existing Situation of Sewerage in Lahore City and its Impact on Ravi River. The Urban Gazette, Lahore, Pakistan

Iqbal, H. H., Taseer, R., Anwar, S., Mumtaz, M., Qadir, A., Shahid, N. 2016. Human Health Risk Assessment: heavy metal contamination of vegetables in Bahawalpur, Pakistan. Bulletin of Environ. Studies, 1 (1): 10-17.

IRI. 1996. Water Quality Tests: under JICA study Lining of Distributaries & Minors in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute, Lahore, Pakistan. Research Report No IRR-Phy/542

IRI. 2009. Research Studies on Artificial Recharges of Aquifer in Punjab. Government of the Punjab, Irrigation Department, Irrigation Research Institute. 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, 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, 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, Lahore, Pakistan. Research Report No IRR-GWMC/101.

Manan, A. 2008. Ecoli affecting groundwater quality. "The Daily Time, Lahore". Available:http://www.dailytimes.com.pk/default.asp?page=2008%5C05%5C20%5Cstory_20-5-2008_pg7_42

Muchuweti, M., Birkett, J.W., Chinyanga, E., Zvauya, R., Scrimshaw, M.D and Lester, J.N. 2006. Heavy metal content of vegetables irrigated with mixture of wastewater and sewage sludge in Zimbabwe: implications for human health. Agric. Eco. Environ. 112: 41-48

Raschid-Sally, L., Jayakody, P. 2009. Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment. IWMI.

Saeed, M. M. & Bahzad, A. 2006. Simulation of Contaminant Transport to Mitigate Environmental Effect of Wastewater in River Ravi, Pakistan. J. Water Resour. 10(2), 4-52.

Singh, V., Garg, A. 2006. Availability of essential trace elements in Indian cereals vegetables and spices using INAA and the contribution of spices to daily dietary intake. Food chem. 94, 81-89.

IDENTIFYING AND DETERMINING POLLUTION LOAD OF AGRICULTURAL POLLUTANTS IN THE CATCHMENT BASIN OF KARUN AND DEZ RIVERS

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Abstract

The impacts of climate change and human induced activities due to the development of urbanization, industries and agriculture are the biggest challenges in the field of water resource management in Iran, especially river water management in Khuzestan Province. Suitable soil and water resources in the Great Karun River basin, extensive areas of natural resources, favorable climate conditions and energy resources have led to the development of agriculture, industry, and population growth in the Karun and Dez Rivers margins. This study aims to identify, quantitatively and qualitatively review and determine the pollution load of agricultural drainages in the basin of Great Karun (Karun and Dez Rivers), determine the volume of drainage water and the impact on the quality of production resources. After field study, sampling (N=96) was done during four seasons in 2013-2014 in 24 input points of drainage water to water sources. The EC, pH, TSS, NO3-, DO, BOD, PO4-3, COD features, Cations, Anions and discharge were measured. Results showed that agricultural pollutants with a volume of 2,374 million cubic meters per year are causing pollution of types TDS and NO3- with 11862 and 65.51 tons per day, respectively. Pollution load of organic materials based on BOD and COD is 29.7 and 211 tons per day, respectively. Results also showed that, the Dez river reach has the largest share in terms of volume of drainage water and incoming pollution load. Moreover, the agricultural drainages of Shoeibieh, Haft –Tapeh Sugar cane, Ajirub and Salimeh, Karun (K), Myanab and Kharur within the Dez river reach, the drainages of Sardarabad (N) and Zahuabad within the Shatit reach and the fish-farming wastewaters within the Gargar river reach are among the most important drainages affecting the quality of water resources and agricultural lands in the downstream basin. Evidences show that in future the situation will be worse if proper measures are not undertaken.

KEY WORDS: Pollution load, Karun and Dez rivers, Soil and water resources, Agricultural drainages, Khuzestan

Introduction

Soil and water as the main elements in agricultural production are of crucial importance;therefore, any damage to them directly affects the quality and quantity of products and irreparably damages these resources (Hillel, 1997). The quality and quantity of these resources is associated with their

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exploitation and operation management (agricultural, urban, and industrial) (Jafarinejadi *et al*., 2010). Water consumers in the agriculture sector are mainly the rural population, and due to their economic and social characteristics which are based on the traditional exploitation of resources, optimal water exploitation management has not progressed much in this sector (Hosseini-Zare, 2004). Currently, water resources exploitation in non-agricultural systems such as in the case of industries and urban wastewater discharge is the same as it used to be in industrialized countries in previous centuries in the West (Hosseini-Zare, 2004). The pollution of soil and water resources has become a serious threat to human societies, environment, and natural ecosystems (Gyawali *et al.*, 2012). Fatouki *et al.* (2003) investigated pollution in the Keiskamma River in South Africa. Their results showed that the discharge of wastewater from the Keiskammahoek treatment plant was the most important point source of pollution load. The most important pollution loads of that river were related to salinity, nutrients, and oxygen-demanding compounds. Essien (2010) studied the pollution load of the Ikpa River in Nigeria and reported that urban development of the Uyo metropolitan center was the major contributor to pollution of the river. It was concluded that pollution was mainly due to the discharge of leachate, urban runoff, and sewage into the river. Deng *et al.* (2010) studied the total pollution load on the Yangtze River in China and examined the share of the pollution load. The total pollution load of COD and ammonia nitrogen, inorganic nitrogen, and phosphate was estimated. Their results show that pollution load resulting from inorganic nitrogen and phosphate is higher than the refinement potential of the system. Mehrdadi *et al.* (2006) studied the pollutants of the Tajan River in the Mazandaran Province and concluded that the Mazandaran Wood Industry, Paksar Dairy Industry, Antibiotic Production Industry of Sari, and Sari urban wastewater and agricultural activities are the most important pollution sources of the Tajan River basin which seriously threatens water quality. Therefore, the increase of water needed in various sectors including agriculture activities and irrigation and drainage networks, shrimp and fish farms, industries, urban development, and water transfer can have a huge impact on the water quality in the Karun River in the future (Karamouz *et al.*, 2004). The Karun and Dez drainage basin, with an area of 21,500 square kilometers, accounts for 33.8% of the Khuzestan Province area. Suitable soil and water resources in the basin and the wide and potential range of natural resources, favorable climatic conditions, and rich oil and gas resources has led to a growing development of agriculture, industry, aquaculture, population growth, and urbanization in the Karun and Dez riverbanks. This has caused various problems across most environmental areas such as the impact on water and soil receiver resources, increased pollution, and reduced natural capacity of the environment in the studied region (Khuzestan Environmental Protection Agency, 2006). The Greater Karun river system consists of the confluence of thetwo major rivers of Dez and Karun and is the greatest surface water system in Iran with an average, maximum, and minimum annual dischargeof 19,174, 38,323, and 7,915 MCM/year, respectively (The Khuzestan Water and Power Organization, 2013). This study aims at identifying and determining the pollution load of various pollution sources in the Karun and Dez basin which affects the quality of water and soil resources in the Khuzestan region.

