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Developing an empirical model for climate change adaptation in river management planning using DPSIR framework at Nabaganga river of Narail district, Bangladesh

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Abstract: This study investigated the integration of ecosystem services and climate change adaption in river management planning in Bangladesh. The research was carried out in the selected villages with high vulnerability to climate change, namely Lohagara, Kalachandpur of Lohagara upazilla, Gazirhat of Kalia upazilla, Narail. The survey was conducted by collecting the data from both primary and secondary sources. For collecting primary data, different methods had been adopted including informal interview, a semi-structured questionnaire survey and Focus Group Discussion (FGD). Present study modified the DPSIR framework to add connection that allow for the integration of ecosystem services and climate change responses in future management plan. In this study, temperature and precipitation, changes in water level of the river from 1982 to 2020, rainfall pattern from 1984-2021 and yearly salinity level series of the river from 2014-2021 were analyzed for assessing the climate change impact on river ecosystem. The changes in fish species diversity were also interpreted in this study and observed that 41 species were available in 2014 but now it has been reduced to 37 species. Some salinity tolerant species were found to be available recently due to salinity intrusion. In this study, present river management practice was compared with community perception by SOWL analysis. The empirical model applied in this study is intended to support adaptation planning and monitoring and can not only be used in Nabaganga River but also in other vulnerable riverine ecosystem to climate change in Bangladesh.

Keywords: Climate change, Adaptation, River management, DPSIR Framework, Nabaganga river, Narail district, Bangladesh

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1 Introduction

Climatic variability has obtained significant attention from the scientific community across the globe. The effects of global climate change are already visible in various components of the environment – sea level is rising (Ramachandran et al., 2017), glaciers are shrinking (Dyurgerov and Meier, 2000) and ice is melting faster (Gregory et al., 2004; Over-peck et al., 2006; Stroeve et al., 2007), natural disasters such as floods, hurricanes, cyclones etc. are becoming more frequent and intense (Van Aalst, 2006; Majumder et al., 2017) and there are also effects on agriculture (Mall et al., 2006; Howden et al., 2007). Rivers are contemplated as the most delicate of all the ecosystems to the negative impacts of climate change, both directly and indirectly by the combination of various stressors (Durance and Ormerod, 2007; Durance and Ormerod, 2009). Impacts of climate change will not only affect the hydrology and dynamics of the river, but also cause terrible risk to the survival and existence of a number of aquatic floral and faunal species, wild life, human population etc.

Proper management planning for adapting with the changing situation is undeniably the key challenge of this century. A lot of previous studies have focused on the conceptual framework of ecosystem-based climate change adaptation (Wertz Kanounnikoff et al., 2011; UNEP, 2009). But a very few have focused on integrating the ecosystem services and climate change responses with river management planning and recognize the vulnerabilities using DPSIR (Driver-Pressure- State- Impact- Response) framework. As being the riverine country, managing rivers properly is necessary but the problems still exist. In the past few decades, Bangladesh has made great efforts in river management but there have still many things that are out of concern. Government has overlooked its own National Adaptation Program of Action (NAPA) for designing and implementing a water resource management plan (Hossain et al., 2010). Management planning, which draws together livelihoods, ecosystem and climate change, is therefore essential. In this study, the DPSIR framework has been used to understand the ecosystem services and the climate change response for developing a management plan for Nabaganga river of Narail district in Bangladesh and obtained people's perception for effective community-based river management.

2 Materials and Methods

2. 1. Study area

This study was carried out in the Nabaganga river of Narail district. The villages vulnerable to the changes alongside of the river namely, Bordia and Gajirhat of Kalia upazila, Lohagara Lakshmipasa of Lohagara upazilla of Narail district, were selected for questionnaire-based survey.

2. 2. Target group

Fishermen and local people alongside the river at Lohagara, Laxmipasha, Kalachandpur, Bordia and Gazirhat upazilla of Narail district were observed. The minimum age of each respondent was considered to be 50 years so that they could provide more accurate information of the previous situation of the river and compare the present condition and the changes.

2. 3. Data collection

In this research, necessary information was collected through primary and secondary sources. Primary data was collected through field survey, questionnaire survey along with Focused Group Discussion (FGD) and also by interviewing the stakeholders face to face, and SOWL analysis was the key component of analysis. In case of secondary data, information was collected from different Government and Non-Government organizations, Statistical report, river management policy report, Flood Action Plan (FAP) reports, articles, published material, officials record etc. Different types of maps were collected from Bangladesh Water Development Board (BWDB) office, Narail. Fishermen's perception was used for better approximation of the changes of fish diversity. The fishermen interviewed were the residents of the villages of Bordia and Gajirhat of Kalia upazilla, Lohagara and Lakshmipasa of Lohagara upazilla, Narail district. Finally, to detect the actual factors which are responsible for fish species degeneration, the experts' opinion and choice were taken into consideration.

2. 4. Conceptual DPSIR ramework

The DPSIR (Driver-Pressure-State-Impact-Response) framework has the potential to integrate ecosystem services and climate change by identifying the pressures, current states and future impacts on ecosystem and their services due to climate and other drivers (Hossain et al., 2015). But in this study, the framework has been modified to add connection that allows for the integration of climate change responses and ecosystem services in future management plans (Figure 1). The current state is determined by assessing the vulnerability of the area to climate change. Finally, the study proposed responses for adaptation to climate and other changes.

