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ORIGINAL ARTICLE

Integrating ecosystem services and climate change responses in coastal wetlands development plans for Bangladesh

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Abstract This study explores the integration of ecosystem services and climate change adaptation in development plans for coastal wetlands in Bangladesh. A new response framework for adaptation is proposed, based on an empirical analysis and consultations with stakeholders, using a modified version of the DPSIR (Driver-Pressure-State-Impact-Response) framework. The framework is tested in the Narail district of Bangladesh, where temperature has increased by about 1 °C in the summer in combination with an increase in rainfall of 0.70 mm day^{-1} yr^{-1} in the last decade. Calibrated model (MAGICC/SENGEN) projections forecast, on average, a temperature increase of up to 5 °C and an increase in rainfall of 25 % by the end of this century. Water diversion in the upstream regions of the Ganges River delta contributes to increase water scarcity in the dry season. Enhanced rainfall and the immense pressure of water discharges from upstream water sources are increasing the risk of floods and river erosion in the dry season. An increase in the water holding capacity of rivers, wetlands and canals by dredging is urgently required. The empirical model of this study is intended to support adaptation planning and monitoring in Bangladesh and can be used in other data-poor areas which will suffer from climate change.

Keywords Climate change · Ecosystem services · Wetlands · Livelihood · Planning · Monitoring · Adaptation

1 Introduction

Bangladesh is one of the most vulnerable nations to climate change due to geographic and climatic features (Maplecroft 2010; Ali 1999). This vulnerability is adding more pressure to the existing problems such as dry season water scarcity and population growth in Bangladesh (ADB 2005). Climate change induced drought has already damaged 1 million tons of food

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grains in 1997 and 50 % of food grain was damaged in 1982 by floods. Rice and wheat production is likely to decrease 28 % and 68 % respectively due to a 1–2 °C increase in temperature (Islam et al. 2011). Moreover, sea level rise (SLR) poses a risk of losses estimated to reach 10 % GDP by the year 2050 (WB 2000).

The United Nations Intergovernmental Panel on Climate Change (IPCC) (2007a) has reported on the possibility of a shift in type and structure of wetland ecosystems due to temperature and rainfall variability. These changes will certainly have consequences for livelihoods because ~80 % of rural households strongly depend on wetland resources (BCAS 2006; Islam 2005; Rahman and Islam 2005). Wetlands contribute around 46 % of all fish consumed in Bangladesh (Ali 1997; DoF 2000).

Increasing population and rural poverty have already done much damage to wetland ecosystems (Rahman and Islam 2005; ADB 2003). Realizing this, there have been significant modifications of floodplain environments since the 1960s. But cost-benefit analysis indicates that most of the projects were not successful because they did not consider the whole socio-ecological system (Rahman and Islam 2005) many misconceived developments created social and environmental conflicts (Ahmed 2011; Hossain and Roy 2010; Islam 2005). Moreover, the coastal area is not only threatened by climate change but also by rising salinity and flood inundation. In this respect, the government has ignored its own National Adaptation Program of Action (NAPA) for designing and implementing a water resource management plan (Hossain et al. 2010). Therefore, development plan draws together livelihoods, ecosystems and climate change is therefore essential.

Adaptation planning for climate change is arguably the key challenge of this century for development in low income countries. Schipper (2007) recommended including adaptation responses in mainstream development planning and a similar policy guideline was proposed by the Organization for Economic Co-Operation and Development (OECD) 2009. It suggested that approaches to planning needed to understand the challenges of climate change, make appropriate adjustments in policy formulation, and integrate climate within the planning and implementation stages. In this respect, ecosystem service (ES) based adaptation (ESbA) is one of the commonly adopted approaches for coping with climate and environmental changes. ES are defined as 'the benefits to people obtained directly and indirectly from the ecosystem'. These services are categorized into four areas: provisioning services (food, raw material, fresh water etc.); regulating services (air quality and climate regulation, protection from disaster etc.); cultural services (educational, inspirational etc.); and supporting services like (nutrient cycling, soil formation etc. (MA 2005). ESbA is defined as the use of ES in supporting people in adapting to climate change (Wertz-Kanounnikoff et al. 2011; Ash and Ikkala 2009; Vignola et al. 2009), largely through the maintaining and building resilience against climate change (Ash and Ikkala 2009 and UNEP 2009).

Previous studies have focused on the conceptual framework of main-streaming climate change in development (Huq and Reid 2004) and ecosystem based climate change adaptation (Wertz-Kanounnikoff et al. 2011; Ash and Ikkala 2009 and UNEP 2009). But few studies have focused on ESbA activities in development plans (Rao et al. 2012 and Andrade et al. 2011) and vulnerability analysis using the ES concept (Metzger et al. 2006). For example, Metzger et al. (2006) mainly limited their study to the vulnerability of ES caused by land use change, whereas other studies (e.g. Krishnamurthy et al. 2011a, b; Ahsan 2010) concentrated on climate change vulnerability analysis, but did not include ES. Rao et al. (2012) and Andrade et al. (2011) have provided guidelines for ESbA with some case studies. But none of these studies provides a conceptual model for ESbA that can be implemented in the real world. Therefore, in this study, we attempt to create a new conceptual model for

ESbA and demonstrate its use in an empirical case study where ES and climate change adaptation are integrated within a development plan. Alongside the methodological development, the study examines the following questions:

1. What are the drivers and pressures of change in wetland ecosystem?
2. What are the ES in wetland ecosystems and how do they relate to the livelihoods of people?
3. What are the kinds of vulnerability in the study area?
4. What will be the future impact of climate change in terms of future rainfall and temperature change?
5. What are the plausible adaptation options for integrating ES and climate change responses in development plans?

2 Materials and methods

2.1 Study area

The south western coastal district Narail comprises an area of 990 sq km with a population of 730,568. It receives 1,467 mm annual rainfall with a 37.1 °C maximum and 11.2 °C minimum temperature (Banglapedia 2011). The hydrological regime of the study area is governed by the Chitra river in the west and Nabaganga River to the north, east and south and by low-lying areas (wetlands) through the interconnected channels and water courses. Soils of this area are relatively fine-textured, heavy, with low permeability (ADB 2005).