Materials and Methods

The study area included the Karun River basin from its entry point into Khuzestan plain (Gotvand) down to Abadan and Khorramshahr and the Dez River from its entry point to the Khuzestan plain (Dezful) to Bande-Ghir, where it join the Karun River and forms the great Karun River. The Karun and Dez Rivers basin is the largest basin in the Khuzestan province in Iran which is located at geographical coordinates of 48° 10' to 52° 30' East longitude and 30° 20' to 34° 05' North latitude in the central Zagros Mountains. The Karun basin has an area of 62,417km^2. Awareness of the present condition, determination of the main pollution sources, and specification of the hierarchical structure of qualitative variables were among the methods used in this study to determine the pollution load.

In the next stage, the entry points of all pollutants, including agricultural drainage, industrial wastewater, and urban wastewater to rivers were determined using Global Positioning System (GPS) and recorded in Excel software along with other data. Twenty-four agricultural drainage systems, nine sources of industrial wastewater, and thirty-eight sources of urban wastewater located along the Karun and Dez rivers, including the wastewater emissions from cities of Dezful, Gotvand, Shooshtar, Ahvaz, Khorramshahr, Abadan, Veis, and Mollasani, were identified. Sampling was conducted over the hydro-year 2013-2014. Figure 1 shows the sampling locations. A Molinet (or volume measurement) was used for determining the discharge rate. Seventy-one samples were collected of which each sampling, amounted to 284 samples of pollution sources over four seasons. Samples were transported to the laboratory and were prepared. Qualitative variables, such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were determined as indicator parameters for the pollution load of organic materials. Qualitative variables such as total dissolved solids (TDS), Cl^-, SO_4^{-2}, and TSS were determined as characteristic indicators of soluble and insoluble solids. The qualitative variables of nitrate (NO_3^-) and phosphate (PO_4^{-3}) were also determined as characteristic indicator of the pollution load of nutrients. Then, the indicator parameters of the pollution load were measured. All steps including sampling, stabilization and transport of samples to the laboratory and the testing methods were as per the Standard Methods for the Examination of Water and Wastewater, 22nd Edition (2012). Contribution of pollution sources and prioritization of the various agricultural, urban, and industrial pollution sources in the pollution load entering the river, was calculated using SPSS20 and EXCELL based on the qualitative and quantitative obtained results of the indicator parameters.

Results and Discussion

The results of the descriptive statistics of parameters using calculations of the pollution load for various pollution sources were determined (Table 1). The results of the pollution load and the degree of importance of soil and water pollution sources of the Karun and Dez rivers basin in terms of pollution load by indicator parameters is shown in Table 2.

