Resilience to Flash Floods in Wetland Communities of Northeastern Bangladesh

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Abstract

Globally, a number of catastrophic hydrometeorological hazards occurred in 2017 among which the monsoon floods in South Asia was particularly disastrous, killing nearly 1,200 people in India, Nepal and Bangladesh. The wetland region (Haor) of northeastern (NE) Bangladesh was severely affected by flash floods early in 2017, affecting nearly 1 million households and damaging US $450 million worth of rice crops. This study investigates how the NE Bangladesh experienced the 2017 flash floods, and to what degree the wetland communities are vulnerable and resilience to flash floods. Focus group discussion, key informant interviews, and household questionnaire surveys (*n*=80) were applied in the study area of Sunamganj district. Results from statistical analyses and regression modelling reveal that poor people are particularly vulnerable to floods but they are also more adaptive and thus resilient; middle-income households are vulnerable as they are hesitant to take up any jobs and accept flood relief; and rich households, despite being less adaptive, are able to recover from flood disasters because of wealth. This study reveals that resilience also stems from deep religious faith in the Haor inhabitants that supports communities to move on by accepting that most natural calamities such as flash floods are divine tests. This study also finds that women are particularly vulnerable and less resilient as they are not normally allowed to work outside of their homes and beyond the Haor communities due to cultural and religious reasons.

Keywords: Flash flooding, resilience, vulnerability, livelihoods, Haor region, Bangladesh

1. Introduction

Globally, hydrometeorological hazards such as floods, droughts, hurricanes, and coastal storm surges pose a direct threat to human lives and impact livelihoods due to widespread destruction and damage to crops, businesses and critical infrastructure. The frequency and strength of natural hazards varies globally. Nearly all continents were hit by some sort of natural hazards in 2017: flooding in South Asia, hurricanes, earthquakes and wildfires in North America, landslides and droughts in Africa, and volcanic eruption in Southeast Asia. Heavy monsoon rain and floods caused devastation in large parts of Bihar and Assam states of India, Bangladesh and Nepal that killed more than 1,200 people over the summer of 2017 and triggered one of the worst humanitarian crises in years with more than 40 million people affected in the region. In Bangladesh alone, 145 people died, more than 100,000 houses were estimated to be completely destroyed and over 8 million people were affected by floods that covered one third of the country (Bamforth, 2017).

Hydrometeorological hazards, particularly floods and coastal inundation to storm surges associated with tropical cyclones, are common in Bangladesh. Due to its subtropical monsoon climate and the geographic location – downstream region of the Himalayan Rivers the Ganges, Brahmaputra and Meghna, every year, floods occur in low-lying areas of Bangladesh (Figure 1) that cover a mean area of 20% (Figure 2) of the 144,000 km^2 area of the country. Based on inundation depth, it is estimated that a 10, 50 and 100-year flood event is projected to inundate approximately 37, 52 and 60% of the country's total land area, respectively (Kundzewicz et al., 2014). Outside the cyclone-affected coastal region where flooding occurs as a result of storm surges in April-May and October–November (Mirza, 2002), there are four main types of flood in Bangladesh (WARPO, 2000): (i) monsoon, riverine floods when the major rivers overflow or cause their tributaries runs off into adjacent floodplains; (ii) flash floods in the eastern (hilly region), northeastern (Haor region) and northern areas (piedmont area) due to heavy and intense rainfall; (iii) localised coastal floods associated with tropical cyclones and storm surges in southern Bangladesh; and (iv) localised urban floods associated with intensive rainfall and/or onrush of river water when protective embankments breach takes place. The normal sequence of floods in Bangladesh starts with flash floods in the northeast, southeast and eastern hilly regions caused by pre-monsoon storms in April and May, and prior to the onset of the monsoon rainfall generally commences in June that normally causes riverine flooding.

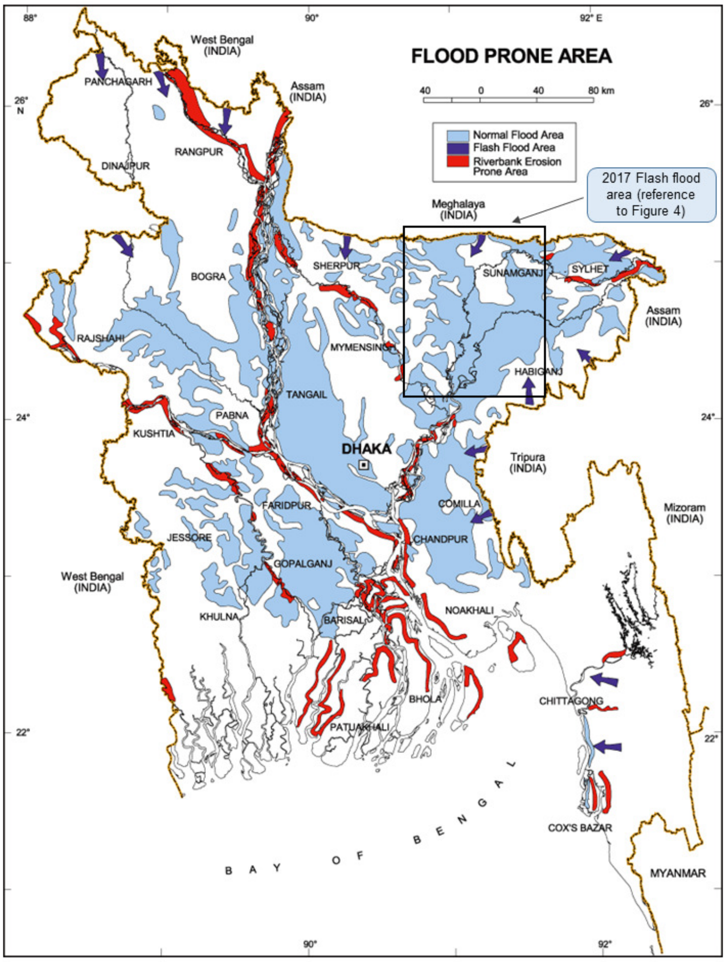

Figure 1. Map of Bangladesh showing the extent of river flooding, areas of river-bank erosion and indicative areas along the eastern, northeastern and northwestern border that are prone to flash flooding and torrential hilly river flows. Map source: Banglapedia (2003).

