Bhuiyan *et al. Environ Syst Res (2017) 6:25*
https://doi.org/10.1186/s40068-017-0102-9

Environmental Systems Research

RESEARCH

Exploring impacts and livelihood vulnerability of riverbank erosion hazard among rural household along the river Padma of Bangladesh

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Abstract

Background: Riverbank erosion has both direct and indirect effects on human life and socio-economy of Bangladesh. The present study investigated the riverbank erosion hazard in study area, its impacts on local people and livelihood vulnerability due to land loss.

Methods: To evaluate the riverbank erosion hazard in the study area, data have been collected from relevant scientific literatures, different government and non-government organizations, informal interview, questionnaire survey and Focused Group Discussion; and analyzed through different computer program and index.

Results: From the study, it was found that from 1973 to 2011, about 189.4 km^2 lands was eroded from the left bank section and only 23.66 km^2 was accreted with a net loss of 155 km^2. Instead, right bank of the Padma River behaved in the opposite manner with 166.53 km^2 erosion and 134.45 km^2 accretions. Comparing to the right bank, left bank was more vulnerable to erosion which destroyed the permanent stable lands. However, the value of the newly accreted char land is very low compare to the main land. Thus this hazard creates a great loss in the local economy. Within the studied time range the monetary loss is about 1414.81 million BDT (17,422,937.16 $). Many wealthy farmers of the study area turn into marginal farmer and even landless due to the erosional hazard. Agricultural land becomes barren land by huge siltation and the cropping pattern has been changed significantly. In addition, the infrastructure and property losses are enormous. From the results of vulnerability index (IPCC-VI) it suggests that the most vulnerable areas are identified as Boyra (0.061), Kanchanpur (0.062), Lesragonj (0.064), Azimnagar (0.067), Sutalori (0.071) and Dhulsonra (0.076) because of more sensitivity and less adaptive capacity. On the other hand, Balara (− 0.017) and Balla (− 0.019) are comparatively least vulnerable comparing to the previous sites.

Conclusions: As, riverbank erosion is one of the most hazardous disasters in the study area; so treating independent separate policies and program for the vulnerable areas might helpful to support the affected community.

Keywords: Hazard, Disaster, Vulnerability, Riverbank erosion, Accretion

Background

Riverbank erosion is an important geo-morphological phenomenon that is very common to fluvial and coastal environment in many countries in all parts of the world; though the nature and impact of erosion may vary (Das et al. 2007; Pati et al. 2008). It is a process in which the bank lines are shifted and bars within the stream are migrated. The factors that affect river bank erosion are; decrease or increase in shear strength, changes of river course, characteristics of erosion prone bank and bed materials, pressure imbalance at the bank face, rapid drawdown, poor vegetation cover, obstacle in the streams, wind wave and boat wakes (Rahman et al. 2015).

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It is a local and recurrent natural hazard that impacts severely on the life and property of the people living in the riverside areas (Ahmed 2016; Islam et al. 2016; Alam et al. 2017). Riverbank erosion is considered as a slow, silent and ranking topmost disaster concerning the losses of property in Bangladesh (Shamsuddoha and Chowdhury 2007; Rahman et al. 2015).

Bangladesh is situated in the Bengal delta which was developed by three mighty rivers i.e., the Ganges, the Brahmaputra and the Meghna (GBM) (Rahman and Islam 2016). The sediments are deposited in the GBM basin is the highest in amount in the world (Kuehl et al. 1989). It has been estimated that, about 1050 million tons of sediments annually discharge from the Bengal basin (Milliman et al. 1995), among 600 million tons are deposited in the Bengal delta (Meade 1996). As a result, the river beds in GBM are silted up and losing their depth. Due to over siltation the river configuration is being adjusted frequently and the river channel is shifting repeatedly. These phenomena are responsible for fluvial flood and riverbank erosion in the country (Elahi et al. 1990). A network of rivers of the Padma, the Jamuna, the Teesta, the Brahmaputra, the Surma, the Meghna and their tributaries covering the country with a high length of about 24,140 km (BBS 2011). More or less all the rivers of Bangladesh are responsible for erosion at various points and annual rivers eroded 10,000 ha of land in Bangladesh (NWMP 2001). Between 1973 and 2004, about 877.90 km^2 of land had been eroded along the Jamuna (Lower Brahmaputra) and 293.90 km^2 along the Padma (Lower Ganges) (CEGIS 2009). Along the bank line there are 283 locations, 85 towns and growth centers are vulnerable to erosion (Islam and Rashid 2011) and about 15–20 million people are at risk from the effects of erosion (Hutton and Haque 2003; Rahman et al. 2015). As a result, a large number of people become homeless due to river bank erosion and they migrate to cities or nearest town and live in the urban slum areas (CEGIS 2009; Das and Bela 2011). Along with floodplain and settlement, the country also loses several kilometers of roads, railways, and flood control embankments annually. No other disasters are as disastrous as riverbank erosion in terms of long term effect on people and society (Elahi 1991).