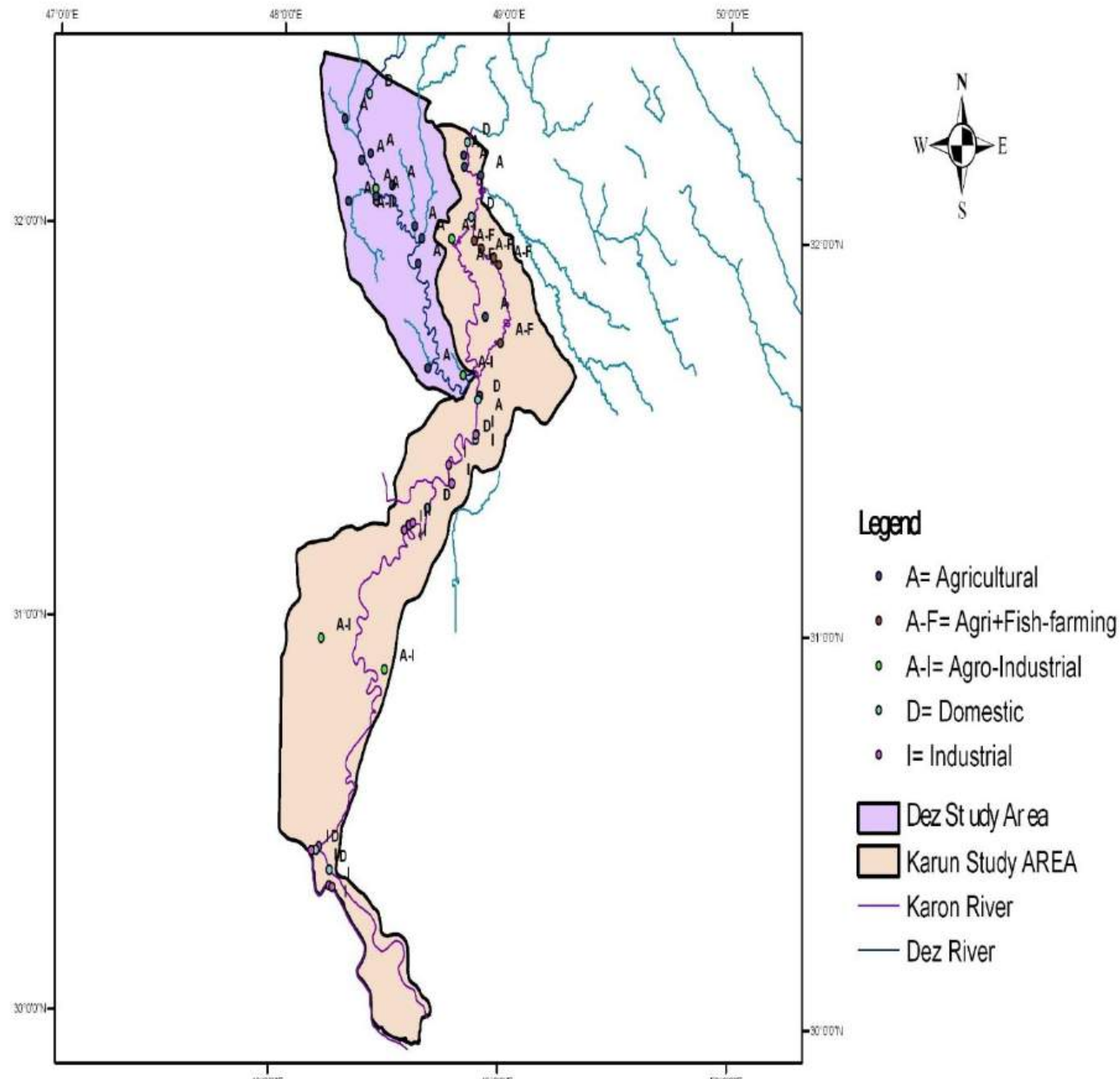

Figure 1. Location of the study area and pollution source

Table 1. Statistical characteristics entering Karun and of pollution load indicators of pollution sources Dez rivers in four seasons of 2013-2014 water year

Pollution Sources		TDS	EC	pH	TSS	NO_3	PO_4	DO	BOD	COD	Total coliform	Fecal coliform	NH_3
		ppm	µmho/cm	-	ppm	ppm	ppm	ppm	ppm	ppm	NO/100ml	NO/100ml	ppm
Agricultural Drainage	Number	24	24	24	24	24	24	24	24	24	24	24	24
	Mean	2221	3263	7.7	59	7.6	0.05	6.8	5.19	32.04	43115	16079	0.73
	Min	451	711	7.3	20	1.27	0.005	3.6	2.14	14.7	8650	2200	0.25
	Max	4882	6540	8.1	180	16.05	0.41	10.2	21.2	115	110000	56150	2.5
	SD	1465	2050	0.19	42.8	3.47	0.085	1.88	3.93	19.33	31348	14746	0.46
Industrial Wastewater	Number	9	9	9	9	9	9	9	9	9	9	9	9
	Mean	2169	3389	7.7	269	10.04	0.27	3.48	59.61	407	85222	31633	0.95
	Min	910	1297	6.9	40	3.47	0.01	0.20	21	68	15000	2000	0.25
	Max	3740	5750	8.5	1440	26.10	0.78	7.30	169	2200	110000	110000	1.5
	SD	850	1325	0.44	447	7.30	0.27	2.68	47.24	682	38228	33535	0.35
Urban Wastewater	Number	36	36	36	36	36	36	36	36	36	36	36	36
	Mean	2107	3291	7.8	255	8	5.1	0	86	209	45×10^6	28×10^6	21.9
	Min	630	981	6.9	24	3.72	1.5	0	29	66	2×10^6	0.25×10^6	5
	Max	4090	6390	8.4	593	19.07	8.5	0	205	509	500×10^6	319×10^6	41.3
	SD	1011	1581	0.45	103	2.9	2.4	0	40	104	95×10^6	64×10^6	10.25

Table 2. Pollution load of pollution sources and their priority in polluting (discharge is in m^3/sec, and the indicators are in Tons/day)

Pollution Sources	Discharge Rate			TDS			BOD			COD			NO3			NH3		
	m^3/sec	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank
Agricultural	75.3	87.3	1	11862	84.3	1	29.7	26.7	2	211	32.6	2	65.51	87	1	4.8	23.6	2
Urban	7.9	9.21	2	1638	11.6	2	53.51	48.2	1	130	20.1	3	5.08	6.75	2	15.25	75	1
Industrial	3.03	3.5	3	569	4	3	27.82	25	3	306.6	47.3	1	4.65	6.2	3	0.25	1.2	3
Total	86.23	100	-	14070	100	-	111	100	-	647.9	100	-	75.24	100	-	20.3	100	-

Table 2. (Continued) Pollution load of pollution sources and their priority in polluting (Discharge is in m^3/sec and the indicators are in Tons/day)

Pollution Sources	PO_4			Cl			TSS			SO_4		
	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank
Agricultural	0.28	9.9	2	2654	80	1	342	47.5	1	4722	89.4	1
Urban	2.5	88.34	1	537.7	16.2	2	178	24.7	3	424	8	2
Industrial	0.05	1.76	3	123.4	3.72	3	199	27.7	2	134.5	2.55	3
Total	2.83	100	-	3315	100	-	719	100	-	5280	100	-

