



Resident perceptions of riverbank erosion and shoreline protection: a mixed-methods case study from Bangladesh

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Abstract

Riverbank erosion is a common hazard in Bangladesh, posing a significant threat to homes, properties, and livelihoods. In recent years, the government of Bangladesh has intensified efforts to mitigate riverbank erosion by hardening shorelines, including the building of concrete revetments, but the local dynamics of these interventions are not well documented. To address this, we present results from a study of community-level response to a 2-mile long concrete revetment recently constructed in the administrative district of Ramgati, in the lower Meghna River basin of Bangladesh. Our study combines quantitative analysis of data from a household survey with qualitative data from semi-structured interviews to assess resident perceptions of the new revetment and its effect on the landscape of riverbank erosion hazard. The study finds, firstly, that hazard awareness is widespread but may be influenced by livelihood factors related to the dynamics of displacement and resettlement. Second, we find that the negative impacts of riverbank erosion vary spatially. Hazard perception in Ramgati is significantly influenced by the physical location of the household, with those residing closer to the river and in unprotected zones north and south of the revetment expressing much greater worry that they will lose their homes, and believing that this will happen much sooner than residents further away or in the zone now protected by the embankment. As an empirically grounded case study, our findings add to the literature on riverbank erosion in Bangladesh and perception studies focused on water-based hazards in similar settings globally.

Keywords Riverbank erosion · Hazard perception · Bangladesh · Revetment

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1 Introduction

Flooding and erosion represent significant environmental risks for residents of coastal, deltaic and riverine systems across the globe (Nicholls et al. 2020; Welch et al. 2017; Williams et al. 2018). The country of Bangladesh is highly susceptible to these hazards due to its location within the hydrodynamic Ganges–Brahmaputra–Meghna (GBM) River delta. For communities and households located within the GBM Delta, riverbank erosion represents a particularly prominent hazard, posing a recurring threat to homes, property and livelihoods across the country (Baqee 1998; Zaman and Alam 2021). In recent years, the government of Bangladesh has intensified efforts to mitigate riverbank erosion by hardening shorelines, most commonly through the construction of concrete revetments (Nakagawa et al. 2013; Oberhagemann et al. 2020). While the phenomenon of riverbank erosion in Bangladesh has received significant attention by scholars, the local impacts and perceptions of these engineering interventions are not well documented. To address this, this paper presents a local case study of a recently built revetment in Ramgati, along the lower left (east) bank of the Meghna River. This portion of the GBM Delta is especially prone to riverbank erosion, and local residents have long been forced to cope with the ever-present hazard posed by the river (de Wilde 2011). Concrete embankments have been built in a number of locations along the Meghna River, but their construction has been sporadic due to limited funding, resulting in a patchwork of shoreline protection. The new revetment in Ramgati has altered the nature and spatial characteristics of the erosion hazard along the river and provides an opportunity to examine how residents perceive the changes associated with shoreline hardening.

In what follows, we describe results from a study combining quantitative analysis of data from a household survey with qualitative data from semi-structured interviews to assess resident perceptions of the new revetment and its effect on the spatial variability of the erosion hazard. As we discuss more fully below, the revetment is generally welcomed by residents, but it has also created geographical disparities in perceived levels of risk. Accounting for these changes, we argue, can provide a fuller picture of the role of engineering interventions in shaping the geographies of riverbank erosion and risk perception.

The remainder of the paper is structured as follows. After situating our research in the literature on hazard perception, we review existing research focused on riverbank erosion and flood control measures in Bangladesh. Next, we describe our study site and methodology, highlighting how riverbank erosion shapes lives and livelihoods in the lower GBM delta. We next describe the events leading to the construction of the revetment, and provide an analysis, using both quantitative and qualitative data, of its effects on local perceptions of riverbank erosion. We conclude with some remarks about the contributions of our study to existing research on riverbank erosion in Bangladesh and to the literature on hazard perception in similar settings worldwide.

2 Literature review

2.1 Hazard perception

Much of the social science research on hazard perception remains indebted to the pioneering work of Gilbert White, who developed an understanding of environmental hazards from the perspective of human adjustment (White 1974). This approach recognizes that the

ways in which individuals respond to a hazardous situation depends upon a combination of perceptions regarding the hazard and an awareness of available opportunities to make adjustments (Burton et al. 1993). Locational decision making in hazardous areas is thus characterized by a range of possible choices, which may include attempts to eliminate or reduce the hazard, efforts to plan for or mitigate potential harms, or simply accepting the risk and bearing any eventual losses (Hewitt 1997). The behavioral response in any given context will be shaped by a range of factors related to hazard perception and experience. Montz et al. (2017) divide these into cognitive factors related to an individual's emotional or psychological disposition, and situational factors deriving from both personal characteristics (such as gender or age) and sociospatial context (such as physical location).

This so-called behavioral approach to hazards has been subject to criticism from political economy perspectives that focus attention less on human adjustment than on the structural factors that create vulnerability and the power relations that sustain them. Blaikie et al., for example (1994), describe a 'pressure and release' model in which disasters are a consequence of underlying vulnerability. Such an approach adds to perception studies by emphasizing the need to account for the "dynamic processes and root causes which generate the unsafe conditions" in the first place (Blaikie et al. 1994, p. 26).

More recent work on hazard perception has placed increased attention on the spatial variability of hazard perception, and on the ways in which place characteristics can shape both landscapes of vulnerability and the horizon of opportunity for human action in the face of risk. In the conclusion to their edited volume on *The Spatial Dimensions of Risk*, for example, Müller-Mahn et al. make the point that "the ways in which risks are understood, identified and dealt with are related to place-specific characteristics, and to the people who live in the places concerned" (Müller-Mahn et al. 2012, p. 204). Valerie November (2008) has suggested something similar, arguing that "the spatial dynamics of risk must be taken into account if we are to achieve a comprehensive understanding of risk" (p. 1523). This recent emphasis on the spatiality of risk perception provides one important context for our case study below of riverbank erosion in Bangladesh.

