# Chapter 3
# Climate Change-Induced Loss and Damage of Freshwater Resources in Bangladesh

**Nandan Mukherjee, John S. Rowan, Roufa Khanum, Ainun Nishat and Sajidur Rahman**

**Abstract** Climate change loss and damage is evident in hydrological perturbations among river systems in Bangladesh. Significant disruptions include changes in the intensity, frequency, and seasonality of peak and low flow characteristics. Over the last few decades, water-related disasters conveyed through the river systems have caused increased economic damage of assets and infrastructure. Other impacts include the loss of fish spawning grounds and reduced agricultural production due to changes in the hydrological regime. This chapter discusses a broad range of generalised approaches to address water-related disasters and changes in hydrological characteristics.

**Keywords** Climate change · Loss and damage · Hydrological alteration
Riverine ecosystem

## 3.1 Introduction

Climate change will induce loss and damage especially through its impact on freshwater resources. Evidence worldwide strongly suggests that climate change will perturb hydrological systems by altering the frequency, intensity, and spatial and seasonal distribution of precipitation (Bates et al. 2008). For example, greater atmospheric moisture content over the warmer Indian Ocean will generally intensify South Asian summer monsoon rainfall and generate stronger extreme weather

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Nandan Mukherjee, University of Dundee, Dundee, Scotland, Corresponding Author, e-mail: n.mukherjee@dundee.ac.uk.

John S. Rowan, University of Dundee, Dundee, Scotland.

Roufa Khanum, Centre for Climate Change and Environmental Research, BRAC University, Dhaka, Bangladesh.

Ainun Nishat, Centre for Climate Change and Environmental Research, BRAC University, Dhaka, Bangladesh.

Sajidur Rahman, Centre for Climate Change and Environmental Research, BRAC University, Dhaka, Bangladesh.

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events, but will also lead to less predictable changes to intraseasonal and interannual variability (Turner/Annamalai 2012). The *Intergovernmental Panel on Climate Change* (IPCC) reports that freshwater availability likely will be severely affected and the potential for conventional adaptation based approaches will be limited if the temperature increases by more than 2 °C (Cisneros et al. 2014). Bangladesh's population of nearly 160 million (BBS 2016) relies heavily upon its hydrological systems and is therefore vulnerable to events which will be exacerbated by climate change, e.g., floods, drought, storm surges, sea level rise, and salinity intrusion. Moreover, unplanned development within river basins and freshwater withdrawal from transboundary rivers by the upper riparian countries will likely intensify climate change-induced loss and damage from salinity intrusion and sea-level rise (Mirza 1998; Rahman et al. 2011).

A range of adaptation and mitigation approaches is outlined in the *Bangladesh Climate Change Strategy and Action Plan* (BCCSAP) (MoEF 2009). However, these proposals need to be geographically specific with regards to financing and potential climate impacts. Depending on local hydrological and socioeconomic characteristics, infrastructural adaptation options—e.g., flood control and drainage structures—may be constrained in preventing significant loss and damage (Kudzewicz et al. 2014). Persistent development deficits may also limit adaptive capacity among affected populations.

This chapter aims to assess the climate change-induced losses and damages pertinent to freshwater systems in Bangladesh and outline broad-ranged approaches to address them. Section 3.2 presents an overview of hydrological conditions and loss and damage from water-related disasters in Bangladesh. Section 3.2.2 reviews the state of current water management systems addressing loss and damage. Section 3.2.5 explores potentially sustainable options for managing residual loss and damage.

