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Erosion and Mitigation Measures in the Teesta River Bank of Bangladesh

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Abstract

This paper aims to explore the erosion conditions and mitigation practices of riverine people at various levels (individuals, communities, NGOs, and GOs)of the River Teesta. To investigate the results, this study is conducted using satellite data as well as primary observation. Selected satellite imageries are used from the year of 1989, 1999, 2010 and 2022. Modified Normalized Difference Vegetation Index (MNDWI) is performed through Geographical Information System (GIS) and Remote sensing technique (RS) to identify the banklines that are used for erosion analysis. Random sampling procedure is applied to define the sample size whereas 426 households out of 955 are selected from three unions named Bojra (Site 1), Thetrai and Daldalia (Site 2) to collect primary data through questionnaire survey. Primary data are analyzedthe descriptive and inferential statistics using SPSS. Bojra, Thetrai and Daldalia experienced noticeable erosion followed by 86.63 ha and 81.91 ha over the period of 2010-2022 respectively. Despite, only traditional erosion control measures such as bamboo piling/*Bundal* were adopted at individual and community levels to combat riverbank erosion. On the other hand, the government has taken both inadequate traditional measures such as Geobags, bamboo piling along with infrastructural measures especially Boulders dumping, Cross/*I-badh* to mitigate riverbank erosion.However, the findings of the present study are expected to provide effective guidelines to the concerned policy makers to ensure sustainable river management in the northern region of Bangladesh.

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1. Introduction

Bangladesh lies within the catchment area of the Ganges, the Brahmaputra, and the Meghna Rivers which mainly drain through Bangladesh into the Bay of Bengal (Brammer, 2014). There are more than 220 rivers across the country with a total length of over 24,000 km, and cover about 7% of the national area (Rashed, 2008). The Teesta is an important transboundary river of the northern region of Bangladesh (Mondal and Islam, 2017).Riverbank erosion is one of the key geomorphologic problems experienced in the floodplains of the alluvial rivers that take place during flood in the channels (Bordoloi, et al., 2020). Teesta River runs alongside this region and meet with the Brahmaputra River. The Teesta basin is one of the most vulnerable river basins in the country from the perspective of the erosive character, and flash floods (Pal et al., 2016). It is a sandy braided river, displaying high seasonal flow variability and cause inundation of floodplains in monsoon and low flow conditions in dry season (Mullick et al., 2010). During monsoons, heavy rainfall and upstream flows cause floods as well as riverbank erosion in the region, which enhances the sufferings of the inhabitants through the colossal loss of lives and properties (Rumana et al., 2023). Many people become homeless and landless due to riverbank erosion. To deal with the adverse environmental and socio-economic impacts of riverbank erosion, people and government have developed a variety of mitigation measures that slightly reduce the risk of bank erosion (Rumana et al., 2023).

Mitigation refers to a sustained action taken to reduce or eliminate risk to people and property from hazards and their effects (Bullock et al., 2013). Riverbank erosion mitigation measures have been categorized as structural, non-structural and biological protection measures (Islam, 2011). Generally, structural measures are practiced, namely, revetment, guide bunds, boulders, brick matressing, groynes, spurs, vanes and submerged bend way weirs etc. On the other hand, some examples of non-structural and biological protection measures are dredging, channelization, geo-bag dumping, bank vegetation, wooden/bamboo piling, willow post and bundling etc(Islam, 2011). In the late 1990s, sand-filled geotextile bagged riverbank revetments were developed in Bangladesh due to the lack of traditional erosion-protection measures. Geotextile bags, first used as an emergency preparedness during the monsoon season, were filled with local sand to allow rapid response to dynamic river changes (Oberhagemann and Hossain., 2011). Efforts to mitigate the impacts of riverbank-erosion in Bangladesh have been largely structural and technological; to the exclusion of non-structural measures which might mitigate the impact of riverine hazards at the individual and community levels (Haque and Zaman, 1994).

In economic point of view, mitigating bank erosion has become an integral part of poverty reduction in Bangladesh (Islam, 2011). The Bangladesh Water Development Board (BWDB) is trying to protect the riverbank with its limited resources and budget to reduce the suffering of the people and minimize the national losses. Several low-cost structures like cross/*I-badh*, geo-bag dumping and *Bundal* were constructed along the left bank of the Teesta River by the BWDB. But in the case of distribution of relief goods to disaster victims the government has issued a general policy which destroys equal opportunity for the victims caused by riverbank erosion due to some conditions for getting relief material (Islam and Rashid, 2011). As a result, the riverbank erosion victims get only two types of assistance such as allotment (cash) for house building, and general relief (Food). NGOs like BRAC, ASHA, TMSS and RDRS are working with riverbank erosion displaces in certain areas of Teesta River. All the public representative including Member of Parliament, Upazilla chairman, Union chairman and members have adopted some mitigation measures like bamboo piling/ *Bundal***,** geobag/sandbag imputing and block-setting despite the lack of financial support. Traditional erosion control measures are practiced by local communities using natural resources such as bamboo and wood as well as tree plantation which has reduced massive losses and prevented bank erosion quickly and sustainably, in left bank of the Teesta River. However, there is no specific/effective policy or program for the riverbank eroded people either in government or in non-government sectors (Islam and Rashid, 2011).

In few decades, a number of researches have been conducted in the Teesta River in Bangladesh. Numerous studies have been focused on various aspects of riverbank erosion mitigation, prevention and preparedness (Bullock et al., 2013; Rahman et al., 2017; Haque, 1997). A number of studies have emphasized on sustainable mitigation measures of riverbank erosion (for example; Islam, 2011; Oberhagemann and Hossain, 2011; Sarker et al., 2011) systematically reviewed the researches on riverbank management using geo-textile bag, concrete block, boulder, mattresse techniques etc. Similarly, several studies focus on traditional erosion control approaches for controlling riverbank erosion and livelihood resilience in Bangladesh (Mamun et al., 2022). Another research was conducted (Maurya et al., 2020) on the problems and the remedial works carried out along the vulnerable areas using soft structural measures. However, the existing literatures pay very little attention to highlight the mitigation measures taken by individuals, communities, GOs and NGOs to mitigate Teesta Riverbank erosion in Bangladesh. Therefore, to fulfill this research gap, the present study investigates various types of mitigation measures adopted by different levels. This research will help policy makers to adopt long-term mitigation measures for vulnerable riparian areas.

2. Materials and Methods

2.1. Study area selection

The Teesta flood plains have been divided into three major units, i.e., Upper, The Middle and Lower Teesta Basin. The Lower Teesta Basin from Teesta-Sevoke Khola confluence zone to the Brahmaputra-Teesta confluence zone at Tistamukh Ghat in Bangladesh (Mitra and Mondal, 2022). This river runs through the five northern districts of Bangladesh such as Nilphamari, Lalmonirhat, Kurigram, Rangpur, and Gaibandha. The present study area Bojra, Thetrai and Daldalia is located on the left bank of Teesta River.

