Transformative Adaptations to Climate Change: Cases from the Jamuna River Fishing Communities of Bangladesh

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ABSTRACT

Study on transformative adaptation to climate change is scarce despite its tremendous importance. This study assesses the transformative adaptation of fishery-based livelihoods of the Jamuna River in Bangladesh (a trans-boundary river called the Brahmaputra in India). Using interviews, focus group discussions and matrices data from two Jamuna River dependent fishing communities (Kalitola Ghat and Debdanga), this study found 80–91 % fishers in both communities have been exposed to floods, storms and riverbank erosion affecting their livelihood capitals, activities, strategies and outcomes. This study identifies five transformative adaptations: migration, building concrete house, livelihood diversification, changes in fishing gear and techniques and tree plantation. In Kalitola Ghat, 57.3 % and in Debdanga, 78 % of fishers have migrated to safer places to minimise the adverse impacts of climatic hazards. To withstand the impacts of storms and floods, in Kalitola Ghat, 5 % and in Debdanga, 6 % of fishers have built concrete houses. More fishers of Kalitola Ghat (56 %) have diversified their livelihoods than Debdanga counterparts (5 %). Around 78 % and 100 % of fishers in Kalitola Ghat and Debdanga have changed their traditional fishing gear and techniques to overcome the impacts of climatic hazards. Traditionally, the fishing communities have coped with or adapted to the impacts of climate change which are not sufficient to maintain their sustainable livelihoods. The findings of this study allow identification of the measures that could help address the impacts of current and future climate change for the fishing communities.

Keywords: Brahmaputra river, Climatic hazards, Developing country, Fisheries, Impacts, Transformational adaptation

INTRODUCTION

Based on the Global Climate Risk Index, Bangladesh is ranked the 7th most affected country in the world (Eckstein *et al*., 2018). Studies on climate change impacts and vulnerabilities have demonstrated that multiple threats of severe storms, floods, sea-level rise, extreme heat waves and droughts will create severe negative consequences for the most vulnerable countries like Bangladesh (Intergovernmental Panel on Climate Change, 2014). Climate change will jeopardize the future economic growth of Bangladesh, and as a result, it may lose 2 % of its annual Gross Domestic Product (GDP) by 2050 and 9.4 % by 2100 (Ahmed and Suphachalasai, 2014).

The continuous variability of climate and the risks of associated changes have a significant impact on fisheries, which is a global concern for the

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Received 31 August 2019 / Accepted 7 May 2020

660-820 million people who lead direct or indirect fishery-based livelihoods (FAO, 2014). In 2016-2017, the fisheries sector of Bangladesh contributed significantly to the national GDP (3.61 %), agricultural GDP (24.41 %), dietary animal protein (60 %) and foreign currency (1.51 %) (Department of Fisheries, 2018). This sector also provides employment opportunities directly or indirectly to 11 % of the 160 million people living in Bangladesh (Department of Fisheries, 2018). Societal vulnerability to climate change-associated risks might worsen the existing social and economic challenges. It is particularly vital for the fishers because of their dependence on aquatic resources and biodiversity, which are sensitive to climate change.

The impact of climate change is observed from natural to human systems. These impacts cover ecosystem changes and fish stock fluctuations (Cheung *et al*., 2009), as well as the destruction of fishery systems and land-based resources and infrastructure (Westlund *et al*., 2007), all of which potentially make fishers and their livelihoods more vulnerable. To minimise the impacts of climate change, fishers have employed some response strategies i.e., coping and adaptation strategies. Coping strategies refer to a collection of short-term responses, whereas adaptation strategies by their nature are long-term responses (Agrawal, 2010). The main difference between coping and adaptation strategies is that coping is done in the short-term, using flexible strategies that fishers often adopt to survive given their unpredictable livelihoods, whereas adaptation involves more permanent livelihood changes, and it occurs when coping strategies have been permanently incorporated into the normal cycle of activities (Coulthard, 2009).

Adaptation strategies can be classified as incremental, transitional or transformative (also termed as transformational). Incremental adaptation is a slow process which includes smaller and discrete changes within the system, whereas transformative adaptation is fundamentally different from the current situation and is considered as a broad change towards the future across many systems (Mustelin and Handmer, 2013). On the other hand, transitional adaptation is an intermediate stage of adaptation between incremental and transformative changes (Roggema *et al*., 2012). Transformative adaptation is considered as the most suitable strategy for activities like development under climate change (Roggema *et al*., 2012).

Most studies on climate change and fisheries have focussed on assessing fish abundance and distribution and the consequences to marine ecosystems, and have covered large-scale industrial fisheries (Yáñez *et al*., 2001; Cheung *et al*., 2009). Fewer studies have assessed the impact of climate change on the fisheries sector and fisheries-dependent communities at national or regional levels (Sadovy, 2005; Allison *et al*., 2009). However, the outcomes from those studies are not particularly suitable at the local or community level (Hahn *et al*., 2009). In Bangladesh, despite the escalating evidence of climate change impacts on livelihoods and socio-economic conditions of coastal fishers, the inland and freshwater fisheries sector (especially riverine fisheries) remain neglected. Recently, a study has assessed the climatic impacts and adaptation strategies of the migratory and non-migratory fishing communities of the Padma River in Bangladesh (Khan *et al*., 2018a). Some other available studies on river fisheries have focussed mainly on fish production, pollution, fish biodiversity and livelihoods of the fishers (Flowra *et al*., 2011; Khan *et al*., 2018b). In spite of critical importance, globally, study on transformative adaption has recently been started and there is a lack of evidence on this from different sectors. This study, therefore, has focussed on the impacts of climate change on the Jamuna River-dependent fishing communities and their transformative adaptation strategies with a view to minimising the impacts of climate change. The findings of this study are expected to help in developing appropriate policies and strategies to reduce the impacts of climate change as well as to reduce poverty, especially for the fishing communities.