The Ganges named Padma in Bangladesh part is an important river system in South Asia which supports the life and livelihoods of millions of people. The Ganges river system, with a catchment area of 1.09 million km^2, originates at the Gangotri glacier in the Himalayas and is one of the largest river systems in the world. Along its 2526 km course to the confluence with the Meghna, it crosses China, Nepal, India and Bangladesh, making it a quintessential international river. India has the largest share (79.1%) of its entire catchment while only 4.3% lies within Bangladesh which is equivalent to 32% of the country and receives average annual rainfall of 1200 mm (Mirza 2004; Sulser et al. 2010). It is therefore, subject to high seasonality and recurrent floods of large magnitude (Sharma 2005) with 80% of the annual total discharge volume occurring during the monsoon season i.e., July–October (Kale 2003). Erosion and deposition statistics of the Ganges indicated that 57 km^2 of land was lost along the right bank whereas around 59 km^2 was gained along the left bank during the period of 1973–2011 (Dewan et al. 2017). Along, the course of Padma in Bangladesh, the most sever riverbank erosion have been observed in the areas of Harirampur, Faridpur Sadar, Char Vodrasion, Dohar, Mawa Ghat, Shiv Char, Tongibari. Harirampur is considered as the most erosion-prone area among the other parts. The people of this area are the most vulnerable community in the lower Ganges floodplain and their fate is regulated by the dynamic river character. Every development sector of this area bears the adverse impact of the erosion. Due to huge socioeconomic losses the people of this area are considered as the most terrible group which are not properly addressed by the scientific community. Previously many researchers i.e., Elahi et al. (1990), Rogge (1991), Dewan and Nizamuddin (2000), Mirza (2004), Rahman (2010), Uddin and Rahman (2011), Chatterjee and Mistri (2013), Rabbi et al. (2013) and Dewan et al. (2017) studied on riverbank erosion status based on geographical and geological point of views. In this circumstance, the present study aimed to investigate the riverbank erosion hazard of the river Padma near Harirampur–Char Vadrasion site and its impacts on socio-economic condition of the inhabitants in study area. The study also intended to identify the potential vulnerable areas due to riverbank erosion, for further disaster management action.

Methods

Study area

Harirampur is situated about 86 km away from Dhaka, the capital of Bangladesh and located on the mostly erosion prone area of the mighty river Padma. It is located at 23.7333°N and 89.966°E (Fig. 1) with an area of 245.42 km^2 and is bounded by Shivalaya, Ghior and Manikgonj Sadar upazilas on the north, Char Vadrasion and Faridpur Sadar on the south, Manikganj Sadar, Nawabgonj and Dhohar upazilas on the east, Shivalaya, Goalondo Ghat and Faridpur Sadar upazilas on the west. Main rivers of this area are the Padma and the Ichamoti; and main depressions are Bhatsala and Gharilpur beels. Harirampur upazila consists of 13 union parishads (subdivision of upazila), which is seriously affected by riverbank erosion (BBS 2011). From early liberation war of Bangladesh 1971 to 2000 the areas face extensive bank erosion by the river Padma.

