Integrated Water Management Approaches for Sustainable Food Production

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Abstract

With growing and increasingly wealthy and urban population, it is likely that the role of agricultural water management in ensuring food security will become more important. However, pressure on water resources is already high. Adverse environmental impacts as a result of sometimes poor management of irrigation and drainage are well documented, calling into question the sustainability of some of the current water resources management practices. Water, food, energy and climate are intrinsically connected. Greater pressure on water resources and, hence, stronger interconnectivity between sectors sharing these resources, call for new, integrated approaches to agricultural water management. This background paper explores the links between water, food, energy, and climate. It then explores the role of irrigation and drainage in food production and in providing other ecosystems services that are essential for the sustainable use of natural resources. The paper argues that looking at water for food production in isolation would miss important developments outside the water sector that determine the sustainability of agricultural water management. Integrated approaches to food production are not only necessary to ensure sustainability. They also lead to higher benefits per unit of water. For example integrating food production with other ecosystem services provided by irrigation and drainage not only contributes to sustainability; it also leads to much higher economic value of benefits. This implies breaking disciplinary boundaries and encouraging greater cooperation from planning to implementation.

1. Introduction

The principles of Integrated Water Resources Management (IWRM) are succinctly described as the desired maximization of the 3 E's: Economics, Equity and Environment (GWP 2000). Because the three objectives are not always achievable simultaneously, water management for agriculture involves tradeoffs more often than maximization (Molle 2008). This is especially true for water management for food production. Agricultural water management has played a key role in increasing global food supply (CA 2007) and contributed substantially to poverty alleviation (Namara et al. 2010). Yet, some 860 million people worldwide are still food insecure (FAO 2011a). Negative consequences of irrigation and drainage on environmental integrity are well documented (Falkenmark et al., 2007; MEA 2005). In some cases this even caused the collapse of ecosystems and the services they provide to local people (Gordon et al., 2010). Consequently, alternative approaches to water management for food production are called for to achieve the triple goal of increased food production, equitable access and environmental sustainability.

This background paper describes the changing context and the linkages between water, land, food and energy. In a globalizing and increasingly interconnected world understanding this nexus is a prerequisite to water management and sharing of water resources. The following sections look into water-food-energy-climate nexus, the environmental impacts of irrigation & drainage and approaches to address these (more crop per drop, environmental flows, ecosystems approach) and the challenges of sharing water between sectors. The paper argues that integrated approaches to water for food -such as managing irrigation and drainage for a range of ecosystems services-contributes to sustainable food production. But it also acknowledges that integrating and sharing water between sectors calls for breaking down barriers between disciplines and sectors and enhancing better collaboration and understanding.

2. Water-Land-Food-Energy-Climate Nexus

Water, food, climate and energy form a complex web of inter-linkages. Agriculture is both energy user and energy generator. Energy generation from biofuel and hydropower are land and water-intensive and sometimes compete with food production over limited land and water resources. Food production accounts for 70% of global water use and 6% of global energy use. Agriculture is a major contributor to climate change but is also the sector most heavily impacted by it. Water management plays an important role in both mitigation and adaptation strategies. Energy and climate change policies and subsidies influence water use for food or energy. In other cases, food policies, subsidies and consumption patterns drive water use. In the sections below we describe the aspects of the nexus.

a. Links between water and food production

Food production requires enormous quantities of water. Crops evaporate an estimated 6700 km^3 of which 18% is provided by irrigation water withdrawn from surface and groundwater sources (Siebert and Doll, 2010). Irrigated agriculture accounts for about 70% of water withdrawals for human purposes. Agricultural water management, and in particular irrigation, contributed significantly to global food production, food security and rural incomes over the past decades (CA 2007, Turral et al. 2010). Siebert and Döll (2010) estimate that at a global average irrigated cereal yields are 4.4 tons/ha while rainfed yields are 2.7 tons/ha. Some 42% of global cereal production comes from irrigated areas. They further estimate that without irrigation global cereal production would be 20% lower[1] (Siebert and Döll, 2010).