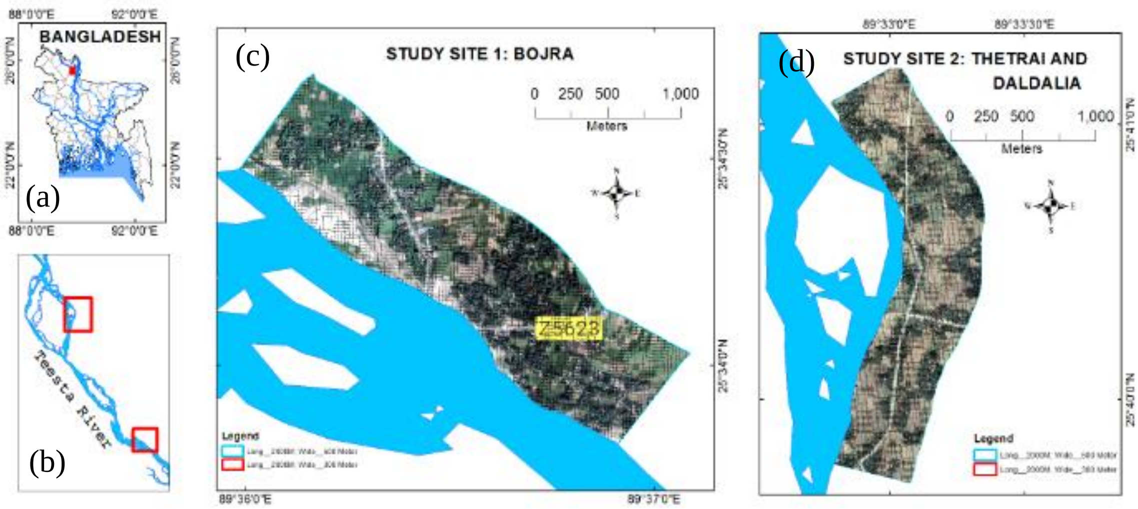

Fig. 1. Location of the study area: (a) Bangladesh (b) Teesta River (c) study site: Bojra (d) study site: Thetrai and Daldalia

The present study was conducted in three villages namely Bojra (Site 1), Thetrai and Daldalia (Site 2) which is located at ulipur upazilla in Kurigram district (Fig. 1). Bojra village is situated in the left bank of downstream of Teesta River, it lies between 25°34'0" to 25°34'30" north latitudes and 89°36'0" to 89°37'0" east longitudes. Thetrai and Daldalia villagesare located in the left bank of downstream of Teesta River, these lie between 25°40'0" to 25°41'0" north latitudes and 89°32'30" to 89°33'30" east longitudes. All the villages were severely affected by riverbank erosion. To select these study areas landsat images 1989, 1999, 2010 and 2022 are used. The MNDWI water index algorithm is generated to classify the images (land and water). To detect the changes along the bankline, classified images are overlaid and on-screen digitizing of bankline is undertaken to create the bankline layers. The noticeable river shifting places are marked by cross-sections while comparing base year to the next immediate studied year (i.e., 1989 to 1999, 1989 to 2010 and 1989 to 2022). For estimating the highest river shifted places, all cross-sections based layers are superimposed and the common cross-section places are selected. Among them, two vulnerable sites are found between 2010 and 2022.The image classification resulted in kappa index of 0.83, 0.85, 0.87 and 0.96 and overall accuracies of 93%, 94%, 95% and 96% for the images of 1989, 1999, 2010 and 2022 respectively.

2.2. Sampling and data collection

The identified riverbanklines for the left (south) banks of the river are digitized from Google Earth. 2 km bankline in Bojra village and 2 km bankline along the riverbank in Thetrai and Daldalia village are drawn. It is transferred by kml to layer on ArcGIS software. After that, the extracted banklines are converted into buffer zones of 300 m and 500 m landward.Subsequently, the entire buffer zone is transferred via ‘layer to kml’ on Google Earth image. Buffer zones are cut with Google Earth images and georeferencing is performed using ArcGIS software. Finally, the buffer zone is divided into 15×15 metre grids to calculate the total number of households in the study villages. It is point to be mentioned here that 15×15 metre grid was considered as a household. Following the simple random sampling procedure, 426 households are selected out of 955 households (Table 1) from the villages at 95% confidence level, and are in proportion to the sample of both villages (Yamane, 1967).

Table 1. Study area and population size

District	Upazilla	Union	Total Household	Sample Household
Kurigram	Ulipur	Bojra	500	219
Kurigram	Ulipur	Thetrai and Daldalia	455	207
Total			955	426

Source: Author

A close and open-ended structured questionnaire is used to collect data using face-to-face interview on March 2023. Besides, during field visits, a printed Google Earth image with study area is utilized to visually identify the exact location, latitude and longitude, and type of the location under investigation. There are two parts of our questionnaire one for the respondents (Close ended questionnaire) and another for the institutions (Open ended questionnaire). In the first portion of the survey, we asked the respondents about riverbank erosion mitigation in different level. Then, in the second part, we wanted to know whether the institutions BWDB (Bangladesh Water Development Board) Public representatives (MP, Chairman, Member) and NGO could solve river erosion problems through proper mitigation. Initially, it is planned to interview with the both male and female respondents of the households. But, after filling the few questionnaires it is observed that male respondents are well known about different types of mitigation measures as they are practicing this approach. It is noted here that respondents are also divided into two clusters one is who lives between 0 to 300metre (Cluster 1) and others respondent those are living between 300 and 500 meters (Cluster 2).

2.3. Data analysis

To measure the river bankline shifting in the study area four landsat images are used i.e., 1989, 1999, 2010 and 2022. Modified Normalized Difference Vegetation Index (MNDWI) is conducted to delineate the banklines of different years (Mentioned before). After the extraction of banklines from the satellite images, the banklines are analyzed to measure the temporal bankline shift, erosion and accretion. Clip and erase functions of ArcGIS are used for these purposes. Major shifting area is marked by cross section (Fig. 3). The measuring tape is then used to measure the maximum shifted area. On the other hand, to know the river erosion mitigation process of individual and institutional level mixed method is used. This approach concurrently consisting of both qualitative and quantitative research.Quantitative research is performed by close ended questionnaire to collect data from respondents. On the other hand, open ended questionnaire is analyzed through qualitative approach to collect data from different institutions. Datacollected through the structured questionnaire are coded and then analyzed using the Statistical Package for Social Sciences (SPSS, version 25). At that time, all data are checked, verified, and edited to minimize errors. The descriptive and inferential statistics are used to analyze data. With the aim of examining the association and dependency of the different variables significant test (e.g., Chi square, χ^2, R^2), percentage along with cross-tabulation and other quantitative and qualitative techniques are followed. In order to know the opinion on various issues that participants are asked about, descriptive statistics such as percentages and frequencies are used to display the results.