2.2 Riverbank erosion in Bangladesh

In the Bangladesh context, previous studies have focused attention on perceptions related to several different environmental hazards, including floods (Ali 2007; Paul 1997), coastal hazards (Parvin et al. 2008), earthquakes (Alam 2016; Paul and Bhuiyan 2010), and climate change (Ahmed et al. 2021; Alam et al. 2017). A significant body of work has focused on the hazard of riverbank erosion as well, and while few studies have examined perceptions explicitly (though see Das 2011 for an example from India), much of this work can be broadly situated in the early behavioralist tradition of hazard perception concerned with human adjustment (see Paul 1997 for a review). Research, for example, has highlighted the range of choices and coping mechanisms employed by individuals and households in the face of riverbank erosion (Hutton and Haque 2003, 2004; Paul et al. 2021; Rahman and Gain 2020; Tanvir Rahman et al. 2015) as well as the dynamics and negative consequences of displacement (Aker et al. 2019; Bhuiyan et al. 2017; Haque and Hossain 1988; Haque and Zaman 1989; Islam 2018; Rahman and Gain 2020).

Taken together, this work has produced significant insights into the opportunities and constraints that shape household responses to riverbank erosion. Our research adds to this body of work in two key ways. First, most studies in Bangladesh have focused on the upper reaches of the GBM Delta system (Fig. 1). The fieldwork for our project, by contrast,

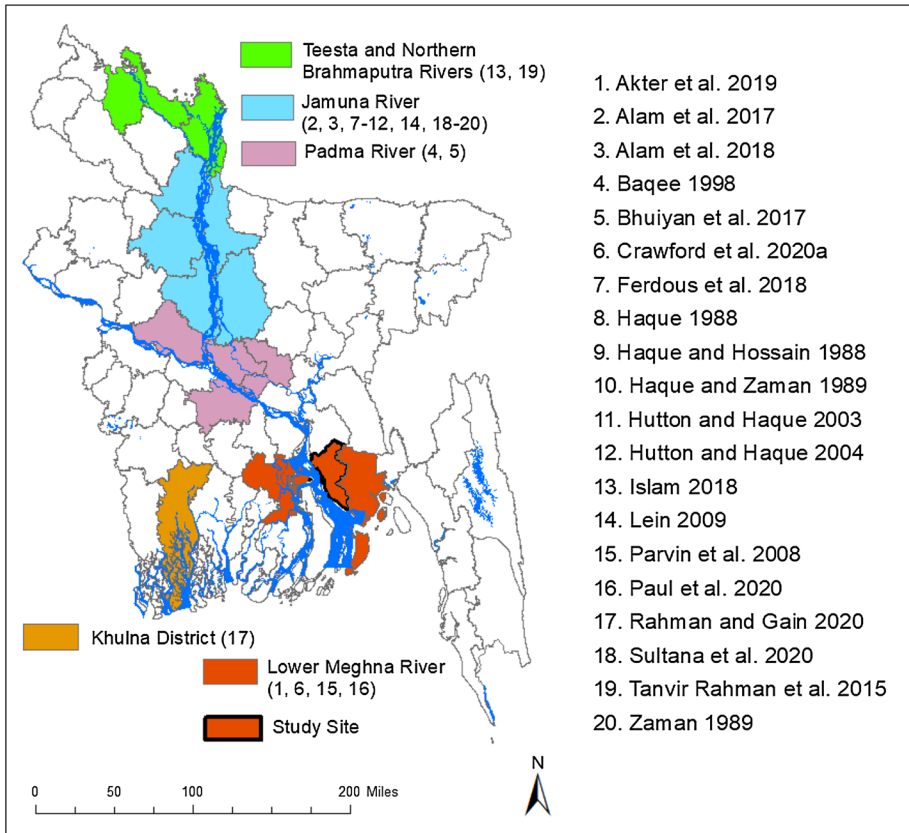


Fig. 1 Location of previous studies related to riverbank erosion in Bangladesh

examined perceptions and livelihood practices in the Coastal Zone area. And second, few studies have examined hazard perception in the context of shoreline protection measures, as we do in what follows (though see Ferdous et al. 2018). Our focus is on the way that perceptions are shaped by an engineering intervention intended to stabilize the riverbank and reduce the risk of erosion.

2.3 Flood control and shoreline protection in Bangladesh

While the revetment that is the subject of our study is a relatively recent phenomenon, structural interventions to address flooding and riverbank erosion have a long history in Bangladesh. Prior to the partition of India in 1947, local Zamindars (landlords) had established a tradition of constructing seasonal earthen embankments to protect agricultural land against flooding and saline intrusion. Following a series of disastrous floods in the mid-1950s, the government of what was then East Pakistan initiated the Coastal Embankment Program (CEP), a large-scale flood control effort based upon the Dutch dike system (Gain et al. 2017). The CEP, started in 1961 with funding from USAID, led to the construction of 136 polders in the southern delta region, along with associated irrigation and drainage canals, sluice gates and pumping stations (Dewan et al. 2015). The polders initially served

to increase agricultural productivity within the delta, but over time they impeded the natural hydrodynamics of the estuary, leading to significant problems of siltation and waterlogging (Nowreen et al. 2014). Many polder areas, particularly in the western part of the delta, have since been repurposed for shrimp aquaculture (Ishtiaque et al. 2017; Paprocki and Cons 2014).

