Facing Climate Change by Securing Water for Food, Livelihoods and Ecosystems

C de Fraiture, V Smakhtin, D Bossio, P McCornick, C Hoanh , A Noble, D Molden, F Gichuki, M Giordano,

M Finlayson and H Turral

International Water Management Institute (IWMI)
PO Box 2075
Colombo, Sri Lanka

Abstract

Future changes in water availability due to climate change (CC) are of paramount importance for food security of millions of rural people worldwide. Many recent extremes of water shortage followed by devastating floods reflect some of the climate change predictions, which are gradually becoming more certain and alarming. Appropriate measures in agricultural water management can greatly reduce poor people's vulnerability to CC by reducing water related risks and creating buffers against often unforeseen changes in precipitation and water availability. An appropriate water research agenda is essential to improve our knowledge of the linkages between water, food and CC and guide the right investments aimed at improving resilience of farming communities and food security. This agenda includes understanding the adaptation and mitigation roles of agricultural practices and water resources management options, characterization of climate change impacts at different scales, and evaluation of water implications of direct climate change mitigation interventions. This agenda will result in strategies that contribute to reduced risk and enhanced resilience of agricultural systems. Building on its research capital in the water, food and livelihood nexus, IWMI is in a good position to help formulate and implement this agenda.

1. Introduction

Climate change (CC) caused by excessive CO_2 emissions (IPCC 2007) will have a profound impact on the natural resources base that agriculture depends upon. Changes in the dynamics of water play a vital role in CC impacts on agricultural livelihoods. Climate models generally foresee an increase of global average precipitation, though the spatial patterns of changes are still debated (Alcamo et al. 2005). Projections point to a strengthening of the summer monsoon. In Asia this might increase rainfall by 10%–20%, but also generate a dramatic increase in inter-year variability (WWF 2005). Arid and semi-arid areas, including the Middle East, parts of China, southern Europe, northeastern Brazil, and west of the Andes in Latin America might become drier. The absolute amount of rainfall in Africa may decline while variability increases dramatically. Annual average river runoff is projected to increase by 10-40% in high latitudes, but decrease by 10-30% in some dry regions at mid latitudes and in the dry tropics (e.g. Milly et al 2005), many of the same areas that are already facing water shortages (CA 2007). CC alters precipitation and river flow seasonality, accelerates glacial melt affecting a large group of countries in Asia and Latin America, disrupts the monsoon pattern leading to fewer days with rain and may lead to longer droughts and more extreme floods.

The CC *impacts on water* –through rainfall, snowfall, soil moisture, riverflow and groundwater recharge- directly translate into *impacts on food, livelihoods and ecosystems*. With a growing population, rising incomes and changing diets, food demand will double over the next 50-80 years - the time-frame when most of the CC impact will be felt. 60 to 90% more water will be consumed by agriculture in the future to meet this demand (Fraiture et al. 2007). This is of great concern given that already 20% of the world's population lives in areas where agriculture is affected by water scarcity (Molden et al. 2007) that will be exacerbate by CC.

Globally there are some 850 million undernourished people, the majority depending on rainfed agriculture for their livelihoods and a disproportional number living in arid and semi-arid areas (Rockstrom et al. 2007). Over 60% of the world's food is produced under rainfed conditions. In sub-Saharan Africa (SSA) where climate variability already limits agricultural production (Thornton et al., 2006), this percentage is 95%. CC induced changes in river flow and groundwater will affect water availability for irrigation, the backbone of the rural economy in South Asia where millions of smallholders depend on irrigated agriculture.

Changes in precipitation, river flow patterns and groundwater availability are highly uncertain, and yet are of paramount importance for food security of millions of rural people. CC points to the new challenges for the water and agriculture sectors but also reveals our limited understanding of changes and how to react to them. Using IWMI's and others' research experience we explore known and possible linkages between CC and agricultural water (section 2) and identify promising approaches in water management (section 3). Based on observed knowledge gaps we propose a research agenda (section 4). Because of its extensive research experience in the water, food and livelihood nexus, including understanding the impact of climate variability, IWMI is in a fortuitous position to help formulate and implement this agenda.