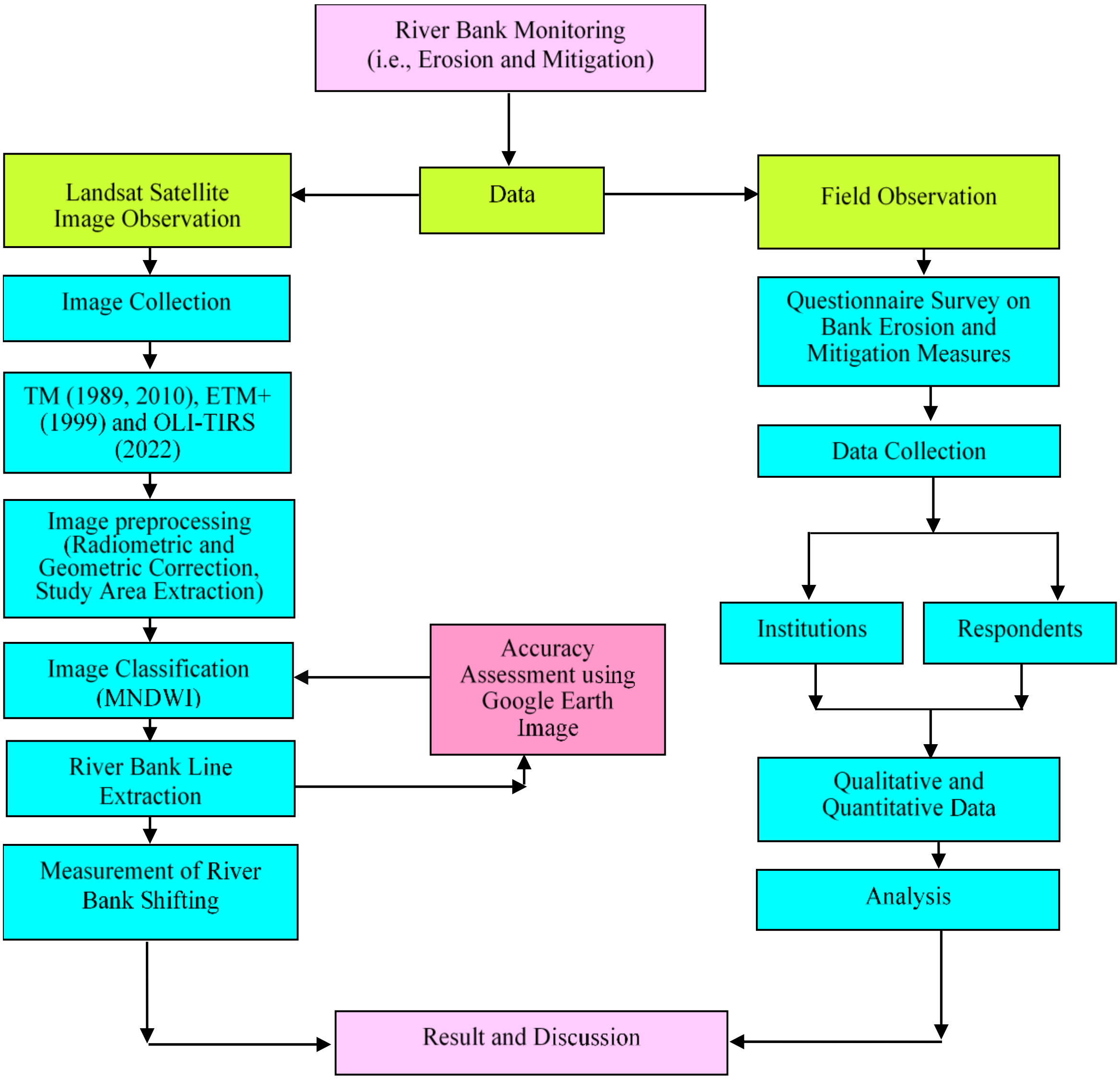

Fig. 2. Overall Methodology

Besides, Geographic Information System (GIS) based mapping techniques are used to delineate the service area.A methodological flow chart of the whole work has been illustrated in Fig. 2.

3. Results

The outcomes of the study are presented into two segments: the first segment represents riverbank erosion of the study area and second segment represents to mitigate the impacts of natural disasters, including riverbank erosion, at household, community, regional and national levels.

3.1. Riverbank Erosion of the Study Area

Riverbank erosion is the most frequent natural hazards in Bangladesh, specifically in the floodplain regions.Teesta is one of the most erode-prone rivers of Bangladesh which is located in the northern part of this country. The most vulnerable zoneof the Teesta Riverlies in Kurigram district.Ulipur Upazila (Kurigram) belongs to the Teesta floodplain and is a newly formed floodplain in terms of topography. The soil type of this place is fine, soft and pliable. Moreover, rise of river bed after sedimentation causes reduction of water holding capacity of river, resulting flood. For this reason, the erosion tendency of this area is noticeable (Fig. 3).