## 3.2 Hydrological Loss and Damage

### *3.2.1 Climate Change and Variability in Bangladesh*

Bangladesh is divided into seven hydrological regions, with most surface water flowing through drainage systems comprised of three transboundary rivers: the *Ganges, the Brahmaputra, and the Meghna* (GBM) (WARPO 2001). Around 700 rivers with tributaries flow through the deltaic floodplain into the Bay of Bengal (Khalil 1990). Glacier contribution is relatively insignificant to the total flow contribution, with rainfall runoff forming more than 90% of the discharge (Jain 2008). Therefore, flow extremes such as floods and droughts are highly sensitive to rainfall conditions. Bangladesh experiences three types of freshwater flooding (Ahmed 2005): (1) flash floods triggered by overflowing of hilly rivers in the East and North during the spring and autumn; (2) rainfall-induced floods resulting from heavy precipitation and drainage congestion; and (3) monsoon riverine floods in the floodplains caused by excess flow in the GBM basins.

Perturbations to the hydrological cycle resulting from climate change and variability affect the intensity and frequency of water-related hazards (Fig. 3.1). For example, a rise in atmospheric temperature can reduce soil moisture content and increase the risk of agricultural drought, and changes in precipitation volume and timing affect flood incidence and exposure. In the latter half of the 20th century, there was an observable increase in the incidence of warm temperature extremes, though changes in precipitation extremes have been less apparent (Klein Tank et al. 2006). Other analyses show that there has been little change to the June–September seasonal mean South Asian summer monsoon rainfall since the mid-twentieth century (Turner/Annamalai 2012). Thus, consistently significant climate-induced alterations to peak flow and discharge regimes have yet to be recorded (Mirza et al. 2001; Gain et al. 2013). However, modelled climate change scenarios suggest that in the future flooding will increase in geographical extent, intensity, and frequency,

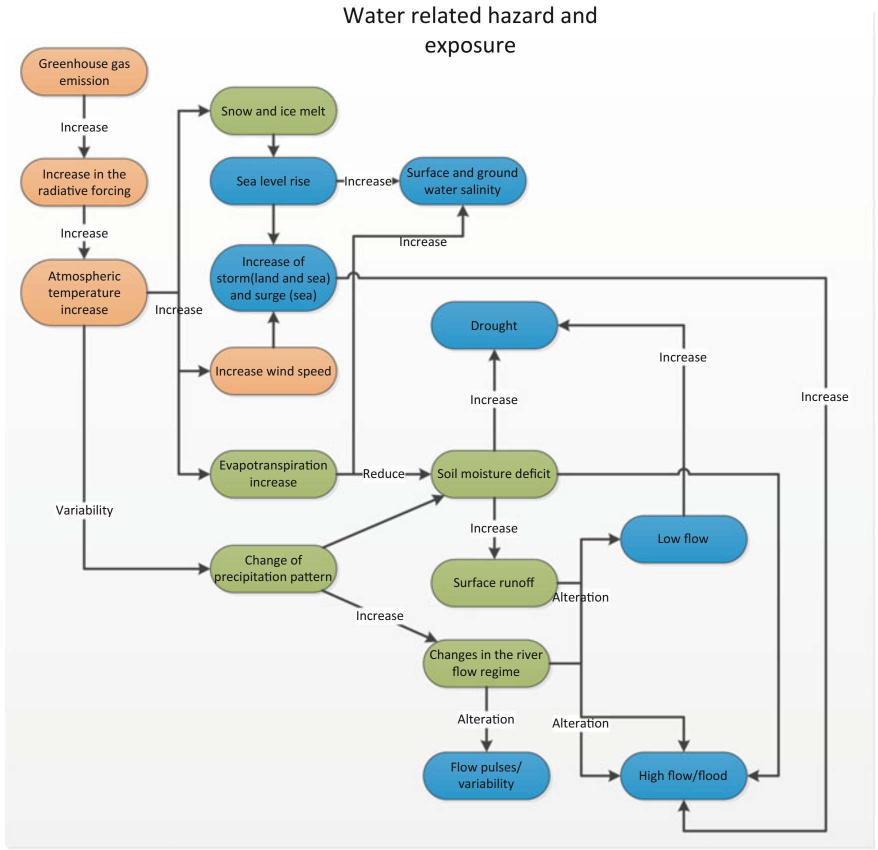

**Fig. 3.1** Climate change impact on water-related hazards. *Source* Adopted and modified from Mirza/Ahmad (2005: 10)

primarily due to Brahmaputra and Meghna peak discharges (Mirza et al. 2003; Gain et al. 2013).