METHODS

Conceptual framework

The Sustainable Livelihood Approach (SLA) has been used in this study as a conceptual frame because it includes all forms of livelihood capital that are influenced by climatic change. SLA also helps to sort out the exact perspective of a fisher's livelihood, which enables the identification of the impacts of climate change and their transformative adaptation strategies. The SLA, an asset-based conceptual framework, has evolved as a way of reforming poor peoples' lives after experiencing many years of changing perspectives of their poverty (Ashley and Carney, 1999). The concept of livelihoods is gaining popularity as a method of theorising the financial activities of poor people undertaken in their respective communities (Adato and Meinzen-Dick, 2003). The SLA has been used broadly and is characterised by six key factors, namely, people-centered, responsive and participatory, multi-level, conducted in partnership, sustainable and dynamic (Ashley and Carney, 1999; Department for International Development, 1999). In research and policy analyses, SLA has been widely examined and adopted (Department for International Development, 1999). It has also been used by many development partners to evaluate communities' adaptive capabilities to withstand climate change impacts (Solesbury, 2003).

The sustainable livelihoods framework encompasses five elements, as portrayed in Figure 1 (Department for International Development, 1999). This framework emphasises the application of structures and processes to react against the vulnerability context and shows linkages among the five sections (Figure 2). Since individuals' decisions and livelihood tactics might be preconceived by both apparent and real vulnerabilities, the vulnerability context incorporates trends, shocks, and seasonality. Factors affecting fishery-based livelihoods are classified into: i) vulnerability context and ii) transforming structures and processes.

Selection of study sites

For this study, two fishing communities (Kalitola Ghat and Debdanga) were selected at Sariakandi sub-district (Upazila) (Figure 3) of Bogra district, Bangladesh based on their dependency on the Jamuna River for fisheries activities and their vulnerability to climate change. The Jamuna is one of the largest rivers in the world and is a trans-boundary river called Brahmaputra in India. The study areas experience frequent climate change-induced hazards (hereafter referred to as climatic hazards) such as storms, floods, erratic rainfall, cold waves, excessive heat, riverbank erosion, etc. The total area of the sub-district is 408.50 km^2 with 75,614 households and a population of 270,719 (Bangladesh Bureau of Statistics, 2011).

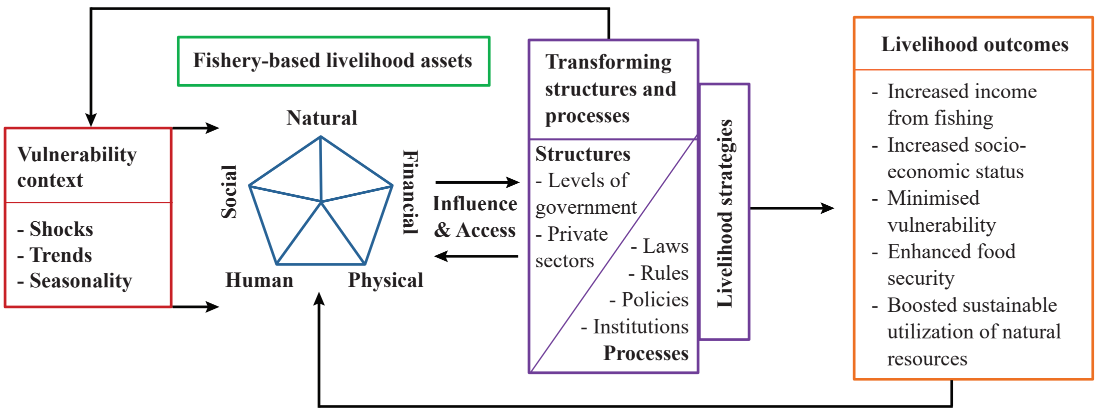

Figure 1. Sustainable Livelihood Framework for fisheries (Modified from Department for International Development, 1999).

In Sariakandi sub-district, 2,492 people are fully dependent on the Jamuna River for their livelihoods (Sariakandi Sub-district Fisheries Office, pers. comm.). A comparative description of the two fishing communities is given in Table 1. Typical settings within the two fishing communities are shown in Figure 4.

The Jamuna River plays an important role in fish production and is considered as an important breeding ground for many finfishes. In 2017-2018, 5,996 metric tonnes of fish and large quantities of carp fry were caught from this river (Fisheries Resources Survey System, 2018). However, according to the world's river system vulnerability map, the Jamuna River is considered as an extremely vulnerable river because of its braided nature (Rahman, 2010). The fourth Intergovernmental Panel on Climate Change (IPCC) Report projections for South Asia reported that monsoon rainfall will increase, which will result in increased flows in the rivers throughout the monsoon. These flows will alter flood regimes and increase riverbank erosion. Severe riverbank erosion and high rates of bank line retreat have been reported along the Jamuna River (Khan and Islam, 2003). Another study reported that recent climate change will alter the rainfall pattern, which might create a direct impact on the water capacity of the Jamuna River. The reconnaissance study also showed that climatic shocks and stresses have affected the livelihoods of both fishing communities.

Table 1. Comparative characteristics of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga in Bogra district, Bangladesh.