2. Climate change and agricultural water linkages

Agriculture consumes more than 3000 liters of water per person per day to meet food demand (Molden et al 2007). Nearly 80% of this water is directly met by rainfall; 20% is diverted from rivers, lakes and groundwater. 60% of all agricultural production comes from rainfed land, while 40% comes from irrigated areas. Besides quantity, quality and the timing of water supply through rain or irrigation is equally important. Crops subjected to water stress, particularly during the flowering period can have greatly reduced harvests.

2.1 Rainfed agriculture

The expected effects of CC on rainfed agriculture vary by area. In arid and semi-arid areas the absolute amount of rain is expected to decrease but variability will likely increase substantially. This may lead to more short term droughts and loss of crops, and further limit crop choice. Changes in rainfall patterns already affect subsistence farming, particularly in sub-Saharan Africa. For example, over the past 50 years in the Makanya catchment of Tanzania, short term droughts, or long dry-spells, have increased in frequency during the long rainy season, while the total amount of precipitation has remained stable. Dry-spells of 21 days or longer occurred in 42% of the rainy seasons between 1957 – 1980, but in 79% of the rainy seasons between 1981-2004. The long dry-spells often occurring late in the season lead to severe yield reductions and adverse impacts on poor people's livelihoods (Enfors and Gordon, 2007; Gordon and Enfors, in press).

In monsoon areas the amount and intensity of rain is projected to increase. Flooding in paddy areas may increase which may prove to be beneficial because of increased water supply and fertile silt deposits. Yet, severe flooding may damage crops and rural infrastructure, and in extreme cases may lead to loss of life. In Cambodia losses in the 2000 flood were US$ 157 million, and 362 people died. The flood in 2001 killed 62 people and the total estimated losses were US$ 36 million. Again, in 2002, floods hit the Mekong Delta countries and for Cambodia alone, it killed 29 people and the total extent of damage was over US$ 12 million (MAO, 2005). Increased inter-annual rainfall variability whether resulting in droughts or floods will lead to high fluctuations in agricultural production and hence farmers' income. Poor farmers might not have the (economic) buffer to cope with smaller harvests in bad rainfall years.

2.2 Irrigated agriculture

CC induced changes in hydrology directly affects irrigated agriculture. Many irrigation schemes, particularly the smaller village level ones, divert water directly from streams and rivers without water storage facilities. These so-called run-of-the-river schemes are particularly vulnerable to changes in river flow ---in quantity and timing (Faures et al., 2007) Changes in rainfall quantities and intensity will affect natural groundwater recharge and therefore the millions of smallholders depending on the groundwater economy in South Asia (Shah 2007). Melting of glaciers that feed major rivers that are used for irrigation could affect millions of hectares of irrigated land on the Indo-Gangetic plain. Millions of cubic meters of water are stored during the winter months in the form of snow pack and ice and gradually released as melting water in spring. The warmer spring weather coincides with the start of the growing season. The faster melting of the snow pack in the spring and the recession of the glaciers may change this flow regime, and without additional storage much water will flow unused to the ocean, leading to water scarcity in the drier months (Barnett et al. 2005; Wescoat 1991; Rees and Collins 2004; Dinar et al. 1998).

Where absolute water quantities decrease farmers may have to give up part of their irrigated area, or reduce the number of crops in the dry season, as is now done under drought conditions (Gaur et al 2007). At the same time water demands from the non-agricultural sectors will increases substantially thus intensifying competition between agriculture and the domestic and industrial sectors (Fraiture et al 2007). As has been the case to date, agriculture in many situations will be the sector which has to respond to the changes in water supply, both in terms of quantity and quality (Molle and Berkhoff, 2006).