Assessment of Pollution Load of Agricultural Drainages

Results showed that of the 86.23 m^3/sec pollutants discharge entering the Greater Karun system (Karun and Dez Rivers) before the Ahvaz region, 75.3 m^3/sec (87.3 %) is related to agricultural drainage. Moreover, the results revealed that the most important problem of agricultural drainage was the level of salinity in the drainage discharge. The total pollution load entering the Karun and Dez rivers on the basis of various agricultural, industrial, and urban pollution sources is presented in Table 2. Accordingly, from a total of 14,070 tons/day minerals and inorganic compounds (TDS) pollution load discharged into the water sources of the Karun and Dez Rivers, 11862.5 tons/day (84.3 %) is due to agricultural drainage. Based on the calculations of the pollution load, agricultural pollutants account for 211.16 tons/day (32.6 %) of organic matter based on COD (chemical oxygen demand) out of a total 647.92 tons/day entering the Karun and Dez rivers. In this regards, agricultural pollutants ranked second after industries. Agricultural drainage accounted for 29.7 tons/day (26.75 %) of organic matter based on BOD (biochemical oxygen demand) of out of a total of 111 tons/day entering the Karun and Dez rivers. Agricultural drainage ranked second in this regard. In terms of chlorides (2,654 tons/day), sulfates (4,722 tons/day) and nitrate (65.51 tons/day), agricultural drainage were the largest contributor of the pollution load entering the river, and since they have a significant discharge rate, pollution load as a result of agricultural drainages is very important. Afkhami (2004), Karamouz (2005), and Hosseini-Zare (2002) studied the pollution sources and their pollution load in the Karun and Dez rivers basin and estimated that the contribution of agricultural drainages in the pollution load of dissolved solids (TDS) and organic load based on BOD and COD as 70, 19 and 23.5 percent, respectively. Due to the significant development of agricultural and aquaculture activities and particularly the implementation and operation of the seven sugarcane industry development plans in the northern and southern regions of the city of Ahvaz in the vicinity of the Karun and Dez Rivers basin, the increased contribution and role of agricultural pollution sources in mineral and organic pollution load discharging into the river during this study as compared to other similar studies is quite predictable.

The Assessment of Pollution Load of Urban Wastewater

The results of inorganic and organic compound pollution load and other indicators of urban wastewater pollution and their comparison with agricultural drainage is shown in Table 2. Results show that the discharge rate of urban wastewater is 7.90 cubic meters per second and constitutes 9.2% of the total 86.23 cubic meters per second of measured discharge rate. Urban wastewater ranked second after agricultural drainage in this regard. Table 2 also shows that from a total of 111 ton per day of organic pollution load in terms of biochemical oxygen demand (BOD) entering the Karun and Dez Rivers, 53.51 ton per day (48.20 %) is due to urban wastewater. The share of agricultural drainage and industrial wastewaters was 29.7 and 27.82 ton per day of organic pollution based on BOD. Results also show that out of a total of 647.92 ton per day of pollution load based on COD, 130.14 ton per day (20 %) is related to urban wastewater. In the case of agricultural drainage and industrial wastewater, 306 and 211 ton per day, respectively, was estimated based on COD. The pollution load of industrial organic compounds was mainly related to the sugarcane-related industries such as paper mills and Silk companies located in the Haft-Tapeh region. Regarding the pollution load of dissolved salts, the total amount of dissolved solids (TDS) is calculated as 14,070 tons/day, and the share of urban wastewaters was calculated as 1638.5 tons/day (11.6 %). Another issue is the ammonia pollution load. Out of the 20.3 tons/day ammonia pollution load, 15.25 tons/day (75 %) was due to urban wastewater. By comparing the results in Table 2, which is based on the final results of the pollution load calculations, it was found that although the concentration of COD and nitrate is higher in urban wastewater as compared to agricultural drainage, the pollution load discharges into the river by agricultural drainage is 1.62 and 12.9 times higher than the urban wastewater respectively. This was due to the very high discharge rate of agricultural drainage as compared to urban wastewater. Regarding organic compounds based on BOD, as shown in Table 2, the BOD levels of urban wastewater is nearly twice the BOD levels of agricultural drainage. This indicates that microbial decomposition of organic matter in urban wastewaters was higher compared to agricultural drainage, and if a considerable volume of urban wastewater, in as such that when the urban wastewater of Ahvaz, enters the river, their oxygen demand would be much higher, which reduces water oxygen content more easily. Most organic materials in agricultural drainage are mainly byproducts of the sugarcane industries and made of cellulose and are thus resistant to microbial decomposition (sugar cane wastes). These material are often transported to the extremes of the river and become a source of organic material based on COD. Regarding control and prioritization of urban wastewater treatment, it can be said that according to the results, although the city of Ahvaz is the capital of the province and is highly-populated, its urban wastewater is directly discharged into the river at the rate of 400,000 cubic meters per day from the gateway of Ahvaz to the southern end of Ahvaz, Ahvaz has been identified as a major center of organic, microbial, ammonia material pollution load. The results of the present study is in agreement with studies conducted by the Environmental Department of Khuzestan (2002), Dezab Consulting Engineers (2001), and Hosseini-Zare (2002), which estimated 10.7%, 33%, and 14% share for TDS, BOD, and COD pollution load arises from urban wastewater, respectively.

Assessment of Pollution Load of Industrial Wastewater

Khuzestan is an agricultural production hub and is also considered an industrial hub due to the existence of large oil, gas, steel, carbon, petrochemicals, and electronic industeries as well as many smaller industries. Contemporary National Iranian Oil company's policies of, development and expansion of current oil fields and new excavations have severely affected the international wetlands of Shadegan and Hour-al-Azim, in addition to the polluting of water resources and dam reservoirs and agricultural land in the Karun and Dez rivers basin and the urban centers of the Province caused by the National Oil Companies unregulated activities. In recent decades, the Khuzistan Province has frequently witnessed failure and rupture in oil pipelines and oil spill pollution of soil and water resources in the various basins of the Khuzestan Rivers. In addition to the aforementioned issues, a reality the Khuzistan province has witnessed in recent years is that due to numerous economical and labor-related problems, and particularly problems caused by sanctions, many industries have closed and others are on the verge of closing. According to authorities, many industries are operating with 40 % capacity, for instance, Khuzestan Pipe Co, Ahvaz Sepanta Co., Ahvaz Sugar Refinement, Ahvaz Khorramnoush, Pasargad Chemical, Abadan Dairy Co., Soap factory. Yas Khorramshahr Co., Khorramnoush Khorramshahr Co., Dezful Sugar Co. This issue has led to large scale unemployment in the Khuzestan province. Unemployment and the necessity to earn a living has caused many to turn to agricultural and aquaculture activities regardless of the economic development capacity of Khuzestan. They have exploited water either by legal permits or illegally which results into the low quality of water and soil resources , causing serious challenges in the short-term and long-term. It has to be noted that sanctions and encouraging non-oil exports, including agricultural products with the goal of self-sufficiency and foreign exchange and overcoming sanctions have put additional pressure on water and soil resources, which has in itself deteriorated the quality of water resources on all levels and increased soluble salts and pollution in base resources. Results shows that industries related to the sugarcane industry, due to the cellulose nature of their materials, and related industries such as paper mill and Silk companies located in Haft-Tapeh area, with a significant organic pollution load of BOD (21.9 tons/day) and COD (285 tons/day), has had the greatest effect on the quality of water, and consequently, soil resources to date.