Food demand is expected to increase by 70%-90% from now till 2050, mostly because of population growth and changes in diets (de Fraiture et al., 2010). Global population is expected to peak in 2050 at 9.2 billion from 6.7 billion today with most of the growth occurring in the emerging and least developed countries (KC et al., 2011). Most people will live in cities. With higher living standards and urbanizing lifestyles, food habits shift from cereal-based to meat-based diets (Rosegrant et al., 2002). The production of livestock products generally takes more water than cereals (Peden et al., 2007; van Breugel et al. 2010). Under a business-as-usual scenario, without improvement of water productivity, demand for water for food production would double in the coming decades.

b. Links between water and food security

In the aftermath of the food crisis in 2008, food security is high on the agenda of governments, donors and NGO's. FAO (2011a) estimates that in sub-Saharan Africa 240 million people (30% of the population) are food insecure, with volatility in food prices since 2008 one of the major contributing factors (FAO 2011a). Food security implies a situation where "all people at all times have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life", according to the definition of World Food Summit in 1996. Hence, food security is not only dependent on the quantity of food but also its quality and people's ability to access it (they need to have sufficient income to buy it if they don't produce themselves). One could succinctly summarize this as the three A's: Availability, Accessibility and

[1] This is lower that the production of cereals under irrigation because they assume that significant crop production can be achieved in many irrigation areas with precipitation water alone.

Affordability. The FAO distinguishes four pillars of food security: production, access, utilization and stability. Water links to all four aspects. First, the production of food in the quantities that are needed to ensure global food security requires an enormous amount of water (see above). The production of non-staple crops that are needed to ensure a varied diet (vegetables, fruit) require good water management and are often grown under irrigation. Second, access to productive use of water is a proven way to ensure poverty alleviation and higher incomes (Castillo et al., 2007; Namara et al 2010). Higher incomes will be used to buy more and better quality food. Third, access to clean drinking water and improved sanitation leads to better health and hence better uptake of nutrients in food and contributes to food security. Fourth, improved water management and irrigation helps buffering variations in rainfall and reducing fluctuations in production and farmer income.

c. *Links between water, food and climate change*

Food production is both a major cause of and adversely affected by climate change. Agriculture is the largest contributor to global non-CO2 GHG emissions: 59% in 1990 and 57% forecasted for 2020 (UN-WWAP, 2012). Direct GHG emissions from the agricultural sector, amounting to 14% of global emissions, include methane from livestock manure and flooded paddy fields, emissions from the production and application of chemical fertilizer, and energy use of machinery in agriculture (IPCC 2007a; FAO 2011b). For example, in India energy used for pumping groundwater for agriculture contributes 4-6% to national GHG emissions (Shah 2009a). On the other hand, groundwater pumping also provides a livelihood to millions of smallholders and is playing a significant role in poverty alleviation and food security (Shah 2009b).

Indirectly, deforestation and conversion of natural ecosystems into agricultural lands contributes another 4-8% of total GHG emissions (FAO 2011b). A special case is the low-lying peatlands[2], for example in coastal areas of Indonesia, which are drained and converted to agricultural land and palm plantations, to produce food and -to a lesser extent- biofuels. Oxidation of peat and deforestation are by far the largest GHG emitters in Indonesia, larger than transport and industry. Globally, agriculture contributes more than 20% of global GHG emissions through direct and indirect effects, making it a major contributing sector after the energy sector (26%) (IPCC 2007a).

Improved water management can play an important role in GHG emission mitigation strategies. For example by reducing energy use in groundwater pumping, reducing methane emission from paddy fields, regulating groundwater levels in peat soils and by enhancing carbon sequestration in soils (refer to the discussion under section 4 below).

Agricultural production is affected by changes in climate, in particular through increased variability in rainfall and a higher frequency of extreme events (floods, droughts, storms, heat waves etc). Water management is an essential part of adaptation strategies, to cope with consequences of increased variability of rainfall (Ragab and Prudhomme, 2002) such as longer and more frequent droughts and dry spells; higher intensity rains during the monsoon and risk of flooding; uncertainty about the onset of the raining season ('false starts'); and changes in river flow regimes depending on retreating glaciers (IPCC 2007b).