Predicted temperature increases might lead to reductions in crop yields, particularly in C4 crops. But these losses might be offset by increases in yields as atmospheric CO_2 acts as 'fertilizer'. The combined effect of temperature rise and CO_2 enhancement could be positive or negative, and impacts vary among crops (Parry et al 1999, Alcamo et al 2005). Farmers might be able to adapt to temperature increases by changing planting dates, using different varieties, or switching to different crops (Droogers and Aerts 2005). With rises in temperature crop evaporation will probably increase, but overall impacts on water productivity –and hence net irrigation requirements- are largely unknown.

2.3 Wetlands

Increased water for agricultural purposes and CC induced hydrologic changes may have profound -but largely unknown- impacts on freshwater ecosystems. Many people directly depend on wetlands, lakes and rivers for their livelihoods, For instance, people in Cambodia get 60-80% of their animal protein from fisheries in the floodplains (Millennium Ecosystem Assessment, 2005). Seasonal flooding and recession agriculture provide livelihoods to people living in valley bottoms (*bas-fonds*) and inland deltas in West-Africa. Wetlands also provide important ecosystem services that are essential to sustain agriculture downstream (such as flood retention, low flow regulation, groundwater recharge and water purification). Changes in wetlands and provision of ecosystem services directly affect those who depend on them, particularly poor people who often do not have an alternative source of income (Falkenmark et al. 2007).

In addition wetlands themselves are crucial to climate stability. The resilience of some of them to adjust to change is likely to be exceeded during this century if warming continues. Although covering only some 4% of the world's land area, wet peatlands, for example, are estimated to hold 30% of the global soil carbon and their draining for agricultural purposes releases this carbon escalating CC (Hooijer et al. forthcoming).

2.4 Water implications of CC mitigation measures

Many CC mitigation measures have –often unforeseen- water implications. Biofuels, promoted because they are nearly carbon neutral, in comparison to fossil fuels, could add to pressure on water resources in areas where water is already scarce (Fraiture et al. forthcoming). For example, China and India have ambitious plans to boost biofuel production. However, given the already over-exploited surface and groundwater resources it is unlikely that both countries can expand the irrigated production of maize and sugarcane for ethanol production without affecting sustainable water use and food crop production.

The Clean Development Mechanism (CDM) – the "carbon sink" provisions of the UN Framework Convention on Climate Change's Kyoto Protocol- promotes conversion of large land areas to forestry. Reforestation leads to the redistribution of water use through increased evaporation and reduced runoff. Using global datasets and Kyoto Protocol rules to simulate CDM-related changes in land-use and impacts on water resources, Zomer et al (2006) conclude that while global impacts on water use are currently limited, local impacts on water use can be substantial. The simulated decrease in runoff varied from 0 to 100% depending on local climate and current land use patterns. Globally the importance of water use for carbon sequestration will increase if, and when, the Kyoto Protocol increases the cap on carbon sink provisions (Zomer et al 2006).

Major uncertainties regarding the linkages between agricultural water, rural livelihoods and CC remain. Scenarios on GHG emissions and temperature are well described (IPCC 2007) but how these translate into precipitation and runoff patterns is less well established. Most climate change impacts are modeled for the global and the regional scale while CC consequences at the basin, catchment or farm scales are still largely unknown. Yet, with already unfolding changes in climate, further fundamental research on these issues should go hand-in-hand with action-oriented research aimed at improving farmers' ability to cope with unforeseen changes.

3. Building resilience through better management of water resources

Improved management of water resources will be a requirement in adapting to present and future climate variability. The main premise of previous IWMI research has been that by better understanding and coping with *existing* climate variability, society will develop resilience to CC[1]. Wise water management can increase productivity, create higher rural incomes and smooth out water supply shocks, thus reducing fluctuations in production and associated risks. Improved water management is an appropriate way to reduce poor people's vulnerability by reducing water related risks and creating buffers against often unforeseen changes in precipitation and water availability.