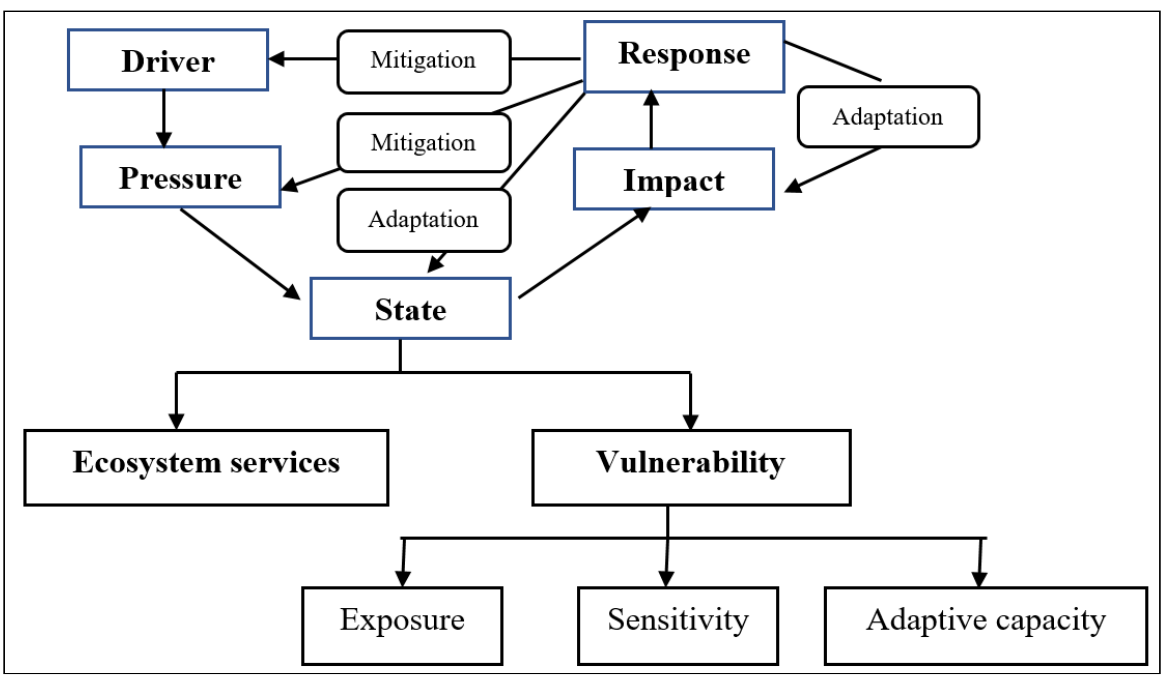


Figure 1: The DPSIR framework for the integration of ecosystem services and climate change responses for future management plans.

2. 5. Vulnerability analysis

Vulnerability assessment was carried out by developing an index:

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

Most of the data (Table 1) for the vulnerability indicators was collected from secondary sources. The spatial variability of hazards data (Table 1) was estimated using a problem matrix during the FGDs (problem matrix is in the result section).

Table 1. Indicators for vulnerability index.

Component	Profile	Input	Data sources
Exposure	Hazard	Area of flooding (km²)	DC Office
		Damage due to river erosion (number of families)	UP Office
		Temperature, precipitation, water logging, flood, erosion, cyclone, lack of irrigation.	FGD
		Salinity level (Naboganga river)	BWDB
Sensitivity	Ecosystem services	Agricultural area, forest area (ha) River area, fish production from river (metric ton per year)	DAE DFO
		Pond area, fish production from ponds	DFO
		Number of fishermen	DFO
		Area of canal (km²)	BWDB
Adaptive capacity	Infrastructure	Roads (solid, kacha and others) Embankments and sluice gates	LGED BWDB
	Socio-economic structure	Population density, educational status, population growth, urban population growth, population below poverty line, children (%), women (%), sanitary coverage, electricity coverage.	BBS

Adapted from Hossain et al. (2013); BBS- Bureau of Statistics, BWDB- Bangladesh Water Development Board, DC Office- District Commissioner Office, DFO- District Fisheries Office, DAE- Department of Agriculture Extension, FGD- Focus Group Discussion, LGED- Local Government Engineering Department, UP Office- Union Parishad Office.

2. 6. Statistical analysis

Both water level and rainfall data were analyzed by the statistical trend analysis in MS-Excel. Statistical linear trend analysis was done to represent the changed level over time series.

3 Results and Discussions

3. 1. River resources and problems identified by local people

3. 1. 1. Resource mapping of the river and its adjacent area

Among the natural resources in and around Nabaganga River, natural fisheries covered

35% and agricultural resources found approximately 15% (Figure 2). Besides agriculture and fisheries resources (35%), livestock (5%), ducks (10%), wildlife (5%), birds (8%), mussel (3%), snail (3%), crustaceans (8%) etc. were also found as common resources of the area (Figure 2).

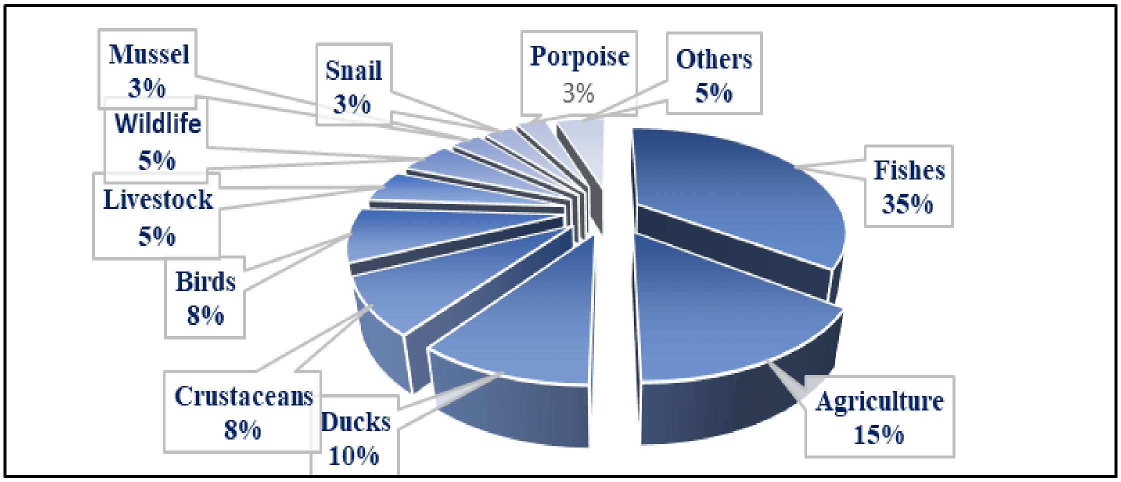


Figure 2: Resources found in and around the river (prioritized according to local people).