In northern and northwestern Bangladesh, low flow conditions also frequently occur due to a lack of precipitation during the dry season (i.e., winter to pre-monsoon) (Shahid/Behrawan 2008). While pre-monsoon drought hinders the minor winter cropping season, delayed or reduced monsoons can significantly impact primary rice and inland fisheries production (Agrawala et al. 2003; Faruque/Ali 2005). More extreme wet-to-dry season flow ratios will also affect sediment transport and deposition, resulting in channel sedimentation and riverbank erosion.

### 3.2.2 *Direct, Tangible, and Economic Loss and Damage*

Accounting for loss and damage from water-related hazards needs to cover both tangible and intangible impacts. Tangible, direct loss and damage include loss of human life, emergency assistance to affected people, and economic damages to property and infrastructure. The frequency of recorded water-related hazards has increased significantly in recent decades, largely due to increased human settlement in flood-prone areas as well as to improved damage monitoring and assessment (Mirza et al. 2001) (Fig. 3.2). EMDAT is an international disaster database that

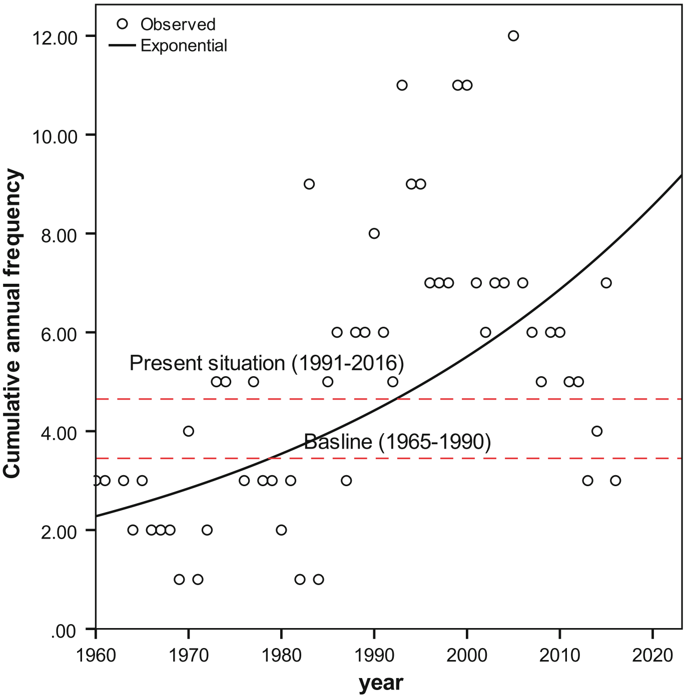

**Fig. 3.2** Frequency of hydrological disasters from 1960 to 2016. *Source* EMDAT data

systematically reports information regarding historical disaster incidences (Guha-Sapir et al. 2017), using several qualifying filters. Disaster events are included when at least ten mortalities occurred, at least 100 people were affected, there was a declaration of a state of emergency, or a call for international assistance by the state was announced.

There were 58 cases of water-related disasters reported in Bangladesh between 1965 and 1990, a count which nearly doubled to 113 between 1991 to 2016. Storm surge and floods comprise 85% of all the hazard incidences. On average, the hazard frequency has been increasing at the rate of approximately 7% per year.

In contrast, the loss estimates, i.e., deaths and the total affected human population, has declined in recent years. The death toll has declined by 57%, from a mean annual incidence of 375 between 1965 and 1990 to 159 between 1990 and 2015. The total affected population has also declined between these two periods, decreasing from 6.8 million to 3.4 million per year. Over the last few decades, national efforts in disaster risk reduction and risk management, such as protective infrastructure and early warning systems, may be contributing to vulnerability mitigation.