3.1 Rethinking water storage

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 hence risks). IWMI's research provides many examples of proven ways to store water through small individual farm ponds, small reservoirs (Liebe et al. 2007) all the way to large reservoirs serving millions of hectares (Gaur et al. 2007. Groundwater irrigation using water stored in aquifers from natural recharge from rainfall and water bodies, can be enhanced through artificial recharge (Shah et al. 2007). Measures to improve rainfed agriculture, such as water harvesting and soil water conservation capture and store water in fields and in the soil. These measures - where possible and necessary combined with supplementary irrigation- can double or even quadruple productivity in drought-prone tropical regions. (Rockstrom et al. 2007, Rockstrom et al. 2003, Sharma, 2007). Small reservoirs, providing water for domestic use, livestock watering and small-scale irrigation allow livelihoods of rural households to be diversified increasing social resilience (Liebe et al, 2007). Water can also be stored as 'virtual water', by storing food. The Comprehensive Assessment on Water Management in Agriculture emphasized the need to consider water in agriculture at all scales from rainfed systems through to the large irrigation systems (CA 2007).

There is a renewed interest in large scale water infrastructure in the developing world with significant investments in fast developing economies (such as China and India) and in sub-Saharan Africa, where there has been a general underinvestment in water related infrastructure (Faures et al 2007; World Bank, 2006). Because of

[1] http://unfccc.int/files/adaptation/sbsta_agenda_item_adaptation/application/pdf/iwmi_cc.pdf.

uncertainties in CC predictions, storage options need to be able to function under a range of CC scenarios. However, many of these on-going and planned developments insufficiently allow for present and future climate variability (Smakhtin et al. 2007). In some cases the expansion of large scale irrigation –the very purpose for which the dams are built- may result in maladaptation, when water storage designs create dependencies and expectations of reliability that cannot be met in the face of CC (Amerasinghe et al, forthcoming). Large scale storage without institutions and policies that safeguard benefits to the rural poor may lead to increased inequity. Processes of storage creation and enhancement directly influence entitlements, organizational arrangements and benefits. For example, rainwater is freely accessible to all, but once it is captured in a village reservoir only those with entitlements can access it. Entitlements can be earned for example by investing labor but there are many other mechanisms that vary widely. Water harvesting and groundwater wells tend to be privately owned and managed. Surface irrigation often requires organization at a higher level. Design parameters and organizational arrangements during construction often determine who benefits and who loses out (Hussain, 2005). It is therefore essential to take a much broader perspective on “water storage” in the context of adaptation to CC. Strategies to improve livelihoods and enhance the resilience of the rural poor vulnerable to CC should thus *include the increased capacity to store water, and diversity of storage types,* considering the full range of storage alternatives, and the processes in which they are created. Every type of storage has its own niche in terms of impact and management considerations, but when considered within the context of a basin or a sub-basin, they can collectively contribute to the overall water security of the population.

It is also imperative that we better manage (or manage differently) the water infrastructure that has already been developed. This includes estimating, implementing and monitoring the environmental flows, which are rising high on the agenda.

3.2 Increasing water and land productivity

Improvement of land and water productivity is important both as a CC adaptation and mitigation strategy. Improving water productivity by deriving more value from water through higher yields, crop diversification, integrating livestock and fisheries is an important means to improve rural incomes, alleviate poverty and reduce risks by diversifying income sources (Castillo et al. 2007, Molden et al 2007). Marginal subsistence farm families are least able to cope with climate variability and uncertainties. At the basin level water scarcity is likely to increase in many parts of the world as a result of CC. Improved land and water productivity is the key to reducing future water requirements and should be seen as a CC adaptation measure.