Narail is a poor, agricultural district vulnerable to erosion and drought (ADB 2005; NAPA 2005). Nearly three-quarters (73 %) of the total population are engaged in agricultural activities and ~50 % of the population have incomes below the poverty line (Saadat and Islam 2011; ADB 2005). About 2 % of the population is engaged in aquaculture (Banglapedia 2011) but most of the farmers are also involved in fishing all year round (Ahmed 2008). 30–50 % of the population actually catches fish during the wet season. Hydro-meteorological changes due to climate and hydraulic engineering are making the community more vulnerable (Moni and Hossain 2010), with climate change dominating over all the other environmental problems in the last decade (Hossain et al. 2010). Narail is not strongly affected by the rising salinity linked to shrimp farming, which is very common in other coastal areas (Fig. 1).

2.2 Conceptual framework

Our starting point is the DPSIR (Driver-Pressure-State-Impact-Response) framework (Kristensen 2004), chosen for its wide capacity to develop management responses (Sekovski et al. 2012) from analyses of socioeconomic issues, environmental changes and policy responses (Bidone and Lacerda 2004). In addition, this framework allows the detailed analysis as an interdisciplinary tool to simplify the environmental complexities in the management process. It has been widely used in different contexts such as the European Union (EU) Water Framework Directive (Mysiak et al. 2005), fisheries management (Mangi et al. 2007), coastal zone management (Sekovski et al. 2012; Bidone and Lacerda 2004), wetland (Lin et al. 2007) and marine protected area management (Ojeda-Martínez et al. 2009).

For our purposes, the DPSIR framework has the potential to integrate ES and climate change by identifying the pressures, current States and future Impacts on ecosystems and their services due to climate and other drivers. Moreover, the 'State' part of the framework is

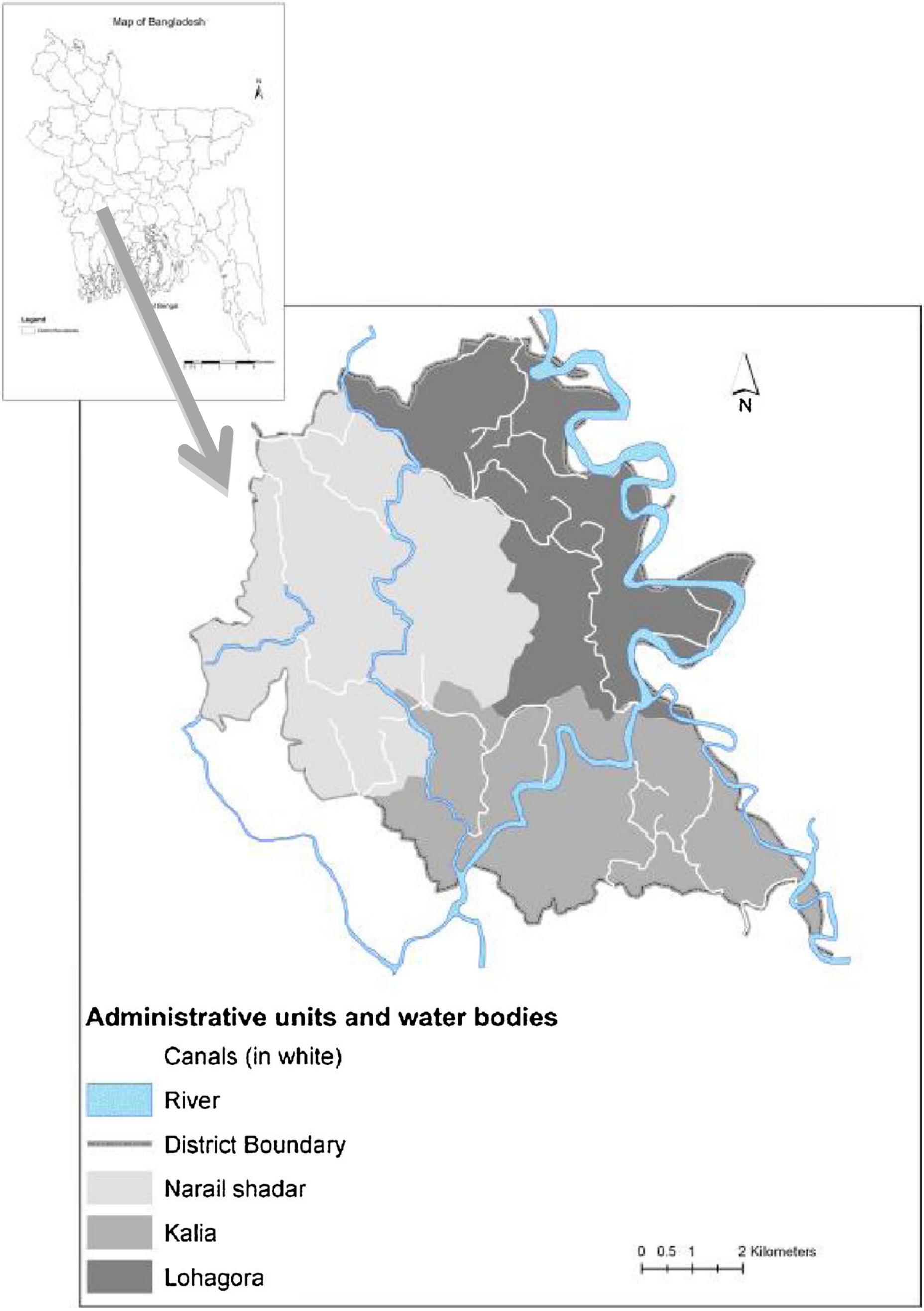

Fig. 1 South west coastal district Narail selected as study area in Bangladesh

useful for identifying ES and their vulnerability to climate. The 'Response' part emphasizes the need to determine mitigation and adaptation options. But we modify the framework (Fig. 2) to include links that allow for the integration of climate change responses and ES in future