Conclusion

The important factors that destroy the quality of soil and water resources and increase the pollution load entering the Karun and Dez rivers can be summarized as follows: Human factors including development in various aspects, such as increasing population, urbanization, development of economic sectors, including agriculture and aquaculture, industrial and issues of inter-basin water transfer, problems caused by sanctions, including bankruptcy and closure of many industries and a rising unemployment rate, and thus, many activities of unemployed people in the agriculture and aquaculture sector , along with natural factors such as climate and climate change and reduced precipitation and consequently reduced runoffs and incidence of droughts. However, human factors, including soil and water resources management, are the most prominent causes of the current situation. Results showed that the major problem of soil and water resources in the Great Karun basin in the Khuzestan Plain is caused by minerals and soluble salts resulting from agricultural activities and the vast areas under cultivation. The discharge of drainage water to River systems is a common practice in Iran. This practice seriously decreases the quality of irrigation water used by farmers in the lower reaches of the river system. Agricultural drainage belonging to the sugarcane industry located in the northern and southern regions of Khuzestan is about 110,000 hectares. These Agricultural drainage along with the Seasonal and high water consumption cultivation of crops , such as the cultivation of paddies in the Karun and Dez rivers basin, and the development of aquaculture are the main sources of water and soil pollution resources in the studied area. The Dez River in the Haft-Tappeh region is considered as a vulnerable and susceptible area regarding its natural assimilative aspect due to the organic pollution load discharged by the sugarcane industries and the related industries, such as paper mill and Silk companies based on biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Results also showed that the city of Ahvaz, as the highly-populated capital of the province, is due to the discharge of urban wastewater from the gateway of Ahvaz to the southern end of Ahvaz, one of the major sources of organic pollution load based on biochemical oxygen demand (BOD) and microbial and ammonia pollution load. There is a clear trend of water quality deterioration as the water moves from upstream to downstream areas. The water quality in the upstream region was found to be good with salinity levels in the range of 0.500 to 0.650 dsm^{-1}. The water quality gradually deteriorated in the Khuzestan Plain as a consequence of the confluence of pollution resources. The water quality at the lower reaches of the river system deteriorated to the extent that the salinity levels of the river water reached between 2.5 to 6 dsm^{-1}. Water quality deterioration has a major effect on the development of salinity and sodality in the irrigated land located in the lower reaches of the basin.

References

Karamouz, M., Krachian, R., Zahraei, b., Jafarzadeh, N.A. 2005. "Planning to Develop Comprehensive Plans to Reduce Pollution of Karun River System"

Karun River Water Pollution Reduction Plan, 2002, Khuzestan Department of Environment

Chandra, A., Saxena, P.N., Ghazala Imam, S and Chandra. G. 2011. Physico-Chemical Studies on Pollution Potential of River Devaha at District Pilibhit (U.P.), Oriental Journal of Chemistry, 27(3):1193-1198

Deng,Y., Binghui, Z., Goo, f., Kun, L., and Zicheng, I. 2010. Study on the total water pollutant Load allocation in the Changjiang (Yangtze River) Estuary and adjacent seawater area , Estuarine, Coastal and shelf Science, 86,331-336

Essien ,O.E. 2010. Effect of Anthropogenic Pollution Loads Along Ikpa River Tributary Under Urbanization Expansion, Journal of Applied Sciences in Environmental Sanitation,5(3):273-282

Fatoki, O.S.,Gogwana, P., Ogunfowokan, A.O. 2003. Pollution assessment in the Keiskamma River and in the impoundment downstream,http://www.wrc.org.za

Hillel, d. 1997. Introductory Overview. Soil and water Civilization. In: Soil and Water Science: Key to understanding our global enviroomeent. Soil Sci. Soc. Am Spec. pub. 41: 1-9.

Jury, W.A. 1999. Forword. Soil and Water Science: Key to understanding our global environment SSSA. Spec. pub. Alivii .

Kacan, E., Ulku, G., Turan, I. Total pollution load discharged to creeks and River buyuk menders near Denizli city,

Jafarnejadi, A.R., M. Homaee, G. Sayyad, M. Bybordi. 2011.Large scale Spetial Variability of Accumulated Cadmium in the Wheat farm Grains. Soil and Sediments Contamination. 2o: 98-113.

Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture', FAO. Irrigation and Drainage Paper.29 Rev (I): 8-96.

APHA, AWWA, WEF.2012. Standard Methods for the Examination of water and wastewater, 22ND Edition

Bhardwaj R M. June 2005. Water quality monitoring in india-achievements and constraints, IWG-ENV. Central Pollution Controlboard, Viena, pp: 1.

Hatt, B.E., et al. 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. Environmental Management 34: 112–124.

Holliday, L. 2007. Agricultural Water Management. Proceedings of a Workshop inTunisia, The National Academies Press, Washington, D.C .178: 231-237.