Land and soil degradation are a major constraint to increasing water productivity on much of the world's arable lands (Bossio et al, 2007). The needed productivity increases will have to be achieved through enhancing current production systems, most of which have undergone varying degrees of degradation (Scherr, 2000). Land degradation has resulted in reduced biomass and soil carbon, thus contributing to GHG emissions, while climate change exacerbates land degradation, thus forming a negative feedback loop (Bellamy et al., 2005). Fortunately inexpensive measures exist that enhance water productivity of both irrigated and rainfed systems, increase carbon sequestration, promote diversification of farming systems, and enhance livelihoods (Kishiev et al., 2005; Lesturgez, et al., 2004; Noble et al., 2007; Hartmann et al., 2007). Soil amendments and farming practices to enhance the productivity of rainfed production systems have resulted in dramatic increases in water productivity, increased soil water and nutrient holding capacity and notable declines in sediment discharge to water bodies (Suzuki et al., 2007; Soda et al., 2006; Noble and Suzuki, 2005; Noble et al., 2004; Valentin et al., 2007). An assessment of 286 simple on-farm interventions in 57 poor countries covering 37 M ha have resulted in increased productivity on 12.6 M farms while improving the supply of critical environmental services (Pretty et al., 2006). It is estimated that with these simple interventions there was derived a potential average carbon sequestration value of 0.35 t C ha^{-1} y^{-1} along with improvements in water productivity averaging 15 to 30% in irrigated systems and 70 to 100% in rainfed systems (Pretty et al. 2006). Diversification and integration of resources on farm is feasible in both economic and ecological terms whilst delivering higher levels of resilience (Tipraqsa et al., 2007; Bossio et al, under review). Curbing land degradation through land and water conservation techniques thus improves people's ability to cope with CC and also may help mitigate rising atmospheric CO_2 levels.

With rising incomes demand for livestock and fish products will increase (CA 2007). Since the production of livestock products generally consumes more water than that of vegetative products, this has important implications for water. The productivity of livestock and inland fisheries can be improved through an integration of the multiple uses of irrigation water (Peden 2007, Dugan et al. 2007). For example, by managing fish stocks in irrigated rice systems, rice yields (due to weed control and the aeration of soils) increased by some 10% while producing up to

1,500 kg/ha of fish, as compared to 120-300 kg/ha in unmanaged systems (de la Cruz 1994; Halwart and Gupta 2004). Feed sourcing strategies for livestock can make a large difference in the amount of water required in the livestock production system (Peden et al. 2007). Integrated crop production, fisheries and livestock systems thus improve the ability to adapt to CC by improving and diversifying rural incomes.

At the global scale improved productivity helps reduce GHG emissions by curbing the need to convert land for agricultural purposes. At present 18% of all GHG emissions originate from land use changes (mainly deforestation); agriculture contributes 14%. Much of the land conversions has taken place in response to greater demand for agricultural products. Particularly the draining and conversion to agriculture of forests and peatlands releases large quantities of carbon, contributing to CC (Hooijer et al. forthcoming). Scenario analysis for the Comprehensive Assessment shows that improved productivity through better water management can reduce the need for additional agricultural land by 85% by 2050 (Fraiture et al 2007). Reservoirs, paddy fields and intensive livestock are important agricultural related emitters of methane. Identification of water management options to reduce these emissions contribute to CC mitigation.

3.3 Basin water management and allocation

A key issue in water management and allocation is the management of trans-boundary rivers-i.e. rivers that flow across international boundaries. Managing these rivers requires cooperation between countries, a process complicated by both flow variability and potential impacts of CC. Analyzing a range of mechanisms which nations have already successfully employed to manage existing variability in trans-boundary waters helps in deriving lessons for managing and adapting to CC (Drieschova et al., under review). This is particularly important in Africa, where transboundary rivers play a big role and potentially large water developments will take place in the coming decades. Water resource variability should be an integral part of trans-boundary water management to ensure that the adverse impacts of CC on those most vulnerable are mitigated (Giordano and Lautze, 2007). Climate change is likely to exacerbate water conflicts associated with flood and droughts. Benefit sharing mechanisms can enhance cooperation among riparian states and thereby facilitate more effective basin wide plans for mitigation and adaptation to climate change.