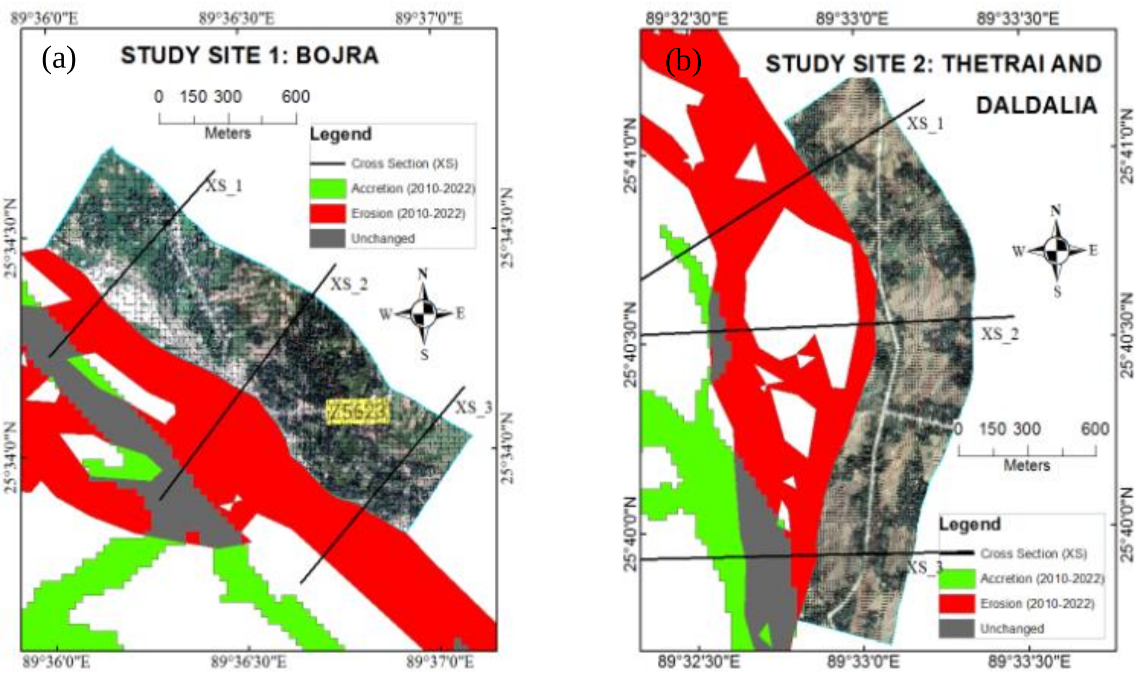

Fig. 3. Erosion of the study area. (a) and (b) represent the bankline shifting along the cross section between 2010 and 2022.

The spatial pattern of erosion was quantified at the site of Bojra, Thetrai and Daldalia spanning the period of 2010 to 2022 (Table 2). Over this period Bojra, Thetrai and Daldalia experienced 86.63 ha and 81.91 ha erosion respectively. The erosional pattern also exposed that both sites observed major erosion annually indicating the instability of the left bank (Fig. 3). On the other hand, the change analysis revealed that the banks of the study areas gained 21.73 ha and 108.60

ha over the entire period of the study (2010-2022).

Table 2. Erosion and accretion

Study site (LB)	Erosion (2010-2022) in hectare	Accretion (2010-2022) in hectare
Bojra	86.63 (7.22 ha y^{-1})	21.73 (1.81 ha y^{-1})
Thetrai and Daldalia	81.91 (6.83 ha y^{-1})	108.60 (9.05 ha y^{-1})

Source: Author

3.2.Bankline shifting in study area

Table 3 represents last 12 year's(2010 to 2022) bankline shifting towards the floodplaincovering the both site of the study area. From this table it can be seen that, the highest shifting has occurred along the left riverbank at XS-2 in both of the study sites whereas 418m in study site-1 (Bojra) and 758m in study site-2 (Thetrai and Daldalia). Between these two sites, it can also be seen that site 2 is significantly affected by riverbank erosion at XS-1 and XS-2. Along these cross-sections more than 600m bankline has shifted toward the floodplain in last 12 years. Similarly, at site 1, more than 400m bankline has shifted at XS-2 and more than 200m has shifted at XS-1 and XS-3. So, overall, it can be argued that, both of the study sites faced significant bankline shifting due to massive bankline erosion.

Table 3. Eroded Area of study locations

Study Site 1 (Bojra)		Study Site 2 (Thetrai and Daldalia)	
Cross Section	Riverbank shifting (Meter)	Cross Section	Riverbank shifting (Meter)
XS-1	217	XS-1	616
XS-2	418	XS-2	758
XS-3	270	XS-3	124

Source: Author

3.3. Reasons of riverbank erosion of the study areas

Excessive monsoon rainfall may be the primary cause of increased riverbank erosion by creating the strong wave and current of river which results in the loss of land and homestead area. According to table 4, the 61.75 percentage of the respondent state that riverbank erode every year due to strong currents caused by flood. Apart from this, 23.75% respondents think that the creation of sand bar (*char*) in the middle of the river is one of the reasons of riverbank erosion. Climate change has contributed to rapid siltation of the river in recent years, which is intensifying riverbank erosion during the monsoon (Islam et al., 2019).

Besides, different types of soil especially in sandy soil are also responsible for riverbank erosion (Table 2). As a result, riverbank erosion creates a vulnerable situation almost every year covering the study villages.The increased sedimentation and erosion rate, irregular rainfall pattern, channel shifting and lack of proper management are other causes of riverbank erosion.

Table 4. Main reasons of riverbank erosion

Reasons of riverbank erosion	Study Site 1 (Bojra)		Study Site 2 (Thetrai and Daldalia)	
	(f)	(%)	(f)	(%)
Strong current	137	62.6	126	60.9
Creation of bar	49	22.4	52	25.1
Soil type	30	13.7	26	12.6
Lack of proper management	2	.9	2	1.0
Others	1	.5	1	.5
Total	219	100	207	100

Source: Field Survey, 2023

Table 5(A). Mitigation measures taken by individual level

Site 1 (Bojra)			Site 2 (Thetrai and Daldalia)		
Mitigation measure (0-300 metre)	(f)	(%)	**Mitigation measure (0-300 metre)**	(f)	(%)
No	44	33.1	No	84	68.9
Yes	89	66.9	Yes	38	31.1
Total	133	100.0	Total	122	100
Pearson chi-square=32.566, df=1 P=.000					

Measures they have taken (0-300 metre)	Site 1 (Bojra)		Site 2 (Thetrai and Daldalia)	
	(f)	(%)	(f)	(%)
No measure	44	33.1	84	68.9
Sandbag / Geo-bag	13	9.8	12	9.8
Transfer of house wall and shed	10	7.5	8	6.5
Bamboo piling	66	49.6	18	14.7
Total	133	100	122	100

Source: Field survey, 2023

Table 5(B). Mitigation measure taken by individual level

Site 1 (Bojra)			Site 2 (Thetrai and Daldalia)		
Mitigation measure (300-500 metre)	(f)	(%)	**Mitigation measure (300-500 metre)**	(f)	(%)
No	80	93.0	No	23	27.1
Yes	06	7.0	Yes	62	72.9
Total	86	100	Total	85	100
Pearson chi-square=77.652, df=1 P=.000					

Measures they have taken (300-500 metre)	Site 1 (Bojra)		Site 2 (Thetrai and Daldalia)	
	(f)	(%)	(f)	(%)
No measure	80	93.0	23	27.1
Sandbag / Geo-bag	0	0.0	20	23.5
Transfer of house wall and shed	2	2.3	5	5.8
Bamboo piling	4	4.6	37	43.5
Total	86	100	85	100

Source: Field survey, 2023

3.4. Mitigation measure to combat riverbank erosion at individual level

As mentioned in earlier that the severity of erosion in the study area is very high, so mitigation of riverbank erosion is an important issue. Because riverbank erosion occurs over large areas, it is not possible to mitigate it at the individual level. However, traditional mitigation methods (bamboo piling/ *Bundal*) can be taken at the individual level for temporary solutions. As shown in table 5(A), people who are living between 0 and 300 metres have taken some measures to prevent riverbank erosion. Out of the 255 respondents living between 0 and 300 meters from riverbank erosion, most of them adopted traditional measures to prevent river erosion. Among them49.6% and 14.7% of the respondents have constructed bamboo piling/*Bundal* to mitigate riverbank erosion. Besides, different proportion of the respondents dumped geo-bag/sand bag and busy to transfer house wall/corrugated iron sheet (Table 5A). In contrast, respondents (Table 5b) who living between 300 and 500 metres are less likely to participate in bank erosion mitigation activities. From the above discussions it can be said that, people, living near riverbanks are more vulnerable than those, living far from the river (Field observation). The Chi-square test finding confirms a significant association between study villages and mitigation measures at individual level.