During the 1970s and 1980s, international donors shifted their focus to smaller-scale and community-based flood control projects and non-structural flood control measures (Dewan et al. 2015). But significant river floods in 1987 and 1988 again captured worldwide attention and placed large-scale engineering works back on the table. This led to the development of the World Bank sponsored Flood Action Plan (FAP), which proposed to embank hundreds of miles along Bangladesh's rivers (World Bank 1990). Efforts to actualize the FAP were met with skepticism from both international donors and Bangladeshi civil society, and in the end the plan's sweeping ambitions went unrealized (Brammer 2010). But it did place the issue of shoreline protection on the agenda, and in the years since many communities in Bangladesh have undertaken efforts to control flooding and riverbank erosion through structural measures.

Among the most common response has been the building of revetments along sections of riverbank in flood-prone areas (Sarker 2011). Revetments can take various forms may be constructed from a wide range of materials, including concrete blocks, geo-bags, boulders, mattresses, stone, riprap, or open asphalt concrete (Oberhagemann et al. 2020). For the most part, shoreline hardening has been a piecemeal effort in Bangladesh. The construction of embankments requires significant funding, and the government of Bangladesh has therefore built them sporadically and on a priority basis. Our study focuses on a recently built concrete block revetment that protects roughly 2 miles of shoreline along the Meghna River. The limited scope of the protection has created a differentiated hazard for households in the area, and offers a unique opportunity to examine the impact of an infrastructural intervention on the perceptions and livelihoods of local residents.

3 Study site and methodology

Our study site is Ramgati upazila (Fig. 2), located along the lower left bank of the Meghna River within Lakshmipur district (a district is the second-largest of Bangladesh's four administrative areas; an upazila is the next smallest). Communities in the region are highly dependent upon the hydrological dynamics of the delta, with both irrigated farming and fishing being important livelihood activities. But it is also an area that is habitually prone to riverbank erosion (Brammer 2014; Braun and Bernzen 2019; Rahman et al. 2021), a risk that is expected to increase by the year 2050 according to one recent analysis (Hill et al. 2020). Ramgati also faces significant development challenges, and has been estimated to have a 'very high' level of social vulnerability according to one recent study based on an index of 13 socioeconomic variables (Rahman et al. 2020).

Our study results derive from a mixed-methods research design that combines an analysis of data from a household survey with qualitative data from semi-structured interviews. The survey was carried out as part of a larger project focused on the vulnerability, resilience and adaptive responses of the population in the GBM Delta in the face of riverbank erosion and monsoon dynamics (Crawford et al. 2020a). A total of 381 randomly selected households used for this analysis were surveyed in Ramgati upazila for that project, and this forms the basis for our analysis below. Households were selected

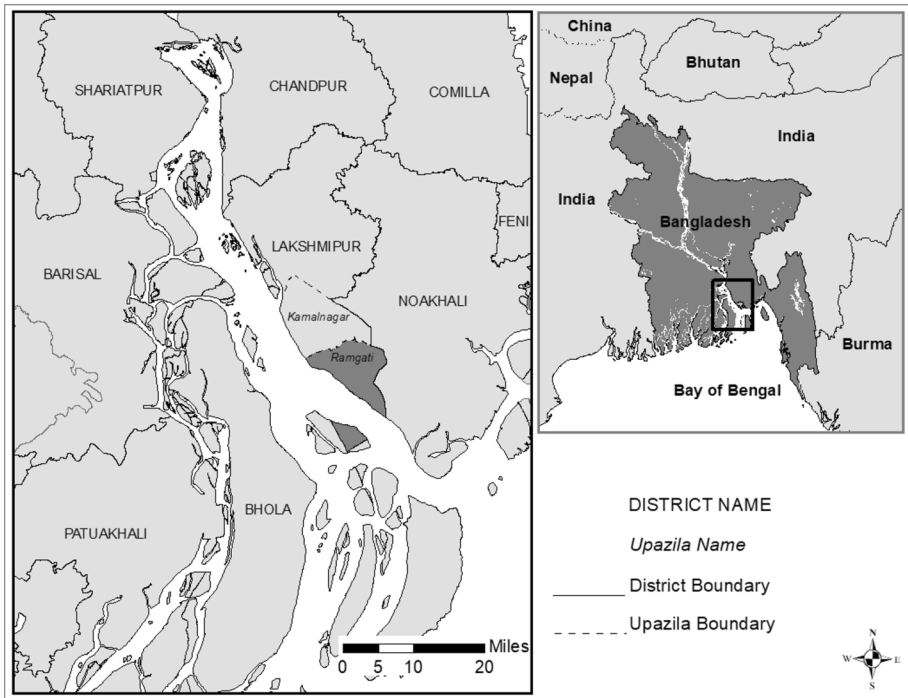


Fig. 2 The lower Meghna river showing Ramgati upazila

through a random spatial sampling of latitude/longitude points, with a higher sampling intensity closer to the river to capture the perceptions of those most at risk. Enumerators in the field surveyed households closest to the randomly selected geo-locations.

The survey instrument contained 97 questions focused around household experiences with, and perceptions of, riverbank erosion and related riverine hazards. In order to test for spatial differences in resident perceptions, we divided the study area into three different zones for analysis (see Fig. 3). The Center Zone represents the area that is now protected by the revetment, with zones to the North and South remaining unprotected. This approach allows us to examine the uneven geographical effects of the revetment on hazard perception in Ramgati.

Survey data are supplemented by a total of 24 in-depth interviews, including 18 households and six key informants identified through convenience sampling. The key informants included local school and college teachers and government officials. The household interviewees were selected on the basis of the household's location and the occupation of the respondents. Six respondents were selected from each of the three zones representing an equal number of farmers, fishers and business owners. All household interview respondents were men, which precludes a qualitative analysis of the gender dynamics of local perceptions and livelihoods. Interviews were conducted using a semi-structured interview guide and averaged 30–50 min. The conversations were conducted in Bangla by the lead author and subsequently transcribed and then translated into English. For the analysis, interview passages were coded for prominent themes related to environmental hazards, livelihood strategies, and perceptions of riverbank



Fig. 3 Sampled household locations by different zone in Ramgati. Occupation of household heads is indicated. Background image is a Landsat 8 (pixel size = 30 m × 30 m) natural color composite dated 21 February 2018

erosion and the recently built revetment. All data collection protocols were approved by the Institutional Review Boards of participating universities.