Current and future inter- and intra-basin water transfers often insufficiently incorporate climate variability and CC. Planning water transfers without taking adequate consideration of the likely impacts of climate change can reduce the performance of such major investments. For example, the research on river-linking in India has highlighted the importance of taking a long-term perspective which is currently constrained by future uncertainties and lack of tools and data for better prediction (Amarasinghe et al, 2007).

Scenario modeling assists in exploring and analyzing CC related uncertainties in transboundary and inter- and intra-basin transfers. For example, various adaptation strategies to CC have been examined in case studies (Aerts, J. and P. Droogers, 2004) in seven contrasting river basins: Rhine (Western Europe), Sacramento, Syr Darya (Central Asia), Volta (West Africa), Mekong (East Asia), Walawe (Sri Lanka) and Zayandeh (Iran). Combining downscaled GCM outputs of global IPCC climate change scenarios, water simulation models and a generic methodology to quantify food and environmentally related impacts, the project concluded that without adaptation, climate change and climate variability will have a profound impact on water resources across the basins studied. Based on the results from these scenarios stakeholders are able to develop and evaluate different adaptation strategies. IWMI continues working with the Mekong River Commission (MRC) to incorporate IPCC CC scenarios into the MRC basin development scenarios and analyze the impacts on the Mekong river flow. Application of river basin modeling tools such as remote sensing, Soil Water Atmosphere Plant (SWAP) model (Droogers and Bastiaanssen 2002) and the Water Evaluation And Planning (WEAP) model (Arranz and McCartney 2007) have proven useful to assist scenario development, particularly for assessing impacts of land and water use changes and of climate change on water, agriculture and environment.

Adjustments in allocation in response to existing climate variability provide insights in adaptation strategies to cope with CC induced reductions in water supplies. In the Gediz basin in Turkey water allocation rules were substantially changed after a major drought in the early 90s (Svendsen et al. 2001.) In another example from central China, farmers have adjusted to changes in water allocation to the Zhanghe Irrigation System by storing rainfall, shifting the water management approach from a large traditional canal system to one that is dependent on a network of small distributed reservoirs. These adaptations were necessary as the irrigation water was reallocated out of agriculture to serve higher-value users: hydropower, cities and industries (Roost, pers. comm.) Farmers in many countries will have to make these adjustments as water availability changes. Examples show that these adaptations already take place where the knowledge and management capacity amongst stakeholders exist.

3.4 Early warning systems, drought/flood insurance

Adaptation research closely links with identification of institutional frameworks required to support effective development and use of water, options to build ecosystem resilience to support long term agriculture and options to build societal resilience in response to CC (such as drought early warning systems, insurance schemes and the transition of some people out of farming).

Drought is a major impediment to development of rural livelihoods, which impacts millions of people in Africa, Asia and Latin America. The world trend is to move away from 'drought response' (reactive approach, focusing primarily on drought relief after it has happened) to drought risk mitigation (pro-active approach, when anti-drought actions are taken in advance). Nonetheless, the reactive approach still dominates most of the developing world. This, if not changed, will adversely affect the ability of many developing countries to adapt to CC. Recent drought research at IWMI identified technical, institutional and policy gaps which exist in India, Pakistan and Afghanistan in drought preparedness and addressed a variety of technical and social issues, including developing a remote sensing data base, regional drought monitoring system, analysis of drought frequency and magnitude using precipitation time series, and analysis of vulnerability of rural population to drought (Smakhtin and Hughes 2007). This is now being followed by further developments in drought monitoring, quantification of low river flows in Iran, and global mapping of drought-related indicators[2]. These products have direct relevance to all those areas which will suffer from CC-induced increased drought duration and frequency, and may help design appropriate institutional responses such as drought insurance schemes.