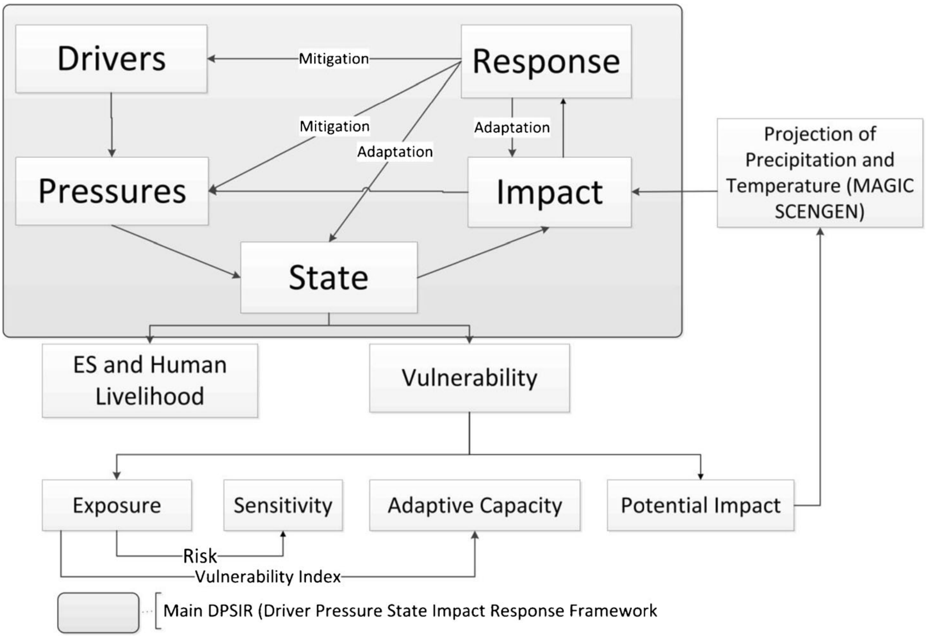

Fig. 2 Conceptual framework for integrating ecosystem services and climate change responses in Bangladesh development plans

development plans. Thus, the current State is determined by understanding the relationship between human livelihood and ES, and by assessing the vulnerability of the area. Future Impacts are assessed by projecting temperature and precipitation, which may impose extra Pressures on the environment. Finally, we propose adaptation Responses to climate and other changes.

2.3 Methods

2.3.1 Identification of drivers and pressures

Drivers and pressures were identified using stakeholder's perceptions through focus group discussion (FGD) with findings validated by analyzing secondary data, literature review and expert opinion. Monitored data records for past climate have been divided into 20 year segments (1948–1970, 1971–1990 and 1991–2007) in order to observe the temperature and rainfall trends. Bangladesh seasons have been classed as monsoon (June–July–August), post-monsoon (September–October–November), winter (December–January–February) and pre-monsoon (March–April–May) (Islam and Uyeda 2007).

2.3.2 ES and livelihoods

The relationships between ES and livelihoods are identified using the information from FGDs and secondary sources. There is a lack of data and literature for cultural, regulation and supporting services so we focus our analyses on the relationships between livelihoods and provisioning services, which are generally considered to be strong and intense (MA 2005).

2.3.3 Vulnerability analysis

A geographic information systems GIS-based vulnerability assessment has been carried out by developing an index:

$$\text{Vulnerability} = f((\text{Exposure} + \text{Sensitivity}) - \text{Adaptive Capacity})$$

These three concepts of exposure, sensitivity and adaptive capacity have been adopted from Krishnamurthy et al. (2011a), Damm (2010), Luers et al. (2003) and IPCC (2001). In this study, we use four domains of information: exposure (hazard), sensitivity (ecosystem services), adaptive capacity (infrastructure plus socio-economic structure) and a number of indicator criteria for climate change, ecosystem services, regional problems, livelihood, economy and society (Table 1). For each of three sub-district (*upazila*) areas, relative indicators were scaled according to $X_i - X_{min}/X_{max} - X_{min}$ (adopted from the International Poverty Index, Lawrence et al. 2002) where X_i is the stated value for that upazila, and X_{min} and X_{max} are the lowest and maximum values across the three *upazila* areas. The calculated indicator value indicates the relative position of the region and lies between 0 and 1. Values for the four domains and hence the vulnerability index were calculated by summing the indicator values for all the datasets within a domain (Table 1). Finally, the total aggregated value was put through a query process to calculate the vulnerability of the area.

Most of the data (Table 1) for the vulnerability indicators was collected from secondary sources. But due to a lack of local data for climate, the spatial variability of hazards data (Table 1) was estimated using a problem matrix during the FGDs (see below). The matrix is based upon identification of the frequency and intensity of known hazards, with ranking on a scale of 1 to 5, and aggregated through the vulnerability index.

2.3.4 Future impacts of climate change

Impacts of climate change were assessed in two steps: first, climate change projections were produced from the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change)-SENGEN (SCEnario GENerator) model version 2 5.3, which is consistent with the IPCC (2007b). The best 4 GCM models identified by Roy et al. (2009) for each of the four seasons in south-west Bangladesh were used to calculate mean seasonal temperature and rainfall for 2030, 2050 and 2100. Using the global data set from the MAGICC/SCENGEN software, data were extracted for the geographic area enclosed by latitudes 22.50–25.00 and longitudes 87.50–90.00 (cf. center of study area 23°7′ 48″ N, 89°30′0″ E). Projections were based on an A1- BAIM scenario. Second, the possible impacts of the projected climate changes were determined from expert judgment and literature sources (Table 2)

2.3.5 Focus group discussion

Plausible adaptation strategies that might include ES were based on stakeholder views and perceptions recorded during FGDs. In total, eight FGDs were conducted in the following sites of three upazila: Lohagora upazila (Permollik Pur and Noagram), Kalia upazila (Molladanga Bongram, Joynagar and Krishna Pur) and Narail Sadar upazila (Singa and Poloidanga Vodrobila). On average, there were 30 participants in each FGD, the majority fishermen and farmers of 40 years age or older who had lived in the area since childhood. These were selected in order to maximize an understanding of changes in the area over several decades, but high levels of illiteracy precluded formal questionnaire approaches.

Table 1 Indicators for Bangladesh vulnerability index 2011

Component		Input	Data source
	Profile	Indicator	
Exposure	Hazard	Area of flooding (km^2), Number of affected families Number of affected people, Crop damage due to flood (Acre), Number of flood affected houses	DC Office
		Damage due to river erosion (Number of families)	UP Office
		Temperature, Precipitation, Waterlogging, Flood, Erosion, Cyclone, Lack of irrigation, Drinking water availability (Ground water depth), Arsenic levels	FGD
		Salinity Level (River) (Summer Season)	SRDI
Sensitivity	Ecosystem services	Agricultural Area, Forest Area (ha)	DAE
		Wetland Area (ha), Fish production from wetlands metric tonnes (t)/yr	DoF
		Pond area (ha), Fish production from ponds (t/yr), Shrimp farm area (ha), Shrimp production (t/yr), Number of fisherman, Riverine area (ha), Fish production from river (t/yr)	DoF
		Number of farmers	DAE
		Area of canal (km^2)	BWDB
Adaptive capacity	Infrastructure	Roads (Solid, Kucha and Others)	LGED
		Embankment and sluice gates	BWDB
		Number of health and education center	DC Office
		Dwelling structure of household	BBS
	Socio-economic structure	Population density, Educational status, Population growth (1991–2001) %, Urban growth (1991–2001) population, Population below poverty line, Children (%),Schooling (children) (%),Women (%),Sanitary Coverage (%), Electricity coverage (%)	BBS