APPLICATION OF BIO-DRAINAGE SYSTEMS FOR THE SUSTAINABLE AND OPTIMAL USE OF IRRIGATED LANDS AND THE PREVENTION OF THE SALINITY AND OVER-DRAINAGE OF ARABLE LAND

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Abstract

Sustainable agriculture in irrigated lands requires a natural or artificial drainage system which will extract the surplus water and salt from the soil. In many regions the natural drainage system fails to be efficient enough and artificial surface or sub-surface drainage systems must be implemented which in themselves are not only costly but also cause environmental problems in the area itself. It is believed that in such areas other methods for the transferring of salt and excess water off the land should be applied. One of the modern methods applied currently is that of bio-drainage which along with dry drainage and Argo-forestry are used for the reducing of environmental damage to drainage sites. In this paper, the author shall be focusing on the application of bio-drainage in the Khuzestan region. The main objective was the sustainable and optimal use of irrigated land in order to prevent the over drainage and salinity of the arable lands in the region. In contrast to artificial drainage systems which rely on mechanical equipment, in bio-drainage systems plants are used for the controlling of salinity and the retaining of the static equilibrium. Plants with the capability of dynamic absorption and transpiration pump groundwater upwards and release it to the atmosphere. This is an economical and assured method for the resolving of drainage problems in arid and semi-arid regions. The efficiency of this method in the controlling of salinity and excess water depends on variables such as the climate of the region, the soil characteristics, type of crop, irrigation method, and the chemical quality of the water used for irrigation. This method is often successfully applied in zones which have a high static equilibrium along with high rates of transpiration. Studies have validated its effectiveness in retaining the static equilibrium in various zones, yet its effectiveness in the decreasing of the salinity of the soil over a long period of time is debatable. It is believed that this method could prove to be a means of diminishing the effects of saline water on soils, and act as a retardant until more effective salinity mitigation measures are put into place. The amount of land required for the creating of bio-drainage systems is less than ten percent which in comparison to the amount of land required for the creating of an artificial drainage system shows a negligible difference. In the development of this type of drainage system one should consider the following; first of all the plants selected should have the capability to thrive in such an environment and the amount of water they consume and their transpiration index should be high. The plants utilized should be beneficial and have sufficient yields while being

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saline resistant. The root dispersion should be vertical and deep in order to tap groundwater sources. More over the plants selected should match the crop patterns publically acknowledged by farmers and the environmental effects of the plants should be carefully evaluated prior to implementation. This is largely due to the fact that the best way to protect and preserve such plants is through public awareness.

KEY WORDS: Bio-drainage, Irrigated land, Saline soils, Static equilibrium, Soil characteristics.

Introduction

It can simply be said that drainage is the process of eliminating the excess water and salts from the soil floor or depth. The aim of drainage in agriculture is to prepare a suitable environment for the plant root to grow (concerning ventilation and salinity). In a more comprehensible definition it can be said that drainage is the natural or artificial elimination of the extra water from an area that is one of the fundamental subjects of engineering hydrology. When the ground is irrigated the level of the groundwater table rises so the ventilation in the root becomes hard. Also concentration of salts make soil saline. Issues caused by the lack of ventilation in soil:

1- Decrease in the breathing of root and living beings;
2- Decrease in permeability and slow movement of the salts;
3- Formation of toxic compounds in soil (performing revival operations instead of oxidation);
4- Decrease in production of food in soil

Sustainable agriculture in irrigated lands depends on the existence of a natural or artificial drainage system that eliminates the extra salt and water from the soil. Natural drainage is insufficient in many areas and creating artificial drains in either open or underground forms, beside the environmental issues, become very costly.

Vertical and horizontal methods of drainage have been used for many years as traditional and standard methods of controlling phreatic surface and salinity. Although these methods have many advantages for beneficiaries, they have some problems too. Modern methods of drainage include bio-drainage, dry drainage and agro forestry drainage.

All plants need water to grow. Since natural precipitations could not always meet the water needs of plant, rest of the plant need for water is resolved through irrigation. Agricultural development in many countries has often been concurrent with development in irrigation. In average, agricultural products from a unit of an irrigated area are two times more than that of a rain-fed area. Irrigation, undoubtedly, plays an important role in protecting world population concerning food supply, clothing, bio-energy and industrial needs and its negative impacts on natural resources have been revealed from which salinity of the irrigated land and their becoming to wetlands can be stated.

Today roughly one third of the irrigated lands of the world is threatened by wetland dangers in a way that two to four million hectares from the world lands are excluded from the production cycle annually. There is no doubt that in the future also, because of so many losses due to low efficiency and using low quality water, new drainage problems will rise. In many places of the world managerial solutions has been presented for resolving drainage problems but most of these solutions are based on engineering approaches such as deep open drains, vertical drains (pumping ground water) or underground drains. These systems, basically, require maintenance and exploitation and also a high initial investment for creating such drains is needed. Furthermore, the output water from these drains is often saline and sometimes polluted and its pumping to the surface water (rivers, lakes, ponds,…) results in environmental issues. So other methods of controlling phreatic surface that are low cost and environmentally accepted are preferred. Bio-drainage is introduced and discussed in this article and its technical aspects, advantages and limitations are studied.

Bio-drainage: the main goal of this method is sustainable and optimized use of irrigated lands and prevention of fertile lands from being drained and saline. While artificial drainage depends on mechanical tools, bio-drainage controls salinity and phreatic surface with the help of plants. Ground water is pumped to the atmosphere by the plants by means of the transpiration pull. This method is introduced as a low cost yet secure treatment to solve drainage problems in dry and semi-dry regions. These methods, generally, are more affordable and eco friendly. Bio-drainage technology, if implemented correctly, can lower the groundwater level resolving the issues related to flood and canals leakage.

Common plant species in bio-drainage

Selecting plant species in bio-drainage depends on environmental conditions. For example, species resistant to salt are suitable for saline condition while species that consume much water are appropriate for controlling penetrated water with low salt and canal leakage.

- Tamarix troupii
- Acasa tortilis and Acasia nilotica
- Eucalyptuses specially Eucalyptus Camaldulensis

Tamarix: is an old tree. Since its root can get to surface water of the ground, it has been said to live more than 1000 years in some places in the tropics. This tree height reaches to 10 to 15 meters. The tree belongs to Tamarix family and grows in different places of the world including Iran.