Criteria	Kalitola Ghat	Debdanga
Total population (no.)	490	1,050
Fishery-dependent households (no.)	70	175
Distance from Sariakandi sub-district	4 km	10 km
Religion	Mostly Muslim	Mostly Hindu
Fishers types		
Traditional (%)	57	78
Subsistence (%)	43	22
Number of fishing trips (day·year^{-1})	240	300
Number of disaster shelters	0	1
Solar facility (%)	0	11.4
Electricity facility (%)	75	80
Sanitary facility (%)	78	97
Drinking water facility (tube-well) (%)	89	92
Medical facility in the community (hospital or clinic or pharmacy)	Absent	Absent
Income per day (USD*) (mean)	3.9	6.3
Number of School (primary)	1	1
Transportation system	Poor	Poor

Note: *USD 1 = BDT 84.45 (Date: 14 April 2020)

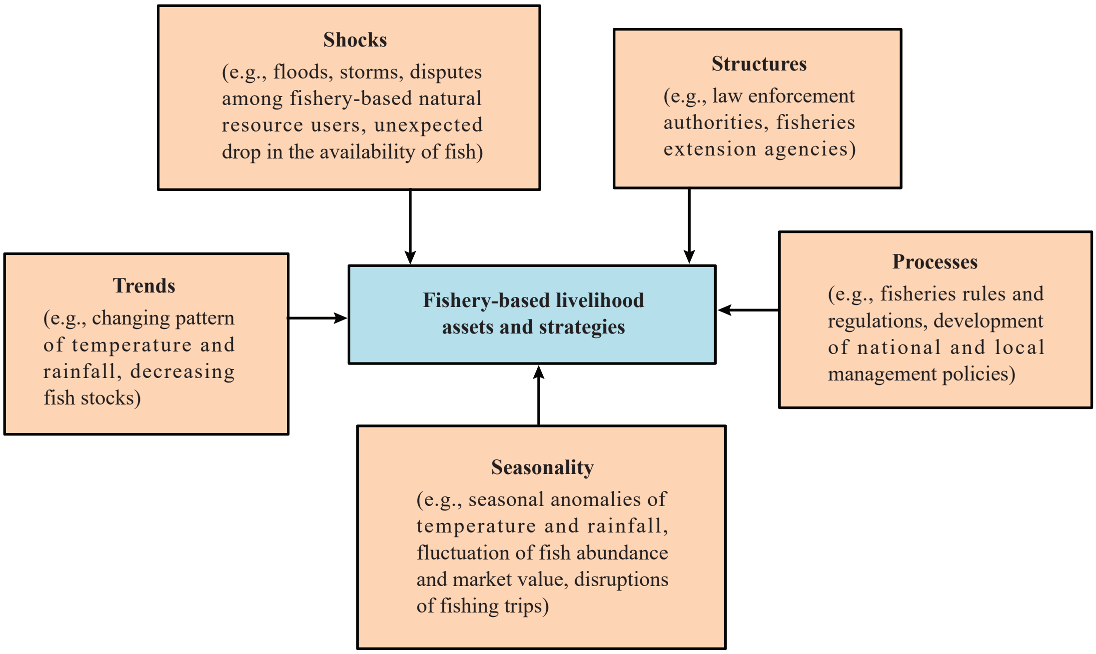

Figure 2. Factors affecting fishery-based livelihood assets and strategies (Modified from Islam *et al*., 2014a).

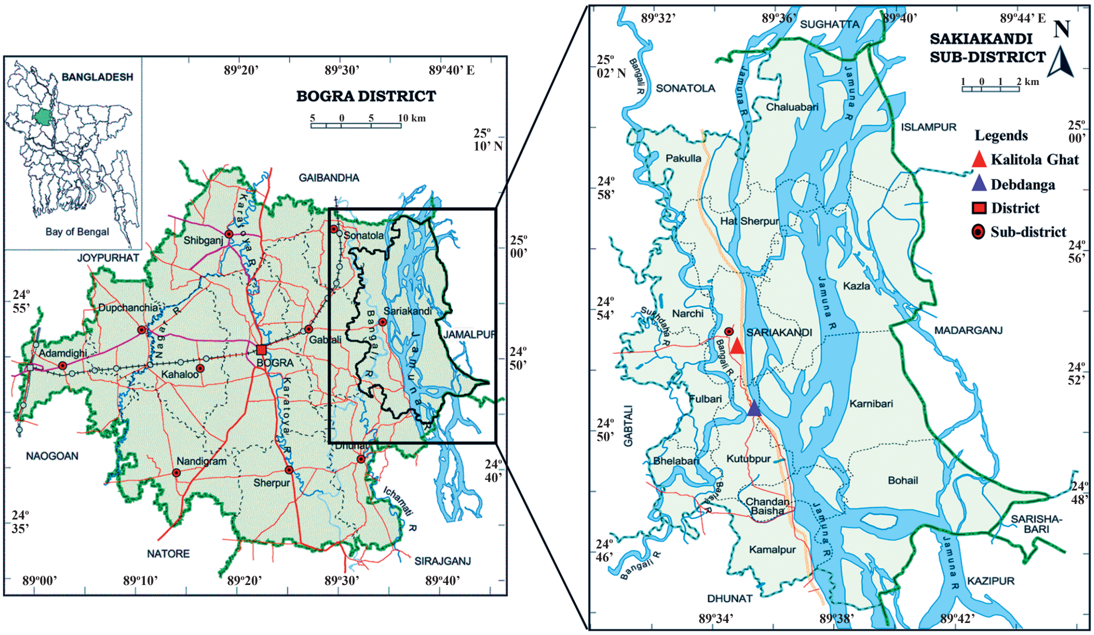

Figure 3. Map of the study sites within Sariakandi sub-district of Bogra district, Bangladesh.