Normalised economic damage estimates (Neumayer/Barthel 2011) increased nearly 65%, from a cumulative estimate of US$68 million between 1965 and 1990 to US$324 million between 1990 to 2015, growing at an average rate of US$9 million per year (Fig. 3.3). However, this trend is not solely attributable to climate

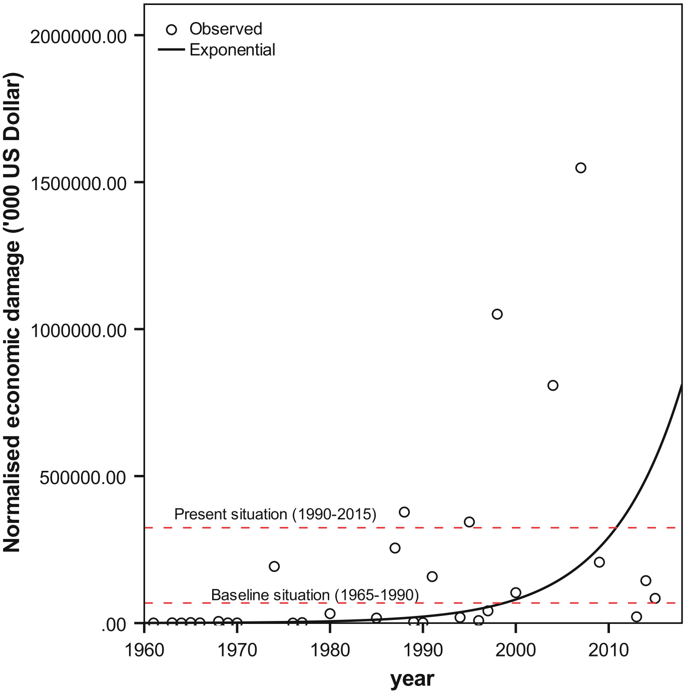

**Fig. 3.3** Trend in the normalised economic damage. *Source* EMDAT data

change and variability, since economic development in disaster prone areas has increased the quantity of vulnerable property and infrastructure.

### *3.2.3 Indirect, Intangible, and Non-economic Loss and Damage*

Indirect dimensions of loss and damage may be more pervasive and long-term, such as hydrological alteration of river flows which negatively affect fish spawning and fishery-based livelihoods, as well as modified flooding regimes which impact agriculture in flood-prone areas.

For example, the Halda River, located in the southeastern hilly region of Bangladesh, is a critical spawning ground for three major carp species: *Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*. The spawning biology for these important fishery species are sensitive to ecological characteristics which are determined by meteorological and flow conditions (Tsai et al. 1981). Spawning occurs following a sudden rise in water level due to thunderstorms during monsoon floods from April to June, and may be triggered by the increased current, turbulence, or up-welling. Therefore, perturbations in the timing and intensity of high flow conditions increase the potential loss of spawning by these migratory fishes. Another example of indirect loss and damage occurs in the haor basin of Bangladesh. Located in the northeast, the haor basin is a mosaic of wetland habitats—including rivers, irrigation canals, seasonal cultivated floodplains, lakes and freshwater swamps—that resembles a bowl-shaped depression (Nishat et al. 2002). This internationally important wetland ecosystem is home to numerous floral and faunal species and migratory birds, and is also one of the largest dry season (boro) rice producing areas of Bangladesh (Uddin et al. 2013). Flash flooding is characteristic of haor regional rivers, which often impedes the boro harvest during the month of May. During the 2004 flood, more than two thirds of the boro production was lost due to an early flash flood event that coincided with the harvest season (CEGIS 2012). Increased frequency and intensity of such events due to climate change would therefore have a deleterious impact on the boro rice harvest.