3. 1. 2. Problem matrix

Problem matrix was done to identify and prioritized the problems found in and around Nabaganga river. The intensity and frequency of the problem had been multiplied and then divided by the total number of participants during the FGD and are shown in Table 2. Dam, sluice gate and bridges (1) are the main problems in the river. Other problems identified and ranked were pollution (2), salinity (3), fish unavailability (4), siltation (5), water logging (6), encroachment (7), flooding (8) and river bank erosion (9).

Table 2. Problem matrix based on the problems identified and prioritized from Nabaganga River.

Sl. No.	Problems	Intensity × Frequency	Score	Rank
1	Dam/sluice gate/bridge	5×3	15	1
2	Pollution	5×3	15	2
3	Salinity	4×3	12	3
4	Fish unavailability	5×2	10	4
5	Siltation	5×2	10	5
6	Water logging	6×1	6	6
7	Encroachment	5×1	5	7
8	Flooding	3×1	3	8
9	River bank erosion	2×1	2	9

3. 2. The DPSIR framework

3. 2. 1. Drivers of change

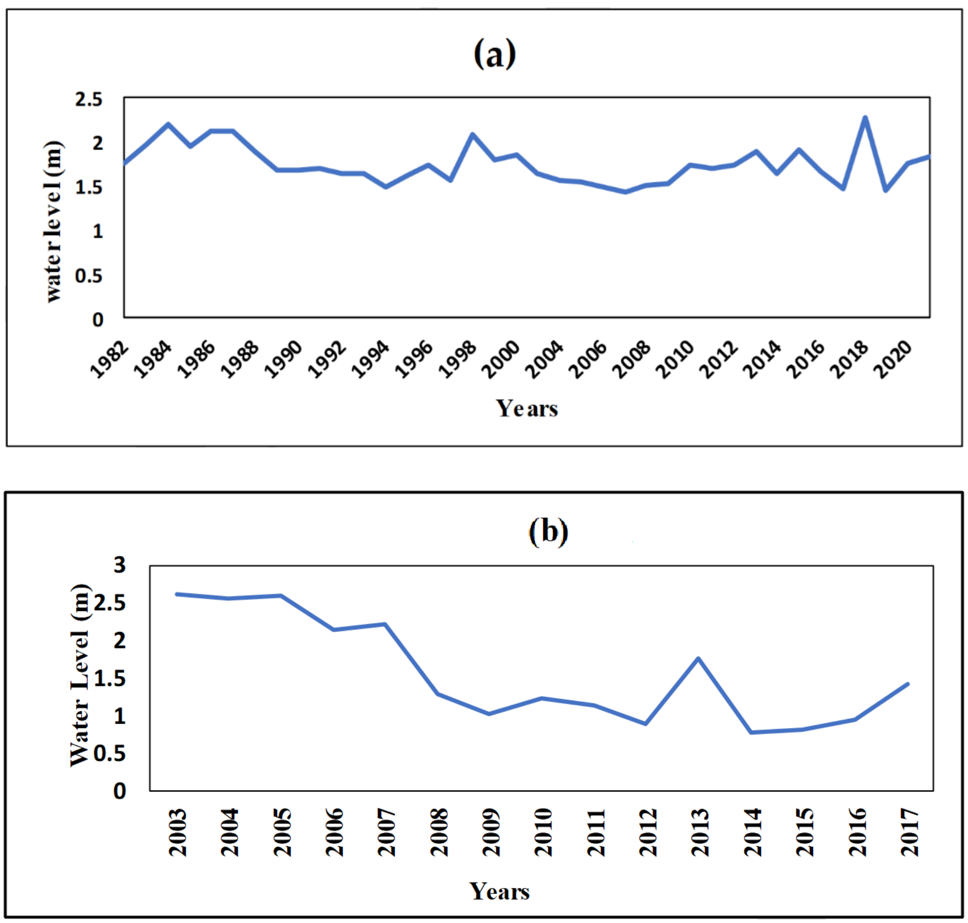
Local peoples identified the hydrological effects of the Farakka Barrage, climate change and population growth as the major drivers affecting the local ecosystems and services of Nabaganga river.

3. 2. 2. Pressures on ecosystem

Many pressures had been identified during the FGDs with the community people and the fisherfolk. Those are as follows:

3. 2. 2. 1. Low water flow

Water flow in Nabaganga river was found to be decreased every year. According to the opinion of local people, the water flow had been reduced since 10 years. Data collected from three stations: Kalachandpur, Lohagara and Gazirhat showed the changes in water level over years. Figure 3 shows the annual and Figure 4 shows the monthly water level changes of the river collected from three stations namely Lohagara, Kalachandpur and Gazirhat. The annual water level showed the decreasing trend of water level over the years. A significant change was found in Lohagara station where the water level was reduced at a regular manner but the other water level stations exhibited some irregularity.