Table6. Relationship between protection measure at individual level and respondent's gender, age, education, income, occupation and distance.

Mitigation measure at individual level (Site 1)							**Mitigation measure at individual level (Site 2)**						
Gender	No		Yes		Total		**Gender**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
Male	87	54.4	73	45.6	160	100	Male	94	53.1	83	46.9	177	100
Female	37	62.7	22	37.3	59	100	Female	13	43.3	17	56.7	30	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	207	100
Pearson chi-square=1.220 df=1 p=.269							Pearson chi-square=.981 df=1 p=.322						
Age	No		Yes		Total		**Age**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
20-35	41	56.2	32	43.8	73	100	20-35	27	54.0	23	46.0	50	100
36-50	52	54.2	44	45.8	96	100	36-50	40	47.1	45	52.9	45	100
51-65	27	65.9	14	34.1	41	100	51-65	32	55.2	26	44.8	85	100
66-80	4	44.4	5	55.6	9	100	66-80	8	57.1	6	42.9	58	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	14	100
Pearson chi-square=2.208 df=3 p=.530							Pearson chi-square=1.285 df=3 p=.733						
Education	No		Yes		Total		**Education**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
Illiterate	55	61.1	35	38.9	90	100	Illiterate	47	56.0	37	44.0	84	100
Primary	33	64.7	18	35.3	51	100	Primary	30	50.0	30	50.0	60	100
Secondary	23	53.5	20	46.5	43	100	Secondary	19	51.4	18	48.6	37	100
Higher secondary	10	50.0	10	50.0	20	100	Higher secondary	7	58.3	5	41.7	12	100
Honours	3	20.0	12	80.0	15	100	Honours	4	28.6	10	71.4	14	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	207	100
Pearson chi-square=10.185 df=4 p=.029							Pearson chi-square=3.890 df=4 p=.421						
Monthly income	No		Yes		Total		**Monthly income**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
Below 5000 taka	32	62.7	19	37.3	51	100	Below 5000 taka	50	51.7	31	38.3	81	100
5000 to10000	63	57.3	47	42.7	110	100	5000 to10000	37	52.1	34	47.9	71	100
10000 to 15000	24	61.5	15	38.5	39	100	10000 to 15000	11	36.7	19	63.3	30	100
15000 to 20000	3	33.3	6	66.7	9	100	15000 to 20000	5	31.2	11	68.8	16	100
Upto 20000	2	20.0	8	80.0	10	100	Upto 20000	4	44.4	5	55.6	9	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	207	100
Pearson chi-square=8.629 df=4 p=.071							Pearson chi-square=8.851 df=4 p=.065						
Occupation	No		Yes		Total		**Occupation**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
Agriculture	50	56.8	38	43.2	88	100	Agriculture	49	62.0	30	48.0	79	100
Business	12	44.4	15	55.6	27	100	Business	21	63.6	12	36.4	33	100
Service	2	13.3	13	86.7	15	100	Service	7	36.8	12	63.2	19	100
Day labour	11	73.3	4	26.7	15	100	Day labour	6	21.4	22	78.6	28	100
Housewife	33	61.1	21	38.9	54	100	Housewife	12	41.4	17	58.6	29	100
Others	16	80.0	4	20.0	20	100	Others	12	63.2	7	36.8	19	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	207	100
Pearson chi-square=19.675 df=5 p=.001							Pearson chi-square=19.446 df=5 p=.002						

Distance from the river	No		Yes		Total		**Distance from the river**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
0 to 100 metre	38	39.6	58	60.4	96	100	0 to 100 metre	58	65.9	30	34.1	88	100
100 to 200 metre	1	4.0	24	96.0	25	100	100 to 200 metre	18	72.0	7	28.0	25	100
200 to 300 metre	5	41.7	7	58.3	12	100	200 to 300 metre	8	88.9	1	11.1	9	100
300 to 400 metre	49	92.5	4	7.5	53	100	300 to 400 metre	13	33.3	26	66.7	39	100
400 to 500 metre	31	93.9	2	6.1	33	100	400 to 500 metre	10	21.7	36	78.3	46	100
Total	124	56.6	95	43.4	219	100	Total	107	51.7	100	48.3	207	100
Pearson chi-square=87.038 df=4 p=.000							Pearson chi-square=38.029 df=4 p=.000						
R=.217 R^2=.047 AdjustedR^2=.030 p=.012													

Source: Field survey, 2023

3.5. Association between mitigation measures and respondent's demographic variables(Individual)

Table 4 represents the relationship between the protection measure at an individual level and some independent variable such as respondent's gender, age, education, income, occupation and house distance from the riverbank.Among these variables, respondent's education level, occupations and house distance showed significant relationship to the mitigation measures of riverbank erosion at an individual level. This implies that the educated people and the people who have vulnerable house due to riverbank erosion are very much concern to take erosion control measures, which may have created resiliency to the respondent's livelihoods (Mamun et al., 2022). In contrast, other variables such as gender, age and monthly income has represented an insignificance relationship (Table 6).However, from the overall analysis it can be said that, despite being significant relationship between the riverbank erosion protection measures and individual level conditional responsibilities, effective mitigation of the riverbank erosion still at an uncertain level. Based on the regression model (R=.217 R^2=.047 Adjusted R^2=.030 p=.012), this study finds that gender, age, education level, income, occupation and house distance from riverbank are all significant factors influencing mitigation measures at individual level.