An obvious response to variability in supply is to store water when it is abundant for use during dry periods (Keller at al 2000). Water storage improves the ability of rural poor to cope with climate shocks by increasing agricultural productivity (and hence income) and by decreasing fluctuations and risks. Water can be stored in large to medium and small reservoirs, small individual farm ponds ((McCarthney and Smakhtin, 2010), small reservoirs (Liebe et al. 2007) or aquifers recharged from

[2] It is estimated that peatlands (covering 4% of the globe) contain 30% of total soil carbon.

rainfall and water bodies or artificial recharge. Water can also be stored in the soil root zone through water harvesting and soil water conservation (Rockström et al. 2010).

Impacts of climate change on water resources have been modeled for several regions. For example groundwater recharge in two watersheds in Cyprus might decrease by more than 20%, in Southern Italy by 21-31% and in North East Brazil more than 35% by 2050, depending on emission scenarios. Surface water flows could decline by 17-20%, 16-23% and more than 34% in the same regions in Cyprus, Southern Italy and NE Brazil respectively (Ragab et al. 2010, D'Agostino et al. 2010 and Montenegro & Ragab 2010). Gorundwater recganrge is also influenced by land use and crop type. Cropping dates may shift as a result of climate change. In Cyprus planting dates of wheat may shift to 10 to 14 days earlier (Ragab et al. 2010 or 2012).

Indirectly, climate change policies affect water allocation and use. For example, because of high energy prices, concerns over GHG emissions and geo-political considerations several countries set biofuel targets as part of their energy/climate policy. The production of biofuels takes substantial amounts of water and leads to reallocation of land and water resources (Berndes, 2002; Searchinger, 2008).

d. Water and energy

Water is both energy supplier and user. Hydropower provides 16% of the global energy (IEA, 2012). It is the largest renewable source of electricity generation (15% of global production in 2007), and it is estimated that two-thirds of the world's economically feasible potential is still to be exploited (UN-WAPP, 2012; WEC, 2010). Hydropower dams often are multifunctional and water released from the turbines is used for irrigation. Water is also essential for the cooling of power plants. The water used in hydropower and cooling is to a large extent non-consumptive and could be reused, though the timing of release for irrigation and energy generation may be conflicting. The production of biofuels takes substantial amounts of water, consumptive water use (de Fraiture et al., 2008), in particular the so-called first generation biofuels based on crops such as maize, sugarcane and vegetable oil. Bioenergy is expected to add to the demand of agricultural produce, in order to increase the supply of transport fuels (i.e. biofuels) as a response to rising energy prices, geopolitics and concerns over greenhouse gas emissions. Future water requirements for bioenergy production have been estimated to range from 4000 to 12,000 km3/yr (Lundqvist *et al*., 2007).

The water sector is also a big energy user. Desalinization of water is very energy-intensive. Given that desalinization plants often use fossil fuel this may contribute to climate change. Further, lifting of water for use in agriculture takes a lot of energy. For example, in India water use in agriculture and energy are strongly linked because groundwater is the main source of water in agriculture, providing an estimated 70% of all irrigation water. Indirectly, energy policies may have a big impact on water use in agriculture. In some states in Western India, generous energy subsidies drive water use and are a major factor in groundwater overdraft.

e. Water-food-climate and energy nexus

Water, food, climate and energy are intrinsically linked. Looking at the water sector in isolation would miss the trends of increasing interconnectivity. The way water is used and allocated is often influenced by processes and policies outside the water sector (Hellegers et al., 2008). The increasing pressure on resources and thus increased interconnectivity between sectors that are sharing these resources, call for new approaches to integrated water management for sustainable food production.

3. Irrigation and drainage for environmental sustainability

At the global level around 18% of the cultivated area is under irrigation, producing 40% of all food (Schultz et al., 2005). Irrigation and drainage played a major role in food production and productivity increases over the past decades and is accredited for the successes during the Green Revolution and eradication of famines in Asia. But irrigation is also blamed for water shortages, severe environmental damage (for example, due to excessive irrigation causing the groundwater table to rise and soil salinuization, pollution due to fertilizers and pesticide application), displacement of people without proper compensation and increased social inequality (CA 2007). At the same time, land and water resources are already under pressure (Rockström et al., 2009). An estimated 1.2 billion people live in water stressed basins (CA, 2007). Major rivers (such as Yellow, Colorado, Murray Darling and Indus) are over-committed and some dry up during several months of the year due to over-abstraction (Molle et al. 2007). Groundwater levels are declining in, among others, Mexico, Western USA, Western India and parts of China (Shah et al., 2007). Agriculture is a major driver in land use change, degradation of aquatic ecosystems and biodiversity loss (Foley et al., 2011). Current international trade patterns may reinforce or aggravate this. For example, man river basins in Southern European countries such as Spain, Cyprus, south of Italy and Greece, currently are water stressed. At the same time the water abundant UK imports 40% of its food and mostly from southern European countries.