Globally, with a population density of ~1,000 inhabitants per km^2 (BBS, 2011), Bangladesh is the country with the highest number of people and assets are exposed to increasing flood hazards (Kundzewicz et al., 2014). River floods can inundate a large area, for example, nearly 60% area of Bangladesh was flooded in the catastrophic floods of 1988 and 1998 that inundated an area of 70% (Figure 2) and killed some 2,379 and 918 people respectively (Dastagir, 2015). Floods in 2007 were one of the 95th percentile flood events inundating 42% of the entire Bangladesh and killed 1,110 people (Dastagir, 2015). These historical large river floods (e.g., 1987, 1988, 1999, 2004, 2007 and 2012) that lasted for a few weeks to 2-3 months, caused substantial damage to crops, houses, and means of livelihood, particularly of poor population in the country. The number of fatalities in these historical floods in Bangladesh has gone down over time (Dastagir, 2015). In contrast to river floods that affect large proportion of land surface every year, flash floods generally affect a much smaller area (typically <5% to 20%) and the duration is smaller, commonly a few weeks to a month, but can have a catastrophic impact on human lives, properties and livelihoods. For example, flash floods of 2007 in northeastern Bangladesh affected ~10% area of the country but killed several hundred people and affected livelihoods in Haor communities (Hashem, 2016).

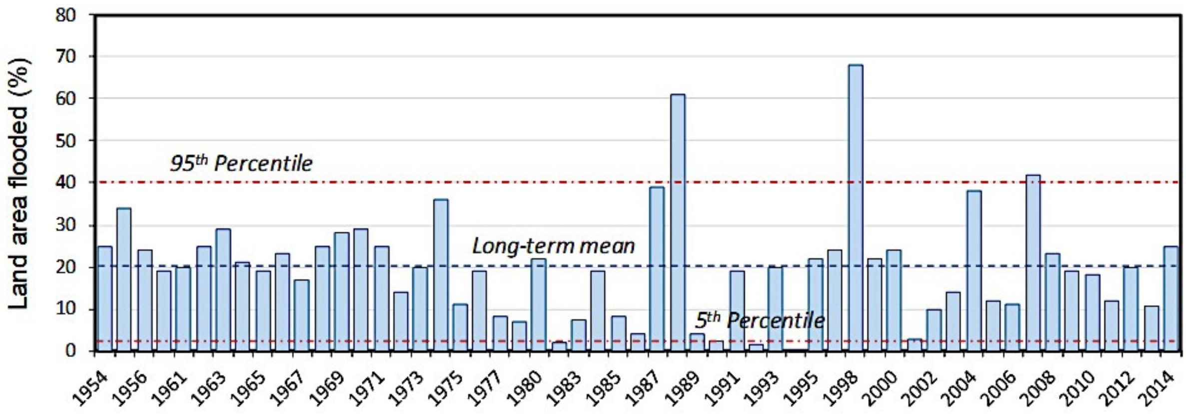

Figure 2. Graph showing proportion of land area in Bangladesh that flooded historically from 1954 to 2014. Horizontal dashed lines show long-term mean, 95th and 5th percentile values. Data source: Flood Forecasting and Warning Centre, Bangladesh.

Over the last few decades, numerous studies were conducted to identify hydrological and climatic drivers of flooding in Bangladesh (Brammer, 1990; Mirza et al., 2003; Suman and Bhattacharya, 2015). On the other hand, a few studies (Khan, 2015; Parvin et al., 2016) looked at social vulnerability to flooding and resilience of communities and individuals, particularly poor people, living in floodplains and coastal regions, who may or may not receive direct support from the government of Bangladesh during disasters. This study aims to better understand the level of vulnerability and resilience to flash floods in the Haor region of northeastern (NE) Bangladesh by applying a number of social-science survey techniques.

2. Vulnerability and resilience to flash floods: theoretical considerations

Haors are low-lying, physiographic depressions or floodplain wetlands that are commonly found in NE Bangladesh. These areas experience greater amount of annual rainfall than the rest of the country. Due to their unique physical and social conditions, Haor inhabitants tend to be vulnerable to both riverine and flash floods. Despite this underlying vulnerability, people in the Haor region have been living with various hydrometeorological hazards (e.g., floods, tropical storms, waterlogging) for centuries demonstrating a strong resilience to these natural hazards in the region (Choudhury and Haque, 2016). What makes the Haor inhabitants resilient to floods? Thus, the present study examines various aspects of vulnerability and resilience in a community that has recently experienced catastrophic flash floods of 2017.

Resilience is highly theorised and contested in the literature across numerous schools of thought (Aven, 2011; Reid, 2012; Alexander, 2013; Pugh, 2014). In disaster risk reduction, resilience generally and in summary converges on the idea of being able to experience hazards without a disaster resulting (Lewis, 1999; Alexander, 2013). Both vulnerability and resilience are processes, occurring from societal decisions, values, and actions over the long-term, which reduce or enhance abilities to deal with influences such as flash floods (Lewis, 1999; Wisner et al., 2004).

These concepts have been applied to Bangladesh. Choudhury and Haque (2016) looked into wetland communities dealing with flash flood disasters in NE Bangladesh and provided a literature review on some theoretical frameworks of vulnerability and resilience to environmental hazards. The literature has highlighted that research on disaster risk reduction (Alexander and Davis, 2012) including climate change adaptation (Khan, 2015) frequently revolves around reducing vulnerability and/or building resilience. Choudhury and Haque (2016) further argue that society's end goal is to reduce vulnerability and enhance resilience to disasters, although the theoretical understandings of vulnerability and resilience in disaster risk reduction are more about interacting, long-term processes (Lewis, 1999; Wisner et al., 2004; Lewis, 2013; Sudmeier-Rieux, 2014).

3. The Case of the 2017 Flash Flood in NE Bangladesh

Flash floods are sudden, localised flood events that occur when an exceptional amount of rain falls over a short period of time (a few hours to days) within a catchment producing a rapidly rising and fast moving river flows. Flash floods in Bangladesh are common and generally occur in early monsoon time (April-May), extensively in the Hoar region due to intensive rainfall within the country and upstream catchments in India. The word ‘Haor’ refers to a round to elliptical shaped, depressed marshy wetland located in the districts (second administrative unit in Bangladesh, after division) of Brahmanbaria, Habiganj, Kishoreganj, Netrokona, Moulvibazar, Sunamganj and Sylhet of northeastern Bangladesh (Figures 3).

