Chapter 12
Joint Management of Water Resources in Response to Climate Change Disruptions

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Abstract Climate change has a profound impact on the water cycle, causing gradual and sometimes marked changes in hydrosystems and natural hydrological processes. Societies and stakeholders are striving to adapt so as to manage and control their interactions with water. Current scenarios indicate, however, an acceleration in global climate change processes, yet with high local variability. In this chapter we present a selection of climate change related research studies focused on three major issues in the field of water resource management: characterizing change patterns, adapting to change via technological innovations and adapting governance to cope with change. These studies were carried out in partnership primarily with institutions in developing countries, with the full participation of local stakeholders in defining and running the projects and disseminating the results.

12.1 Water Cycle and Climate Change—The Issues

The water cycle is clearly the global biophysical process most affected by atmospheric temperature changes (modified evaporation, evapotranspiration and rainfall regimes, cryosphere melting). The forms, expressions and trends in this cycle are readily perceptible as they involve the atmosphere, oceans, terrestrial and aquatic ecosystems, as well as all living organisms. Significant changes in rainfall and

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Fig. 12.1 Irrigated rice cropping in Majes Valley, Peru (© B. Locatelli/CIRAD)

surface water flow volumes, sequences, durations, forms and intensities, as well as in inland and marine water quality, represent the bulk of the direct and indirect impacts of climate change on water resources.

Climate change therefore induces gradual and sometimes marked changes in hydrosystems and natural hydrological processes. It also disrupts water-dependent manmade systems such as livestock farming, rainfed and irrigated agriculture. Water and aquatic environments, as well as their users, are highly dependent on climate patterns: water resource availability and quality, spatiotemporal variability, extent of needs, especially agricultural. In return, irrigated agricultural activities, especially in submersion conditions, contribute substantially to the emission of methane, a powerful greenhouse gas (Fig. 12.1). It is hence estimated that irrigated rice crops emit 9–13 % of anthropogenic methane (IPCC 2014).

Societies and stakeholders strive to adapt to these interrelationships, in line with the intrinsic variability in these processes to which they are accustomed. This enables them to manage and control their interactions with water by altering flows via adjustments in their land use patterns or mobility. Current scenarios indicate, however, an acceleration in the intensity of this variability. Substantial scientific and lay skills, knowledge and know-how concerning practices, especially agricultural production and resource management practices, have turned out to be less relevant or insufficient to address these changes and should therefore be updated or revised.

In this change and uncertainty setting, we present a selection of climate change related research studies focused on three major issues in the field of water resource management:

- characterizing change, to gain further insight into modifications in natural and manmade systems induced by climate change, to model the short- and long-term impacts and risks, and to represent the interweaving of climate change with other socioeconomic, institutional and political changes under way;
- proposing technical solutions to support stakeholders in adapting their practices in order to achieve greater resilience to risks and identify technical solutions to cope with change;
- adaptation of governance to cope with change, to take emerging questions on water management and usage within territories into account.

12.2 Characterizing Change

The first major issue is to characterize change processes under way. A first series of studies focused on water resource availability, including characterization of the role of climate change in altering rainfall patterns. Regarding the current trend in the monsoon regime in Southeast Asia, for instance (Singhrattna et al. 2009), this weather pattern occurs later, while being more erratic and of harsher intensity. The development and combination of statistical climatic and mechanistic hydrological models confirmed that regional temperatures in the China Sea are robust predictors (at 1–4 months) of pre-monsoon rainfall and (at 6–12 months) of monsoon and dry season rainfall on a catchment scale in Thailand. The use of these predictors (by downscaling) paves the way for medium-term rainfall forecasting and management of related risks (floods and droughts).

This change in rainfall regimes may be perceived in different ways depending on the season and land-use pattern. Trends in the Sahel indicate that a decline in rainfall could result in an increase in flood peaks over a shorter period (Mahé et al. 2010). In addition to the increased intensity of storms, land-use changes have caused increased runoff, resulting in a faster concentration of flows along the main hydrological drainage lines. The impacts of flood recession on agriculture are greater than when only the trend is considered, indicating that increased water management is necessary. For a given production system, climate change thus leads to a change in water use conditions.