Consequently, alternative approaches to water management for food production are called for to achieve the triple goal of increased food production, equitable access and environmental sustainability. In this section we first describe some of the major environmental problems and then explore several concepts and approaches to tackle these problems.

a. *Environmental impacts of water use in agriculture*

Water use in agriculture has adverse impacts on the environment by changing terrestrial and aquatic ecosystems because of damming rivers and changing flow regimes, lowering groundwater, polluting soils and water, salinization and draining wetlands. Environmental impacts of water use in agriculture have been described and analyzed in numerous case studies and analyses, in particular, for large scale irrigation (Falkenmark et al., 2007, Gordon et al., 2010). The combined effects of many dispersed small agricultural water structures on downstream river flows and groundwater recharge is relatively underexplored, though research from South-India indicates that small water harvesting structures can have substantial adverse impacts on water quantity and quality downstream (Bouma et al. 2011). Environmental impacts of small scale irrigation or water harvesting is not necessarily less.

Water pollutants of surface and groundwater include soluble salts, agricultural chemicals (fertilizer and pesticides), toxic elements, pathogens and sediment. Improper and excessive fertilization can disturb soil-plant-water balance and damage the soil texture with nitrate and nitrite residues and pollute ground water (Kendirli et al., 2005; Cakmak et al., 2007). Large part of this pollution is avoidable through improved application practices of fertilizers and integrated pest management. However drainage systems should not be considered a mechanism for controlling pesticide runoff (FAO and ICID, 1997). Excessive water application in irrigation can lead to losses due to surface runoff and deep percolation. In some cases these losses may be reused elsewhere, in other cases they are irrecoverable due to saline sinks, or high costs. Low irrigation efficiencies may lead to problems such as water logging, high water table, salinity and alkalinity problems. On-farm water management practices, improved water distribution (e.g. canal lining or using pipe lines) and infrastructure (such as pressurized pipe systems and using modern irrigation systems such as sprinkler and drip) can reduce these avoidable water losses. Proper drainage minimizes problems of water logging, rising water tables and soil salinity. Bahçeci and Nacar (2008) stated that subsurface drainage is more effective in removing salt from the soil profile and salt cleaning process can begin immediately after providing suitable drainage. Selection, design and implementation of best proper irrigation methods based on land characteristics and implementation of proper irrigation programs will provide an effective water resource utilization and preservation. At the same time, improvements in irrigation performance and water management are critical to ensure the availability of water both for food production and for competing human and environmental needs (FAO, 2007; FAO 2011b).

Using poor quality irrigation water such as drainage water, saline groundwater and treated wastewater, adversely affects the environment. The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil. The use of these waters in irrigated lands requires the control of soil salinity by means of leaching and drainage of excess water and salt. Training and extension are a prerequisite to ensure fields are properly irrigated and efficiently drained to remove salts added to soil with the irrigation water. Also efficient and effective use of water in irrigated agriculture will ensure significant savings in water use (FAO, 2001; 2002). A major concern related to excessive drainage is the loss of nitrate through tile drains. Thinking of controlled drainage and shallow drainage developed in recent years, aims to prevent excessive drainage. Controlled drainage keeps the water table high during the off-season when crops are not growing. The high water table increases the rate of de-nitrification as soon as the saturated soil warms up in the spring and reduces nitrate loss to the environment (FAO and ICID, 1997, http://web.extension.illinois.edu/bioreactors/index.cfm, last accessed Aug 2013).