### *3.2.4 Approaches to Reduce Loss and Damage from Hydrological Disasters*

Flood control, drainage, and irrigation (FCDI) have been the most common forms of structural intervention for water resource development in Bangladesh. These include river embankments, dam construction, reforestation, drainage channels, and pump drainage (Faruque/Ali 2005). Such interventions are the principle adaptation options for minimising the loss and damage from monsoon flooding in the northwest and north central region, tidal flooding in the northeast region, coastal flooding and storm surge in the southern coastal region, and water scarcity and irrigation demand mitigation in the northwest and southwest region.

Typical FCDI strategies are organized around three annual rice cropping seasons: (1) Kharif-I (mid-April to mid-July); Kharif-II (mid-July to mid-November) and Rabi (mid-November to April). The strategies are designed to protect crops against early river floods during Kharif-I; expand the cultivated area through flood exclusion during Kharif-II; and retain water in the system to reduce drought risk during the Rabi (Faruque/Ali 2005). The main objective is to reduce losses due to flooding or drought, in order to encourage farmers to invest in the greater inputs required by high yielding food crops, resulting in greater agricultural productivity. However, flood control structures which inhibit fish migration and reduce annual floodplain inundation may reduce the productivity of freshwater capture fisheries, while allowing culture fisheries to expand within protected zones.

The *Bangladesh Water Development Board* (BWDB), as the principle implementing authority under the Ministry of Water Resources, has completed roughly 700 FCDI projects since the early 1950s. The BWDB estimates that the FCDI projects have cost about US$3 billion (unadjusted) since their inception (Nishat et al. 2011). More recently, the United Nations Development Programme has estimated that new water resources development projects have cost US$1.3 billion between 1999 and 2011. In terms of the total investment, FCDI projects are dominated by flood control, drainage, and irrigation projects (24%); town protection projects (22%); river bank protection projects (16%); and irrigation and command area development (10%) (Fig. 3.4).

The *National Water Management Plan* (NWMP) (WARPO 2001), prepared in line with the National Water Policy (MoWR 1999), is the latest long-term strategy for water resources. Although the NWMP did not directly address climate change adaptation, it outlined 84 project portfolios regarding water and river resources, emphasizing year-round water management, stakeholder engagement, and social and environmental needs (Faruque/Ali 2005). Subsequently, the *Ministry of Environment and Forest* (MoEF) enacted the first *National Adaptation Plan of Action* (NAPA) (MoEF 2005), which reiterated the continued importance of building FCDI infrastructure as an adaptation option. More recently, the *Bangladesh Climate Change Strategy and Action Plan* (BCCSAP) (MoEF 2008) revisited the NAPA propositions and recommended a total of 44 projects under six thematic areas including infrastructure development for combating natural disasters. BCCSAP also proposed the retrofitting of existing FCDI infrastructure as well as the building of additional infrastructure-based protection for exposed coastal zones and river flood plains.

Despite noticeable progress in water resources development, some initiatives may be maladaptive despite claimed benefits in the short term. For example, flood or coastal protection embankments and drainage control structures reduce vulnerability by preventing floods or storm surges from reaching the settlements. However, in most cases, the intended benefit occurs only for a short period. In the longer term, flood embankments restrict the sediment inflow to the flood plain, which ultimately reduces the nutrient availability of the topsoil and raises the