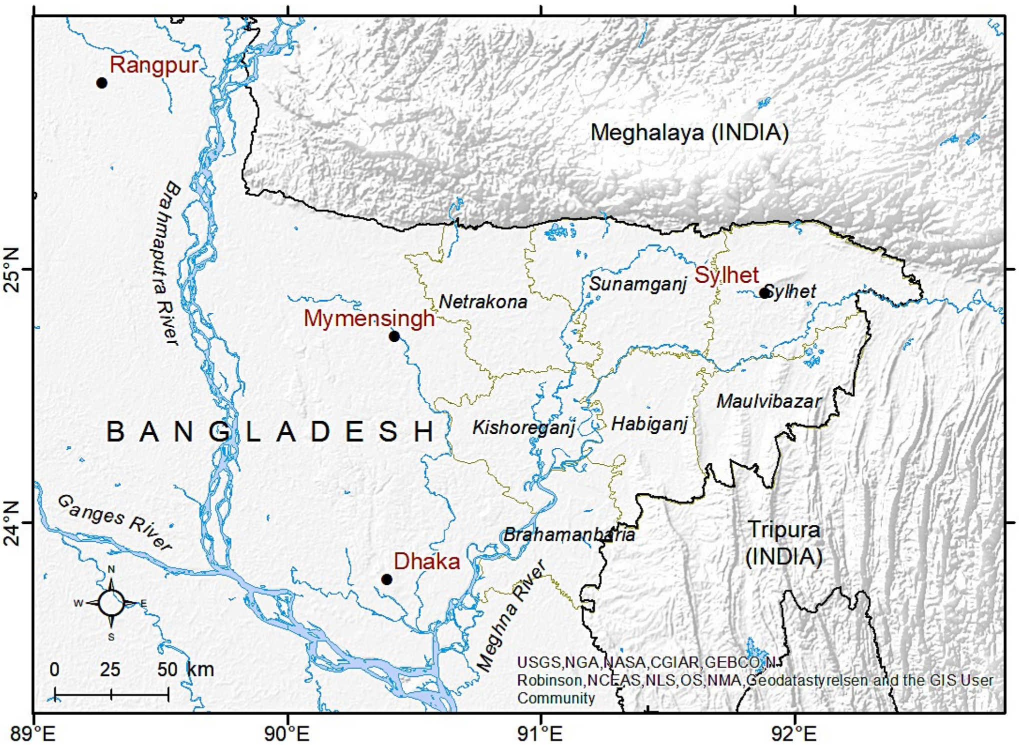

Figure 3. Map showing the seven districts (light brown lines) in the northeastern Bangladesh that form the greater Haor region. The background shaded relief map shows a sharp contrast in topography and surface elevation between NE Bangladesh and neighbouring Indian states.

The northeastern Haor region consists of nearly 400 wetlands covering an area of ~19,700 km^2 with nearly 23 transboundary rivers that enter from the neighbouring India (Suman and Bhattacharya, 2015). The topography of Haor region is more or less flat with the maximum land surface elevation being <10 meters. Haor wetlands are normally submerged under floodwater for 7-8 months to a typical depth of 0–5 meters during the monsoon. Haor region is characterised by the highest rainfall in the country with an average annual rainfall ranging from 2,200 mm along the western boundary to 5,800 mm in its northeast corner and is as high as 12,000 mm in the headwaters of river catchments in the neighbouring Meghalaya State of India (CEGIS, 2012). In both rainy and dry seasons floodplains of the Haor region are used for rice cultivation. Recently, high-yielding *Boro* rice is cultivated in most part of these wetlands with supplementary irrigation from groundwater that comes from shallow alluvial aquifers in the Haor region. As a result, most popular occupations of the Haor population are cultivation, fish, poultry and cattle farming, and day-labouring.

In 2017, rapid rise of surface water levels in various rivers in the Haor region due to heavy rainfalls both in northeastern Bangladesh and neighbouring upstream hilly catchments within India led to torrential runoff in the ‘flashy’, hilly rivers that inundated a portion of floodplains and wetlands. The first hit of flash-flood was recorded in the Haor region in April 2017 (Figure 4), and subsequently, a country-wide devastating river flood took place in July-August of 2017. The second phase of river floods ultimately affected 32 of 64 districts. The five districts of the Haor region namely Sunamganj, Netrokona, Moulvibazar, Brahmanbaria, and Sylhet were affected during flash floods (March-April) prior to river floods that happened in July-August 2017.

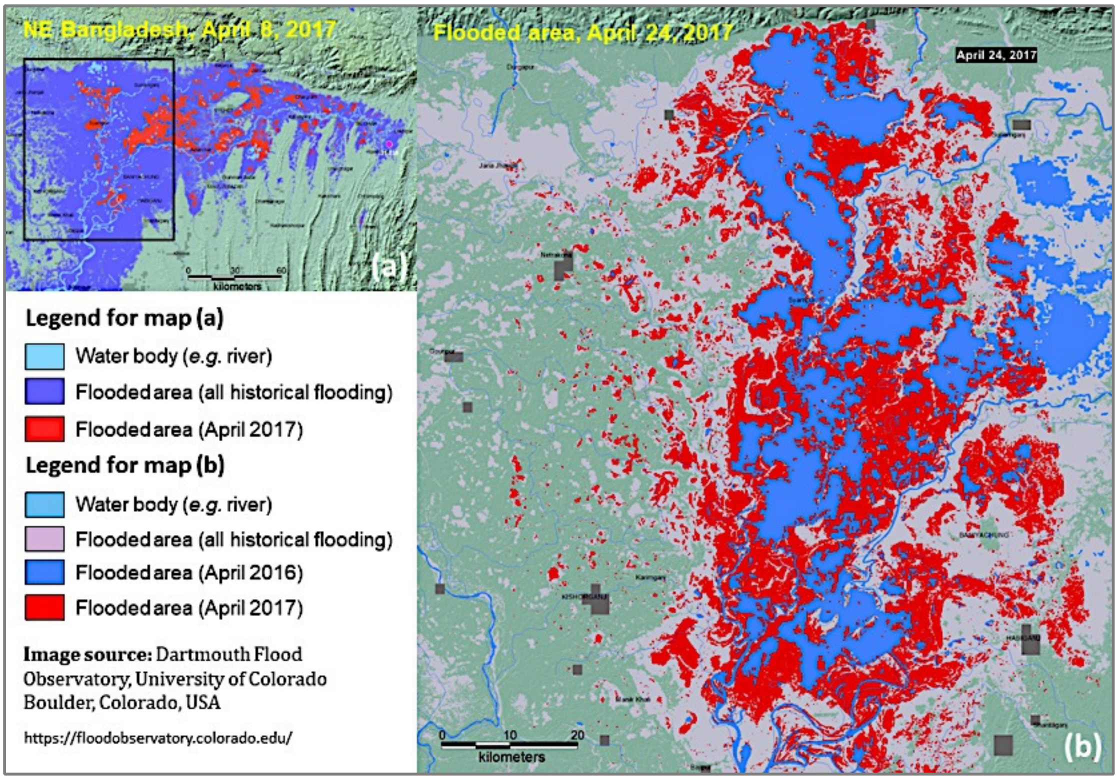

Figure 4. Extent of the 2017 flash flood in the northeastern Haor region of Bangladesh: **(a)** flooded area in late April 2017 placed in the context of historical flooded area in the region, and **(b)** a close-up view of the flooded areas in the Haor region on April 24th 2017. Data source: Dartmouth Flood Observatory, University of Colorado, Boulder, USA.