4 Riverbank erosion in Ramgati

As we have noted, a number of studies have documented high rates of erosion along the east bank of the Meghna River (Brammer 2014; Crawford et al. 2020a, b). An analysis of shoreline change from USGS Landsat imagery confirms this to be the case for Ramgati as well. Figure 4 depicts shoreline change from 1990 to 2020 and shows evidence of shoreline erosion over time.

Figure 5 shows the changes of water and land from 1990 to 2020 using the same images. To estimate the loss of land, we classified a part of west border of Ramgati into water (river) and land (houses, agricultural lands, forest and all other infrastructure) using interactive supervised classification in ArcMap 10.6.1. We found that the west border of Ramgati lost 12.65 square miles between 1990 and 2020 (Table 1). Key informant interviews provide further evidence for the receding shoreline, with one respondent noting that “in my childhood...this riverbank was 10–15 km [6–9 miles] away...But now you see this river is very near to my house” (teacher, female, 30s).

Our findings suggest that the hazard posed by riverbank erosion shapes the fortunes of Ramgati residents to a considerable degree. Of those who participated in the household survey, 49% reported that they had experienced a residential move as a result of erosion, and stories of personal loss were also common among those who were interviewed (Fig. 6a). “Five years ago, I had a big house and farmland,” said one respondent, “but now I have nothing. I have lost everything” (fisher, male, 60s). Another interviewee stated that “riverbank erosion is a huge problem. People are suffering unbelievably. It’s hard to describe how powerless they are. It is a very difficult task to rebuild in another place after losing your house in the river” (fisher, male, teens). Riverbank erosion also has an impact on the wider economy. One business owner stated that “some of my regular customers have

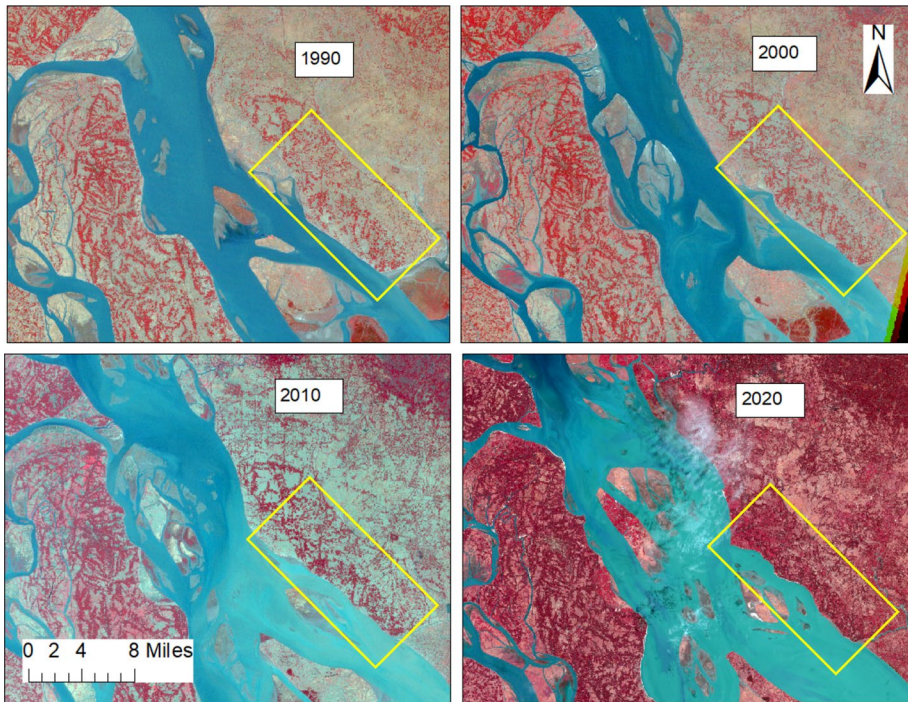


Fig. 4 Temporal variation of shoreline along Ramgati from 1990 to 2020 (the box is highlighting the west border of Ramgati). For 2020 we used Landsat 8 imagery (pixel size = 30 m × 30 m) which was acquired 3 March 2020. For 1990, 2000, and 2010 we used Landsat 5 imagery (pixel size = 30 m × 30 m). Those were acquired, respectively, on 7 April 1990, 19 January 2000, and 30 January 2010

been forced to move due to riverbank erosion. Some customers owed me money that I will never get back now” (male, 20s).

5 Construction of the revetment

Sparked by longstanding concerns about riverbank erosion, local residents in Ramgati began to organize to put pressure on the government to protect the shoreline. Starting in July of 2016, a social media campaign emerged to highlight the problem of riverbank erosion in both Ramgati and neighboring Kamalnagar. One of the interview participants was directly involved with the protests at that time. As he recalled:

When this river started coming very near to us, I thought a lot about the local communities. It seemed the government was absent. I thought, why is the government ignoring the suffering of the people? I even saw wealthy people who were landlords become homeless due to erosion ... So we staged protests and made human chains, actions to gain attention from the government. Our demand was to build an embankment to protect us from erosion.