BBS Bureau of Statistics, BWDB Bangladesh Water Development Board, DoF Department of Fisheries, DC Office District Commissioner Office, DAE Department of Agricultural Extension, FGD Focused Group Discussion, LGED Local Government Engineering Department, SRDI Soil Resource Development Institute, UNO Upazila Parishad Office

Table 2 Best 4 GCMs for each of the 4 seasons in South-West Bangladesh for projecting temperature and precipitation

GCM rank	Winter (DJF)	Pre-monsoon (MAM)	Monsoon (JJA)	Post-monsoon (SON)	Annual
1	ECHO-G	ECHO-G	INMCM-3.0	UKHADGEM	UKHAD-CM3
2	GISS-ER	CCCMA-3.1	UKHAD-CM3	UKHAD-CM3	INMCM-3.0
3	GISS-EH	MRI-232A	GFDLCM2.0	CNRMCM3	CCSM-3.0
4	CSIRO-3.0	INMCM-3.0	CSIRO-3.0	GFDLCM2.1	CCCMA-3.1

Roy et al. (2009)

First, we asked the participants about the existing hazards in the area and the possible impacts on livelihood and ES. We also asked the participants about how to reduce the vulnerabilities, including the use of ES assets. Then we asked the participants about the drivers of the vulnerabilities that they had stated. Then we framed the discussions as per our conceptual framework and validated the overall group messages using a flip chart diagram. In open discussion we learned about the changes in the drivers and the pressures.

The same framework was used to collect data from professionals in non government organizations (NGOs), the Water Development Board, Agricultural Department, Fisheries Department, and academics who have worked in the area. The outcomes of the FGDs, especially water-related, were validated through consultation with experts. Finally, we drew upon national strategies, including the Bangladesh National Adaptation Program of Action (NAPA 2005) and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP 2008) to deduce and recommend final adaptation options. Some of the options, such as improving literacy, are regular development priorities but were retained as recommendations if there was evidence that they were explicitly linked to desirable adaptation options.

3 Results

3.1 Drivers of change

Stakeholders identified the hydrological effects of the Farakka Barrage, climate change and population growth as the major drivers affecting the local ecosystems and services. Table 3 shows that the population increased over the period 1951–2001. Though population growth rate has declined (0.53 %/yr) since 1991, population has doubled within a 40 year time period.

3.2 Pressures on ecosystem

Flood and river bank erosion Narail experienced a severe flood event in 1987 that affected around 300,000 people and damaged 32,000 acres of crops. In 1988, flooding affected 1,000 km^2 and 385,000 inhabitants. Lohagora upazila was severely affected compared to other upazila. Around 10,000 people were affected by the floods of 2007. The 2004 and 2008 floods inundated ~19 % and ~40 % area of district respectively. In 2011, around 2,000 households were affected by river bank erosion but there is no previous statistical data.

3.2.1 Low water flow

Water discharge values of the Gorai-Modhumoti river show a declining trend in the period 2001–2010. Water discharge declines in both the monsoon (−84 m^3/s/yr) and post monsoon

Table 3 Population growth and density in Narail District, 1951–2001

Characteristics	1951	1961	1974	1981	1991	2001
Population	310,000	379,000	505,000	588,000	655,000	698,000
Population Density (Narail)	319	383	510	595	662	705
Population Density (Urban)	–	–	518	573	640	673
Population Density (Rural)	319	383	502	886	945	1055

Bangladesh Bureau of Statistics (BBS)

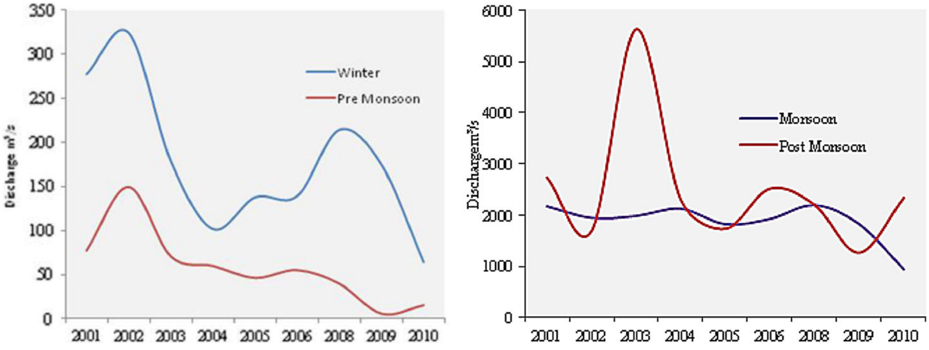

Fig. 3 Dry (*left*) and wet (*right*) seasonal water discharges in Gorai Madhumoti river over the period 2001–2010. *Data Source* Bangladesh Water Development Board

(−158 m^3/s/yr) season. Though the post monsoon rate is declining, this is because of the extreme value (<5000 m^3/s) in 2003, whereas the average water discharge is ~2000 m^3/s from 2001 to 2010. The winter season trend also shows a declining trend (−19.89 m^3/s) for the same time period. Community people and experts have reported that these declines are linked to the water diversion project in the Indian section of the Ganges, the upstream part of this river network (Fig. 3).

3.2.2 Temperature and precipitation

Overall temperature has increased 0.39 °C to 0.79 °C in the time period 1970–2007. Monsoon temperature has increased by 1 °C within the past 60 years. Temperatures declined in post-monsoon and pre-monsoon periods by −0.21 °C and −0.11 °C respectively before 1990, followed by increasing trends of 0.79 °C and 0.39 °C respectively after 1990s. Only the winter temperature shows a declining trend after the 1990s (Tables 4 and 5). Since the 1990s, mean daily rainfall in the wet seasons has increased (monsoon: 0.83 mm/day and post-monsoon: 1.94 mm/day/yr) while mean daily rainfalls in the dry seasons have declined (pre-monsoon: −0.24 mm/day/yr and winter: −0.30 mm/day/yr).