The characterization issue also applies to stakeholders through the identification of the importance of climate change relative to other global changes, i.e. all changes that occur in the context of a stakeholder's water use and for which the stakeholder has no direct control. This may involve changes in national or supranational agricultural or environmental policies, economic changes related to changing markets, demographic modifications or changes in land-use policies. Users do not always distinguish the effects of these changes in terms of their origin, e.g. the separation between signals associated with a change in energy policy resulting in closure of a dam or related to low rainfall (Box 12.1), whereas there is a causal relationship between climate change and land-use policy changes. Climate change is not always considered as the most important factor, at least in the short term. Farmers are aware of climate variability and argue that they can handle it most of the time (Faysse et al. 2014), resulting in less need for adaptation than taking other factors into account (Mertz et al. 2010). This leads to a higher response threshold (delayed reaction) for climate-related changes than for other changes.

Box 12.1. Large dams in West Africa—a climate change adaptation solution or a source of problems?

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After a long pause, in the last few years West African governments and a few donors from emerging countries have indicated their willingness to heavily reinvest in large dams to meet the pressing demand for reliable and less expensive renewable energy and the development of irrigation. The latter is considered to be one of the best climate change adaptation instruments for rural communities. These arguments and the accompanying new funding only partly explain the renewed interest in dams. There is ongoing controversy on whether large dams are actually needed, and on the different impacts of these structures in West Africa.

The West African region is especially vulnerable to climate change. The still poorly understood high climate variability appears to be especially high in this region. Rainfall and flow forecasts are highly uncertain because of the coexistence of natural cycles and climate change related trends. In the past, the production of large hydroelectric and agricultural dams revealed a high vulnerability to climate variability. Irrigated areas in West Africa are still extremely limited in size, and their economic results disappointing, but there is considerable room for improvement and development. Some forms of irrigation can also be developed without building large dams. Moreover, dams have a negative impact on traditional riparian systems, especially on forage production, wetlands and downstream riparian ecosystems. The decline in traditional irrigated systems should be offset by more efficient irrigation.

Current knowledge and acquired experience indicate that large dams are not a panacea in the adaptation to climate change in West Africa. In addition to the climate change issue and the prevailing uncertainty, hydrological regimes required for efficient power generation are seldom sufficient in this region, and the provision of cheaper renewable energy is not guaranteed. Moreover, agricultural systems irrigated with dam water are not efficient. The development of new irrigated areas should be coupled with increased irrigation efficiency and agricultural system performance.

This perception of the relative importance of climate change and of the need to adapt to it varies in different parts of the world. It seems lower in the Sahel and North Africa, but higher in Nepal (Manandhar et al. 2011). In this highly agricultural country with extremely diversified environmental conditions, associated especially with a marked elevation gradient, studies have focused on perceptions of climate-related changes and on adaptive measures taken in small family farms. The results revealed accurate perceptions, in line with trends derived from a historical meteorological data analysis (1977–2006), concerning the decrease in rainfall, the increase in temperature (minimal) or the higher frequency of droughts and floods. Farmers develop multifaceted responses to changes with regard to both cropping and farming systems (Table 12.1). They are based mostly on stakeholders' knowledge and experience (human capital) but are constrained by the general lack of other capital. Moreover, they are individualistic, empirical and sometimes inefficient, highlighting the need for better action planning, greater reliance on external knowledge and technological solutions, collective action and approaches that will boost adaptation and resilience to change.