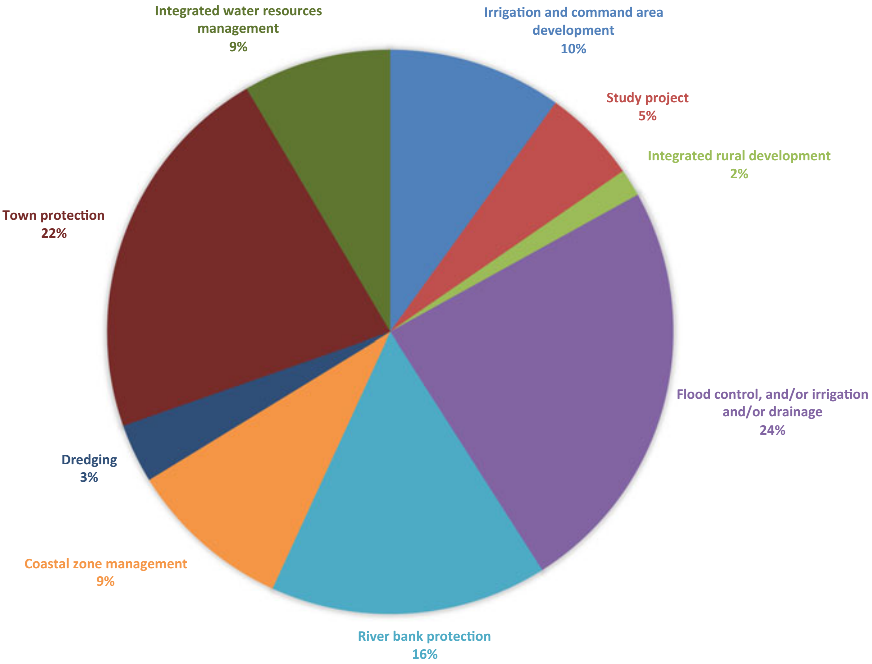

**Fig. 3.4** Cumulative investment proportion in different categories of water sector development projects (1999–2011). *Source* Graph is drawn using the data from annual development program, Ministry of Finance, Gob, adopted from Nishat et al. (2011)

adjacent river bed, causing an imbalance in the sediment budget of the river system (Brouwer et al. 2007). Siltation and poor maintenance of drainage channels further exacerbates congestion and waterlogging (Faruque/Ali 2005).

Flood embankments constructed upstream increase the risk of flooding and geomorphological instability (i.e., erosion or accretion) in the downstream sections (see Jauhari/Gadhalay 2011). Earthen embankments also often create a false sense of security among the inhabitants living inside the embanked area, resulting in a greater hazard when the structures are breached or overtopped by megafloods or storm surges. Permanent waterlogging within poldered areas in Southwestern Bangladesh (Brammer 1983; Nowreen et al. 2014) and loss and damage from mass embankment failure during the Cyclone Sidr (Islam et al. 2010) are documented examples of maladaptive consequences.

Additionally, utilising excessive groundwater or pumping water from rivers are common adaptation options for providing irrigation water for agriculture as rainfall becomes less predictable. However, these practices have long-term impacts on groundwater availability, increasing the risk of land subsidence and compromising natural flows in the river systems (Safiuddin/Karim 2001; Hoque et al. 2007).

Therefore, conventional water management interventions have limits which might cause further loss and damage to the environment and society. Instead, water management interventions should do the following:

1. Reduce the exposure of the vulnerable population, assets and infrastructure efficiently and without invoking a false sense of security. Instead of relying on conventional large scale FCDI projects, ecosystem based adaptation options could be explored (see Chap. 5 of this volume).
2. Proactively plan adaptation options so that the residual loss and damage to society and the environment is minimised. The conventional design of large water management infrastructure mostly relies on historical inundation regimes. However, given the unpredictability of climate change outcomes, uncertainty and the limits of adaptation and mitigation must be considered and incorporated into adaptive water management principles (see Box 3.1).
3. Maximise the potential for complementary or dual benefits from climate adaptation and greenhouse gas mitigation. For example, a coastal green belt could both provide coastal protection and while sequestering carbon (Chow 2017).
4. Manage each river at the basin scale as a single, living system, avoiding country-wide interventions. Calculation of the environmental flow requirements of the river system is long due in river basins around the globe. Recently, New Zealand's parliamentary approval of a bill recognising the Whanganui river as having the same legal rights as human beings—as well as the Ganges and Yamuna rivers having been declared living entities by the government in Uttarakhand, India—are bold examples of such propositions.