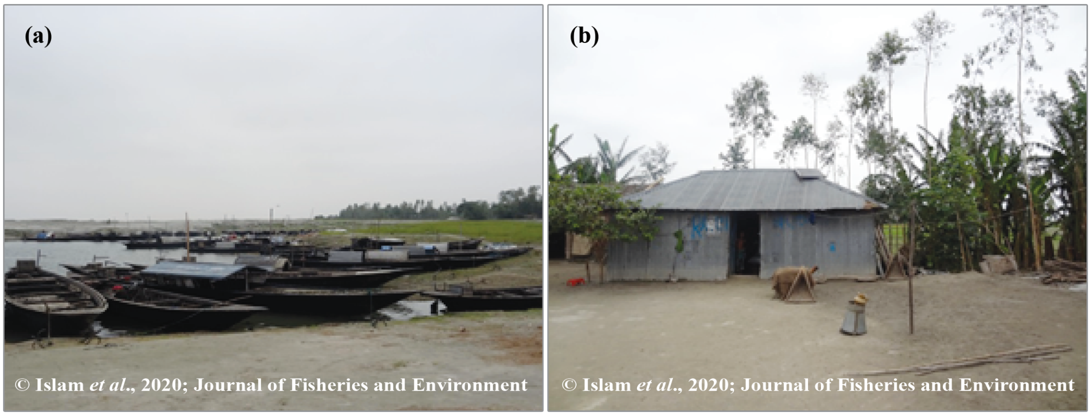

Figure 4. Photographs of the study sites: a) fishing boats are moored at Kalitola Ghat and b) a typical fisher house in Debdanga, Sariakandi sub-district, Bogra district, Bangladesh.

Data collection and analysis

In this study, a list of fishery-dependent households in Sariakandi sub-district was collected from the sub-district fisheries office. The respondents (35 fishers in Kalitola Ghat and 50 fishers in Debdanga) for semi-structured interviews were selected using simple random sampling from the list. Quantitative and qualitative data were collected from primary and secondary sources between May and December, 2015. Primary data were collected from the fishery-dependent households by using a mixed-method approach (Table 2).

The semi-structured interviews were conducted for preliminary assessment of the fishers' socio-economic conditions that could potentially be influenced by climatic hazards. A cluster analysis was done for a preliminary assessment of the two fishery-dependent communities (Table 3). In this study, household heads were interviewed because they have practical experience regarding their household's vulnerability, security and livelihood. A list of all livelihood capital of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga is given in Table 4.

Five focus group discussions (FGDs) were conducted in two phases: during the scoping study phase (to develop research objectives and methodology) and during the main data collection phase (to gather data on fishers' livelihood vulnerability and their transformative adaptation strategies to minimise or overcome the impact of climate change). Each FGD consisted of 7-8 household heads and continued for about 2.5-3 h.

A total of four impact matrices were conducted in each community and each group consisted of 6 to 8 household heads to elucidate how fishers' livelihoods were impacted by climate-related factors. For impact matrices, the methodology developed by Dazé *et al*. (2009) was used after adapting to the local context. Each group prepared an impact matrix on a sheet of paper. The group members identified five important resources for their livelihoods and then wrote them horizontally on the top of the matrix on the paper. The fishers were also requested to identify climatic hazards that affected their livelihoods, and the hazards were written vertically along the left side of the matrix. After that, fishers were asked to rank the climatic hazards based on impacts on their resources on a scale of one to five, where 5 = significant impact, and 1 = no impact. The members of each group were also asked to explain how the climatic hazards affected their livelihoods and what the strategies would be to respond against those hazards. Particular emphasis was given on the transformative adaptation strategies.

Table 2. Summary of methods used for data collection from the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga, Bogra district, Bangladesh.

Data collection tools	**Sample size**	**Data types**
Semi-structured interview	Total 85 (35 in Kalitola Ghat and 50 in Debdanga)	- Livelihood status of household heads - Impacts of climate change on fisheries and households' livelihood capital - Coping and adaptation strategies (incremental to transformative) to minimise the adverse impacts of climate change
Cluster analysis	Total 6 (3 in each community)	- To understand the overall socio-economic characteristics of each fishing community
Focus group discussion	Total 5 (2 in Kalitola Ghat and 3 in Debdanga)	- Climatic impacts on fishers' livelihoods - Fishers' adaptation strategies to overcome the climatic impacts
Impact matrix	Total 2 (1 in each community)	- Ranking of the climatic hazards - Ranking of the most vulnerable types of livelihood capital
Key informant interview	Total 5 (3 in Kalitola Ghat and 2 in Debdanga)	- To understand the overall impacts of climatic hazards on the fishing community and their adaptation strategies

Table 3. Clusters of socio-economic characteristics of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga, Bogra district, Bangladesh.

Variables	**Kalitola Ghat**			**Debdanga**		
	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 1**	**Cluster 2**	**Cluster 3**
Total number of household members	4	6	5	7	6	6
Involvement in fishing (years)	27	23	33	34	35	42
Fishers types	T	S	T	T	T	T
Duration of fishing operation ($h \cdot day^{-1}$)	13	10	10	13	14	13
Average amount of income from each fishing trip (USD*$\cdot day^{-1}$)	8.9	2.9	7.7	4.8	9.2	6.7
Income from fishing (%)	100	97	95	100	100	100
Income from farming (%)	0	3	5	0	0	0
Quality of fishing materials (mean)**	3.3	2.8	3.2	4.1	4.2	3.7
Condition of houses (mean)**	1	1	1	1	1	1
Usage of technology (mean)**	1.7	1.9	2.0	1.9	2.0	1.9
Index of social capital (mean)**	1.7	1.1	1.8	0.8	1.0	1.0
Index of natural capital (mean)**	0	0.2	0.4	0	0	0

Note: T = traditional and S = subsistence; *USD 1 = BDT 84.45 (Date: 14 April 2020); **Coding was done on a scale of 0–5, where 0 = very low, 1 = low, 2 = moderate, 3 = medium high, 4 = high and 5 = very high.

Table 4. Summary of livelihood capitals of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga, Bogra district, Bangladesh.