An often neglected link is health impacts of CC through water-borne diseases. Development of, for example, malaria risk maps and early warning tools that may be able to predict, the impacts of CC on malaria hazard (Briet et al., 2005) are additional tools that will be available to help support societal adaptation to CC.

[2] http://www.iwmi.cgiar.org/drw/

In the future, CC will further increase river flow variability and the associated magnitude and probability of both low- and high-flow events which often, even in present day conditions, fall outside the bounds of existing institutional designs, and are therefore not properly managed. These hydrological shocks, which in many developing countries are already occurring with increasing frequency, not only impact the local population during the event, but have also long-lasting impacts on the economy and livelihoods (WB 2006). Establishing targeted safety nets for farmers who are unable to adjust quickly enough, providing credible insurance against catastrophic asset losses and facilitating rapid recovery will all be crucial, given the expected CC impacts.

3.5 Changes in crop and land use patterns

Better understanding of CC impacts also includes assessment of the impacts of shifting agricultural production patterns on food and trade. CC may render parts of the world less / more suitable for agriculture and shifts in major production areas will occur. The implications of these shifts for investments in water infrastructure and agricultural water management need to be understood and they may not necessarily be negative. The use of GCM outputs and downscaling approaches to define areas which will become more suitable for agriculture or hydropower, for example and at what time horizons (e.g. 2050 or 2100) can lead to identification of "winners and losers" at global, regional and most importantly - national and basin scales.

Recent scenarios developed by IWMI through Comprehensive Assessment, using the WATERSIM model (CA 2007) are already used to inform decision makers on various factors impacting water availability and water use such as increased population growth, changing diets, trade agreements and biofuels. Linking GCM with spatial predictions on future food production requirements and water use, assessing what the impact of climate variability (in particular droughts and floods) could be on water availability and hence food production and poverty alleviation, will provide a better assessment of CC-related problem areas. The challenge will be to make this information meaningful and complement it by assessments of economic costs and benefits in the future.

Global spatial databases, including for example, the IWMI World Water and Climate Atlas (http://www.iwmi.cgiar.org/WAtlas/ that provide information on climate and moisture availability for agriculture, are of direct relevance to CC researchers, planners and those carrying out adaptation activities. IWMI's global irrigated area and rainfed maps http://www.iwmigiam.org/info/main/index.asp provide similar tools for understanding how CC will differentially impact food production across the globe and can also be used for assessment of CC mitigation through cropland management (Thenkabail et al. 2006, 2007).

4. Towards a new research agenda

CC points to new challenges for the water and agriculture sectors on one hand and reveals our limited understanding on the other. This challenge creates a great need for pro-active research in the years to come. Since water scarcity and variability are very likely to increase in many parts of the world, improved water productivity, water scarcity mitigation and enhancement of human capacity to adapt are the keys to meeting CC-induced changes. Meeting these new water challenges also requires accurate quantification of the likely CC alterations to water systems themselves. In addition, it is critical to understand the water implications (sometimes severe and often not highlighted in policy discussions) of CC mitigation efforts aimed outside the water sector. CC mitigation and adaptation measures go hand in hand and each is likely to have, often unexpected, water implications. Finally, many CC impacts are predicted to be most severe in developing and emerging economies, and this is where resources are most limited and future research efforts should focus there if poverty eradication is to progress.

The above considerations point to new dimensions of the water research agenda which are essential to guide the right investments aimed at improving resilience of the water sector, farming communities and agro-ecosystems to CC. We identify four areas of inter-related research issues:

1. ***What are the most promising measures in water management to minimize small farmers' vulnerability to climate change in different regions? What are the implications of these measures for the environment? What are the enabling conditions?***

Existing IWMI studies provide examples how small farmers, vulnerable to climate risks adapt to existing climate variability. Yet, a systematic inventory and comprehensive assessment of different climate variability related coping strategies of land and water management, ranging from soil moisture storage in rainfed systems through to large dams and irrigation schemes –now lacking- would help identify promising water management techniques and provide insights in what works where. A research challenge is to extrapolate observed responses to more extreme climate events due to CC and identify breaking points.