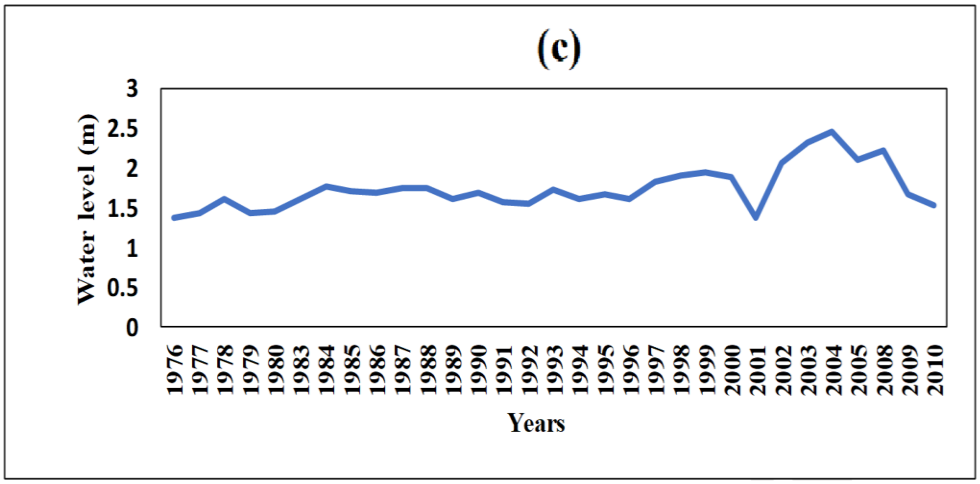
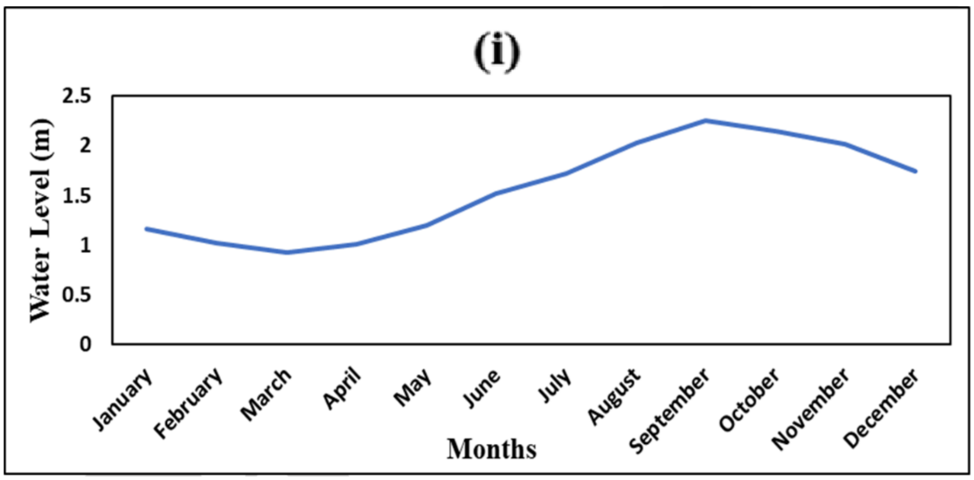
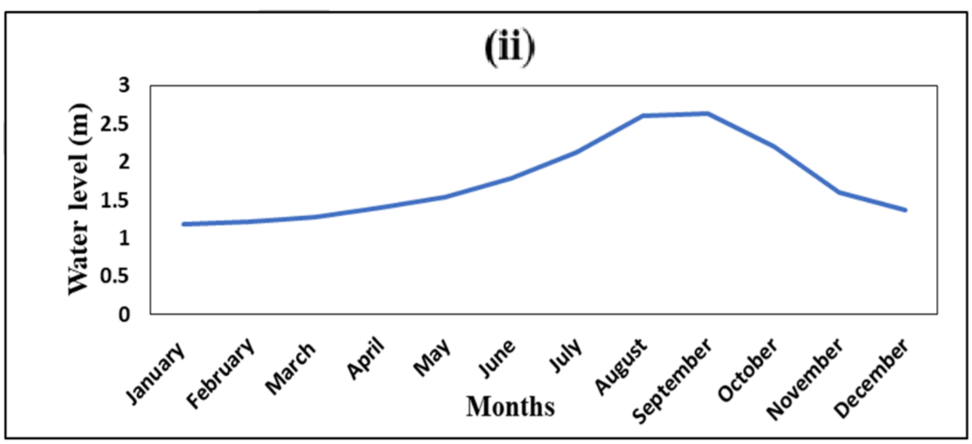


Figure 3: Annual water level changes of Nabaganga river of three stations namely Kalachandpur (a), Lohagara (b) and Gazirhat (c). [Data source: BWDB (Bangladesh Water Development Board)].





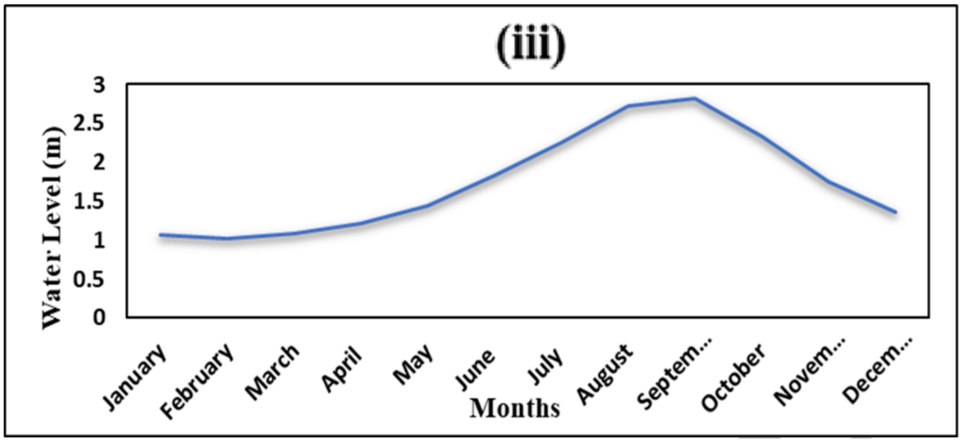


Figure 4: Monthly water level changes of Nabaganga river of three stations namely Lohagara (i), Gazirhat (ii) and Kalachandpur (iii). [Data source: BWDB (Bangladesh Water Development Board)].