According to the Department of Disaster Management (DDM) of Bangladesh (http://www.ddm.gov.bd/) daily disaster reports of 28 April 2017 (Table 1), a total of 850,088 households were affected by flash floods in six Haor districts, which were 29.3% of the total households in those districts. Among these, the highest proportion of households were affected in Sunamganj district (39.2%), alone followed by Sylhet (35.7%) and Netrakona (34.9%). The lowest proportion of households were affected in Habiganj district (18.9%).

An estimated 0.29 million *ha* of agricultural lands were cultivated in the Haor region which constitute above 6% of the country's total *Boro* rice production. Huge damage to rice crops (~800,000 tonnes *Boro* rice; worth US $450 million) thus resulted in food shortage and increased price level of foods. Some other important *Robi* or winter crops such as groundnut, wheat and potato were heavily damaged in the 2017 flash floods.

Table 1. Statistics of affected administrative units, houses and agricultural lands.

Districts	**Upazilas Affected**	**Unions Affected**	**Households Affected**	**Fully Damaged Agricultural Lands (*ha*)**	**Damaged House**	
					Fully	Partially
Sunamganj	11	88	172,617	102,436	2,600	15,000
Sylhet	13	105	212,570	26,715	20	10
Netrakona	10	86	167,180	19,566	0	0
Kishoreganj	13	56	148,687	45,256	0	0
Habiganj	08	64	74,440	15,953	46	51
Moulvibazar	07	60	74,594	9,914	194	284
Total	**62**	**518**	**850,088**	**219,840**	**1,860**	**15,345**

Data source: Department of Disaster Management (DDM) of the Government of Bangladesh (Dhaka, April 28th 2017)

Following the unprecedented damage of crops, considerable deaths of fish, ducks and ducklings in the Haor region, and outbreak of water-borne diseases further exacerbated the overall condition of those affected by flash floods. Fishing was temporarily banned in the Haor area as piscine diseases spread out following the flood. According to the Sunamganj district Fisheries Office, 44 metric tonnes (MT) of fish worth US $52k died in 20 wetlands. An estimated loss of US $12 million was reported from the flood damage in Sunamganj district alone. The cause of sudden death of livestock and fishes in such an unprecedented number led to huge economic loss to Haor communities.

4. Methods and Field Study Instruments

4.1 Study Area

The Haor region of northeastern Bangladesh is a low-lying, bowl-shaped basin covering about 6,000 km^2 in Sunamganj district (Figures 3 and 5) of Sylhet Division (Salaudin and Islam, 2011). The Surma River and Kushiyara River run through the district whilst Ratna River criss-crosses the district and beyond. The River Da'uka or Danuka also run through Sunamganj district. Sunamganj has a total population of 1,968,669 of which 51% are male and 49% are female. People of Sunamganj are racially and ethnically diverse, ranging from Arab Semite to Aryan and Dravidian including Jarwa, Gabar and Jangil tribal populations. There are also about 6,643 people of Manipuri, Khasi, Garo and Hajong ethnic groups from the neighbouring states of India. Since 1960 Sunamganj has been known for its construction stones and sand supplies throughout Bangladesh. As a result, stone crushing and river-sand collection is a flourishing business in the region. More than a thousand people are involved in these businesses with fifty thousand workers are directly dependent for livelihood.

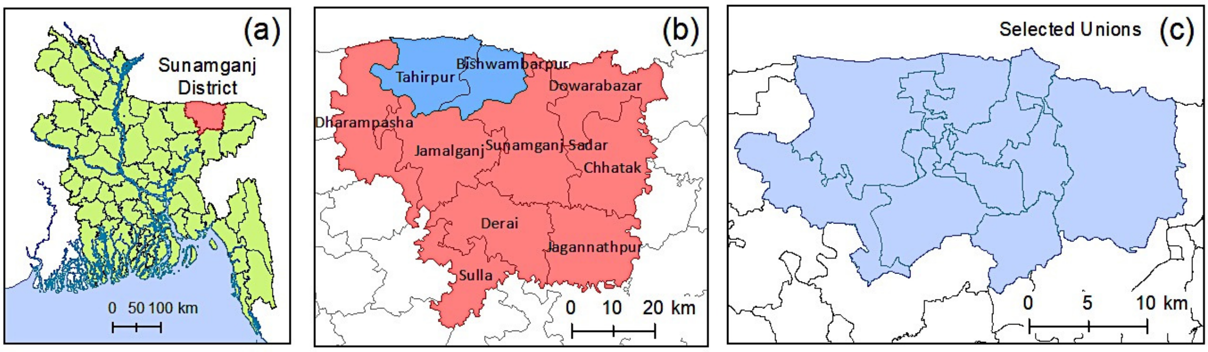

Figure 5. (a) Location of Sunamganj district within Bangladesh; **(b)** Location of the two sub-district or Upazilas within which a number of unions were selected **(c)** for social science studies applying various field instruments.

Sunamganj is a major source of freshwater fish; Tanguar Haor is one of the largest freshwater wetlands located in Tahipur upazila (Figure 5b) in NE Bangladesh and is also recognised as an "Ecologically Critical Area" by the Government of Bangladesh (Alam et al., 2012). Sunamganj has more Haors and seasonal wetlands than any other districts in Bangladesh and this makes it famous for the fishery industry in the country. Tahirpur upazila was the most affected place in Sunamganj district in the 2017 flash floods. Total area of Tahirpur upazila is 315 km^2 of which 93% is covered by land surface. Almost 74% land area is very flat and low-lying where the maximum elevation is <10 m above mean sea level (msl). There are 7 unions and 243 villages in Tahirpur upazila. Total population is 215,200 with a density of 682 people in per square kilometre. Total household number is 37,931. Mainly *Aman* and *Boro* rice crops are cultivated in the floodplains and seasonal wetlands in the upazila. Fishing is also a popular occupation among the people who live in the upazila (CEGIS, 2012).