As Zaber et al. (2018) describe, the movement to stop riverbank erosion in Ramgati made extensive use of social media and represents an innovative approach to protest in the

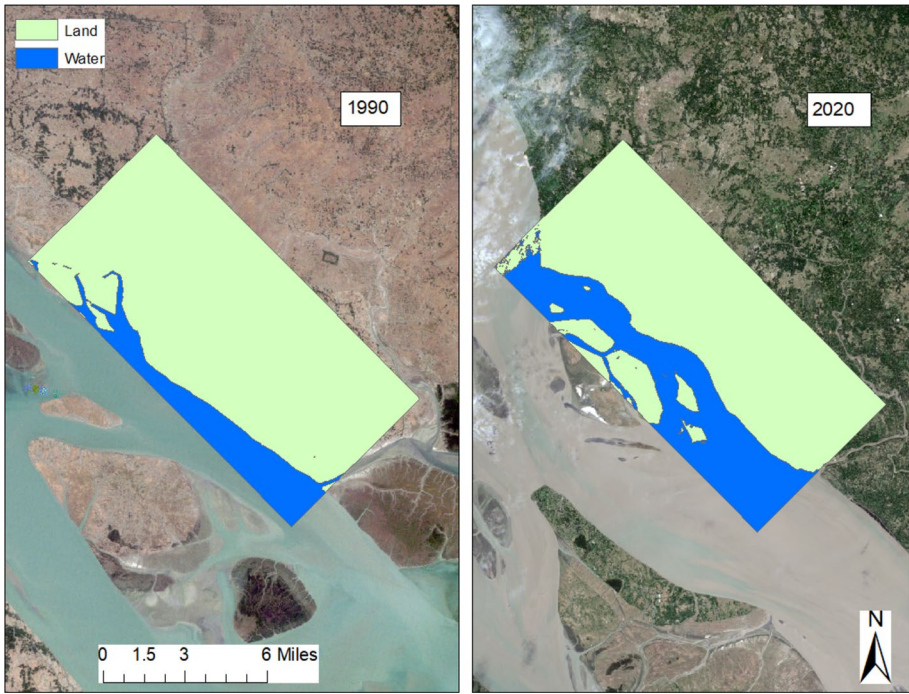


Fig. 5 Spatial–temporal changes of water and land from 1990 to 2020 along the west border of Ramgati

Table 1 The statistics of land and water changes along the Ramgati shoreline

Class	1990	2020	Loss and gain
Land (square mile)	78.95	66.30	Land loss = 12.65
Water (square mile)	12.43	25.08	Water gain = 12.65



Fig. 6 Evidence of riverbank erosion (a); and the revetment in Ramgati (b)

context of hazards. The younger generation of Ramgati, many of whom reside in cities such as Dhaka or Chittagong or live abroad, posted photos, videos and commentary on Facebook related to riverbank erosion. One post asserted that “we have only one slogan—‘Save us from the mighty Meghna’” (quoted in Zaber et al. 2018, p 7). The activists promoted the use of specific hashtags, such as #SaveRamgati and #SaveKamalnagar.

Eventually, the local Member of Parliament (MP) visited Ramgati and told local residents that the Bangladesh government would build an embankment. One online activist later described the scene in a Facebook post:

This Monday (11-07-16) at 6.20 pm in the afternoon, our honorable MP Mr. Al Mamun and a team of officials came to Ramgati to visit erosion-affected areas. The MP had the opportunity to talk to people who were affected by erosion recently. He assured to initiate bank protection measurement as soon as possible (quoted in Zaber et al. 2018, p 8).

The MP helped to secure funding from the Bangladesh national government, and later in 2016, the engineering division of the Bangladesh Army started the embankment construction work. The revetment was completed in 2017 (Fig. 6b).

As we noted above, the funding was sufficient to protect 2 miles of the 10-mile Ramgati shoreline. The area that is now protected is the location of the upazila administrative offices as well as schools, a hospital, and the largest marketplace. As one key informant noted, “*you know, the upazila headquarters is here, and the municipality is also here. This is the heart of Ramgati—all of the government institutions are here. That was the reason the revetment was built in the center*” (government official, male, 30s).

When asked for their opinion about the new revetment, most Ramgati residents view its construction in a positive light. For example, when asked to respond to the statement that “I think the embankment construction in recent years near my area is a positive thing,” 97% of survey respondents either agreed or strongly agreed. Comments from interview respondents generally support this positive view. While the revetment is generally regarded as a positive development, areas to the north and south of the town center remain unprotected. This provides an opportunity to investigate the role of shoreline hardening on the geography of risk perception related to riverbank erosion.

6 Analysis of hazard perception

To assess the factors that influence perception of the erosion hazard in Ramgati, we carried out an ordinal regression using data from the household survey. For the dependent variable (risk perception), we used responses to the following survey question: “For this current year of 2018, how worried or concerned are you that your home will fall into the Meghna River due to riverbank erosion?” Survey responses were recorded using a 5-point Likert scale (from ‘Very not Worried’ to ‘Very Worried’), which was coded numerically 1 through 5. As shown in Table 2, we included in the model a number of independent variables that have been shown in the literature to influence hazard perception, including demographic characteristics, socioeconomic status, length of time living in the area, and previous experience with the hazard. We also examined whether distance from the river or a location behind the revetment (within the Center Zone) was associated with perceived worry about riverbank erosion. The ordinal regression was

Table 2 Characteristics of respondents (N = 381)

Variable (continuous)		Mean Value
Monthly income (Taka)		20,073
Distance from the river (m)		1071
Age (Year)		44
Number of years living in current union		39
Monetary loss in previous experience of erosion		1,941,978
Variable (categorical)	Category	Frequency (%)
Protection against erosion	No protection	67
	Protection by revetment	33
Education	Primary school or less	64
	beyond primary	36
Past experience of erosion	No	52
	Yes	48
Gender	Male	68
	Female	32

performed using SPSS. Tests of parallel lines yielded a satisfactory Chi-square value ($p > 0.05$), suggesting that the proportional odds assumption was not violated.