List of livelihood capital		Percentage of fisher households	
		Kalitola Ghat	**Debdanga**
Human capital			
Educational status	Only 1-5 years of literacy	17.1	26
	Only can give written signature	51.4	5.6
	Illiterate	31.41	18
Training for skill development	Furniture-making skill	15	0
	Farming skill	70	0
Occupation	Job migration	56	5
Physical capital			
Housing facility	Own house	100	90
	Corrugated tin shed house	76	65
	Split bamboo and straw house	6	7
	Concrete column, split bamboo and straw house	13	22
	Concrete house	5	6
Technological facility	Access to cell phone	95	98
	Access to television	65	78
Fishing crafts	Boats	87	78
	Seine net	76	78
	Gill net	65	42
	Darki trap (one type of trap for catching fish)	72	65
	Hazari line (where thousands of lines are used)	60	62
	Whirling line	32	30
Natural capital			
	Ownership of agricultural land (at least 1 acre)	22	0
	Ownership of water body (at least 1 pond)	2	0
Financial capital			
	Access to government bank	0	5
	Access to NGO credits	80	65
	Jewelry	0	2
	Poultry	98	98
	Livestock	73	81
Social capital			
	Access to fishery-related association or committee	Yes	Yes
	Access to political favor	Low	Moderate
	Social bonding with neighbors	Moderate	Strong

The key informant interviews (KIIs) were conducted to get in-depth information about climatic impacts in the area and fishers' adaptation strategies to minimise the impacts. The key informants included individuals from inside (e.g., members of fishers' cooperative society) and outside the communities (e.g., Sub-district Fisheries Officers). A total of five key informant interviews were conducted.

The qualitative data were audio-recorded and later transcribed in Bengali. Qualitative data were analysed using three steps: i) preparing and organising, ii) reducing data into themes through coding, and iii) representing data in tables. During data processing, all the identified adaptation strategies were carefully assessed depending on three specific criteria: i) enlarged scale or intensity, ii) novelty (new adaptation) and iii) path-shifting (different places and locations) (Kates *et al*., 2012). Adaptation strategies that fulfill these criteria are termed as transformative adaptation. The quantitative data were analysed using descriptive statistics in Microsoft Excel (version 2013).

RESULTS

Impacts of climatic hazards

Three climatic hazards i.e., floods, storms and riverbank erosion that adversely impact on the fishers' livelihood capital have been identified in the study areas (Table 5). The impacts of climatic hazards on fishers' livelihood capital are described below:

Impacts of floods

This study has reported that both fishing communities are affected by major or minor floods almost every year. According to the Bangladesh Meteorological Department (BMD), the major floods that have affected both fishing communities were occurred in 1978, 1987, 1988, 1998, 2002, 2004 and 2007. During the semi-structured interviews, fishers from these two fishing communities have claimed that the floods of 1988 and 1998 were most devastating among them.

This study has found that all livelihood capitals of the fishers are affected by floods. The impact matrices have revealed that fishers' human capital has more severely affected by floods, followed by natural and physical capitals (Figure 5). According to semi-structured interviews and FGDs, impacts on human capital have included temporary or permanent unemployment, displacement of home, increased water-borne diseases like diarrhoea, dysentery and many skin diseases, and increased risk of poisonous insects and snakes (Table 6). Floods have also interrupted children's education, as fishers from both communities have taken temporary shelter in the primary school during the floods. Impacts on fishers' natural capital have included inundation of land and physical capital, damage to houses and fishing equipment such as boats and nets, and other infrastructural impairment of both fishing communities in several ways.

Floods have affected fishers' social capital indirectly (e.g., increased level of conflict between fishery and non-fishery based households). Floods

Table 5. Frequency of major climatic hazards occurring over the last five decades and the percentage of fishers affected by those climatic hazards in Kalitola Ghat and Debdanga, Bogra district, Bangladesh.

Climatic Hazards	**Frequency of major climatic hazards occurring over the last five decades (mean)**		**Percentage of fishers affected**		**Sources of data**
	Kalitola Ghat	**Debdanga**	**Kalitola Ghat**	**Debdanga**	
Flood (1972-2015)	7	9	91	90	Semi-structured interviews and focus group discussions
Storm (1972-2015)	6	7	91	84	
Riverbank erosion (1972-2015)	6	6	80	84	

Table 6. Overall impacts of climatic hazards on livelihood capital of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga, Borga district, Bangladesh.

Climatic Hazards	Impacts of climatic hazards on fishers' livelihood capital	Percentage of households	
		Kalitola Ghat	Debdanga
Flood	Temporary or permanent unemployment	86	90
	Increasing water-borne diseases like diarrhoea, dysentery, etc.	77	66
	Disruption of child education	46	50
	Displacement of home	57.3	78
	Damage to houses	29	80
	Damage to fishing equipment like boats, fishing nets, fishing traps, etc.	91	72
	Inundation of agricultural land	49	0
	Disturbance of fishing trips	80	82
	Loss of income from fishing	63	70
Storm	Loss of fishing equipment	91	72
	Physically wounded	51	66
	Damaged homes and other infrastructure	29	80
	Damaged schools	14	34
	Damaged hospitals	0	8
	Missed fishing trips	80	82
	Loss of income from fishing	63	84
Riverbank erosion	Loss of agricultural land	6	0
	Loss of houses	23	38
	Changes in fishing grounds	71	70
	Loss of income from fishing	63	84
	Disruption of social relationships	49	72
	Increased social conflicts between traditional and newly-emerged fishers	14	26