Table 7(A). Mitigation measures taken by community level

	Site 1 (Bojra)		Site 2 (Thetrai and Daldalia)	
Mitigation measure (0-300 metre)	(f)	(%)	(f)	(%)
No	29	21.8	42	34.4
Yes	104	78.2	80	65.6
Total	133	100	122	100
Pearson chi-square=5.046, df=1 P=.025				

Measures they have taken (0-300 metre)	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No measure	29	21.8	42	34.4
Sandbag / Geo-bag	17	12.7	31	25.4
Transfer of house wall and shed	1	0.7	1	0.8

Bamboo piling	78	58.6	41	33.6
Working as a group	6	4.5	6	4.9
Others	1	0.7	1	0.8
Total	133	100	122	100

Source: Field survey, 2023

Table 7(B). Mitigation measures taken bycommunity level

	Site 1 (Bojra)		Site 2 (Thetrai and Daldalia)	
Mitigation measure (300-500metre)	(f)	(%)	(f)	(%)
No	53	61.6	8	9.4
Yes	33	38.4	77	90.6
Total	86	100	85	100
Pearson chi-square=50.793, df=1 P=.000				
Measures they have taken (0-300 metre)	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No measure	53	61.6	8	9.4
Sandbag / Geo-bag	14	16.2	19	22.3
Bamboo piling	15	17.4	58	70.7
Working as a group	2	2.3	0	0.0
Total	86	100	85	100

Source: Field survey, 2023

3.6. Mitigation measures to combat riverbank erosion at community level

The study reveals that out of 255 respondents (Both sites) living between 0 and 300 metres, about 71.9% respondents said they have taken measures at community level to prevent riverbank erosion (Table 7A). Among them majority of the respondents practiced to mitigate riverbank erosion with bamboo piling/ *Bundal*. According to local resident Sohel Miah (42), *"we often collect subscriptions or bamboo and make bamboo piling/Bundal at community level."* In contrast, few respondents those are living between 300 and 500 metres have taken steps to mitigate riverbank erosion, which is much less than those living closer to the river (Table 7B). Above all, community participation in riverbank erosion mitigation requires all the possible resources to make it more sustainable. Chi-square test finding unveils significant association between study villages and mitigation measures at community level.

3.7. Association between mitigation measures and respondent's demographic variables(Community)

This section (Table 8) examined the association between variables (gender, age, education, income, occupation and distance) and community level mitigation measures for riverbank erosion. The variable income has significant relationship (p=.003 and p=.014) between mitigation measures which indicates that if they have sufficient money, it will be possible for taking any steps for riverbank erosion mitigation. The occupation of the respondents is another important factor that influences the adoption of mitigation measures. The variable occupation of respondents represents significant relationship between riverbank erosion mitigation. Occupation enhances people's capacity for work and ensures a secure livelihood. In such a situation they can take any steps to prevent riverbank erosion. Distance represents highly significance association with the dependent variable at (p=.000) which means people who living along the riverbank took various mitigation measures in terms of loss of habitations and agricultural land. In the study area (Site 1) education has found strong association with riverbank erosion mitigation measures (p=.047). Because, educated people know very well about various mitigation measures. Though, most of the respondents of the study village (Bojra) were illiterate. However, among other independent variables like gender and age have no significant relationship with mitigation measures at community level (Table 8). Based on the regression model (R=.201 R^2=.041 Adjusted R^2=.023 p=.030), this study finds that gender, age, education level, income, occupation and house distance from riverbank are all significant factors influencing mitigation measures at community level.

Table8. Relationship between protection measure at community level and respondent's gender, age, education, income, occupation and distance.

Protection measure at community level (Site 1)						
Gender	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Male	57	35.6	103	64.4	160	100
Female	25	42.4	34	57.6	59	100
Total	82	37.4	137	62.6	219	100
Pearson chi-square=.838 df=1 p=.360						
Age	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
20-35	29	39.7	44	60.3	73	100
36-50	38	39.6	58	60.4	96	100
51-65	13	31.7	28	68.3	41	100
66-80	2	22.2	7	77.8	9	100
Total	82	37.4	137	62.6	219	100
Pearson chi-square=1.816 df=3 p=.611						
Education	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Illiterate	35	38.9	55	61.1	90	100
Primary	23	45.1	28	54.9	51	100
Secondary	17	39.5	26	60.5	43	100
Higher secondary	6	30.0	14	70.0	20	100
Honours	1	6.7	14	93.3	15	100
Total	82	37.4	137	62.6	219	100
Likelihood ratio=9.647 df=4 p=.047						
Monthly income	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Below 5000 taka	22	43.1	29	56.9	51	100
5000 to10000	48	43.6	62	56.4	110	100
10000 to 15000	11	28.2	28	71.8	39	100
15000 to 20000	0	0.0	9	100.0	9	100
Upto 20000	1	10.0	9	90.0	10	100
Total	82	37.4	137	62.6	219	100
Likelihood ratio=16.291 df=4 p=.003						
Occupation	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Agriculture	29	33.0	59	67.0	88	100
Business	10	37.0	17	63.0	27	100
Service	1	6.7	14	93.3	15	100
Day labour	9	60.0	6	40.0	15	100
Housewife	23	42.6	31	57.4	54	100
Others	10	50.0	10	50.0	20	100

Protection measure at community level (Site 2)						
Gender	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Male	46	26.0	131	74.0	177	100
Female	4	13.3	26	86.7	30	100
Total	50	24.2	157	75.8	207	100
Pearson chi-square=2.243 df=1 p=.134						
Age	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
20-35	10	20.0	40	80.0	50	100
36-50	16	18.8	69	81.2	85	100
51-65	20	34.5	38	65.5	58	100
66-80	4	28.6	10	71.4	14	100
Total	50	24.2	157	75.8	207	100
Pearson chi-square=5.316 df=3 p=.150						
Education	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Illiterate	23	27.4	61	72.6	84	100
Primary	14	23.3	46	76.7	60	100
Secondary	9	24.3	28	75.7	37	100
Higher secondary	3	25.0	9	75.0	12	100
Honours	1	7.1	13	92.9	14	100
Total	50	24.2	157	75.8	207	100
Pearson chi-square=2.716 df=4 p=.606						
Monthly income	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Below 5000 taka	30	37.0	51	63.0	81	100
5000 to10000	10	14.1	61	85.9	71	100
10000 to 15000	5	16.7	5	83.3	30	100
15000 to 20000	3	18.8	13	81.2	16	100
Upto 20000	2	22.2	7	77.8	9	100
Total	50	24.2	157	75.8	207	100
Pearson chi-square=12.459 df=4 p=.014						
Occupation	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)
Agriculture	27	34.2	52	65.8	79	100
Business	4	12.1	29	87.9	33	100
Service	5	26.3	14	73.7	19	100
Day labour	5	17.9	23	82.1	28	100
Housewife	3	10.3	26	89.7	29	100
Others	6	31.6	13	68.4	19	100