3. 2. 2. 2. Temperature and precipitation

Decadal temperature data were collected from the published information of Hossain et al. (2013) and are presented in Table 3. Overall temperature was increased from 0.39 °C to 0.79 °C in the time period of 1970–2007. Monsoon temperature was increased by 1°C within the past 60 years. Temperatures were declined in the 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.

Table 4. Decadal temperature change (°C) over the period 1948–2007 in Narail, Bangladesh. (Adopted from Hossain et al., (2015))

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

Monthly and annual rainfall data was collected from Bangladesh Water Development Board, Jashore. Data was available from 1984 to 2021. It had been observed that the rainfall patterns were changing over the years. It could be seen from Figure 5 that there were no significant changes occurred in rainfall patterns from 1984 to 1991. But in recent years the intensity of rainfall has been increased. From 2019, the rainfall increased at a significant rate in Narail district. From the monthly rainfall distribution data, it has been found that July had the highest and January had the lowest precipitation.

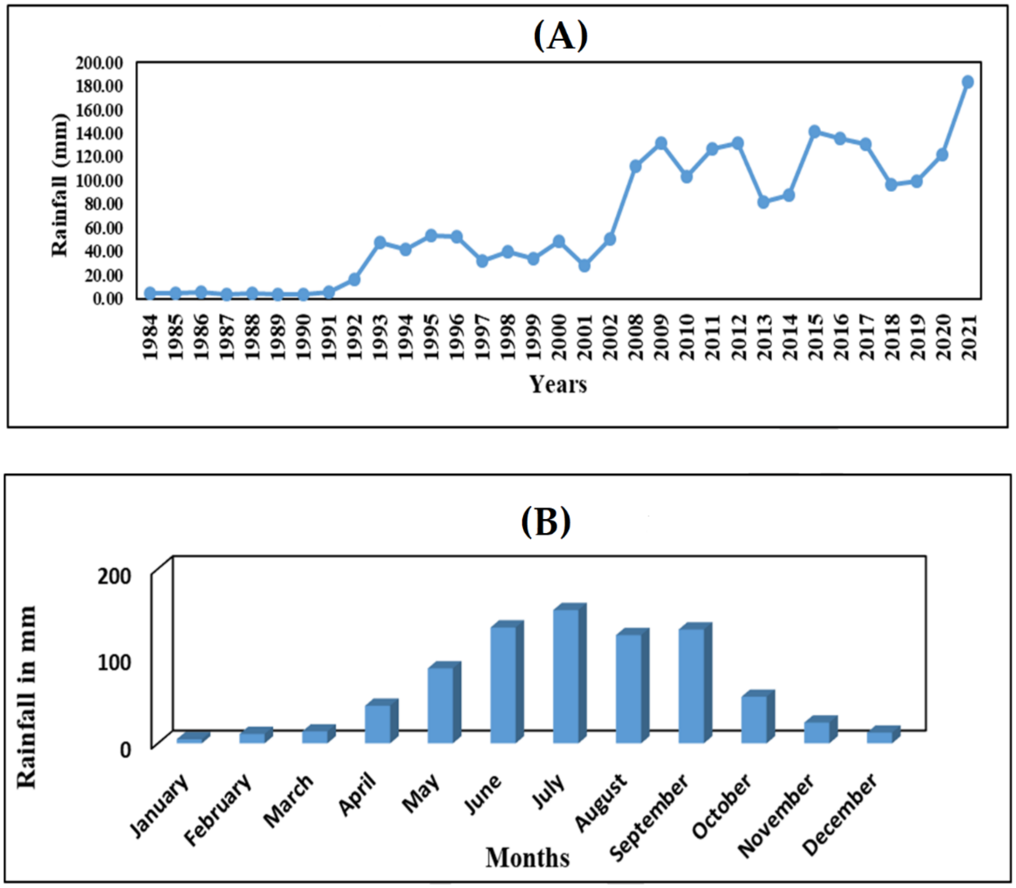


Figure 5: Annual (A) and Monthly Rainfall Change (B) (mm/day/yr) Over the Period 1984–2021 in Narail, Bangladesh.

3. 2. 2. 3. Assessment of changes in the salinity

Salinity is the third main problem identified by the community people. The yearly salinity level series of last 7 years (Figure 6) were considered for the analysis of salinity level. Salinity data were collected from Bordia station of Narail district. It is shown that the salinity level ranged approximately from 0.5 to 4.14 ppt.