Wetlands are important biodiversity hotspots. Further, wetlands provide water, fish, wood, herbs and other ecosystem benefits, sustaining local inhabitants who often belong to the poorer groups of society. With growing population pressure, many wetlands are being converted to more intensive agricultural uses. Irrigation and drainage canals are constructed by government agencies, development projects of international donors and by farmers themselves with the twin objectives of ensuring food security and poverty reduction. On one hand, the development of irrigation & drainage increases local food production and enhances rural incomes. On the other hand, it threatens vulnerable wetlands and the ecosystems services that they provide to local inhabitants (such as fresh water, fish and wood).

b. *Reduce withdrawals by improving water productivity; increase supply from unconventional sources*

An obvious approach to minimizing adverse environmental impacts of irrigation is to reduce the amount of water withdrawn for crop production. Improvements in water productivity are necessary to attain increased food production and food security goals while at the same time safeguarding the environment. These gains are needed and possible in both rainfed and irrigated agriculture. Agricultural water management encompasses the whole spectrum between rainfed agriculture and fully irrigated (Molden et al., 2007 'setting the scene'). Management of soil water in rainfed agriculture combined with in-situ water harvesting can contribute significantly to improve yields Rockström et al., 2010)

There is considerable scope for improving water productivity of crop, livestock and fisheries at field through to basin scale. Practices used to achieve this include water harvesting, supplemental irrigation, deficit irrigation, including the partial root drying method, PRD, subsurface, precision irrigation techniques and soil–water conservation practices. Practices not directly related to water management impact water productivity because of interactive effects such as those derived from improvements in soil fertility, pest and disease control, crop selection or access to better markets (Molden et al., 2007). While there is considerable scope to improve water productivity, there are also reasons to be cautious about its potential (Molden et al., 2010). Further, when the value of output per unit of water increases this may be an incentive for individual farmers to abstract more water and irrigate more area, where possible (Molle et al., 2004). To be effective for water saving, measures to improve water productivity needs to go hand in hand with caps on water use.

Improvements of water productivity aim at reducing the quantity of water consumed for crop production. But there may be tradeoffs between water quantity and quality. Where yields are low due to limited nutrient and water supply, water productivity can be enhanced through higher fertilizer gifts and improved water supply. This limits the amount of additional water needed to meet increased food demand, thus leaving more water in rivers to meet environmental requirements. But increased fertilizer gifts also increases the amount of nutrient leaching, thus adversely affecting water quality of groundwater, rivers and lakes (Nangia et al., 2008).

Reducing the demand on fresh water could also be achieved through reducing the water demand on fresh water (Hamdy et al., 2003) by using the non-conventional water resources (e.g. treated waste water, saline brackish water) and by selection of less water consuming crops (e.g. quinoa, amaranth instead of the classical cereals such as wheat).

c. Environmental flows for environmental sustainability

Agricultural water use can affect the environment not just by reducing the amounts of water available, but also by polluting water, altering river flow patterns, and reducing habitat connectivity by drying up parts of rivers and streams. Not everywhere is agricultural water use leading to environmental concerns, depending, among others, on the quantity of water withdrawn relative to the amount available and on the vulnerability of the aquatic ecosystem. Co-managing water for agriculture and the environment can minimize these impacts (CA 2007). One way of doing so is ensuring sufficient water in the river at the right quantities at the right time. Environmental flow is the amount of water required to sustain aquatic ecosystems (rivers and wetlands) and the services they provide for people's livelihoods. It describes the minimum and maximum amounts of water in the river that area needed at different times of the year to maintain essential ecosystems functions. Environmental flows thus determine the amount of water that could be withdrawn or drained for agricultural development (Arthington et al. 2006). River ecosystems have evolved under a given flow regime over extended (millennia) periods of time. The natural river flow and the communities they contain, include variable flow regimes bounded by periods of low, base, flow and high flows that spill into the surrounding floodplain (WWF 2010).

Maintaining or restoring environmental flows can be a real challenge where economic growth and development intensify the competition for water resources. Reallocating water from irrigation to meet environmental flow requirements may lead to a reduction in production, though in some cases these may be offset by improving irrigation efficiency (Amarasinghe et al., 2013).

d. Ecosystem services approach

Ecosystems services are benefits to humans provided by natural systems (MEA 2005). Four types of services are distinguished. 1) *Provisioning* ecosystem services are products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water. 2) *Regulating* ecosystems services include the benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water cycle and groundwater recharge. 3) *Supporting* ecosystem services include nutrient recycling, soil formation, pollination, among others. The fourth category of ecosystem services includes cultural, aesthetic and touristic benefits.