Total	82	37.4	137	62.6	219	100	Total	50	24.2	157	75.8	207	100
Likelihood ratio=13.549 df=5 p=.019							Pearson chi-square=11.185 df=5 p=.048						
Distance from the river	No		Yes		Total		**Distance from the river**	No		Yes		Total	
	(f)	(%)	(f)	(%)	(f)	(%)		(f)	(%)	(f)	(%)	(f)	(%)
0 to 100 metre	24	25.0	72	75.0	96	100	0 to 100 metre	33	37.5	55	62.5	88	100
100 to 200 metre	3	12.0	22	88.0	25	100	100 to 200 metre	4	16.0	21	84.0	25	100
200 to 300 metre	2	16.7	10	83.3	12	100	200 to 300 metre	5	55.6	4	44.4	9	100
300 to 400 metre	30	56.6	23	43.4	53	100	300 to 400 metre	4	10.3	35	89.7	39	100
400 to 500 metre	23	69.7	10	30.3	33	100	400 to 500 metre	4	8.7	42	91.3	46	100
Total	82	37.4	137	62.6	219	100	Total	50	24.2	157	75.8	207	100
Likelihood ratio=39.477 df=4 p=.000							Pearson chi-square=24.419 df=4 p=.000						
R=.201 R^2=.041 Adjusted R^2=.023 p=.030													

Source: Field survey, 2023

Table9. Riverbank erosion mitigation measures

The role of NGOs in mitigating riverbank erosion	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No	217	99.1	196	94.7
Yes	2	.9	11	5.3
Total	219	100	207	100
Pearson chi-square=6.966, df=1 P=.008				
Measures taken by NGOs	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
Cross badh	101	46.1	78	37.7
Bamboo piling/bundle	32	14.6	31	15.0
Block dumping	24	11.0	17	8.2
Geo bag	36	16.4	65	31.4
Tree plantation	19	8.7	14	6.8
Others	7	3.2	2	1.0
Total	219	100	207	100

Source: Field survey, 2023

3.8. Role ofNGOs in riverbank erosion Mitigation (Respondent's view)

Most NGOs perceive that infrastructural/engineered erosion control measures to prevent and mitigate riverbank erosion are the responsibility of the government because of the necessity of financial and technological input (Luna, 2001). Table 9 indicates that according to 96.9% of the respondents in the study villages NGOs have no role in mitigating riverbank erosion. However, very few respondents said that NGOs participated but it was limited to distribution of relief and rehabilitation of displaces in certain areas after riverbank erosion. Data also reveals that about 41.9% respondents opine that NGOs can provide cross dam to mitigate riverbank erosion. Different proportions of respondents (Table 9) mentioned, NGOs can practice traditional measures by constructing bamboo piling/*Bundal*, dumping geobags and blocks to mitigate riverbank erosion as well as they (NGOs) can undertake tree plantation programmes in coordination with locals.As the infrastructural approach is very expensive, NGOs can coordinate with the government to build permanent structures such as permanent dam and block settings. Above all, the people of Bojra, Thetrai and Daldalia mentioned, NGOs can take emergency preparedness measures to prevent riverbank erosion by forming groups with villagers during riverbank erosion.The chi-square test results also indicate that the mitigation measures taken by NGOs is statistically significant with both study locations.

3.8.1Role ofNGOs in riverbank erosion Mitigation (NGOs opinion)

BRAC, ASHA, TMSS, RDRS, Mahidev and other NGOs continue their programmes in the study area (Bojra, Thetrai and Daldalia). During post-erosion period, they continued some activities including lending money, food and other services. NGOs are also active in emergency evacuation and in taking people to shelters. But in the case of riverbank erosion mitigation NGOs do not play any significant role. Even, NGOs do not participate in any permanent or temporary programmes to mitigate riverbank erosion. But,if allocate enough budget to this sector, they are willing to adopt traditional mitigation measures (tree plantation, bamboo piling/*Bundal*, geobag/sandbag). Some NGOs have emphasized on awareness building and training programme so that the people safe them temporarily from the riverbank erosion. Moreover,they also expressed interest in informing their higher authorities for riverbank erosion mitigation.

Table 10. Types of mitigation measures

Measures taken by public representatives	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No	157	71.7	129	62.3
Yes	62	28.3	78	37.7
Total	219	100	207	100
Pearson chi-square=4.235, df=1 P=.040				
Measures they have taken (300-500 metre)	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No measure	157	71.7	129	62.3
Sandbag / Geo-bag	47	21.4	69	33.3
cross/*I-badh*	4	1.8	1	0.5
Inform higher authorities	9	4.1	8	3.8
Bamboo piling	2	0.9	0	0.0
Total	219	100	207	100

Source: Field survey, 2023

3.9. The role of public representatives to combat riverbank erosion (Respondent's view)

The role of public representatives is very important in the development of any area. About one third (32.8%) of the respondents mentioned that public representatives have adopted measures to mitigate riverbank erosion. Table 10 shows that among the measures taken by the public representatives, dumping sand bag/geo bag were one of them, although it was insufficient compared to the requirement. For example, according to local people only 20 geobags are dumped every 150 metres area which is not sufficient for mitigating riverbank erosion. The chi-square test also reveals that the mitigation measure taken by public representatives is statistically significant at 95% confidence level with all the study areas.

3.9.1 *The role of public representatives to combat riverbank erosion (Upazilla/Union chairman and members opinion)*

The local government (Chairman and member) has taken various measures to mitigate temporary riverbank erosion. Among the measures adopted by the local government (chairman, member), noticeable are dumping geobag/sandbag and bamboo piling/*Bundal*. They generally take these measures considering the overall vulnerable situation. Besides, they also receive public opinion to mitigate the imminent riverbank erosion.The upazilla chairman also reported that he has adopted same kind of traditional measures (Bamboo piling/*Bundal*, geobag/sandbag). According to, Upazila chairman such traditional measures helped to protect bankside school, madrasa and business institutes and even large area of Thetrai and Daldalia union.