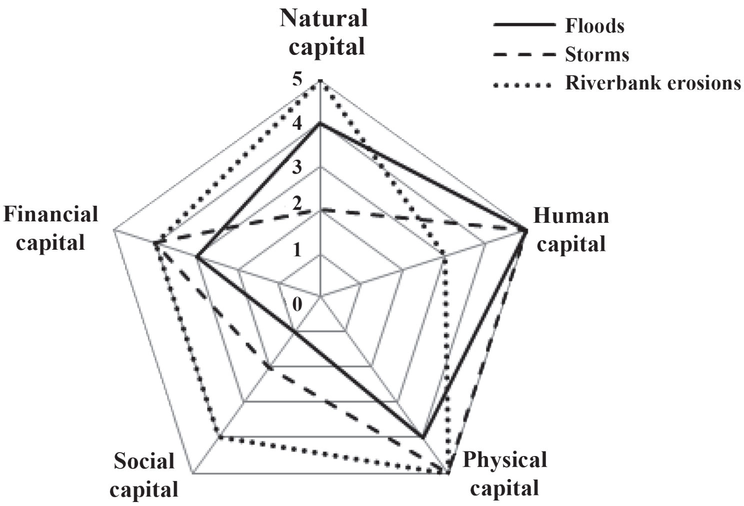

Figure 5. Impacts of climatic hazards on five livelihood capital of the Jamuna River-dependent fishing communities of Kalitola Ghat and Debdanga, Bogra district, Bangladesh. Impacts are represented on a scale of 0-5 where 5 = very high impact, 4 = high impact, 3 = medium impact, 2 = low impact and 1 = very low impact.

have resulted in loss of jobs for the non-fishery based households in Kalitola Ghat. Non-fishers of this community have diverted their traditional activities to fishing as fish stocks have increased just after the flooding. This diversion has resulted in conflict with the fishery-based households. A fishery-based respondent has said, *"Because of the involvement of non-fishers in fishing activities during and after flooding, we have lost our fishing opportunities as competition arises"*. In contrast, a non-fishery based respondent has reported, *"We cannot support our livelihoods during and after flooding as we do not have any savings. We need to grab any opportunity for living and that's why we consider fishing a quite reasonable occupation to support our livelihoods"*.

This study has revealed that impacts of floods on fishers' physical, natural, human and social capital have deteriorated overall financial capital. Fishers have reported during household interviews that their fishing trips are disturbed in many cases during floods, which have resulted in decreasing income from fishing. FGD participants have reported that fish catch has increased after immediate flooding. However, erratic rainfall has caused an adverse impact on fish production (e.g., affecting fish breeding), which might have reduced yields from fishing and thus affected fishers' overall livelihoods.

Impacts of storms

This study has found that almost every year, both fishing communities are affected by heavy storms and violent winds. According to BMD, storms with wind speed ≥ 62 km·h^{-1} have affected both fishing communities in the past few decades.

From the impact matrices, it has found that storms have affected fishers' physical and human capitals more severely than financial, natural and social capitals (Figure 5). In terms of physical capital, storms have mainly damaged the fishing gear (e.g., boats, nets and other equipment), and sometimes, during fishing in the river, fishers' human capital has also threatened by storms. Moreover, storms have severely injured fishers' health and could even result in death in extreme cases. FGD participants have reported that each year, one or two fisher(s) lose(s) their lives because of boats overturning during the sudden onset of a heavy storm. One FGD participant has said, *"Two people died in the storm of April in 2015 and almost every person has lost many things; even I have lost my fishing nets"*. Storms have damaged houses and other infrastructure, which have resulted in temporary shelter loss for the fishers. Damage to schools and hospitals have interrupted education and treatment facilities, respectively, which have made the poor people more vulnerable to the climatic hazards. According to the KIIs and FGDs, fishers have missed fishing trips during storms due to adverse weather conditions. In addition, their yields from fishing have reduced because they could not catch enough fish due to adverse winds. Overall, physical, natural and human capitals have ultimately deteriorated fishers' financial capital.

Impacts of riverbank erosion

The impact matrices have illustrated that riverbank erosion has severely affected fishers' natural and physical capitals, followed by financial, social and human capitals (Figure 5). It has found that most of the fishers of both fishing communities have lost natural and physical capitals, and as a result, their households had to migrate to a new community which has increased the population density in those communities. One respondent of Kalitola Ghat has remarked, *"In my lifetime, I have experienced riverbank erosion nine times"*, whereas another respondent of Debdanga has reported, *"We have faced riverbank erosion for at least nine times in our lives"*. Thus, riverbank erosion has created a completely new dimension to the social capital of the fishing communities. This study has found two types of fishers in Kalitola Ghat: native fishers (who are fishing generation after generation on the Jamuna River) and newly-emerging fishers (who have migrated from other villages and switched their occupation to fishing). Generally, the native fishers have shown political powers to get a better opportunity to fish in certain areas than the newcomers. Because of this situation, competition has raised between the two groups over fishing territory, which has disrupted social unity and fishing opportunities.

This study has found that riverbank erosion has affected fishers' human capital in diverse ways (e.g., temporary or permanent unemployment). According to the household interviews, riverbank erosion has also caused a number of deaths to the fishing communities, especially when women and aged persons have failed to reach a safer place during a sudden episode of riverbank erosion. The respondents during household interviews have reported that after the devastation of riverbank erosion, different types of epidemic diseases have spread in the area.

Fishers have reported that riverbank erosion has caused changes in fishing grounds, which might have affected fishers' regular fishing routines. According to the fishers of Kalitola Ghat during FGDs, riverbank erosion has caused the formation of sandbar or char (newly-emerged land in the river as a result of accretion), which has re-directed the water flow to an adjacent river channel, and away from the main channel that might resist regular riverbank erosion. They have also stated that siltation due to riverbank erosion has decreased river depth and hampered the regular movements, breeding and feeding of fishes, which might ultimately result in reduced fish catch. Consequently, income from fishing has reduced. Therefore, the impacts of riverbank erosion on physical, natural and human capitals have threatened the fishers' overall livelihoods.