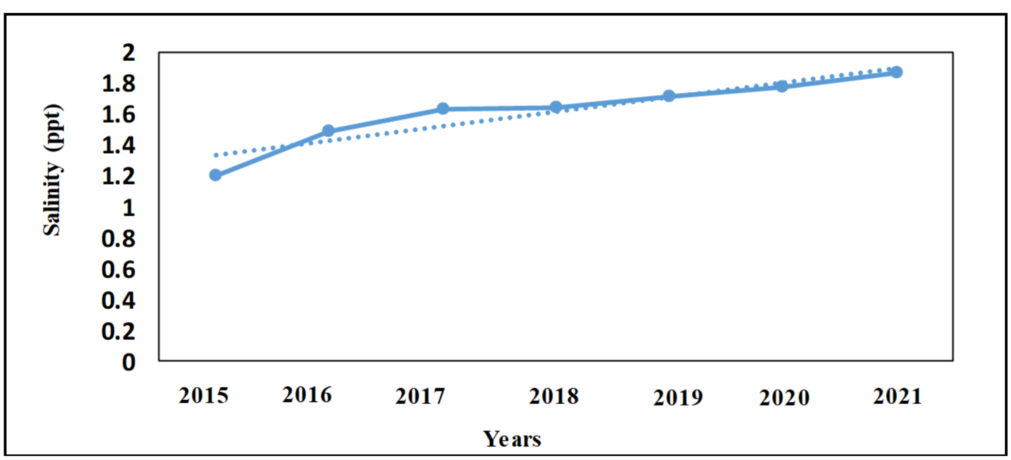


Figure 6: Yearly salinity level series of Nabaganga River, Narail.

3. 2. 3. State of ecosystem

3. 2. 3. 1. Vulnerability index

Comparative vulnerability analysis (Figure 7) was done considering exposure to hazards, sensitivity and adaptive capacity in three administrative areas of Narail district (Lohagara, Kalia and Narail sadar upazilla) to identify which area is most vulnerable to exposures.

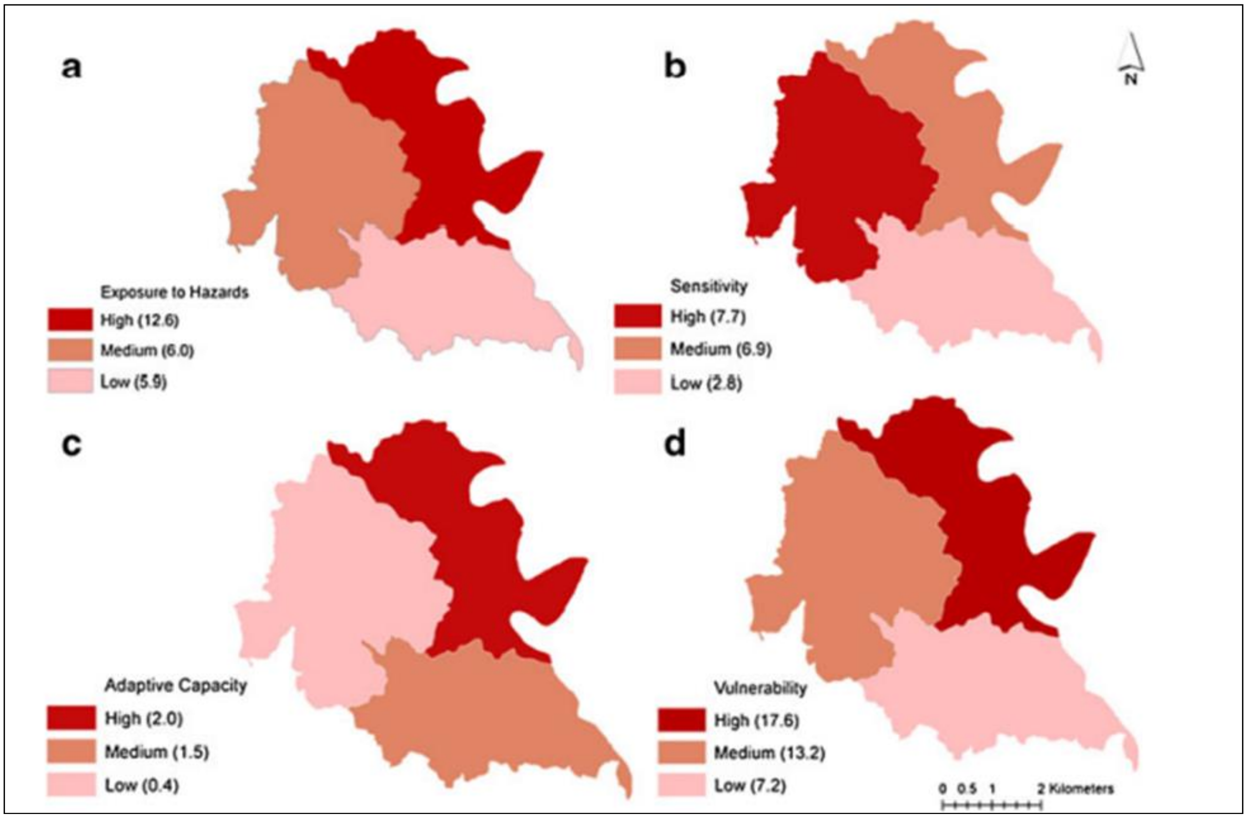


Figure 7: Comparative vulnerability analysis (d) in the three administrative areas of Narail district (Lohagara, Kalia and Narail Upazilla) in Bangladesh considering exposure to hazards (a), sensitivity (b) and adaptive capacity (c).

Maps of the aggregated vulnerability index showed that Lohagara upazila had the highest levels of risk exposure (Figure 7a), twice as high as Kalia and Narail Sadar. Although it had a high adaptive capacity (Figure 7b), Lohagara had high sensitivity (Figure 7c), making it as the most vulnerable area (Figure 7d) to hazards.