The regression model found that perceived worry has a statistically significant relationship with two spatial variables, geographical zone and distance from the river, and two variables associated livelihood dynamics, income and number of years living within the same union (the smallest administrative unit in Bangladesh). Age, gender, education, and previous experience with riverbank erosion were not found to be associated with perceived likelihood of loss (Table 3).

Table 3 Ordinal regression for the perception of losing households in river due to the erosion

Variable	Coefficients/estimates	SE	Sig.
Monthly income (Taka)	3.675E–5	8.400E–6	0.000*
Distance from the river (meters)	– 0.001	0.000	0.000*
Age (Year)	0.001	0.008	0.879
Number of years living in current union	– 0.018	0.007	0.008*
Monetary loss in previous experience of erosion	– 1.631E–7	1.453E–7	0.262
Protection by revetment (north and south zones = 0; center zone = 1)	– 1.094	0.245	0.000*
Education (primary school or less = 0; beyond primary = 1)	0.217	0.244	0.373
Past experience of erosion (yes = 1)	0.254	0.254	0.316
Gender (male = 0)	– 0.165	0.240	0.489

Dependent variable: “For this current year of 2018, how worried or concerned are you that your home will fall into the Meghna River due to riverbank erosion?”

* $p < 0.05$

In terms of livelihood variables, higher household income is associated with greater worry about losing one's house in the river. We surmise that this may be related to the greater loss that would be incurred by households with more assets, as well as the potential loss of status resulting from relocation. As one key informant suggested:

Poor people can usually adapt to any kind of challenge after a disaster. They can easily change their occupation. I think that when wealthy people lose significant property, it is more difficult for them. If they are forced to move, they may not be respected in their new community. Rich people care more about their status (teacher, female, 40s).

Newer arrivals to their local union also express greater worry. We believe that this may be related to the dynamics of settlement in Ramgati. Data from the household survey suggest that newer arrivals are more likely to live close to the river. This relationship is suggested in Fig. 7, which shows a cluster of households in the North Zone that have lived in their union for less than ten years and are located close to the riverbank.

Our research also suggests that some recent arrivals may have been previously displaced by riverbank erosion. Among survey respondents who have been living at their current residence for less than ten years, 93% report a previous move due to erosion. This is compared with 25% of those who have lived at their residence for more than 10 years. These results paint a picture of ongoing displacement commonly followed by resettlement in areas relatively close to the river. Interestingly, however, previous displacement due to erosion was not itself a significant predictor of expressed level of concern about losing one's house.

Regarding the spatial dynamics of hazard perception, the model shows that distance and locational characteristics both play an important role in perception. Perhaps not surprisingly, those who live closer to the river and those living in areas not protected by the embankment express higher levels of concern that their house will fall into the river.

To examine the spatial variability of perception in greater detail, and to further assess the impact of the revetment on levels of worry, we performed a Chi-Square test to see which Zones within the upazila are associated with perceived likelihood of losing one's house. To do so, we divided households in each of the three Zones (north, central and south) into 'near' and 'far' quadrants. We selected 870 m from the riverbank as the

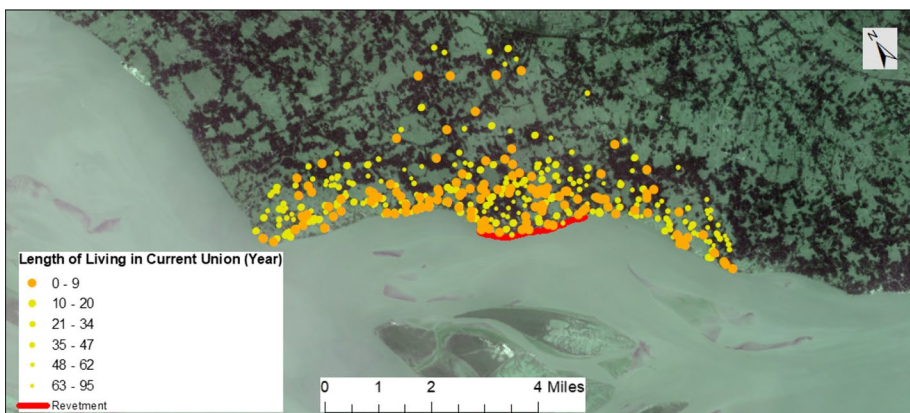


Fig. 7 Length of living in current union for residents in the study area

dividing line between ‘near’ and ‘far’, as it represented a natural break close to the median distance across the study area (846 m).

The Chi-square test found that there is a statistically significant association ($p=0.00$) between the location of households relative to the river and level of concern of losing one’s house. We performed a post hoc analysis to determine which quadrants across the study area expressed significant difference and across which responses on the survey question. According to the value of adjusted z score residuals, there are clear spatial patterns in the levels of worry expressed by survey respondents. First, distance from the shore influences perception. Residents who live in quadrants closer to the shore and unprotected by the revetment (Near North and Near South) were more like to respond that they were ‘Very Worried’ and less likely to respond that they were ‘Not Worried’. Those unprotected but living in the ‘Far’ quadrants, by contrast, were significantly less likely to state that they were ‘Very Worried’ compared to the overall study sample. Second, the existence of the revetment ameliorates worry. Those in the Center—in both near and far quadrants—were less like to say they were ‘Very Worried’ and more likely to say that they were ‘Not Worried’ compared to the overall population. Although not surprising, this finding provides further evidence that the impact of the revetment on hazard perception in Ramgati is spatially uneven (Table 4).

Results from the survey also allowed for an assessment of perceptions regarding the immediacy of the hazard, which is indicative of how residents view the rate of river-bank erosion in the different quadrants. The Ramgati household survey asked residents to respond to the following question: “If you think your house will fall into the Meghna River, what is the number of years that you think it will be until your house falls into to river?” Mean responses across the study area quadrants are shown in Table 5.