Transformative adaptation

Fishers have employed some transformative adaptation strategies to minimise or overcome the adverse impacts of climatic hazards in both fishing communities as described below:

Migration

Migration is the most important and effective transformative adaptation strategy taken by the fishers (Table 7). Household interviews have revealed that 57.3 % of fishers of Kalitola Ghat and 78 % of fishers of Debdanga have migrated because of floods, storms and riverbank erosion. One fisher from Kalitola Ghat has reported during interviews that his family has migrated temporarily (short-term basis) during flooding and taken shelter on the embankments or other higher areas as water engulfed their houses. Some fishers have also claimed that they have taken shelter in the primary school buildings (in Kalitola Ghat) or disaster shelter (in Debdanga) to minimise the impacts of storms and floods. They have migrated to other areas where they are less vulnerable to the exposure of floods, storms and riverbank erosion. This type of migration meets the "path-shifting" standard of transformation as fishers have moved to new locations. Fishers who have migrated permanently to other areas due to riverbank erosion have shaped their lives differently as they have diversified their livelihoods.

Table 7. List of transformative and incremental adaptations to minimise the impacts of climatic hazards in the Jamuna River-dependent fishing communities of Kalitola Ghat and Dendanga, Bogra district, Bangladesh.

Adaptation strategies to minimise the impacts of climatic hazards		
Strategies	**Types**	**Standards**
Migration	Transformative	Path-shifting: e.g., displacement or changes in location
Building concrete houses	Transformative	Novelty: e.g., fundamental change in the fishing communities
Livelihood diversification	Transformative	Path-shifting: e.g., transform occupations
Change in fishing gear and technique	Transformative	Novelty: e.g., newly introduced in the fishing communities
Tree plantation	Transformative	Enlarged scale: e.g., mass scale reforestation program in the areas
Change in fishing duration and fishing grounds	Incremental	Transformation is temporary, cost-effective

FGD participants have reported that fishers of Debdanga have the opportunity to fish in different fishing grounds, which have improved their living. In addition, they have moved to other rural areas during crop harvesting and sowing season to make more income. This study has also found that fishers have preferred group migration when they have faced severe riverbank erosion, and they are forced to settle in different parts of the country as a group.

Building concrete house

In this study, construction of concrete (blocks joined together with cement and iron rods or steel, and hereafter referred to as concrete) houses is considered as a transformative adaptation to reduce the impacts of storms (Table 7). Fishers have used concrete to construct houses and plinths of houses instead of soil and bamboo to prevent house collapse during storms and floods. In Kalitola Ghat, 5 % and in Debdanga, 6 % of fisher households have built concrete houses to avoid the loss that has occurred due to storms. On the other hand, 35 % of fishers in both communities have used only concrete columns to give extra support to their houses against the impacts of storms, as they could not afford to build a whole house of concrete. Concrete house and plinth reconstruction meet the "novelty" standards of transformation and therefore, it is considered as a transformative adaptation. The "novelty" standard is met because building construction with concrete is a new technology for the fisher households in the study area, whereas only the rich households previously have concrete houses or plinths, as the process is quite expensive.

Livelihood diversification

In this study, livelihood diversification is also considered as a transformative adaptation strategy (Table 7). According to household interviews and FGDs, fishers of Kalitola Ghat have diversified their livelihoods through non-fishery related jobs (56 %) such as farming, day labouring, selling vegetables or used bottles, etc. By the "path-shifting" standard of transformation, these works are considered as transformative adaptation strategies, as fishers of Kalitola Ghat have left their traditional fishing for non-fishery related jobs, which are new to those households. In contrast, 95 % of fishers of Debdanga have reported during household interviews and KIIs that they have no alternative jobs except fishing, and as a result, they have taken loans with high interest from different non-governmental organisations (NGOs) and 'Dadon' (i.e., advance money taken by the fishers from the money-lender with strict conditions). In many cases, the fishers of Debdanga have simply waited for the proper time to resume fishing, as they have no alternative jobs except fishing. These livelihood diversifications meet the "path-shifting" standard of transformation, as adaptation occurs as a response to suppressed economic activity when fishers have felt that there has no appropriate livelihood alternative except fishing in the area.

Changes in fishing gears and techniques

Most of the fishers of both communities have reported that they have changed their traditional fishing gears and techniques. In Kalitola Ghat, 78 % of fishers have used different types of nets (e.g., seine nets, gill nets, etc.). However, traditional fishers of Kalitola Ghat have used only seine nets (Ber Jal) and some kinds of fishing traps that are not as convenient as those are used by the newly-emerging fishers. In Debdanga, most of the fishers have replaced their traditional fishing gear and nets by more efficient fishing gear and nets, which are considered as a transformative adaptation strategy. They have also used mechanised fishing boats to move quickly in the river. Fishers of Kalitola Ghat have constructed several pond-like structures adjacent to the riverbanks to reserve water for fishing in future. This is a new technique of fishing in the study area, and because of its "novelty", it is considered as a transformative adaptation.

Tree plantation

Tree plantation is considered as a transformative adaptation strategy in this study; it is done for preventing riverbank erosion and providing shelter against storms by reducing wind speed, rather than for forestation. Many of the fishers have reported that they have planted trees along the riverside to reduce riverbank erosion.

One key informant in Debdanga has reported that a mass-scale reforestation program has started with the help of local communities. Based on the "enlarged scale" standard of transformation, the tree plantation program is considered as a transformative adaptation. However, some of the respondents have claimed that branches could destroy the roofs of houses if the trees are uprooted during storms.