3. 2. 4. Impacts

3. 2. 4. 1. Impacts on icthyodiversity

Data collected from the subsistence and commercial catches of local fishermen and market survey revealed that the river Nabaganga has 37 fish species from 35 genera and 16 families (Table 5). The specimen was sorted out with the help of the fishermen. Availability of freshwater species was reduced and 16 species were in vulnerable condition in 2000 (Islam et al., 2016). Those 16 vulnerable species were *Brachydanio rerio*, *Danio devario*, *Esomus danricus*, *Labeo rohita, Puntiu sconchonius, Puntius sophore, Rasbora daniconius, Ailia coila, Wallago attu, Colisa fasciata, Mastacembelus pancalus, Notopterus notopterus, Monopterus cuchia, Chelonodon fluviatilis, Oryzias melanostigma* and *Aplocheilus panchax*. In 2014, it has been observed that 6 species of this vulnerable group became disappeared. Those disappeared fishes were *Puntius conchonius, Puntius sophore, Ailia coila, Colisa fasciata, Mastacembelus pancalus* and *Notopterus notopteru*. Abundance of only 7 species have been found to be increased like *Lates calcarifer, Penaeus monodon, Notopterus chitala, Aorichthys seenghala, Aorichthys aor, Salmostoma phulo, Salmostoma bachaila* because these are saline water-friendly species.

Table 5. Fish species diversity.

Family	Bangla name	English name	Scientific name	NH	Status	BG	RG	TG
Ambassidae	Chanda	Elongate glassy perchlet	*Chanda nama*	RS	Ci	RB	Pl	O
	Lal Chanda	Indian glassfish	*Chanda ranga*	RS	Ci	RB	Pl	O
Anabantidae	Koi	Climbing perch	*Anabus testudines* (Bloch)	FS	C	FB	Ph	I
	Kholisha	Giant Gourami	*Colisa fasciata* (Bloch & Scheinder)	FS	C/R	FB	Nb	I
Bagridae	Aire	Bagrid catfish	*Aorichthys aor* (Hamilton)	MS	C	RB	Nb	C
	Guizzaaire	Bagrid catfish	*Aorichthys seenghala* (Sykes)	MS	C	RB	Nb	C
	Bujuri tengra	Bagrid catfish	*Mystus tengra* (Hamilton)	FS	C	FB	Pl	C
	Tengra	Striped dwarf catfish	*Mystus vittatus* (Day)	RS	Ci	RB	Ph	P
	Gulsha tengra	Striped drawf catfish	*Mystus bleekari* (Day)	RS	Ci	RB	Ph	P
Channidae	Taki	Snakehead	*Channa punctatus* (Bloch)	FS	C	FB	Gr	C
	Shol	Snakehead	*Channa striatus* (Bloch)	FS	C	FB	Gr	C
Clariidae	Magur	Walking catfish	*Clarias batrachus* (L.)	FS	C	FB	Pl	D
Clupeidae	Chapila	Herring	*Gudusia chapra* (Hamilton)	MS	Ci	RB	Br	P
	Hilsha	Hilsha shad	*Tenualosa illisha* (Hamilton)	MS	Ci	RB	Br	P
Cyprinidae	Mola	Minor carp	*Amblypharyngodon mola* (Hamilton)	FS	Ci	FB	Ph	P
	Catla	Major carp	*Catla catla* (Hamilton)	MS	C	RB	Br	P
	Mrigel	Major carp	*Cirrhinus mrigala* (Hamilton)	MS	C	RB	Br	B
	Chebli	Minor carp	*Danio devario* (Hamilton)	FS	NC	FB	Ph	O
	Darkina	Flying barb	*Esomus danricus* (Hamilton)	FS	NC	FB	Ph	O
	Rui/ Rohu	Major carp	*Labeo rohita* (Hamilton)	MS	C	RB	Br	P

Family	Bangla name	English name	Scientific name	NH	Status	BG	RG	TG
Cyprinidae	Jaitpunti	Barb	*Puntius sophore* (Hamilton)	FS	C/R	FB	Ph	O
	Tit punti	Tic-tac-toe barb	*Puntius ticto* (Hamilton)	FS	C	FB	Ph	O
	Vhangon bata	Bata labeo	*Labeo bata* (Hamilton)	RS	NC	RB	Ph	H
	Ghonia	Kuria labeo	*Labeo gonius* (Hamilton)	RS	NC	RB	Ph	H
	Katari	Minor carp	*Salmostoma bacaila* (Hamilton)	MS	C	RB	Br	O
	Phul chela	Minor carp	*Salmostoma phulo* (Hamilton)	MS	C	RB	Br	O
Gobiidae	Baila/ Bele	Tank goby	*Glossogobius giurus* (Hamilton)	FS	Ci	RB	Ps	C
Heteropneustidae	Shing/ Shingi	Stinging catfish	*Heteropneustus fossilis* (Bloch)	FS	C	FB	Pl/ Gr	D
Latidae	Koral/ Vetki	Barramundi/Seabass	*Lates calcarifer* (Bloch)	BS	Ci	MB	Nb/Gr	D
Mastacembelidae	Guchi	Spiny eel	*Mastacembelus pancalus* (Hamilton)	FS	C/R	FB	Ps	B
Notopteridae	Chitol	Featherback	*Notopterus chitala* (Hamilton)	MS	C/R	RB	Nb/Gr	C
	Foli	Featherback	*Notopterus notopterus* (Hamilton)	FS	C	RB	Nb/Gr	C
Palamonidae	Galda chingri	Giant freshwater prawn	*Macrobrachium rosenbergii* (Fabricius)	MS	Ci	MB	Nb/Gr	D
Penaeidae	Bagda chingri	Giant tiger shrimp	*Penaeus monodon* (Fabricius)	MS	Ci	MB	Nb/Gr	D
Siluridae	Pabda	Butter catfish	*Ompok pabda* (Hamilton)	MS	C	FB	Pl	C
	Buali pabda	Butter catfish	*Ompok bimaculatus* (Bloch)	RS	Ci	RB	Pl	O
Synbranchidae	Kuchia	Gangetic mud eel	*Monopterus cuchia* (Hamilton)	FS	NC	RB	Ps	C