We can see that in areas protected by the revetment, respondents believe that they are free from risk for at least a decade, with average responses being 12 years in the Near Center quadrant and 16 years in the Far Center. For unprotected residents in the Far Zone, the average assessment was 4½ years in the North and nearly 7 years in the South. For those within 870 m of the unprotected shoreline, by contrast, the perceived threat is

Table 4 Spatial patterns in the levels of worry among survey respondents

Level of concern	Near north	Near center	Near south	Far north	Far center	Far south
<i>Very worried</i>						
%	43.8	5.5	35.2	11.7	2.3	1.6
Adj. residual	6*	− 3.5	6*	− 2.5	− 5.6*	− 2.6*
<i>Worried</i>						
%	18.3	18.3	21.7	20	13.3	8.3
Adj. residual	− 1.4	1	0.7	0.3	− 0.9	0.9
<i>Not worried</i>						
%	4.9	27.5	5.9	17.6	36.3	7.8
Adj. residual	− 5.6*	4.5*	− 3.9*	− 0.3	6*	1
<i>Very not worried</i>						
%	27.5	14.2	18.7	18.7	17.3	5.8
Adj. residual	0.5	− 1.8	− 3.4*	3.1*	0.7	1.1

*Value of adjusted z score residuals above 1.96 or bellow − 1.96

Table 5 Perceptions regarding the immediacy of erosion risk in Ramgati

Region	Mean number of years	Number of responses	SD
Near north	0.97	89	1.31
Near center	11.93	41	9.62
Near south	1.24	62	1.74
Far north	4.57	83	6.68
Far center	15.96	74	8.94
Far south	6.70	27	4.12

imminent, with an average prediction of 16 months in the South and less than a year in the North.

Recent satellite imagery allows us to gauge the possible accuracy of these predictions. Figure 8 shows the location of households at the time of the survey, and again overlaid onto a more recent satellite image. Although we have not verified these outcomes in the field, it appears plausible that some number of houses, particularly in the North Zone, were indeed lost to the river in the two years after the survey was carried out.

The geographic variability in perception that is evident in our survey analysis was also captured in the interview data, with many respondents identifying differences in risk

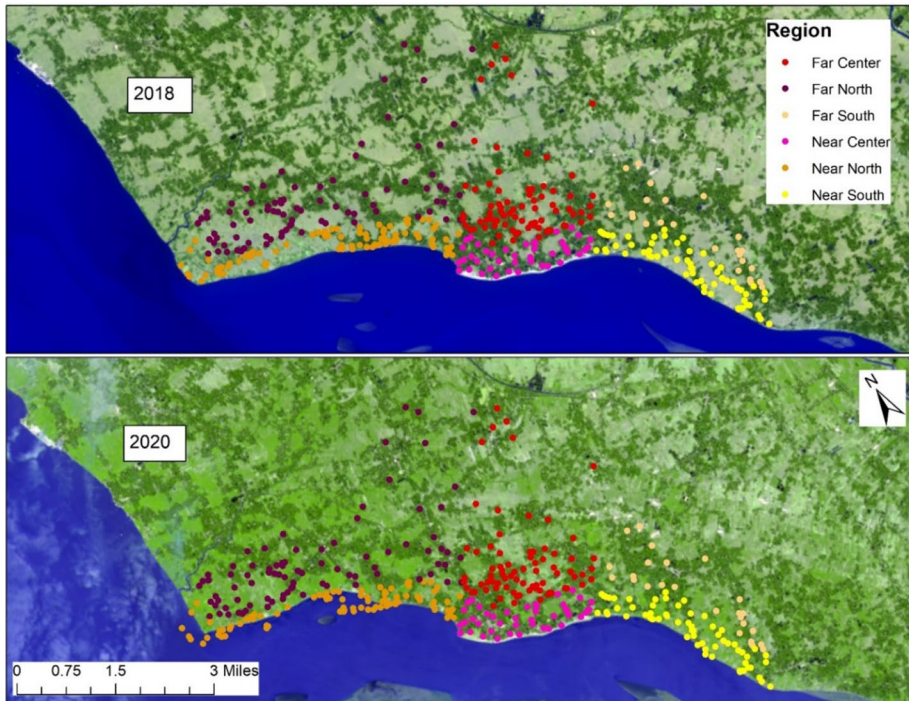


Fig. 8 The location of surveyed Ramgati households in 2018, and overlaid onto a 2020's satellite image. Background images are Landsat 8 natural color composite, dated 21 February 2018 and 3 March 2020, respectively

exposure created by the new revetment. For those in the now-protected zone, there is a clear sense of relief. As one business owner relayed:

Before the revetment was built, my house was very close to the riverbank and I was very worried. Where would I go if I lost my house? I prayed to Allah to save my house. During that time, most of the night I could not sleep. But by the grace of Allah, now we are feeling very good and safe (male, 30s).

Those who live north and south of the revetment, on the other hand, express a clear understanding that they are less fortunate than those who live in the center. As a local fisher put it:

No, I am not safe. My house is exposed to the river, so I am always at risk of erosion. The people who got the revetment, their houses are now safer than ours. They do not have to face problems of erosion or flooding (male, 40s).

Given these spatial disparities, it is not surprising that most respondents favor extending the protection of the embankment. One question on the household survey, for example, asked respondents how strongly they agreed with the statement that “An engineered concrete embankment should be constructed to protect the entire Meghna shoreline of my union.” Of those responding, 99% support the extension of the concrete embankment. As one interviewee from the South Zone put it, “*this is our demand to the government, to extend this revetment. We always hope that the revetment will be extended. Otherwise we will lose our houses very soon*” (business owner, male, 40s).

7 Conclusion

The case study presented here provides an illustration of hazard dynamics playing out across the GBM Delta of Bangladesh, as riverside households and communities face the ongoing risk of erosion. Our findings add to the literatures on riverbank erosion in Bangladesh and perceptions of water-based hazards in similar settings globally. A number of conclusions can be highlighted.