### *3.2.5 Reducing Loss and Damage Through Managing Risk*

Risk management efforts, including adaptation, mitigation and disaster risk reduction, are contingent upon perceptions of risks which are acceptable, tolerable, or intolerable depending on the frequency of occurrences and the scale of the consequences (Klein et al. 2014). Acceptable risks are those so minor that action is considered unnecessary, whereas tolerable risks potentially can be kept at reasonable levels through adaptive management efforts. Intolerable risks, however, can threaten human welfare and ecological sustainability due to the lack of practicable or affordable adaptation options. Uncertainty magnifies risk, particularly when climatic events change in terms of intensity, frequency, and spatial and temporal variation. Due to the limits of mitigation and adaptation activities, residual loss and damage from climate change will occur. If loss and damage are considered intolerable, they can either be accepted or avoided via dramatic adaptive transformation of the social or natural system (Klein et al. 2014).

Risk reduction approaches are intended to manage loss and damage of assets, infrastructure, and human life. Risk reduction methods can be divided into two categories, structural and non-structural. Structural approaches mostly reduce risk by altering the exposure dimensions, e.g., reducing the population's exposure to risk from living in the flood plain by constructing new defences or raising the plinth or base of the critical infrastructure above the flood level. These also include retrofitting the height of the flood embankment and drainage infrastructure. However, structural measures may trigger further loss and damage to the environment and ecosystem. Therefore, risk retention and risk pooling measures are necessary to complement risk reduction activities, given the limits of infrastructural adaptation options.

Non-structural risk reduction approaches include early warning systems and community-based disaster management initiatives. Non-structural options mainly address vulnerability issues, either by reducing the sensitivity of the exposed element or by enhancing the adaptive capacity of the same. In Bangladesh, although the Flood Forecasting and Warning Center can forecast flood levels at some locations 48 hours in advance, public awareness systems are limited to print and electronic media (Faruque/Ali 2005; Mirza/Burton 2005). Other non-structural options include zoning, hazard preparedness, shelters, emergency services, and improved public communications and education. However, these activities are not widespread in Bangladesh (Mirza/Burton 2005).

Risk retention measures aim to enhance the capacity of the exposed population to absorb the shocks of loss and damage. The principle focus is on improving adaptive capacity through pre- and post-disaster emergency response, launching social safety net programmes, and also by introducing microfinance tools and instruments. This particular approach works well when risk reduction strategies fail due to the unprecedented scale of natural hazards. Risk pooling options are intended to shift economic risks from an individual or organisation to an insurer (UNFCCC 2012). This approach works well for managing economic loss and damage that cannot be prevented through risk reduction or retention based methods. Microfinance instruments like micro insurance or index-based insurance for agriculture are common risk transfer options.

Most kinds of structural adaptation options related to water resources management may have significant residual environmental and social impacts even when supported by a robust environmental management framework. Intangible and residual loss and damage may occur because of the unprecedented nature of climate change induced hydro-meteorological hazards, which may overwhelm efforts to reduce vulnerability. Ecosystem-based options usually have much less residual impact than traditional structural adaptation strategies. A single, myopic approach is not sufficient to address the broad horizon of loss and damage.

## 3.3 Conclusion and Recommendations

The frequency of reported hydrological disasters has been increasing in recent years, as have their associated economic damages. The river system in Bangladesh is highly vulnerable to hydrological alterations in a changing climate, including:

(1) low flow situations becoming longer, more frequent, and more intense;
(2) flood peaks coming earlier, receding later, with more frequent small and large flood events; and
(3) increased flow variability.

In spite of recent declines in the human death toll and suffering from floods in Bangladesh, the economic damage has increased by several-fold, which underscores the role of economic development in amplifying infrastructural vulnerabilities. The changes in the hydrological regime—in the magnitude and seasonality characteristics of the flow system—may also trigger species extinction due to unfavourable spawning environments and impeded migration routes. Moreover, agricultural production losses may be caused by low flow situations, early flood incidences, and later recession of floods.