4.2 Field Survey Instruments

The field-study was conducted in Tahirpur upazila through a two-step procedure: (1) a rapid field visit was conducted in Sunamganj in the first week of May 2017 in the first step, and (2) in the second step, a follow-up field visit was conducted in June 2017 at the same locations. Firstly, meetings were held with officials of local government departments, journalists, and locally-informed people in Sunamganj district headquarters, Bishwambharpur and Tahirpur upazilas. Later, group meetings were held on common land courtyards at household level referred to "Aatis" (cluster of households living in small island-type places inside the large water body of Haor) in Shanir Haor at Tahirpur upazila (Figure 6). These meetings helped understand the nature, depth and severity of the 2017 flash floods. Draft checklists were developed followed by these meetings. Secondly, a follow-up field visit was conducted in June 2017 at the same locations. Cross-checking of the draft field instruments was conducted during this visit, which were used in the final field survey in the first week of October 2017, using the following social-science research techniques:

(i) Focus Group Discussion (FGD): four FGDs were arranged in small inland, island-type communities ("Aati" in local term) where people were affected by the 2017 flash floods. It was applied as an effective PRA (Participatory Rural Appraisal) exercise enabling the team to collate a broad range of information. FGD is a good way to gather together villagers who experienced flash floods in 2017. The project team facilitated the group discussion where participants freely discussed topics ranging from livelihoods, preparedness for flash floods, adaptive capacity, and community resilience. The advantage of focus group discussion is that the participants are able to discuss amongst themselves and can provide a range of opinion and ideas, and inconsistencies and variations that exists even within a community that may appear to be highly homogeneous. This survey also offered an opportunity to cross-check as several groups of respondents representing a homogeneity were involved in the FGDs.

(ii) Key Informant Interview (KII): KIIs are qualitative in-depth interviews with resource person who is often a community leader, a professional, or a resident who has the first-hand knowledge about subject of investigation. Four KIIs were conducted with the Upazila Parishad Chairman of Tahirpur, the Deputy Director of Department of Agricultural Extension, Fisheries Officer of the district and a representative of a national daily newspaper, *Vorer Kagoj*. They provided the team with macro-level qualitative data on flood damage and loss in Tahirpur upazila.

Figure 6. (a) Tahirpur upazila as seen on Google Earth satellite image; (b) Shanir Haor – locally known as the grain bowl of Sunamganj district that was badly affected in the 2017 flash floods due to onrush of hill waters through a collapsed embankment; and (c) a village where some of the social-science survey techniques were applied by the research team.

(iii) Personal Interview: to understand the experience that the inhabitants of the Haor area underwent during the challenging time of the 2017 flash floods a series of in-depth interviews were conducted in the study area. A number of villagers was interviewed by the research team about their personal experiences that include questions about their total investment in rice cultivation, household income, and how the floods affected their livelihoods and how they were planning to get through the disastrous situation into the next cropping season.

(iv) Household Questionnaire Survey: a household quantitative survey was conducted in 80 households located within 11 unions in Sunamganj district (Figure 5c) to collate quantitative information related to the 2017 flash floods. Households are grouped rather indicatively into poor, middle-income and wealthy or rich based on household assets. A comprehensive questionnaire (see the survey instrument in Supplementary Material) was developed by the authors' research teams consisting of a series of both closed- and open-ended questions. The survey instrument consists of a series of questions ranging from household demographics, livelihood patterns, descriptions of flood impacts, coping strategies, preparedness for floods, sources of financial support, and adaptation to flood disasters.

The questionnaire survey was conducted in two stages: (1) in the first stage, to test the questionnaire instrument, a group of household heads (typically a male) affected by the 2017 flash floods was arbitrarily selected at a town centre which is considered to be a rural economic hub in Tahirpur upazila. The most severely affected Shanir Haor and Matain Haor are located next to the town headquarters; (2) in the second state, a small group of local people who participated in the first stage of questionnaire testing, were asked to guide the survey team for the next stage of the household survey. The survey was conducted in this manner that enabled the survey team an easy access to communities in flash-flood affected areas who are often conservative and not open to outsiders. Those local people accompanied the survey team to households that are located within the local Hoar communities.

5. Results and Discussion

5.1 Qualitative results from FGDs and KIIs

Qualitative data collation through FGDs and interviews in the study areas of Tahirpur upazila reflect on livelihoods and the way Haor inhabitants live their day to day life and provides a narrative description from the sufferers of how the flash-flood affected their lives and livelihoods (see Box 1 for 4 case stories in the supplementary information). One of the respondents described in their words:

"*No one could understand our sufferings unless they see them with their own eyes. Within minutes hectares and hectares of agricultural land went under floodwater, taking away with them, all our hopes (rice) that we planted with great care and expectation*."

Dry-season *Boro* rice crops were their only source of income. They tried to cut the submerged crops, at least, for their cattle to eat. However, they had a very little success of recovering some crops as the floodwater came in very fast and flooded the land. Although several other families recovered submerged rice plants, already party rotten by the time they recovered, many were unaware of the health consequence of feeding the rotten straws to cattle. During the FGD, a District Livestock Officer opined that feeding rotten straw to livestock is unhealthy and can result in diarrhoea. There were reports of death of many ducks and ducklings due to feeding on the rotten fish. According to Tahirpur Upazila Parishad Chairman the fisheries in Tahirpur lost about US $50k due to death of large number of fish in the flood. Sudden decrease in dissolved oxygen in water due to washed-off fertilisers and rapid decomposition of rotten rice crops caused death of fish at a large number. Those who simply dependent of fisheries for their livelihoods suffer the most.

The study reveals that the livelihood of the Haor population is not highly diverse. Haor inhabitants primarily rely on agricultural farming and fishing for their livelihoods. Some of them works as day labourer and some have small businesses. During cropping season (October to May), villagers work to earn for the livelihood for a whole year. Some find a second occupation temporarily for the rest of the year. However, the study finds a significant number of people involved in off-farm wage labouring. This narrow range of livelihood diversification makes the population more susceptible to any change in the region. Their response to sudden external shock such as the 2017 early flash flood leaves them with reduced scope of employment. A reporter from a national daily newspaper, *Samakal* was present told the survey team that most people in the region primarily depend on single rice crop and fishing was their seasonal occupation. However, fishing was difficult as seasonal wetlands were leased to influential, rich businessmen for a period of 3 to 6 years, who forbid the local fishermen to fish in the wetlands. Similar findings were reported in a recent study from the same region (Choudhury and Haque, 2016) suggesting that leaseholders are often chosen from the ruling political party, and that leaseholders try to maximize their profits by allying themselves with local political leaders to gain favour in the bidding process.