First, Ramgati residents displayed a high degree of awareness of the negative impacts of riverbank erosion on local livelihoods. Indeed, the widespread nature of these concerns was a factor in the local activism that culminated in the construction of the revetment in Ramgati. Roughly half of those surveyed had experienced a forced relocation due to riverbank erosion, and interview respondents described the negative consequences of erosion on both individual households and the local economy. These findings are consistent with previous research from other regions of Bangladesh, which has documented recurring dynamics of erosion-induced displacement, as well as the resulting negative impacts on households and the coping mechanisms adopted in response (Bhuiyan et al. 2017; Haque and Zaman 1989; Hutton and Haque 2004; Parvin et al. 2008; Rahman and Gain 2020).

Second, results from our model provide insight into both demographic and geographical factors that are associated with greater perceived worry about riverbank erosion. Among demographic variables, we found that higher income is associated with increased worry. This finding is at odds with a number of flood perception studies that have found no significant relationship between income and perceived risk (Botzen et al. 2009; Combest-Friedman et al. 2012; Gray-Scholtz et al. 2019; O’Neill et al. 2016; Rana et al. 2020). We believe that the local Bangladeshi context may play a role in this relationship, with higher incomes

correlating not only with greater potential asset loss from erosion, but also a potential diminution of community status.

Our model also found that length of residence is inversely associated with perceived worry. This result also diverges from existing studies, a number of which have found that length of residence increases knowledge of a hazard and can therefore lead to increased perception and worry (Domingues et al. 2018; Gray-Scholtz et al. 2019; Lechowska 2018). In explaining our result, we find some evidence that local livelihood dynamics may play a role, with more recent arrivals more likely to have experienced displacement and relocation close to the river. This is a finding consistent with our previous work from Ramgati, which shows that displaced residents seldom migrate and instead tend to remain close to their previous residence (Paul et al. 2022). In explaining this, Paul et al. note that “the river provides primary and alternate livelihoods for many residents ... the river is ruthless, but it is also benevolent, leading residents to accept ‘living with the river’” (2020, p. 6). This kind of acceptance and livelihood adaptation has been described from other flood-prone areas, including the Okavango Delta of Botswana (King et al. 2018), Coastal Vietnam (Ngo et al. 2020), and floodplains in Cambodia (Nuorteva et al. 2010) and Cameroon (Laborde et al. 2018).

Our analysis also assessed the spatial dimensions of hazard perception. Our model results show that in Ramgati, worry decreases with distance from the river, and survey data show that residents living in the ‘far’ zone of our study predict that it will take three to five years longer for riverbank erosion to affect them than those in the ‘near’ zone. These results may seem unsurprising, but existing research has come to somewhat variable conclusions about the role that proximity to a hazard plays in hazard perception (Lechowska 2018). In a study from the Philippines, Combest-Friedman et al. (2012) found, similar to our study, that the perceived risk of coastal hazards was inversely correlated with distance from the coast. Botzen et al. (2009) reached similar results in a study from the Netherlands. Gray-Scholtz et al. (2019), on the other hand, found that while elevation was a predictor of perceived flood risk among residents in Calgary, distance to the river was not significant. And O’Neill et al. (2016) in a study from Dublin found that perceived distance from the floodplain was a predictor of flood worry but actual distance was not, suggesting that residents’ ‘cognitive maps’ may be at odds with the realities of flood risk. Our results regarding proximity, as supplemented by our qualitative interview data, suggest that residents in Ramgati generally have a high degree of awareness of the spatial dimensions of the hazard posed by the Meghna River and in general possess an understanding of the rate of erosion taking place within the upazila.

Finally, our study allows us to examine the geographical variability of perception in the wake of the new revetment, which now protects some but not all households in our study area. Several previous studies have assessed the role of structural mitigation initiatives on hazard perception. Somewhat counterintuitively, this work has not generally demonstrated a decrease in perceived risk or worry related to various kinds of protective measures. In their study from the Netherlands, Botzen et al. (2009) found that residents of floodplain areas not protected by dikes expressed a lower degree of perceived risk than residents in protected areas. In a study from the U.S. Gulf coast, Scyphers et al. (2019) found similarly that residents with armored shorelines expressed greater concern about coastal erosion than homeowners with natural shorelines. And residents of coastal Benin, as described in de Longueville et al. (2020), reported that their perceived sense of safety increased only marginally four years after the installation of a series of protective groins along the coast.

In contrast to these studies, our research found that the revetment in Ramgati has a statistically significant influence on level of worry regarding riverbank erosion. Results from

both the ordinal regression model and a Chi-square analysis show that those residing in unprotected zones north and south of the revetment express greater worry that they will lose their homes to riverbank erosion, and believe that this will happen sooner than residents in the Center Zone who are protected by the embankment. These results are corroborated by our interview respondents, who clearly expressed to us an understanding of the new spatial landscape of risk and were aware of whether their household location was safer after the construction of the revetment.

As an empirically grounded, mixed-methods case study from the southern coastal zone, the research described here adds to our knowledge of riverine hazards in Bangladesh. Conceptually, our results contribute to existing literatures assessing the livelihood dynamics and perceptions associated with common environmental hazards such as flooding and coastal erosion. For policy makers, our work suggests that local residents in Bangladesh generally welcome engineering interventions to mitigate erosion hazards and that they have a spatially attuned sense of the differential impacts of such interventions on erosion risk. We emphasize in closing that hazard dynamics are context dependent, and we believe that additional research will be needed to provide a more complete picture of how communities and households respond to the recurring challenges of riverbank erosion and to government efforts to ameliorate its negative impacts.

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Declarations

Conflict of interest The authors have no financial or non-financial interests to disclose.

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