DISCUSSION

This study has reported that fishers' livelihood assets are affected by climate variability and change, which supports the findings of Badjeck *et al*. (2010), who reported that the loss of houses and community infrastructure might result in displacement and disruption of livelihoods. Storms have destroyed the fishing gear, including nets and boats of fishers in the study areas. Similar findings are also reported after Hurricane Gilbert, which destroyed 90 % of fishing traps and 5 % of boats of the fishers in Jamaica (Aiken *et al*., 1992). Sometimes, fishers have been physically wounded. Physical injuries might destroy the physical capabilities of fishers to participate in fishing activities and ultimately affect their livelihoods (Badjeck *et al*., 2010). This study has also found that floods have affected fishers' houses, physical infrastructure and fishing activities. The destruction of physical, natural, human and social capitals has deteriorated their financial capital (Badjeck *et al*., 2010). The reduction of financial capital has engendered lower adaptive capacity, which has increased vulnerability (Connolly-Boutin and Smit, 2016).

To minimise the climatic impacts on fishers' livelihoods, their response strategies have been ranged from incremental to transformative adaptation, where transformative adaptation is based on three standards: enlarged scale or intensity, new adaptations, and different places and locations (Kates *et al*., 2012). There is a significant difference between transformative and incremental adaptation, and the factors behind this difference also vary. These consequences have made it very complex to exclusively define what qualifies as a transformative change in different areas (Nelson *et al*., 2007). Transformative adaptation, such as involuntary migration, has mostly resulted in conflicting livelihood outcomes, and therefore, it has considered as maladaptation (Barnett and O'Neill, 2012). Forced migrants could suffer from reduced access to common-pool resources, lack of land, employment, home and food security (Islam *et al*., 2014b). Migration constitutes an important livelihood asset for climatic hazards like floods, storms and riverbank erosion, which have relocated large numbers of people around the world (Intergovernmental Panel on Climate Change, 2014). The relocation of people has been expected to rise due to climate change. Migration has some impacts on local fishers as population density has raised due to the newly-arriving migrants. Fishers who have migrated to new places and adapted themselves to their new environments are able to minimise the adverse impacts of climatic hazards. Islam *et al*. (2014b) reported that migration could result in positive livelihood outcomes and be recognised as largely successful if it has taken place as a group (community). However, those who have failed to migrate to new locations could not share this benefit. Mostly, success depends on their resources and their social relations when they have migrated from one place to another.

The SLA has recommended that migration outcomes can differ based on vulnerability perspective (trends, shocks and seasonality), institutional structures and processes, and migrants' livelihood resources (Scoones, 1998). Diversification of livelihood opportunities as a consequence of migration could reduce climate change impacts (Paavola, 2008). Short-distance migration might create opportunities for new livelihood assets or activities, whereas long-distance migration could provide financial benefits for households who have stayed at home (Paavola, 2008). Migration might enhance adaptation or reduce vulnerability to climate variability and change (Black *et al*., 2011). In contrast, it might also increase vulnerability because of asset loss and reduced opportunities in the new location (Hunter, 2005).

Building concrete houses and disaster shelters are important transformative adaptation strategies for minimising the adverse impacts of storms and floods. In this case, this study has agreed with Minar *et al*. (2013) and Hadarits *et al*. (2017). For example, building a house on a raised basement or elevated plinths is an effective transformative adaptation to flood (Woodroffe, 2003; Fenton *et al*., 2017). Also, raising ducks instead of chickens might be a transformative adaptation strategy to minimise the adverse impacts of floods (Fenton *et al*., 2017). On the other hand, concrete house-building or concrete plinths of houses are vulnerable to severe riverbank erosion. However, Anik and Khan (2012) suggested that embankment construction or tree plantation might help to adapt to riverbank erosion. Badjeck *et al*. (2010) reported that livelihood diversification is an important way of reducing vulnerability and increasing adaptive capacity. Livelihood diversification has been recognised as a method that rural households use to adapt to climatic hazards and changes (Ziervogel and Calder, 2003). But livelihood diversification depends on fishers' skills and training. In some cases, fishers cannot diversify their livelihoods as they have no alternative skills.

This study has found that in response to reduced fishing yields, fishers become involved in non-fishery related activities to support their livelihoods. This finding has agreed with those of Daw *et al*. (2009). Innovations in fishing techniques are considered to be an important transformative adaptation. A large or multi-scale change like reforestation is also considered as a transformative adaptation to minimise the impacts of storms. Matyas and Pelling (2015) reported that transformative changes open new horizons beyond the existing systemic forms. The absence of such transformative adaptations might cause an increased number of deaths, more damage to fishing equipment and other household resources, and ultimately result in a lower income from fishing. Transformative adaptation has focussed on long-term changes and acknowledged uncertainty in the future. In contrast, incremental adaptation is smaller, discrete, and it has focussed on the current conditions and short-term change without considering future uncertainties (Mustelin and Handmer, 2013). However, transformative adaptation should not be proposed as a universal solution. Incremental adaptation can be used in normal scenarios and transformative adaptation should only be applied in the most extreme scenarios.

CONCLUSIONS

This study has assessed the transformative adaptation strategies to climate change impacts in two fishing communities dependent on the Jamuna River. This study concludes that several climatic hazards affect the Jamuna River fisheries-dependent communities. Fishers' transformative adaptation strategies are mostly focussed on future and long-term changes of the communities. These strategies include migration, building concrete houses, livelihood diversification, changes in fishing gear and techniques and tree plantation. The short-term incremental adaptation strategies are not sufficient to minimise the climate change impacts; in the near future, climatic impacts on fishery-based livelihoods may substantially increase. The fishing communities will also be affected by floods, storms and riverbank erosion, which are projected to be exacerbated due to climate change. The results of this study will help to identify possible measures to face the current and upcoming climate change impacts on fishing communities in Bangladesh and elsewhere with similar context. However, more studies need to be conducted to elucidate other transformative adaptation strategies in different parts of the world.

ACKNOWLEDGEMENTS

We thank the International Foundation for Science (IFS), Sweden for financial support (Grant number S/5556-1). We are also thankful to all the participants for their voluntary participation. Finally, we would like to thank the anonymous reviewers and editors for their comments and suggestions to develop the manuscript.

CONFLICTS OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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