The study also finds that most households in the study area belong to marginalised population whose children often suffer from malnutrition. There were also reported cases of water-borne and skin diseases, which had intensified as the floodwater in the Haor became polluted by rotten crops, fish and other contaminants. There was scarcity of drinking water in the area during and long after the flooding as revealed in the FGDs and household surveys. Sanitation and hygiene facilities were also badly affected; broken sanitation systems further spread pollutants to surface water that is normally used for bathing and domestic purposes.

When asked about the migration pattern of the flood-affected areas, the respondents said that due to high unemployment rates, a substantial proportion of the population migrate to other big cities such as Chittagong, Sylhet and Comilla, for example. Gender discrimination was also prevalent in the area. Women are not often allowed to work outside their homes in deeply religious communities. Women often feel insecure when their husbands temporarily migrate to other areas leaving the family behind.

The FGDs and interviews reveal that the middle-income families suffered the most due to flood-led disaster in the region. The main reason of why the middle-income families found themselves vulnerable as they were not ready to accept flood aids or relief goods unlike the poor, marginalised people who did not hesitate to get a day-labourer job or in accepting relief goods from the government or NGOs. Many middle- to low-income families rather took loans from local business or microfinance institutions such as BRAC (Bangladesh Rural Advancement Committee), ASA (Association for Social Advancement), and Grameen Bank that operate in the area. Many families find it difficult to repay the loan in weekly instalments with high interest rates as their livelihoods suffered due to catastrophic flood event. The Chairman of Tahirpur Upazila Parishad opined that the suffering of the flood-affected people would continue until the next harvest season. The Chairman also added that the rehabilitation and relief aids were not adequate. Also, it was discussed during the FGDs that flood relief goods were not distributed properly and often inappropriate individuals (i.e., a person who was not affected by the 2017 flood) were selected for aids by the local power groups who are linked to the ruling government party or local elites.

5.2 Physical observations and interpretation of quantitative data

Data were collated at field sites from interviews, household surveys as well as physical observations by the survey team. This section provides a description of the quantitative information and data under several physical, social and economic indicators that help develop statistical models to explain the degree of vulnerability and resilience in the Haor region. Summaries of quantitative data are provided in a series of tables as supplementary information (Tables S1 to S31) and briefly described below.

The survey team finds that food-grain supply in the Haor region is primarily met by crops produced locally in floodplains and seasonal wetlands. People's livelihood is linked to rice-crop cultivation and fisheries in perennial and seasonally flooded wetlands. So normal flooding is beneficial to fish farming and crop production as it brings fertile soil along with it. However, in the event of an unprecedented flash flooding Haor inhabitants can become highly vulnerable to losing their livelihood and income from crop productions and fisheries.

During the 2017 catastrophic flash-flood event, nearly 88% people experienced some sort of damage to properties and economic loss to a degree. About 51.3% people were affected by a loss of income. Other type of losses includes crop damage, fishing-net damage and damage to houses and land properties – all of which contributed to income losses. Those who suffered total loss of crops became economically the most vulnerable to flood-related loss. In addition, 68.8% respondents reported that they lost household asset to a degree.

The study finds that during the 2017 flash-flood event, more than 50% sources of clean drinking, primarily hand-operated tubewells, were not critically affected as the tubewell platforms are generally located at a slightly elevated location in the households. Households whose water sources were affected (30%) attempted to recover them as quickly as they could; however, 70% respondents said that they did not take any measure to protect their drinking sources before the flood commenced. Approximately, 61% people who were surveyed use traditional pit latrines for sanitation of which nearly 80% facilities were affected by the flash floods. Some (14%) households who had some savings were able to repair or even construct another toilet after floodwater receded. More than 70% households had no other choices but to use the partly-damaged toilets or someone else's toilets or to defecate openly.

During the flash floods a number of schools were damaged. In the survey, 76% respondents said that local schools were not damaged or very slightly damaged. It is noteworthy to mention that in many parts of Bangladesh schools are multipurpose, strongly built buildings at a slightly elevated ground. During natural hazards like cyclones or floods people find temporary shelter in local schools. During the flood time school-going children were not able to attend classes and many schools remained closed.

Nearly 81% respondents said they faced disruption in accessing healthcare services during flash floods. This is not because of the healthcare centres were closed during flood time but to due to poor local transportation and remoteness of location. Those who responded that they used healthcare services during flood time, 66% preferred to go to the upazila health complex (public hospitals) and the rest relied on local medical practitioners or traditional healthcare services. Most households experienced some sort of medical problems among which the breakout of cholera and typhoid fever were most common.

A number of respondents with middle to low-income (i.e., grouping of households is considered indicatively) background said that they had to borrow money soon after the flash floods as their regular sources of income were disrupted. Those who did not have any savings ended up borrowing money from various sources including close relatives, neighbours, local NGOs, and traditional moneylenders ("mahajans"), often with high interest rates. The flood-affected extremely poor people received some support under the government's social protection programme including 30 kg of rice and BDT 500.00 (US $6.00) per month from local government. About one-fifth of the respondents claimed that they did not receive any relief goods from the government.

The survey finds only 7.5% respondents had access to current weather forecasting and tried to take necessary preparations for the imminent flooding. Approximately 65% respondents did not take any precaution or preparedness measures for a possible major flash flooding in 2017. Most people were ignorant or unaware of how effectively they could prepare themselves to avoid damage from floods. Only 35% respondents did indeed take some preparedness measures such as strengthening house structure and saving money, but were not sure about their effectiveness either. The study finds that being completely unprepared of potential flood calamities while living in flood-prone Haor region is deep-rooted in a strong religious belief that floods or other natural events are from god and, therefore, cannot be avoided; it's mainly on god's will who would suffer and who would be spared.

The study finds that moving away or migration during and immediately after the flood was low. Among the respondents 53% migrated, mostly temporarily, during flooding and the rest did not. From the respondents' responses it was understood that people did not want to migrate for a number of reasons including the fear of losing household assets, uncertainty of getting a job, and finding a place to live. Only a minor fraction of the Haor inhabitants migrated temporarily to continue fishing in other places that were not flooded.