Table 12.1 Technical solutions implemented at the farm level in two regions of Nepal in response to locally-perceived climate change (from Manhandar 2010; Manhandar et al. 2011)

Types of change and perceived risks	Lowland regions (Rupandhei district)	Highland regions (Mustang district)
Reduced rainfall	Crop diversification shift in cropping calendars Implementation of simple water and soil management/conservation techniques (e.g. small stone walls, small-scale manual supplementary irrigation)	Development of domestic water recovery/recycling techniques crop diversification
Increased occurrence of flood and drought periods	Adoption of shorter cycle or more tolerant Indian rice varieties Introduction of small-scale aquaculture in lowland flood plains crop diversification	
Increased temperature, combined with increased pest attacks or more frequent fogs		Apple orchards moved to higher plots crop diversification

12.3 Proposing Technical Solutions

The second major issue is to propose and test technical solutions to cope with climate change, or rather spatiotemporal changes in water resource availability. We investigate three options: resource regulation, mobilization of alternative resources and technological innovations in water use. Dams provide a way to store water for use in shortage periods (see Box 12.1), but they also give rise to problems for users. These may not have relevant knowledge to foresee water releases or induced potential morphological changes (Ferry et al. 2012). Dam construction also generates changes in the hydrological regime such as fisheries (Cecchi 1998) or health effects. The management of dams also raises questions because it involves collective investments that are sometimes hard to implement and manage if they are not underwritten by legitimate authorities (Faysse et al. 2010).

Alternative resources such as brackish water, wastewater and groundwater can offset the increased variability in surface freshwater. However, despite their potential (Molle et al. 2012), tapping these resources still raises questions concerning technological development and assessment of their economic interest. They may also have negative impacts on environmental quality. Regarding uses, irrigation is still a good climate change adaptation solution, especially compared to other solutions specifically focused on crops (Santikayasa et al. 2014). The development of water-efficient technology is not entirely focused on adaptation to resource scarcity, it rather addresses the question of increasing production while not increasing water use. Drip irrigation is, for instance, an emerging technology developed as a response to climate change as well as in favour of various interests (Venot et al. 2014). These technical solutions are nevertheless a continuation of adaptation expertise acquired on past variability patterns for a change of intensity that is a priori not commensurate with the expected changes. This adaptation capacity based on previous patterns may be a hindrance when considering the changes to come.

Regionally, another approach involves predicting changes in land production potential according to regional current and future climate change patterns, for planning purposes, especially for large-scale plantations, e.g. tea, rubber and coconut in Sri Lanka (Jayathilaka et al. 2012). Spatial and temporal maps of climate and production patterns are plotted using historical data and compared. Relationships between crop yields and climate data are established by hierarchical multicriteria analysis and using simple crop models. An analysis of regional climate change patterns underlined the decrease in rainfall, especially in wet areas of the island, and the increase in the average temperature trend. Six agroecological zones were identified and their spatial analysis compared for two periods (1980–1992 and 1993–2007) revealed changes in climatic conditions and the risk of production losses due to shifts in the optimal climatic zones (Fig. 12.2). The maps produced were discussed with stakeholders in the concerned sectors to help guide future plantation planning and rural development overall.