Eucalyptus: belongs to myrtle family which is originally from Australia and constitutes dense forests in that country. The tree reaches a height of 145 meters with a trunk perimeter of 25 meters.

some Australian researchers have claimed, in an article titled "natural gold particles in the leaf of Eucalyptus and its relation to discovery of underground resources of gold" published in scientific journal Nature, that Eucalyptus tree is capable of absorbing the gold laid in the ground depth and transferring it to the surface of the ground hence making mine discovery possible.

Materials and methods

This method of drainage is an unstructured method and purposes of the underground drainage are fulfilled through growing plant (mainly unfruitful ones). Choosing the type of plants to grow (several years or permanent) should be done considering the resistance to salt or preferably halophytes. To implement this method of drainage trenches are allocated to grow water intensive plants in the proximity of arable areas. This kind of plants makes a lower aquatic potential in soil face due to their high transpiration. So underground drains that have a higher aquatic potential move toward the aforementioned trenches and the water table level decreases in farming areas and, in fact, drainage is accomplished in a biotic procedure.

In the studied associated with bio drainage some items have to be considered such as water and salts balance, water level required for growing plants (unfruitful ones), need for water of the plants practiced in bio drainage method, quality of the groundwater and the extend of the impact of the trenches made in agricultural areas. According to the studies, Tamarisk, Acacia, Mimosa and Eucalyptus are the appropriate trees for this method of drainage.

Results and discussion

In normal conditions indices of a hydrological system such as precipitation, evaporation, transpiration, soil moisture supply changes and drainage are in balance. High precipitation in some periods may temporarily increase drainage flow and raise the phreatic surface or moisture supply but finally, after a period of 5 to 10 years, the balance will be restored.

Plants play an important role in water balance indices (evaporation, transpiration, moisture supply). When agricultural plants or trees replace natural plant cover, the region aquatic balance changes the leakage to groundwater table may increase or decrease compared to its previous status. Indeed, the development of irrigated agriculture generally followed by an increase in water leakage into the groundwater table. As an example, in Australia the depth of penetration in semi-dry regions was measured before and after change in using method. The degree of penetration before the change, in which the area was covered with native eucalyptuses, was less than 0.1 millimeter per year and after the change and growing agricultural plants, the penetration dramatically changed and increased about 5 to 30 mm per year.

The driving force in bio drainage is of plants water consumption. So, cultivation of fast-growing tree species like eucalyptus during feeding (irrigation or precipitation), decreases the penetration of water into groundwater table and when irrigation or precipitation stops, that results in lowering of phreatic surface. Initial studies conducted in Australia suggest that the amount of transpiration and groundwater consumption of trees of low phreatic surface areas (5 to 8 meters beneath the surface of ground) is very high and is 3 to 6 times (1200 to 2300 mm per year) more than yearly transpiration of pasture species (400 mm).

In 1998, Morris and co-workers reported that the amount of two types of eucalyptus (Grandis, Camaldulensis) in shallow and saline water table was about 300 mm per year. They also claimed that trees ability to drain groundwater away from the soil with a low hydraulic conductivity declines when phreatic level decreases. Other studies also were conducted on different types of eucalyptus concerning transpiration. Their water needs were suggested to be almost equal.

Salt balance is also one of the basic factors that contribute to the growth and water consumption of plants. The salt that is transferred to root area, if not water-washed, absorbed or eliminated by the plant, will kill the plant.

Characteristics of plants root are very effective in water consumption efficiency. Plants with deeper root, besides having more access to water, consume more water and can lower the surface several meters.

During the penetration of irrigation water or rain water into the groundwater table, existence of trees with deep roots reduces the chance of penetration of water into the water table.

Bio-Drainage in rain-fed regions

The main problem with Bio drainage in rain-fed or humid regions is that plants water need is usually low in winter or precipitation season. So drainage takes place with a delay in a way that soil is saturated in winter and unsaturated in summer. With Bio drainage in rain-fed lands is designed according to the following different purposes:

Feed control

In high and rain-fed lands the input water stream usually under the root in upstream areas toward downstream and is drained into groundwater table. This makes the downstream areas saline. The process in which depth penetration of upstream is reduced to solve the drainage problem in downstream is called feed control.

In Australia plant cover or growing agricultural trees in the upstream has been the most important measure to control salinity. In this situation, planting trees in a small part of the upstream areas is enough. But plant cover in upstream has also negative impacts. If the evaporation ability of the new plants is great, it may make the land dry, decrease the flow of rivers and wells or making them go dry.

Preventing or blocking groundwater flow

By planting trees in some points in downslope, where water has rather a good quality, groundwater flow toward downstream is reduced so the drainage problem of downstream is partly resolved. The location for planting also is of great importance. That depends on status and construction of layers, upstream slope, feeding quantity, groundwater quality and the depth of phreatic surface.

Draining increase

Lands with low phreatic surface are often the places where drainage of groundwater takes place. In case that these lands have exits and their canals are drained into rivers, salt balance will be kept. But if no exit exists or if there is no penetration of groundwater into lower depths, then salinity of the lands will be inevitable. In these conditions the stability of bio-drainage system is found to be uncertain. Today in Australia, it is generally believed that bio-drain in downstream and smap lands finally results in salinity unless ordinary drainage systems are applied to control the salinity.

Bio-Drainage in irrigated lands

Irrigated lands work as feeding surfaces during irrigation and penetration of water into soil. They also operate as draining surfaces at irrigation intervals when evaporation-transpiration takes place. Bio-drainage in irrigated lands is designed according to the following purposes:

- Control of phreatic surfaces
- Prevention of canal leakage
- Composite system (ordinary drain + bio-drain)

In condition that salt accumulation of salt in root area limits the growth of bio-drainage plants, engineering solutions seem to be essential for system stability. In these situations, a combination of ordinary drainage and bio-drainage systems may be helpful.