3.3 State of ecosystem and livelihood

3.3.1 ES and Livelihood

We identified three types provisioning services covering around 28 types of different crops, and freshwater fish, including cultivated area and agricultural production (Table 6). The wetland ecosystem supports the production of ~235,000 t rice, 7,000 t wheat, and 63,000 t

Table 4 Decadal temperature change (°C) over the period 1948–2007 in Narail, Bangladesh

Year	Monsoon	Post Monsoon	Winter	Pre Monsoon
1948-1970	28.99	26.15	19.05	27.89
1971-1990	29.25	25.94	19.69	27.78
	+0.27	-0.21	+0.63	-0.11
1991-2007	29.98	26.73	19.56	28.17
	+0.72	+0.79	-0.12	+0.39

Bangladesh Meteorological Department

Table 5 Decadal rainfall change (mm/day/yr) over the period 1948–2007 in Narail, Bangladesh

Year	Monsoon	Post Monsoon	Winter	Pre Monsoon
1948-1970	19.47	10.07	5.11	0.57
1971-1990	19.34	9.16	6.28	1.18
	-0.13	-0.904	+1.17	+0.60
1991-2007	20.17	11.11	5.98	0.94
	+0.83	+1.94	-0.30	-0.24

Bangladesh Meteorological Department

vegetables per year. It also produces ~4,000 t fish and 1,000 t shrimp together with 2,000 t potatoes and ~4,500 t different types of spices. These provisioning services are the sources of income for around 134,000 farmers and 16,000 fishermen and also contribute to the food security of 700,000 inhabitants. Surplus goods from these provisioning services are exported to the national and international markets after local demand is met.

Wetland in this area has the potential to accumulate around 126,700 CO_2 e[1] km^{-2} yr^{-1} to 253,500 CO_2 e km^{-2} yr^{-1} (calculated as per Crooks et al. 2011). The study area covers around 69,000 ha of wetlands area which acts as a water reservoir during the dry season. Hence, the wetlands serve as the source for irrigation water during the dry season and fish production. Moreover, Hizal (*Barringtonica acutangula*) and Koroch (*Pongamia pinnata*) plants grow in wetland areas, are the feeding and breeding zone for fish. Water reservoirs including rivers, wetlands and canals protect life and property by acting as water storage during flood time.

Income generated from the provisioning services enables people to celebrate cultural and religious programs. Farmers and fishermen also have their own cultural program such as *Nouka Baich* (boat race) and Nobanno (festivals after rice harvesting). The low production results insufficient income to meet their daily need, whereas they also could not celebrate religious and cultural festivals. Moreover, this wetland serves as the source of aesthetic, religious experience (for instance, Hindu people do worship in rivers and wetlands) and also a source of educational value. From this, it could be concluded that ecosystem services and human livelihood are strongly correlated and without the ecosystem, livelihood in this area could not be sustained.

3.4 Vulnerability index

Maps of the aggregated vulnerability index show that Lohagora upazila has the highest levels of risk exposure (Fig. 4a), twice as high as Kalia and Narail Sadar. Although it has a high adaptive capacity (Fig. 4b), Lohagora has high sensitivity (Fig. 4c), making it the most vulnerable area (Fig. 4d) to hazards. Narail Sadar is the second most vulnerable upazila which is mostly threatened because of the low adaptive capacity and high sensitivity. Kalia upazila has low vulnerability due to the medium level of adaptive capacity together with low levels of sensitivity and exposure to hazard.

3.5 Future impacts of climate change

The GCM outputs provided by MAGICC/SCENGEN for the study area indicate that there will be a further increase in seasonal temperature over the period 2030–2100 (Fig. 5). By 2100, the length of the summer will be extended and reach an average temperature of 30 °C

[1] 1gC≡3.67 gCO2e

Table 6 Quantification of provisioning services in the study area

Services	Functions			
Food	Food item		Cultivated area (Hectare)	Production yr−1 (M.T)
	Rice	*Oryza sativa*		
	Ropa Amon		33,000	71,000
	Boro		36,000	141,000
	Aus		5,000	7,000
	Bona Amon		15,000	15,000
	Wheat	*Triticum aestivum*	3,000	7,000
	Corn	*Zea mays*	3	9
	Grass Pea	*Lathyrus sativus*	11,000	9,000
	Lentil	*Lens culinaris*	3,000	2,000
	Pea	*Pisum sativum*	52	350
	Chick Pea	*Cicer arietinu*	500	37
	Mung Beans	*Vigna radiata*	190	182
	Black Gram	*Vigna mungo*	52	38
	Mustard	*Brassica nigra*	4,500	2,000
	Linseed	*Linum usitatissimum*	43	305
	Peanuts	*Arachis hypegaea*	419	741
	Chili	*Capsicum annum*	653	1,000
	Potato	*Solanum tuberosum*	135	2,000
	Sweet Potato	*Ipomoea batatas*	84	1,400
	Vegetable		4,412	63,000
	Til	*Sesamum indicum*	1,740	1,000
	Sugar Cane	*Saccharum officinarum* L.	580	26,000
	Fish		9,900	4,000
	Shrimp		2,000	1,000
Raw material	*Spices*			
	Onion	*Allium cepa*	499	3,700
	Garlic	*Allium sativum*	98	533
	Ginger	*Zingiber Officinale*	12	72
	Turmeric	*Curcuma longa*	80	240
	Coriander	*Coriandrum sativum*	454	350
	Jute	*Corchorus capsularis*		109,000 bell
Fresh water	Type of source		Area hectare	
	Wetlands		6,000	
	Ponds		1,000	
	Rivers		1,900	

BBS (2011)

for all seasons. Although there will be an increase in temperature, there will be seasonal variations and the seasons will still be distinguishable in 2030 and 2050 (Fig. 5).