Table11. Types of mitigation measures

Measures taken by government officials	**Site 1 (Bojra)**		**Site 2 (Thetrai and Daldalia)**	
	(f)	(%)	(f)	(%)
No	40	18.3	44	21.3
Yes	179	81.7	163	78.7
Total	219	100.0	207	100.0
Pearson chi-square=244.727, df=1 P=.000				
Types of measures	(f)	(%)	(f)	(%)
Traditional	95	53.1	150	92.0
Structural	19	10.6	2	1.2
Both	65	36.3	11	6.7
Total	179	100.0	163	100.0
Traditional	(f)	(%)	(f)	(%)
Geobag/sandbag dumping	139	86.9	145	90.1
Bamboo piling/*Bundal*	20	12.5	16	9.9
Tree plantation	1	.6	0	0.0
Total	160	100.0	161	100.0

Structural	(f)	(%)	(f)	(%)
Block setting	58	69.0	12	92.3
Permanent dam	1	1.2	0	0
Spur	1	1.2	0	0
Cross/I dam	24	28.6	1	7.7
Total	84	100.0	13	100.0

Source: Field survey, 2023

3.10. The role of GOs to combat riverbank erosion (Respondent's view)

The disaster management concept of the Government of Bangladesh is to reduce the risk of the people, especially the poor and the backward (Salehin et al., 2020). There is no alternative to government action for a permanent solution to a major problem like riverbank erosion. Most of the respondents of the surveyed areas (Bojra, Thetrai and Daldalia) about 80.2% (Table 11) agreed that the government has taken both traditional and infrastructural approaches to mitigate riverbank erosion. Different types of traditional measures have been applied to mitigate riverbank erosion e.g., bamboo piling/*Bundal*, geobag/sandbag and tree plantation (Table 11). On the other hand, as structural approaches respondents mention about block setting and cross/*I-badh*. It can be noted here that although temporary mitigation of riverbank erosion is possible by adopting traditional methods, but infrastructural approaches must be adopted for sustainable protective measure. In this situation, the people affected by riverbank erosion in the areas feel that the government should come forward by taking appropriate measures to deal with the riverbank erosion mitigation.The chi-square test results also reveal that the mitigation measure taken by GOs is statistically significant at 95% confidence level with both the study locations.

3.10.1 The role of GO institutions to combat riverbank erosion(BWDB opinion)

According to BWDB, the department has practiced infrastructural measures to prevent riverbank erosion in the study area. Among these, cross/*I-badh* and block setting are significant (PictureFig. 4). Cross/*I-badh* is a type of flood protection barriers. Undertaking such activities an area of about 1.50 km has been protected from riverbank erosion (West Bojra). Besides, every year Teesta basin experiences riverbank erosion during the monsoon season. The immediate action at this time is to identify the most erosive areas and mitigate the riverbank from erosion by dumping sandbags or geobags.

From the above discussions, it is found that though the various types of mitigation measures haveadopted by different institutions in the study villages but most of them are not adequate and sustainable. Government documents and the NGO literature indicate that there is a wide recognition that effective disaster response at the local level is not possible by government agencies alone and that the cost of management needs to be shared by all stakeholder.

PictureFig.4. Concrete block (Bojra) adopted by GO

4. Discussion

The findings indicated that majority of the households adopt a various type of mitigation measures. The study identifies that respondents practice bamboopilingfence/*Bundal* for mitigating riverbank erosion at the individual and community level (PictureFig. 5). Because, the material of this traditional approach (bamboo) is very cheap and available as well as the local people are very familiar with this method. Newport and Jawahar, (2003) mentioned that an effective mitigation measure cannot be implemented without participation of the vulnerable community and the public in general. Although they adopt this measure as an emergency preparedness during the rainy season, they expect it would be better during the dry season. The analysis reveals that vulnerability is higher among households in nearby and scattered settlements due to sudden riverbank erosion and inadequate land. Mamun et al., (2022) found that most households living along the riverbank have directly faced erosion impacts on their socio-economic and livelihoods.A significant difference is noticed among the various factors that influenced the erosion control approaches that create livelihood resilience. Education, income, occupation and distance from river all positively increase the likelihood of adopting erosion control measures at the individual and community level. Education is regarded as one of the more important factors in riverbank erosion mitigation, both in terms of promoting survival as well as in enhancing quality of life (Hutton and Haque, 2004). But gender and age have no significant effect on erosion control approaches. Though, aged homestead families have more information also, according to their age experience. This study provided useful recommendations to increase the mitigating capacity of riparian people.

PictureFig. 5. Bamboo fencepiling/*Bundal*(Daldalia)

Although temporary mitigation is possible at the individual and community level but infrastructural approaches must be adopted for sustainable protective measure. The engineering erosion control approaches are very time-consuming and expensive, and local households are not involved in these measures (Mamun et al., 2022). People expect direct support from the government to implement a sufficient number of geo bags and structural mitigation measures in their areas, which can be implemented by local government institutions. This paper unveils that despite the lack of financial support GO and public representatives try to mitigate riverbank erosion through boulder, geo-bag dumping and construction of cross/*I-badh*(PictureFig. 6). For example, the Bangladesh Water Development Board makes demands for river erosion mitigation before the monsoons, and they hire contractors before the budget allocate. Currently, the Water Development Board administers the planning and management of riverine hazards in Bangladesh, and focuses on engineering and structural responses (Haque and Mutton, 2004).

Further initiatives are required for incorporating the measures of different organizations as well as strengthening institutional machinery through decentralization and root-level disaster mitigation planning. From a disaster-management perspective, attention must be paid to ensure that vulnerable populations are not excluded from planning and decision-making considerations. That is, disaster management must be an inclusive and democratic process, as much oriented towards human development as towards mitigation and prevention of natural hazards (Haque and Mutton, 2004). Combined with respondents' opinion and involvement will be helpful for the decision makers to formulate a wellorganized mitigation measures for sustainable transboundary river management.

PictureFig. 6.Geobag/Sandbag (Thetrai)

5. Conclusion

In terms of discharge, Teesta is the fourth largest river in Bangladesh which falls into the Brahmaputra/Jamuna River. Numerous chars/bars can be seen in this river and the weak alluvial soil of the banks of the Teesta is a dominant factor for erosion after each successive flood. Besides various bank protection works, riverbank erosion remains a constant threat to the riparian inhabitants and the land-scarce country. This paper used geospatial techniques to measure channel characteristics in two study areas as well as collect data from respondents through questionnaire surveys to know about river erosion mitigation measures at different levels. The findings show that traditional erosion control measures such as bamboo fencespiling/*Bundal* at individual and community levels and structural/engineered erosion control methods at public representative and GO levels have been adopted to mitigate riverbank erosion. The structural/engineered erosion control approach should be part of development planning, and it can be effective when they involve all stakeholders' government, local communities, NGOs, media, the private sector, academia, neighboring countries, and donor communities.

However, this study provided useful recommendations for enhancing the mitigation capacity of riparian people. Government should take more effective measures to reduce the impact of river erosion. Apart from taking preventive and protective measures, there should also be some rehabilitation and livelihood-based measures, which will help vulnerable people to find their way back into the mainstream society. Proper rehabilitation and evacuation process should be developed for them on priority basis to deal with river erosion. This study helps to better understand the impact of river erosion on such residents, which will assist the government in formulating policies to improve the livelihood of the affected. Furthermore, such findings from this study will be helpful to examine the effectiveness of vulnerability mitigation measures for other natural disasters such as floods and droughts in other regions of Bangladesh.

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