Design principles

The following items have to be considered in development of bio-drainage systems:

1- Water balance: bio-drainage plants are supposed to be able to absorb groundwater enough for them to feed so that the phreatic surface beneath the root is maintained.
2- Cultivation surface: bio-drainage cultivation surface needs to be small as much as possible since the basic purpose of agriculture (especially in irrigated areas) is to grow valuable crops.
3- Salt tolerance: the plants used for drainage purposes have to be salt tolerant as groundwater is usually more saline than irrigation water; with an increase in salinity to 8 ds/m water consumption is reduced to half.
4- Cultivation arrangement: plants must be cultivated in blocks or ridges with certain distance so that phreatic level between them and in irrigated areas below the depth of plants root. Since access

to trees is more possible in roadside areas and borders, these places are recommended for planting bio-drainage trees.

5- Salt balance: the development of irrigation projects without considering drainage leads to the salinity if lands. The keep balance of salt, cultivated plants should be able to absorb salt and they have to be removed after a harvest. This can be fulfilled only in case that the salinity of irrigation water is very low.

6- Economic aspects: management of the exploitation of bio-drainage trees and plants differs from that of valuable farming plants. The income from bio-drainage plants is earned several years later than the initial investment (the cost of planting and preservation).

And the most important item is:

7- Public acceptance: growing new plants like trees will affect the social status of a village. New markets may arise. Careful safety attention for these trees is different from that required for ordinary plants (illegal rescission or cutting trees for firewood; and a fire may ruin the results of several years in a day). To resolve the issues and prove that the interests of bio-drainage system are gained as much as possible, active contribution of local communities to develop and plant bio-drainage trees is highly important.

8- Salt balance, an important issue in drainage.

No biological system can survive without a salt equilibrium. Salinity balance is one of the important issues that must be studied before considering bio-drainage as a managerial technique. Salt absorption by plant is slight compared to the total salt that enters the root through irrigation water. Studies have shown that only 1 to 1.5 percent of the total salt that enters the soil is removed from the soil by the plant.

Lambert (1981) calculated the amount of salt removal from soil by eucalyptus as 400 kg per hectare that is equal to percent of the salt entered the soil through the irrigation water.

So plants ability to eliminate salt from root area is not encouraging and other techniques such as salt washing and other drainage methods have to be used simultaneously.

Bio-drainage system lifetime

The experiences regarding bio-drainage in different places of the world belong to the recent years and no report confirming the long-term performance of these systems has been received. The lifetime of these projects is estimated at 10 and maximum of 15 years according to researches (1385). The main cause that makes these systems inefficient after 10 years of operation is the salinity issue.

Some other items:

In Gandhi's stream project in Ragestan, India, planting eucalyptus trees wetland areas near the irrigation stream caused groundwater surface to lower 15 meters in a period of 6 to 7 years. Drilling

performed in an area of trees to a depth of 10 meters showed that eucalyptus roots extend to a minimum depth of 10 meters.
Kapoor (2003) found bio-drainage helpful for water with salinity below 12 ds/m.

Akram (1385) claimed that maximum water and soil salinity that can be controlled in bio-drainage method is 5 ds/m. environmentally friendly bio-drainage methods by far have a better performance in a situation that restricting layers are so deep.

Conclusion:

1- Bio-drainage is very effective in resolving swamp issues in irrigated and rain-fed lands, having a desirable performance in areas with high phreatic surface and evaporation rate.
2- Plants ability to eliminate salt from root area is not so desirable. So they are helpful for postponing the transfer of salt to root area or in case of low salinity of irrigation water.
3- When salt accumulation of salt in root area limits the growth of trees, engineering solutions are essential for system stability. A combination of ordinary and bio-drainage systems can help.
4- If the area is more humid and water needs are low, then bio-drainage is found to have higher efficiency.
In similar reaserch Akram et al. (2008) applied the SAHYSMOD model in order to determine the sensitivity of the various elements influential on irrigation and their effect on bio-irrigation schemes, and obtained the following results:

- The major constraint of bio-drainage in arid and semi-arid regions is salt balance and the accumulation of salt in tree plantation strips. The sustainability of the system, however, is questionable except where the irrigation water is quite suitable and/or in humid regions with high annual precipitation
- In saline environments, hybrid systems that combine bio-drainage and conventional engineering-based technology will be needed to achieve sustainability.
- The effectiveness of the system is higher where the neighboring strips are narrower
- In most cases salinity of crop strips in bio-drainage is independent from the hydraulicconductivity of the soil
- A bio-drainage system could not be expected to be considered successful in areas where the barrier depth is too shallow
- Bio-drainage is very sensitive to the amount of applied water. The higher the water applied, the lower is its effectiveness in both water table and salinity control in plantation strips. A bio-drainage system could not be expected to be considered successful in areas where the barrier depth is too shallow,

- Sustainability can only be achieved where some sort of salt removal mechanism is included in the system.

The obtained results approximate the results obtained in conventional irrigation schemes.

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References

Akram Sina., Kashkouli H.A., Pazira E., 2008; Sensitive variables controlling salinity and water table in a bio – drainage system.

Irrigation and Drainage System; 22(3): 271 – 285; DOI: 10.1007/s10795 – 008 – 9056 – 4.

Akram, Sina. 2006. Analysis of Biological Drainage Systems to Salt Sensivity Provided with Sahysmod (Mathematical Models), 4th Technical Drainage Workshop. IRNCID.

Akram, M., 2001. New Approaches in Drainage Designing., 2nd Technical Drainage Workshop. IRNCID.

Akram, M., 2003. Drainage Developments., 3rd Technical Drainage Workshop. IRNCID.

Liaghat, A.Majid., Bio-Drainage, 3rd Technical Drainage Workshop. IRNCID.

Heuperman Albertus F.2002. Biodrainage (principles, experiences andapplications).

Khamzina. A, Lamers. J. 2005. Evaluation of young and adult tree plantations forbiodrainage management in the lower Amudarya River Region, Uzbekistan.

Ram. J, Garg. V.K, .2006. Biodrainage potential of Eucalyptus tereticornis for reclamation of shallow water table areas in north-west India.

Zhao. C, Wang. Y, Song. Y. 2004. Biological drainage characteristics of alakalized desert soils in north-western China.