Winter temperature will increase from 2 to 5 °C between the years 2030 and 2100 (Fig. 5). There will be ~1 °C, 2 °C and 4 °C temperature rises in the pre-monsoon season in years 2030, 2050 and 2100 respectively. Although the changes in monsoon and post-monsoon temperatures

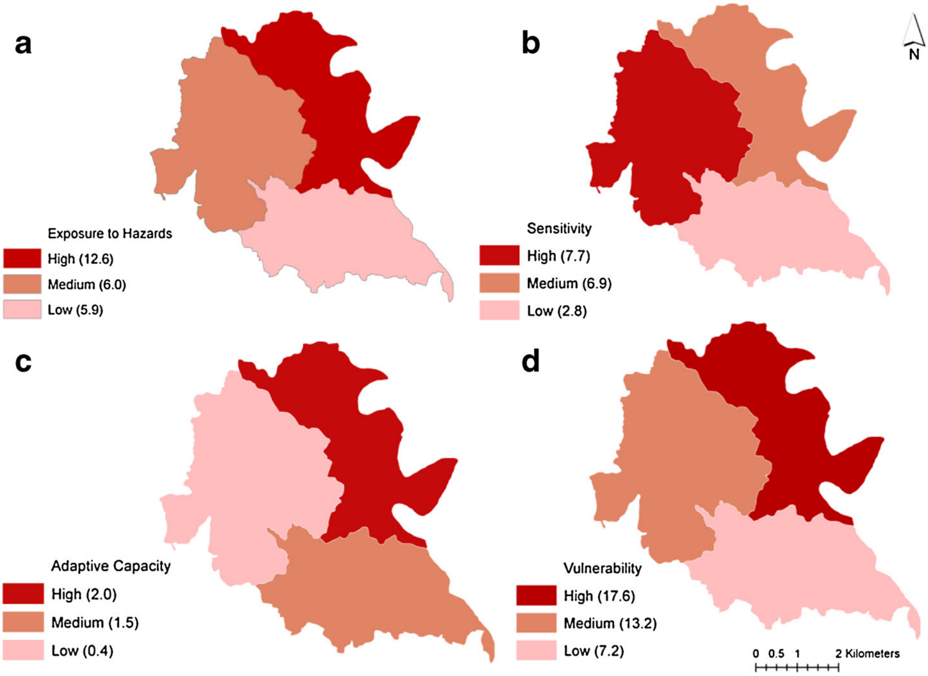

Fig. 4 Comparative vulnerability analysis (**d**) in the three administrative areas of Narail district in Bangladesh considering exposure to hazards (**a**), sensitivity (**b**) and adaptive capacity (**c**)

(1–3 °C) are not high compared to the winter and pre-monsoon seasons, these increases are still substantial because the mean temperatures will be higher (Fig. 6). An increase of ~3 °C is predicted both in monsoon and post-monsoon seasons for 2100.

During the community consultation, it was reported that, recently, rainfall is occurring more intensively within a short duration. Whereas the monsoon period usually has the peak rainfall season, observations suggest that the post-monsoon season is now showing higher rainfall

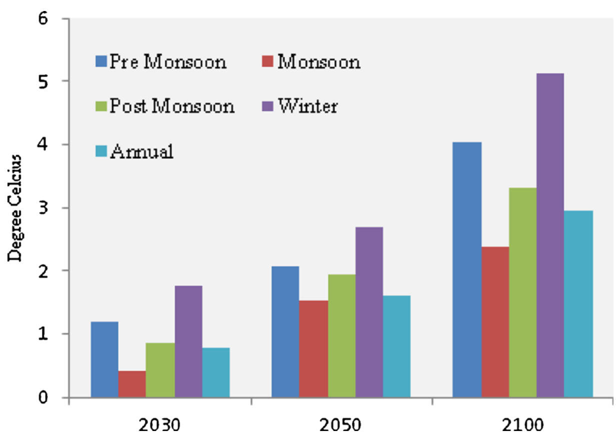

Fig. 5 Forecasted changes in Bangladesh seasonal temperature over the period 2030–2100 by using GCM models

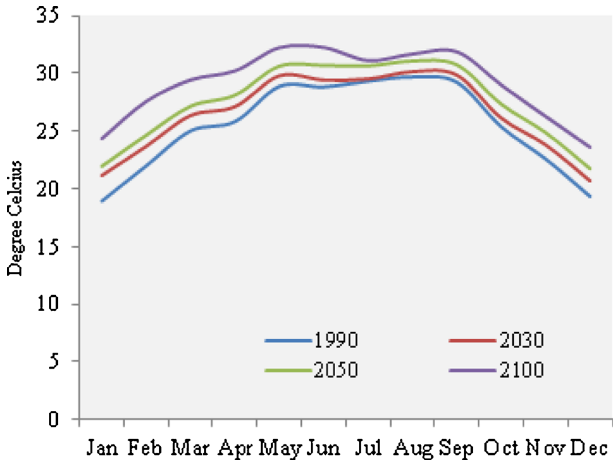

Fig. 6 Forecasted changes in Bangladesh monthly temperature over the period 2030–2100 by using GCM models

totals. GCM outputs (Fig. 7) suggest that these recent changes will continue in the future. Rainfall increases will not occur in all seasons but will occur intensively in the mid-monsoon and post-monsoon seasons, with the post-monsoon season seeing the largest increases.

Forecasted changes in rainfall show a reduction in winter by around 60 %, 10 % and 90 % in the years 2030, 2050 and 2100 respectively (Fig. 7). In contrast, changes in the monsoon and post-monsoon rainfall will show a sharp increase. There will be a 14 %, 8 % and 23 % increase in monsoon rainfall by the years 2030, 2050 and 2100 respectively. These increases in rainfall will also continue into the post-monsoon season (by 6 %, 12 % and 9 % by the year 2030, 2050 and 2100 respectively). The plausible impacts of these temperature and rainfall increases in the Narail district are summarized (Table 7) as changes in DPSIR Pressure and States.

In summary, the production of local grains (rice and wheat) is expected to decline with a projected 1–5 °C increase in temperature, which will also affect the growth of vegetables like potato. These plausible changes in provisioning services will pose a threat to the food security of the area. Where the seasonality of rainfall changes, the late monsoon may see a heightened risk of flood and water logging, while there is likely to a worsening of water availability in the dry

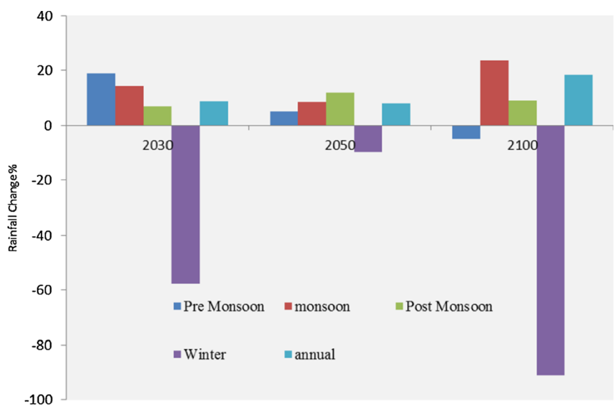

Fig. 7 Forecasted changes (%) in Bangladesh seasonal rainfall over the period 2030–2100 by using GCM models

Table 7 Possible impacts of temperature and rainfall change on pressures and states in Narail district