5.3 Quantifying Vulnerability and Resilience

The objective of the research is to characterise vulnerability and resilience of the Haor inhabitants to floods in one of the highly flash-flood prone areas in Bangladesh. Haors are low-lying wetlands and social conditions mean that the inhabitants tend to be vulnerable to both flash- and riverine floods. Nonetheless, people in the Haor region have been living with floods for centuries. The level of vulnerability and resilience of a household or an individual to natural hazards including flash floods can be manifested in a range of indicators (Keim, 2008). A number of variables (Table 2) is used to indicate the level of vulnerability and/or resilience emanating from and response to flash floods in the household survey.

Table 2. A number of variables used in statistical analyses of vulnerability and/or resilience.

• Household income	• Whether the household has taken any safety measures
• Remoteness of the household	• Whether the source of safe water was affected in flash floods
• Disease experienced by any member of the affected household	• Damage to house
• Whether any loan was taken by the household	• Household asset or property loss
• Base of the house (plinth height)	• Received monetary support from any source
• Adaptation strategy taken by the household	• Sanitation recovery following flash floods

5.3.1 Evidence from correlation analysis

We first examine the correlation strength between a pair of variables indicating vulnerability and resilience to flash floods in the Haor region. A total of 12 variables (Table 2) are used for correlation where indicative categorical variables (e.g., whether or not loan was taken) are converted to binary or dummy (1 for yes, 0 for no cases) variables. In addition, in order to address the uncertainty in correlation coefficient depending on methods and the distribution of data, here we employ both Spearman and Pearson's correlation methods to numerical variables, and the Spearman method only for categorical or binary variables. The pair-wise correlation coefficients are summarised (see Table S31 in the supplementary information). Correlation analysis shows that a number of variables show statistically significant ($p < 0.05$) associations but correlation strength varies from weak ($r = 0.1$ to 0.3) to moderate ($r = 0.3$ to 0.5). For example, correlation analysis reveals that the variables, 'household income' and 'safety measures' considered or not by households are positively correlated (Spearman correlation, r=0.20 and p=0.07) suggesting that households with greater income were more inclined towards safeguarding their household properties. In contrast, households that had lower income were not equipped with proper safety measures that led to greater damage to houses and loss of assets. Likewise, variables such as 'adaptive strategy' and 'damage' are found to be positively associated (Spearman correlation, r=0.35 and p=0.001) suggesting that those households that suffered more damage by historical floods have indeed become more adaptive or resilient to floods.

5.3.2 Statistical modelling of vulnerability

To what degree households are vulnerable or resilient to floods is analysed using regression modelling of collated variables indicators for vulnerability and resilience. To examine various dimensions of vulnerability of flood-affected households in the Haor region, we consider *DAMAGE* (i.e., *DAMAGE* indicates whether the household experienced any physical damage due to flash floods) as a representative response or dependent variable demonstrating the level of vulnerability to flash floods. The independent variables in the regression model are: (i) *DIST* (distance of the household from upazila headquarters, an indicator of remoteness of the location), (ii) *BASE* (base or plinth type of the house), (iii) *AIWF* (whether the household has access to information of weather forecasting), (iv) *SFTY* (whether the household has taken safety measures), and (v) *INCOME* (natural log of income of the household). Below we are reporting the results from a multiple linear regression model (equation 1) where the dependent variable, *DAMAGE* is regressed through a linear combination of a number of independent or explanatory variables to explain the level of damage due to flash floods in the study area.

The following equation specified to examine the factors affecting flood damage:

$$DAMAGE_i = \alpha_1 + \alpha_2 DIST_i + \alpha_3 BASE_i + \alpha_4 AIWF_i + \alpha_5 SFTY_i + \alpha_6 INCOME_i + e_i \qquad (1)$$

where,
α_1 = Intercept
α_2 to α_6 = Slope coefficients
DIST = Distance of the household from upazila headquarters (km), an indicator of remoteness
BASE = Base of the house
AIWF = Whether the household has access to information of weather forecasting
SFTY = Whether the household has taken safety measures
INCOME = Natural log of income of the household
i = Number of observations (*i* = 1, 2… 80)

Dependent variable: $DAMAGE_i$	Coefficient (Robust SE)	
	Model (1)	Model (2)
$DIST_i$	0.009 (0.008)	0.016* (0.008)
$BASE_i$	–0.124** (0.048)	–0.165*** (0.055)
$AIWF_i$	–0.592*** (0.187)	
$SFTY_i$	0.093 (0.083)	0.037 (0.085)
$INCOME_i$	0.059 (0.103)	0.089 (0.085)
Constant	0.462 (0.915)	0.198 (0.756)
R^2	0.25	0.03
F (5,74), (4,76)	4.66*** (0.000)	2.73** (0.03)

Notes: numbers in parentheses indicate standard deviation of the respective regression coefficients. Asterisks (***, **, *) indicate statistical significance of the modelled coefficients whether they are reported at 1%, 5% and 10% significant levels.

To assess flood damage, two multiple linear regressions models are developed. In the first model, all independent variables of equation (1) are considered, whereas, in the second model access to information of weather forecasting is dropped to examine whether any other variables turn out to be important factors explaining flood damage. In the first model, which explains 25% variance in the dependent variable (*DAMAGE*), covariates *BASE* and *AIWF* are found to be statistically significant but negatively associated to *DAMAGE*. This suggests that when the base of a house is low, it is easily inundated in floodwater and, therefore, suffers more damage. The lack of access to weather forecast led to less preparedness taken by some households that ultimately suffered more damage in floods. The second regression model that drops the term (*AIWF*), fails to explain (R^2=0.03) the overall variance in *DAMAGE* but reveals that remoteness measured as distance from headquarters is statistically significant in explaining damage to household properties. The overall explanatory power of these statistical models are low as indicated by a low R^2 value, which could be due to confounding factors (e.g., skill set) that are not included in the models. Furthermore, these results are rather indicative given the small sample size (n=80) of the household survey and homogeneous nature of households in the flash-flood damaged area.