2. ***What water related investments are needed, where, to increase poor people's resilience to climate shocks? Is more storage and inter- and intra-basin water transfer needed? If so, in what form? What are the implications of these measures for the environment? Who should invest where, when and why?***

Water storage will often top the agenda of nations and international development banks when considering climate change risk mitigation strategies. However, tools and methods currently used are usually inadequate to allow fully informed decision making. In particular understanding of environmental impacts, and long term feasibility of larger scale interventions needs urgent attention.

3. What are the impacts of CC on water at farm and river basin scales? How will these changes impact local livelihoods? What are the water implications of proposed climate mitigation policies and measures?

Existing climate models quantifying IPCC scenarios result in predictions that remain too general for practical decision making. The spatial scale of existing GCMs and their number leave predictions of effects of CC at farm and basin level very uncertain. The issue is therefore to design ways of downscaling these predictions to the level of basins and communities. An important methodological aspect is the prediction of flow and extreme events in ungauged basins (i.e. where no flow records exist, as is the case in most of the world). If climate changes – conventional hydrological techniques, which are all based on stationary hydrometeorological time series, may no longer be suitable. The entire world effectively becomes even more 'ungauged' than now.

A further research challenge is to translate these downscaled climate predictions into impacts on rural livelihoods, in terms of increased vulnerability to risks due to climate variability and extremes. The crosscutting issue in understanding the CC impacts is the issue of tipping points, i.e. how severe the impact (and associated crisis or benefit) should be to trigger policy changes. Some developing countries at present heavily reliant on foreign food aid (e.g. Ethiopia) from the developed world. If CC forces food providers to stop this and use resources internally this will become a major issue for developing world, which will have to rely more on its own resources. Similar issues may arise at national scales. The expectations of some Indian States hit by a drought – to receive support from the Federal government may fail under future CC and they may be forced to design and implement drought mitigation plans – something which is long overdue. These policy "time bombs" of climate change need to be identified, there probability – anticipated and proactive measures – put forward.

4. What are the water implication of CC mitigation strategies, such as biofuels, CDM and reforestation?

Mitigation measures in various sectors could adversely affect water availability and use. These impacts should be identified, quantified and taken into account to avoid unnecessary euphoria at present and disappointment in the future. For example, replacing fossil fuels with biofuels may take as much land and water as currently used for all food production. Planting trees (as part of the CDP process), which use water, changes watershed water balances and river flow regimes and can make direct CC-induced changes in flow regimes even more pronounced and/ or accelerated. Overall there seems to a lack of integrated assessments of the impacts of CC on runoff quantity and quality, biodiversity, water pricing, trading policies at the basin, national and regional scales - which are essential for informed adaptation to CC.

Conclusions

Future changes in water availability due to climate change are of paramount importance for the food security of millions of rural people worldwide. Appropriate measures in agricultural water management can greatly reduce poor people's vulnerability to CC by reducing water related risks and creating buffers against often unforeseen changes in precipitation and water availability. This paper provided an overview of the linkages of CC and water in irrigated and rainfed agriculture and wetlands. It explored water management options to build resilience of farmers vulnerable to changes in rainfall and water supply. CC points to the new challenges for the water and agriculture sectors on one hand and reveals our limited understanding on the other. This challenge creates a great need for pro-active research in the years to come. An appropriate water research agenda is essential to guide the right investments aimed at improving resilience of farming communities and food security. This agenda will result in strategies that contribute to reduced risk and enhanced resilience of agricultural systems. Because of its extensive research experience in the water, food and livelihood nexus, IWMI and its partner CGIAR sister centers are in a good position to help formulate and implement this agenda.

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