Climatic parameters	Change in pressure	Changes in state
Increase of 0–5 °C temperature	Flood magnitude and frequency are likely to increase (IPCC 2007b)	Increase in flood area 25–50 % for 2–5 °C (IPCC 2007b)
Change in rainfall pattern with increase of rainfallup to 20 % in monsoon, post-monsoon and pre-monsoon	Inhibition of primary production (IPCC 2001)	Enhanced evaporation demand may cause an increase in irrigation demand (IPCC 2007b)
	Changes in surface water quality and ground water characteristics (IPCC 2001)	Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change
	Increase of coastal erosion (IPCC 2001)	Low water flows are likely to decrease in many regions
	Seawater intrusion into fresh groundwater (IPCC 2001)	Soil properties and processes including organic matter decomposition, leaching, and soil water regimes will be influenced by the temperature increase (IPCC 2007b). For example, > 11 % loss of soil organic matter with a 3 °C rises in temperature (Khan et al. 2011).
	Elevated ground and water temperatures (IPCC 2001)	−35 %–30 % *Aus* yield decrease for 2–4 °C
	Increase of drought (IPCC 2007b)	−8 %–4 % *AMON* yield reduction for 2–4 °C
		−4 % *Boro* yield reduction for 2–4 °C
		−63 %–22 % wheat reduction for 2–4 °C
		(Karim et al. 1996)
		Mean temperature >20 °C will depress tuber initiation and bulking of potatoes.
		Pollen loses its viability at temperatures >36 °C (Khan et al. 2011).
		Water scarcity in wetlands and canals will lead to disruption of wetlands (IPCC 2007b)
		Increase of salinity (IPCC 2007b)
		More socio-economic damage due to flood, erosion and extreme weather events. Increased flood inundation in post-monsoon due to excessive rainfall (IPCC 2007b).

season. However, increases in temperature and salinity will increase the suitability of shrimp farming which could be attractive as an alternative livelihood, despite the evidence that this land use has already had serious negative consequences in the coastal zone.

4 Responses

Potential adaptive management responses to climate change through an integration of ecosystem services with development plans are shown in Table 8.

4.1 Mitigation and adaptation

For mitigating the drivers, population growth reduction is the only one that can be addressed directly by the Bangladesh government, because other drivers (climate change and water resource management) are dependent on international and regional scale (south Asian) policies. Thus, most

Table 8 Response framework for integrating ecosystem services and climate change in development plans. Hazards and vulnerability are summarized from the FGD and vulnerability analysis findings, where plausible impacts are summarized from the future impacts of climate change (Table 7). Finally, responses for adaptation and mitigation strategies are proposed from stakeholder consultation and the national policy review

Vulnerability Classification (hazard)	Vulnerability-Situation	Plausible impacts on Ecosystem Services	Responses
Temperature: • Rise of Temperature • Extension of Summer • Drought Precipitation • Shifting of rainfall pattern. • Sudden and intense rainfall • Abrupt changes in rainfall Flood River Erosion Water Logging Salinity	Loss of food grains production Increase in production cost. Fisheries resource reduction. Surface water salinity in dry season. Inundation of agricultural land due to water logging. Less rainfall in pre-monsoon and monsoon season is increasing dependency on irrigation water Sudden and heavy unseasonal rainfall is increasing river erosion, water logging and ultimately damaging crops, houses etc. Increase of temperature and extension of summer are decreasing water availability in river, wetland, and ponds. Salinity rise in dry season due to declining rainfall trends and temperature increase	Provisioning services: ~30 % local rice (Aus) and verities and ~50 % wheat produce reduction for 2–4 °C. Reduction of fresh water Regulatory Services: 1–5 °C temperature increase from 2010 to 2100. Intense summer and the average temperature of 30 °C over the years in 2100. 20 % rainfall increase in monsoon and post monsoon season. Rainfall shifting from monsoon to post monsoon season. Increase of flood (25–50 %) Low water flow Increase of salinity and river erosion. Supporting services: Inhibition of primary production 11 % decrease of soil organic matter for 3 °C Cultural Services: For reduction in local crops especially rice varieties, some of the cultural services (Nouka Baich, Nobanno) will be extinct.	Mitigation to Drivers • Water resource management ✓ Maintaining required water flow in dry season ✓ Construction of barrage in downstream to store the wet season water flow • Climate change mitigation • Reduction of population growth Mitigation to pressures • Dredging of Rivers • Excavation of Canals • Restoration of wetland ecosystem Adaptation to state • Fair trade policy • Stakeholder communication policy • Development of sanctuary and financial Support • Regular Maintenance of existing infrastructural • Training and creation of awareness • Fair distribution of fertilizer, seed and availability of energy for irrigation Adaptation to impacts • Increase of literacy rate and sanitation facility • Research for innovation of new variety • Fertilizer Management • Water storage (digging of wells and rain water harvesting) • Construction of road network with drainage facilities • Management of Ground Water Resource

mitigation responses will be in terms of responses to pressures, like dredging rivers and excavating canals. Char lands (new land created through river sedimentation) could be dredged to reduce the river erosion, particularly in Lohagora upazila. Excavation of the canals should be executed without widening the boundary. Silt obtained from the river dredging can be used as asset to raise the river bank and surrounding area to protect from flooding and river erosion. Community based wetland restoration, particularly the conservation of the native plants and reconnecting the wetlands and canals are recommended to enhance the water storage capacity.

Adaptive responses to changes in states can link to current vulnerability problems. For example, enhancing the water storage capacity of the water bodies, or introducing fair trade policies adjusted and monitored according to the costs of production and flood disasters in that particular year. In addition, reduction in the prices of seeds and fertilizer together with adequate supply of energy (e.g. electricity, diesel) for irrigation would help to ensure an increase the agricultural production. In this regard, replacement of electricity by solar power with increased awareness of energy-saving practices would help to provide sufficient energy for irrigation.

A policy for communicating with all stakeholders' policy is required in order to provide the guidelines for the design and implementation of development projects. For example, communities have reported not only the conflicts between indigenous fishermen groups and new migrants, but also the conflicts within existing development projects because of the lack of communication and right of access to information.

With regards the fisheries, regular monitoring and maintenance of the existing infrastructure (e.g. sluice gates) in this area are recommended rather than new physical interventions. Sanctuary development could be an important option for enhancing the fisheries production. Catching fish in the breeding months (April and May) should be prohibited, and within that period, artificially propagated local fish varieties could be released to the wetlands. Financial support for the fishermen during the prohibition period would be needed in order to promote this management programme.