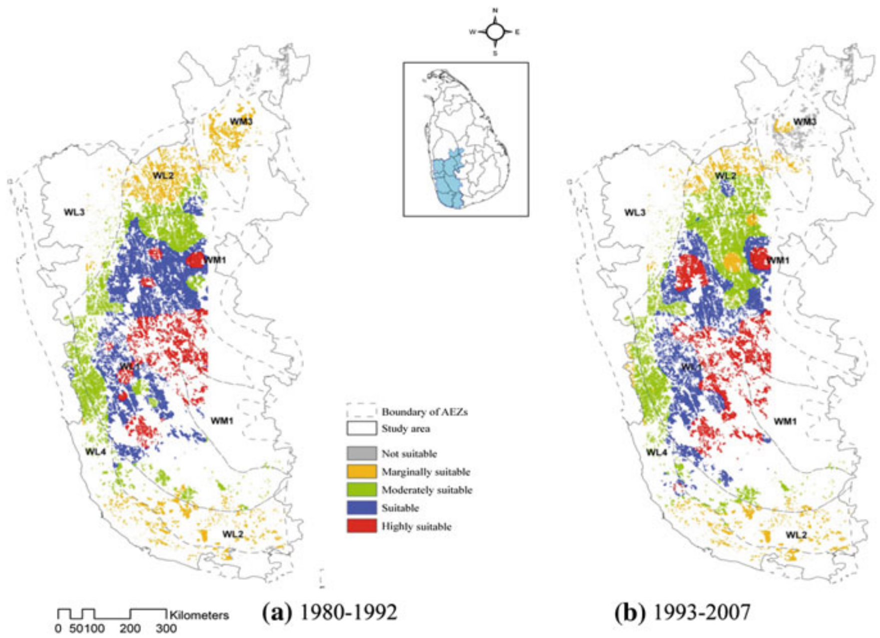

Fig. 12.2 Map showing zones suitable for tea cropping in Sri Lanka, according to climatic criteria and changes between two periods (from Jayathilaka et al. 2012). *Dotted lines* correspond to agroecological areas predefined at the beginning of the study and designated by the acronyms WL and WM, e.g. *WL1* wet area at low elevation no. 1, or *WM3* wet area at medium elevation no. 3, etc.

12.4 Adapting Governance to Cope with Change

The third major issue—an upshot of the previous issues—concerns the possibility of changes in the governance of hydrological areas. This should include non-technical adaptation solutions such as taking into account the increased migration to offset income variability (Mertz et al. 2011), the increased medium-term forecasting capacity (Diarra et al. 2013) or the economic assessment of alternative scenarios for water resource allocation in catchment basins (Hassan and Farolfi 2005). New methods are required to inform the decision making process for users and managers. The assessment of climate change impacts and adaptation options requires insight into the induced effects, particularly in terms of social justice. Although not directly related to climate change, the land-grabbing phenomenon currently affecting many poor countries is an example of the dynamics that should be monitored. Researchers, in partnership with water management stakeholders, are thus working towards developing methods and tools to facilitate the inclusion of heterogeneous viewpoints in development and adaptation choices.

The participatory modelling and simulation kit Wat-A-Game (WAG) supports all stakeholders for gaming and negotiation on water management and usage

(Fig. 12.3). Minority stakeholders are thus able to express their viewpoints on change and adaptation proposals (Ferrand et al. 2009). Its application in eastern and southern Africa has facilitated the involvement of all village communities and governments in preparing their collective development strategies (Legrand et al. 2014).

Fig. 12.3 A Wat-A-Game session in Kenya in 2014 (© N. Ferrand/IRSTEA)

12.5 Other Studies

Mitigating climate change via studies on greenhouse gas emissions by irrigated cropping systems and possible solutions, especially via irrigation water management, have also been the focus of many studies (e.g. Perret et al. 2013; Thanawong et al. 2014) which are discussed in Chap. 20 regarding environmental assessments through life cycle analysis.

Some studies have highlighted the indirect impacts of climate change on water resources. In particular, there is growing demand for alternative renewable energy resources. This demand is often politically promoted as a climate change mitigation measure in close interaction with water resources. The demand for biofuels induces changes in land use and in water demand. These modifications could have major consequences on the regional or local water demand (Gheewala et al. 2013, 2014), surface water flows and soil erosion risks (Babel et al. 2011). Moreover, the development of hydroelectric dams modifies river regimes and riparian hydroecosystems (see Box 12.1).

12.6 Conclusion

This non-exhaustive panorama was focused on adaptation to climate change with respect to water-dependent agricultural systems, their territories and water resource management and governance. The presented research studies were carried out in partnership, primarily with institutions in developing countries, in close collaboration with local stakeholders in developing and running the projects, as well as disseminating and using the results. Research activities are generally conducted locally, according to participation and action-research principles, with the involvement of farmers, decision makers, and development agents. Such investigations also take into account and compare different viewpoints, use co-construction approaches for analysis, assessment and solution-seeking, and also favour result sharing, training and capacity building throughout the research process.

These are the original features of the studies reported here. They help to better associate the different stakeholders involved in climate change adaptation processes. The aim is to form a continuum of scientific and lay expertise, know-how, local practices, external technologies and information to fuel decision-making channels involved in adaptation processes regarding rural populations, farms and public policies.

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