5.3.3 Econometric analysis and statistical modelling of resilience

To understand resilience of the Haor inhabitants to floods through statistical analysis, we develop multiple linear regression models to explain the resilience. The response or dependent variable in our model is *ADAPT* (i.e., whether or not the household took any adaptation strategy during floods) and the independent or explanatory variables include different types of loan or sources of financial support, education and loss of income. Below we are reporting the results from a multiple linear regression model (equation 2) where the dependent variable, *ADAPT* is regressed through a linear combination multiple independent or explanatory variables to explain the level of adaptation strategy considered by households.

$$ADAPT_i = \alpha_1 + \alpha_2 BASE_i + \alpha_3 DAMAGE_i + \alpha_4 LOAN_i + \alpha_5 EVUL_i + \alpha_6 LMFI_i + \alpha_7 LRN_i + \alpha_8 LOTH_i + \alpha_9 LCOOP_i + \alpha_{10} EDU_i + \alpha_{11} INCOME_i + e_i \quad (2)$$

where,

α_1 = Intercept

α_2 to α_{11} = Slope coefficients

ADAPT= Whether the household has taken any adaptation strategy during flood

BASE = Base of the House

DAMAGE = Whether the household lost any asset due to flood

LOAN = Whether the household has taken any loan during flood

EVUL = Whether the household has taken loan from *Mahajans* during flood

LMFI = Whether the household has taken loan from MFIs during flood

LRN = Whether the household has taken loan from relatives & neighbours during flood

LOTH = Whether the household has taken loan from other sources during flood

LCOOP = Whether the household received any assistance from cooperatives during flood

EDU = Education of the head of households

INCOME = Loss of income of households

Dependent variable: $ADAPT_i$	Coefficient (Robust SE)		
	Model (1)	Model (2)	Model (3)
$BASE_i$	0.078 (0.226)	0.092 (0.229)	0.121 (0.211)
$DAMAGE_i$	0.435^{**} (0.175)	0.444^{**} (0.174)	0.415^{**} (0.179)
$LOAN_i$	0.320^{**} (0.154)	0.319^{**} (0.154)	
$EVUL_i$			0.357^{**} (0.170)
$LMFI_i$			0.253 (0.202)
LRN_i			0.310^{*} (0.172)
$LOTH_i$			0.458^{**} (0.224)
$LCOOP_i$	-0.352^{***} (0.106)	-0.344^{***} (0.103)	-0.309^{**} (0.138)
EDU_i	0.008 (0.014)		0.009 (0.016)
$INCOME_i$	-0.256^{***} (0.094)	-0.247^{***} (0.098)	-0.258^{***} (0.096)
Constant	2.254^{**} (0.882)	2.189^{**} (0.911)	2.238^{**} (0.896)
R^2	0.357	0.353	0.364
F (6,73), (5,74), (9,70)	14.11^{***} (0.000)	11.77^{***} (0.000)	9.39^{***} (0.000)

Notes: numbers in parentheses indicate standard deviation of the respective regression coefficients. Asterisks (***, **, *) indicate statistical significance of the modelled coefficients whether they are reported at 1%, 5% and 10% significant levels.

To assess how considering an adaptive strategy helps households during floods, three multiple linear regressions models are developed. All three models show that a linear combination of a set of independent variables are able to explain the variance of the response variable (*ADAPT*) fairly well (R^2 values ≈ 40%), and some independent variables are statistically significant at 1–5% level. Independent variables, *DAMAGE* and *LOAN* demonstrate a positive association (significant at 5% level) with adaptation strategy implying that people who have experienced damage to their households to flood disasters are more adaptive and resilient to floods. In other words, people who previously suffered from floods might have learned lessons from their experience and, therefore, could be more resilient to floods. A positive association between *ADAPT* and *LOAN* suggests that resilient households are more prepared to tackle financial difficulties due to floods by taking loan. The model reveals that is the covariate of assistance from cooperatives is negatively associated with adaptation strategy, suggesting that people's trust on local cooperative as a financial institute is rather poor and doesn't lead to resilience to floods. Models do not show any significant association between adaptation and education. Further, to test which type of loan is associated with adaptation strategy the tern *LOAN* is dropped from the model. The resulting model (3) reveals that households, which consider taking loans from relatives, neighbours, Mahajans or other sources (e.g., work), are shown to have a strong resilience to flash floods. Surprisingly, the model reveals that wealthy or rich households are less adaptive. Wealthy households with higher income tend to be less vulnerable to floods and, therefore, might not consider actions for becoming more adaptive. The wealthy households often take a strategy of 'come what may, we will put it off'.

6. Conclusions

The Haor (wetland) region of northeastern Bangladesh is a flash-flood prone area due to its low-lying flat topography and high annual rainfall. Given the social conditions, wetland communities therefore become highly vulnerable to flood-related disasters. The 2017 flash floods in Bangladesh were especially abrupt and catastrophic compared to the flash floods of 2004, 2007 and 2012. The present study looks at vulnerability and resilience to flash floods in the Haor communities. The research was conducted to better understand how disaster-prone communities respond to hazards through resilience. Following the catastrophic 2017 flash floods in northeastern Bangladesh, this opportunistic study looked at resilience to flash floods through focus group discussion, key informant interviews, and household questionnaire surveys in Sunamganj district – located in the heart of the Haor region. The Haor inhabitants were especially vulnerable to the 2017 flash floods as these coincided with the harvesting season for the dry-season *Boro* rice, which is the only source of income for many households. The flash floods killed 100s of tonnes of fish and have left the fish-farming households economically too weak to recover from the disasters.

Focus group discussions, key informant interviews, and household questionnaire surveys all suggest that the lack of adequate weather forecast (93% respondents did not have access to any weather information) made the wetland inhabitants more vulnerable to flash-flood disasters. Statistical modelling reveals that households suffered physical damage due to remoteness, lack of access to weather forecast and poor construction (low plinth or weak foundation). Similarly, statistical models for resilience suggest that adaptation stems from community's previous experiences to flood-led damage to houses and properties. Poor households are more adaptive than wealthy and middle-income households as poor people do not hesitate to take up any kind of jobs whereas middle-income households are generally reluctant to get flood relief or support from government; and rich households lack drive or motivation for devising any adaptive strategy as the general perception is that they are resilient in recovering quickly from economic losses because of wealth.

The study also finds that women are particularly vulnerable and thus less resilient as Haor communities are predominantly religious and do not allow women to work outside of their homes or even beyond their own communities. Interestingly, resilience in Haor communities also stems from deep religious faith that natural calamities are divine tests from god and, therefore, the only way forward is to accept them and move on. This study also finds that those inhabitants who took loans to recover from flood disasters tend to migrate to other cities in search of jobs so that they can pay back their debts. A carefully planned educational programme to raise awareness of natural hazards and empowering women through training and helping them find self-employment at household or community levels can increase resilience of Haor communities to flash floods and other natural hazards.

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