Training in new techniques and raising environmental awareness can enhance the capacity of farmers and fishermen. It is known that a lack of literacy caused fishermen to provide erroneous information in the 2008 voter list, to their disadvantage. Even, the sanctuary development programme will not be successful without developing the fishermen's capacity to use different techniques.

In fact, while specific adaptation options can be recommended for coping with future impacts, the longer term ability of local communities to adapt lies with raising levels of adaptive capacity through on-going learning from the adaptation options.

A general increase of literacy will enhance the capacity of the people not only to find alternative livelihood options, but to use alternative technologies to cope with the impacts of climate change. For example, the increasing frequency of flood and water logging poses severe health risks if conventional sanitation arrangements are not replaced with newly designed sanitary latrines. Not only are regional and national research institutions needed to design new rice varieties, but they need to provide guidelines for fertilizer management and the use of organic fertilizer.

Low cost technologies like rainwater harvesting and digging wells should be offered as alternative options by which excess water in the wet season may be stored for use in the dry season. Scientific advice about the management of ground water resources through setting minimum distances between tube wells could help reduce the stresses on ground water resources. With both these options, excess water can be used as an asset for people as well as the natural ecosystems.

5 Discussion

Our vulnerability analyses underline the importance of addressing potential adaptation and mitigation measures at several scales. Indirect mitigation measures are available to the local population, for example, increasing the water holding capacity of rivers, wetlands and canals by dredging. Many other suggested responses (e.g. raising literacy; improving sanitation) are already part of on-going development processes, emphasizing the identified need (e.g. Adaptation Knowledge Platform 2013) to include adaptation responses as an integral part of regular development. Increasingly this process will have to take into account local economic policy. For example, many farmers currently suffer through the lack of a fair price for their produce, and similar situations exist for other areas of Bangladesh (e.g. IFPRI 2013). Moreover, increasing imports of rice (Reuters 2011) may be demotivating farmers in the long run, as we found among jute farmers. Extending a fair trade policy is therefore essential to maintain the livelihood of the farmers. Thus, although general mitigation and adaptation responses are recommended on the basis of stakeholder meetings, experts' interviews and national policy guidelines, the future implementation of actions will need to address the immediate social, economic and ecological conditions.

The exceptions are those mitigation measures that address large scale, international impacts. The mitigation of upstream water discharge and regional climate change is only possible through wider international control and negotiation. Yet, water discharge continues to decline even after negotiations between India and Bangladesh 1977 and 1996 sought to reconcile the resource conflict (Hossain 1998). The proposed construction of a new barrage in the downstream part of the deltaic system would help reserve water for use in dry season and also could provide~160 MW electricity (The Daily Star 2010; The Financial Express 2010; bdnews24 2010). However attractive, new initiatives would be necessary to maintain water discharge in the long term, and the current negotiation processes need to be improved in order to meet the increasing water demand in the dry season.

This study is limited to the quantification of provisioning services and has not attempted to quantify services like cultural and habitat services due to lack of data. We have overcome this limitation by using the qualitative information collected from the FGD and the quantification of provisioning services to establish the relation between ecosystem and livelihood, and these are intensively dependent on provisioning services (MA 2005). In the absence of a weather station in the study area, we analyzed the nearest weather station climate data, and we used community perceptions for mapping the spatial dimension of climatic hazards.

Our methodology could be further developed by including land use change patterns from remote sensing as a basis for understanding better the link between ES and hazards. Palaeoenvironmental records could be used to give temporal records of ecosystem processes and regulating services, like terrestrial biodiversity, water quality and soil stability (Dearing et al. 2012). Modelling of future flood extremes would significantly extend the vulnerability analysis but we have demonstrated that an integrated approach to ES and climate change provides a useful basis on which to identify adaptation and mitigation measures.

The methodology could be applied to adaptation planning and monitoring at the national level and vulnerability analysis, especially as most of previous vulnerability studies (Krishnamurthy et al. 2011a; Ahsan 2010; Krishnamurthy et al. 2011b) have not linked climate change and ES. Where ES have been considered (e.g. Metzger et al. 2006) these have been limited to land use change and farmers livelihoods. Therefore, integrated and comprehensive vulnerability analyses should become an important element in development plans.

6 Conclusion

Climate change, population growth and regional environmental change in the form of the Farraka Barrage are the major drivers which invoke pressures on the Narail district wetlands by increasing risks of flood, river bank erosion, low water availability and the changes in temperature and precipitation. The area experienced massive scale damage in floods of 1987, 1988 and 2007 yet water discharge has declined over the period 2000–2010. Declining rainfalls (21 mm/season/yr) and the increase in mean temperature (0.39 °C/yr) in the pre-monsoon season suggests that the dry season is has faced a growing water crisis since 1990. In contrast, the wet season has become warmer and wetter since the 1990s.

We determined 3 types of provisioning services which include 28 types of different crops, are obtained from this wetland. This ecosystem provides around 235,000 t rice, 4,000 t of fish and others, and these are the sources of income for around 30,000 farmers and fishermen contributing to the food security of ~7000 inhabitants of Narail district. Income from the provisioning services enables them to celebrate cultural festivals. The quantification of provisioning services and the qualitative assessment of social information indicate a direct and strong relationship between ES and livelihood.

Vulnerability analysis shows that within the Narail district, Lohagora upazila has the highest levels of vulnerability, particularly to river erosion and flooding. However, all three upazila are similarly exposed to hazards and particularly affected by variations in temperature and precipitation.

The GCM outputs indicate that there will be an extended and intense dry season by 2100. Seasonal variation is likely to remain distinguishable until 2050. GCM outputs also suggest that rainfall will occur intensively in mid-monsoon and post-monsoon seasons, increasing the risk of river bank erosion and flood, whereas dry season water scarcity will increase salinity, pressures on irrigation water and a reduction in fresh water availability. The increasing temperature (up to 5 °C) is likely to reduce crop production yield and soil health.

Mitigation and adaptation responses are interlinked with regular development activities to cope with climate and other environmental changes, but an increase in the water holding capacity of rivers, wetlands and canals by dredging is urgently required.

The modified DPSIR model in this study might be helpful for the adaptation planning and monitoring in Bangladesh, and has potential in other data-poor areas where there is a strong relationship between ES and human livelihood. It is increasingly recognized that development should incorporate ES and this methodology provides a useful means for integrating ES-based adaptation and vulnerability analysis.

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