Abbreviation: B = Benthivore, BC = Brood Career, BG = Breeding Group, BC = Broad Caster, C = Carnivore, Ci = Commercial, D = Detritivore, EB = Estuarine breeders, FB = Floodplain Breeders, FS = Floodplain species, Gr = Guarders, H = Herbivore, I = Invertivore, Lb = Live bearer, Li = Lithophils, M = Molluscivore, Mb = Mouth brooders, MB = Marine Breeders, MS = Migratory species, (MS = Marine species), NC = Non-commercial, Nb = Nest builders, NH = Natural Habitat, O = Omnivore, P = Planktivore, Pe = Pelagophils, Ph = Phytophils, Pl = Phytolithophils, Ps = Psammophils, R = Rare/threatened species, RB= Riverine breeders, RG= Reproductive guild, RS= Riverine species, BS= Brackish water species, TG = Trophic guild.

3. 2. 5. Responses

Potential adaptive management responses to climate change through an integration of ecosystem services with management planning of the river are shown in Table 6. In this table, mitigation and adaptation strategies were also shown with the existing hazards and plausible impacts on ecosystem services. The responses included - mitigation to drivers, mitigation to pressures, and adaptation to the state of ecosystem and adaptation to the impacts.

Table 6. Response framework for integrating ecosystem services and climate change in river management planning.

Vulnerability classification (Hazards)	Vulnerability situation	Plausible impacts on ecosystem services	Responses
Temperature: • Rise of temperature. • Extension of summer. • Drought	• Fisheries resource reduction. • Surface water salinity in dry season. • Inundation of agricultural land due to water logging.	Reduction of fresh water.	**Mitigation to drivers:** **1.** River management. **2.** Climate change mitigation. **3.** Maintaining required water flow in dry season
Precipitation: • Shifting of rainfall pattern. • Sudden and intense rainfall. • Abrupt changes in rainfall.	Sudden and heavy unseasonal rainfall is increasing river erosion, water logging and ultimately damaging crops, houses etc.	20 % rainfall increase in monsoon and post monsoon season.	**Mitigation to pressures:** **1.** Dredging of River. **2.** Excavation of Canals. **3.** Restoration of riverine ecosystem.
Flood **River erosion** **Salinity** **Water logging**	• Increase of temperature and extension of summer are decreasing water availability in river. • Salinity rise in dry season due to declining rainfall trends and temperature increase.	• Rainfall shifting from monsoon to post monsoon season. • Low water flow. • Increase of salinity and river erosion.	**Adaptation to state:** **1.** Fair trade policy. **2.** Stakeholder communication policy. **3.** Development of sanctuary and financial Support. **4.** Regular Maintenance of existing infrastructural. **5.** Training and creation of Awareness.
			Adaptation to impacts: **1.** Increase of literacy rate and sanitation facility. **2.** Research for innovation. **3.** Construction of road network with drainage facilities.

3. 3. Developing a new concept by comparing existing river management strategies through SOWL analysis

The SOWL (Strength, Opportunity, Weakness and Limitation) analysis of the river management during FGD suggested that river management should be changed from project-based manner to the resource-oriented manner, with special emphasis on ecosystem conservation. Table 7 showed the strength, opportunity, weakness and limitations of the present river management practices. it had been observed from Table 7 that present river management analysis of Bangladesh are mainly infrastructure and project based where lack of co-ordination and co-operation is one of the main weaknesses. The limitations involved the changes in riverine biodiversity as most of the decisions were made without any consultation of local people. Table 8 gives an over view of the strength, opportunity, weakness and limitations of community-based river management. It was found that there were some limitations and weakness like conflicts among local people, public awareness problem and lack of education must have a negative effect on the process implementation. But with the help of government and various community-based NGO's, these constraints could be mitigated.

Table 7. SOWL analysis of present river management.

Strength	Various infrastructure buildings like dam, sluice gate, bridges etc.
Opportunity	Irrigation facilities with river erosion and flood control measures.
Weakness	Low water flow, less fish production, water logging problem, siltation, salinity intrusion, lack of proper maintenance, lack of co-ordination and co-operation and poor water management policies.
Limitations	Decisions were taken without any consultation of local people, changes in the biodiversity were not considered.

Table 8. SOWL analysis of community based river management.

Strength	River management is conducted with the consultation of local people
Opportunity	Proper management of river, higher agricultural facilities, higher rate of fish production, no waterlogging problem, employment of local people, all the water management policies will be incorporated and maintained.
Weakness	River management related conflict among local people
Limitations	Public awareness problem, lack of proper education and training.

4 Conclusion

The study developed a methodology which, provides a useful means for integrating ecosystem service-based vulnerability adaptation and mitigation. The modified DPSIR model in this study was helpful for specifying the main drivers and pressures on Nabaganga river ecosystem. Declining rainfalls (21 mm/season/yr) and the increase in mean temperature (0.39 °C/yr) in the pre-monsoon season suggested that the dry season faced a growing water crisis since 1990. In contrast, the wet season has become warmer and wetter since the 1990s. Vulnerability analysis showed that within the Narail district, Lohagara upazila had the highest levels of vulnerability, particularly river erosion and flooding. Likewise, Nabaganga River in those areas are similarly exposed to hazards and uniquely affected by variations in temperature and precipitation. Overall, the analysis revealed that proper management of river by considering the perception of local people is urgently required. Finally, there are many scopes for further understanding and research in this field. The modified DPSIR model used 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 ecosystem services and climate change responses.

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Conflict of interests

The authors have no conflicts of interests to declare that are relevant to the content of this article.

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