Agriculture can be viewed as ecosystems that are modified, at times highly, by activities designed to ensure or increase food production. Agro-ecosystems maximize the output from one ecosystem service (food provision), often at the expense of other regulating and supporting ecosystem services.

However, by managing land and water differently multiple ecosystem services could be supported, ultimately leading to greater range of benefits (Gordon et al., 2010, Matsuno et al. 2006,).

The primary goal of irrigation and drainage is to improve agricultural production, increase rural incomes and minimize risks due to dry spells. Irrigated agro-ecosystems (such as irrigated rice fields) tend to maximize agricultural production (e.g. rice and shrimps together in paddy rice fields) but when managed well they can provide other -often unintended- services, such as erosion control through terracing, flood retention, sediment retention, groundwater recharge and birds' habitat. The economic value of ecosystem services may be substantial and are sometimes larger than the value of crops. For example, Xiao et al. (2011) estimate that the economic value of ecosystems services provided by paddy fields in China exceed the value of rice production by a factor of 3 to 8. Natuhara (2013) estimates the value of services that regulate ecosystem functions derived from irrigated paddy fields in Japan at US$ 72.8 billion.

e. *Ecosystem services provided by irrigation and drainage*

Irrigation and drainage potentially provide important ecosystems services. Its primary goal is food production, a provisioning service. Other provisioning services include the provision of fish and wood (from trees along canals and water bodies within and outside the command area). Regulating ecosystems services are, among others, groundwater recharge, flood and sediment retention, and carbon sequestration. Potential supporting ecosystems services include erosion control, accumulation of soil organic matter, recycling of soil nutrients, and supporting species diversity by providing a habitat of flora and fauna.

Groundwater recharge: Groundwater decline because of over-pumping is a problem in many agricultural areas in the world. Seepage from canals, reservoirs, farm ponds and irrigation fields contributes to groundwater recharge. For example, farm ponds in Madhya Pradesh, constructed to capture and store runoff for irrigating crops, also contribute to groundwater recharge and biodiversity (Malik et al., 2013). The importance of many small reservoirs in Tamil Nadu for village irrigation schemes is in decline but many now function as de-facto groundwater recharge structures (Palanisami and Amarasinghe, 2008; Shah, 2008). Liu et al. (2005) estimate that seepage from paddy fields accounts for 40% of groundwater recharge in Taiwan, with an economic valued of nearly 60% of the value of the paddy production.

Flood retention: Acting as flood retention basins, irrigated paddy fields can play an important role in flood mitigation. Because of the capacity to retain water and the combined effect of seepage and evaporation from bunded paddy fields, the runoff is significantly lower than from rainfed fields. This has a significant mitigating effect on floods (Wu et al. (2001). During high intensity rainfall events during the monsoon, flooded paddy fields around the city of Colombo in Sri Lanka delay peak runoff and hence reduce flooding in the city center downstream, without significant effects on rice yields. With the conversion of paddy fields into housing areas flooding in the city of Colombo increases (de Fraiture, pers.com.). By installing flood control devices in existing paddy fields in one district in Japan, the flood damage caused by 50-year return period rainfall event was reduced to that of 10-year return period rainfall event (Yoshikawa et al., 2010).

Soil erosion: Water erosion is one of the major causes of soil loss and soil degradation. Terracing is an effective ways to stop or reduce the degrading effect of soil erosion. Terracing of irrigated paddy fields in the hill areas is one of the oldest means of saving soil and water. Reducing tillage, restoring land cover and keeping water in the soil, increase agricultural productivity but also delivers benefits to other ecosystems, such as reduced erosion (Boelee, 2011).