Under these circumstances, ecosystem-based adaptation options need to be explored extensively to reduce residual and net loss and damage. At the same time, the trade-off between securing agricultural production and ecosystem conservation needs to be balanced effectively. An integrated basin-wide approach is long due to protect the health of the transboundary rivers in the greater GBM Basins region. Inaction and delayed action may continue to cause irreversible loss and damage of ecosystem components and services.

**Box 3.1:** The Water-Food-Climate Nexus – implications for long term adaptive planning such as the Bangladesh Delta Plan by Catharien Terwisscha van Scheltinga.[1]

Water management of the future starts with planning today. This is a highly uncertain and very complex matter. The Bangladesh Delta Plan 2100 aims to assist in this longer-term planning, and to facilitate long term economic development through improving food security, water safety and availability. An adaptive plan is developed and side by side implementation is started to improve future land and water management, in relation to water safety and food security.

The Bangladesh Delta Plan aims at adaptive planning. It focuses on bringing various strategies in the picture, and optimizing the interventions and investments taking into account climate change and other uncertainties (Box Fig. 3.5).

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[1] Bangladesh Delta Plan Technical Assistance Team. Contributions of BDP colleagues Dewan Abdul Quadir, Zahurul Karim, Giasuddin Choudhury, Zahirul Haque Khan, Professor Shamsul Alam, Taibur Rahman, Mofidul Islam, Mirzanur Rahman, Fulco Ludwig, Maaike van Aalst, William Oliemans and Jaap de Heer are kindly acknowledged.

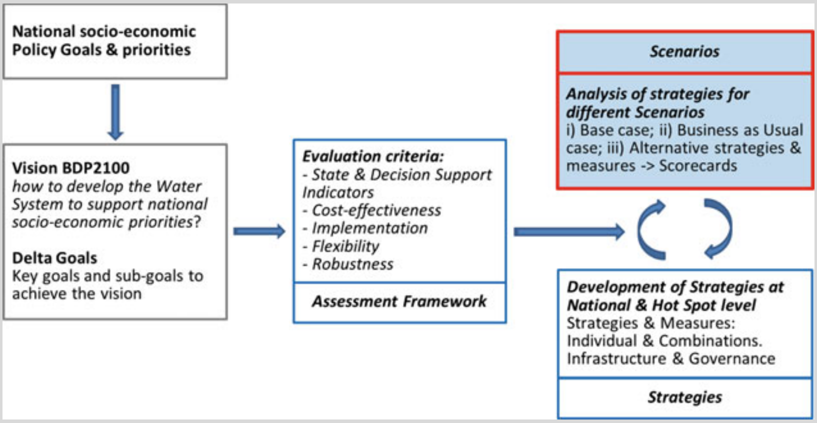

**Fig. 3.5** Schematic of the Bangladesh Delta Plan. *Source* Catharien Terwisscha van Scheltinga

Climate change has large impacts on both water and agricultural systems in Bangladesh. Climate change affects water available for irrigation but also directly influences plant growth. Land use changes to improve agricultural production have a large impact on water management both in terms of flood protection and to supply water for food production. In addition, in the southwest, climate change and upstream developments have a large impact on salt water intrusion. This salt intrusion causes large scale changes in the agricultural production systems. In the development of the delta plan this close relationship between climate change adaptation, food security and water management is taken into account, using a hotspot approach: in each of the hotspots, a strategy is being formulated, based on which measures for future development can be formulated. In the course of 2016 it is expected that further information will be available regarding the strategies. Infrastructure, knowledge development and institutional changes will go side by side in order to ensure food security for the country.

So far, national goals have been translated into a vision BDP2100 with delta goals. Together with scenarios for delta management which have been developed,[2] and the strategies for the different hotspots currently being developed, this provides a basis to come to an assessment of strategies and measures for the future.

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[2] Maaike van Aalst, William Oliemans, Fulco Ludwig, Catharien Terwisscha Scheltinga and Kymo Slager, with contributions from the BDP2100 team (2015), *Process of scenario development and draft scenarios for the BDP2100*.

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