Carbon sequestration: Agriculture is the biggest contributor to climate change through direct GHG emissions and indirectly through land use change (conversion of natural ecosystems into agricultural land). Agriculture is also seen as the sector with the largest potential for mitigation, in particular through carbon sequestration in soils (IPCC 2007), for example through conservation tillage and the re-growth of native vegetation on abandoned agricultural land. Irrigating arid and semiarid regions may be another method to contribute to carbon sequestration. The addition of water to arid and semiarid soils increases plant growth (above and below ground biomass) and, ultimately, carbon deposition into soil (Entry et al., 2004). Yields on irrigated lands are typically double as compared to those on rainfed land. Expanding irrigated lands and converting an equal amount of rainfed lands to native forests would increase agricultural production while at the same time substantially mitigate GHG emissions (Entry et al., 2002). Longterm irrigated farming can significantly increase the amount of soil organic carbon because of the addition of biomass (root residues) to the soil (Wu et al., 2008).

However, Schlesinger (1999) warns for over-optimistic estimates of carbon sequestration through irrigation. The net carbon balance may be negative if CO2 emissions from energy use for groundwater pumping are higher than the carbon sequestered in the soil. The application of fertilizer, often accompanied with irrigation, may tip the negative carbon balance even further. Moreover, groundwater of arid regions often contains dissolved Ca and CO2 that is released to the atmosphere when water is applied. (Schlesinger 1999).

Paddy fields contribute to climate change through methane emission. Alternative water management practices such as alternate wet-dry irrigation or aeration through mid-season drainage reduce methane emissions (Tyagi et al., 2010). Oxidation of peat lands that are drained and converted to agriculture, contributes substantially to CO2 emissions. Emissions can be reduced by improved drainage practices that balance high groundwater levels to reduce GHG emissions and low groundwater levels that allow cropping (Damayanti 2012). Usingshallow groundwater and sub surface drainage system as a subsurface irrigation (controlled groundwater levels), could also reduce the need for energy to pump out groundwater (and hence GHG emissions).

Supporting biodiversity: In particular irrigated paddy fields often are rich in birds and other flora and fauna. Natuhara (2013) describes a paddy area in Japan where more than 5000 species have been recorded in the fields and surrounding areas. Biodiversity-conscious rice farming has been promoted by collaborations among stakeholders and by biodiversity certification programs. Incentives include direct payments and premium prices that consumers pay for certified produce (Natuhara 2013).

f. Irrigation and drainage for food production and other ecosystems services

Human survival depends on the continuous flow of ecosystems services. Irrigation and drainage play an essential role in the provision of food and feed, and to a lesser extent fiber and biofuels. The emphasis on the maximization of agricultural production may come at the expense of other ecosystem services that irrigation and drainage can provide. However, several studies provide evidence that harnessing a wider range of ecosystem services make economic and ecological sense. The value of benefits derived from irrigation by managing water for a range of ecosystems services is much larger than an exclusive focus on agricultural intensification.

Improving water productivity and environmental flow requirements are reducing environmental impacts of irrigation & drainage by lessening the amount of water needed for crop production and ensuring a certain quantity of water to sustain riverine ecosystems. Water productivity is sometimes narrowly defined as ‘more crop per drop’ and maximizing the amount of agricultural output per unit of water. Some include the multiple uses such as drinking water, domestic water, fish ponds, small cottage industries or other income generating activities in the definition, i.e. ‘more value per drop’ and ‘more jobs per drop’. However, the focus on these provisioning services may ignore the much larger economic gains by including a broader range of ecosystems services. This may imply a tradeoff between maximum food production and maximum benefits from a range of ecological services.

We would argue to redefine water productivity as ‘benefits per unit of water’ or ‘net return for a unit of water used’ (Molden et al., 2010) to include all ecosystem services that agricultural water management can provide. Integrating these different benefits, such as food production, groundwater recharge, flood retention, biodiversity and carbon sequestration, in the framework of agricultural water management requires breaking down disciplinary boundaries between, among others, engineers, ecologists, agronomists, economists, hydrologists and climate scientists.

Finding the right balance between maximization of food production for livelihoods and ecosystems' integrity requires a different mindset among agronomists and farmers who would like to maximally exploit land and water resources to achieve food security and conservationists who would like create preserves of biodiversity.

Most research so far on the assessing the potential and value of ecosystems services provided by irrigation is limited to paddy rice fields. Also little is known yet on best practices in agricultural water management to enhance ecosystems services while at the same time produce sufficient food.

4. Challenges and approaches to sharing water

Water management has come a long way in terms of identifying integrated water resources management approaches as the guiding principle to coordinate efforts in the development and management of water, land and other related resources. When governments, businesses and related entities implement IWRM with proper institutional measures, structures, and capacity, an optimal overall resource management can be ensured. There are very good examples of this around the world and in multiple sectors. However, the implementation of IWRM is still far behind its acceptance as the norm.

The state, use and management of water resources are heavily impacted by externalities such as drivers of change for water; and decisions and actions taken in other sectors. As ‘water sharing between sectors’ is not a straight-forward, mechanical process, the collective outcome of water’s externalities is that the level of challenge is elevated from one of making decisions within the ‘water box’ to dealing with the mechanisms through which the above work, and the mechanisms that address these.

Drivers include demographics, economic development, technological change, climate change and social/cultural factors. Decisions and actions taken in sectors and for issues such as food, energy, security, environment, shelter, health, poverty, trade, manufacturing etc impact the quantity, quality and distribution of water resources; the demand for water; and how water services are shaped and operated. Many of the above not only impact water resources but also have implications on one another. They also play a role in shaping social behavior as well as political and community priorities.

Water managers are seldom a part of these mechanisms and often have very little input while the individual and aggregated outcomes of these externalities constrain their decision space, which is further complicated by the need to manage risks, trade-offs and synergies. It is therefore imperative that the water managers, with the help of professionals, scientists and others from within the water domain, have the best available information and tools not only to allocate water, but also to understand the impacts and interactions within the broader spectrum. They have to inform those in the other sectors and domains who are taking the decisions and implementing them. Those who are making these decisions and implementing them should be aware that ignoring water can seriously jeopardize the availability and the quality of the water that they need; seriously decrease the profitability of their operation; compromise public health; and lead to unintended, adverse consequences.

While the recent nexus discussions indicate a positive change and a shift from recognition of a fact towards addressing it, much remains to be done. It is therefore imperative to address the challenges of collaboration across sectors. As water is cross-cutting to all aspects of social and economic life, each time a 'boundary' is crossed, challenges involved change. In many cases the governance structures are incompatible and/or impervious to coordination. In other cases, costing and pricing mechanisms differ greatly; while in many sectors, the demand/supply linkages and relations between sectors can be markedly detached.

The acceleration in the drivers as well as the recent global issues of concern (such as the global economic crisis, climate change, urban development, environmental degradation, food crises, water-related disasters) makes this an issue of urgent, global significance. All involved, from individuals to corporations, and governments to civil society, should make collaboration across sectors a priority and adapt themselves and the structures they control/work within to this challenge.

5. Concluding remarks

Water and land management decisions often involve trade-offs. Agricultural production needs to be expanded to feed a growing and increasingly rich and urban population. This implies that water in agriculture, and other sectors such as industry, domestic and tourism, needs to be used much more efficiently and productively. In water stressed regions, demands from water for food security and water for energy need to be balanced. Both demand and supply management plays a role. Harvesting rainwater at different scales (roofs, microcatchment and macrocatchment), artificial recharge to aquifer, cloud water harvesting, underground dams, are few of many examples to increase water supplies. Policies on water allowing the use of poor quality water in agriculture, in cooling power generation towers and allowing farmers to abstract and store water from rivers during high flows contribute to reducing the pressure on freshwater resources. Changing cropping patterns to less water demanding crops or varieties and more efficient irrigation systems help in using the limited fresh water resources more efficiently. In some areas new water resources need to be developed while ensuring that ecosystems continue to provide environmental services.

On the other hand, environmental concerns over overexploitation and poor management of water resources are growing. Loss of vital ecosystems services in some areas may threaten the sustainability of the land and water resource base on which agriculture depends. Approaches to water management that integrate the provision of food, energy and other ecosystem services are essential to balance the multiple demands on increasingly scarce resources. These approaches require breaking disciplinary boundaries and encouraging greater cooperation from planning to implementation.

There are several examples where water management for food production significantly contributes to the enhancement or restoration of ecosystems services. These examples show that the economic value of ecosystems benefits is generally high, sometimes exceeding the value of agricultural products. Most of these examples come from irrigated paddy areas. Little is known about the possible environmental benefits in other irrigated areas. Further these benefits are often unintended by-products. The question remains on how to actively manage water for both food production and environmental benefits and what incentives could be implemented to ensure the right balance.

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