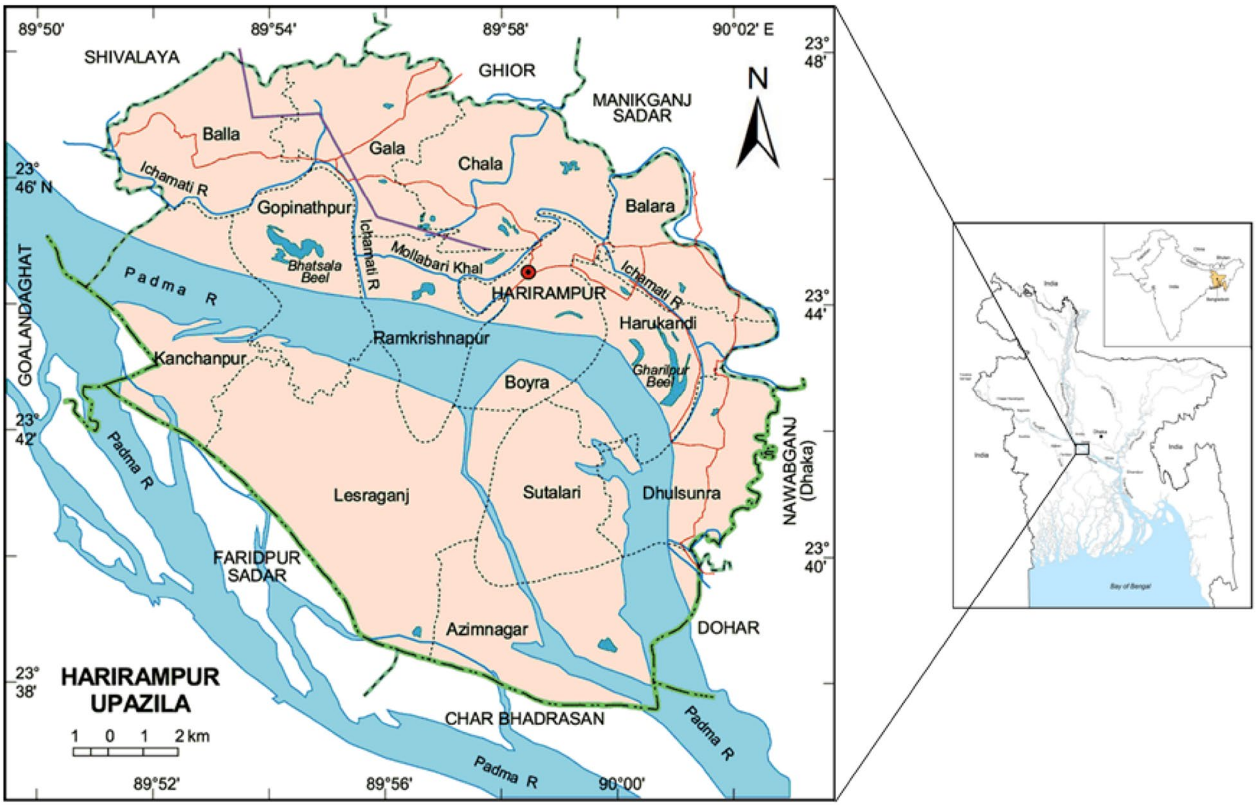

Fig. 1 Map showing the location of study area

Data source and sampling procedures

The study was conducted since 2015, based on both primary and secondary data. To collect primary data different methods had been adopted like informal interview, a pre-formulated questionnaire survey and Focused Group Discussion (FGD). For questionnaire survey, sample size was kept within 260 in number, which was done through target group sampling techniques. Informal interview and FGD were also conducted in the study area. There are 25 interviews and 1 FGD carried out in each union. For FGD, 10 people have been chosen with same ratio of both male and female. The age range of the people was between 25 and 65 years. The occupations of the correspondents were farmer, day labor, business man, service holder, house wife, fishermen and teacher. The views of the local government officials responsible to various departments like; Bangladesh Water Development Board (BWDB), Department of Public Health and Engineering (DPHE), Police, Food, Agriculture, Social Welfare, Family Planning, Hospital authorities and other offices were also collected. Secondary data has been collected from different journals, reports, research papers, websites, and different government and non-government organizations i.e., UNO office, Agriculture office, Department of Agriculture Extension (DAE), Local Government and Engineering Department (LGED), The Bangladesh Bureau of Statistics (BBS, Census Wing) and local NGO's. SPSS (Version 16.0), MS Excel (2007) and GIS (Version 10.1) have been used in this study for data analysis and presentation.

Selection of indicators and calculation of vulnerability

Vulnerability indicators provide a potentially useful means of monitoring vulnerability over time and space, identifying the processes that contribute to vulnerability, prioritizing strategies for reducing vulnerability, and evaluating the effectiveness of these strategies in different social and ecological settings (Adger et al. 2009). The Intergovernmental Panel on Climate Change (IPCC 2001) provides a useful typology, suggesting that vulnerability may be characterized as a function of three contributing factors i.e., adaptive capacity, sensitivity, and exposure (Schneider 2007).

$$\text{Vulnerability} = f\left(\text{Exposure, Sensitivity, Adaptive capacity}\right) \quad (1)$$

A number of indicators were selected to represent these contributing factors (Table 1). These indicators were selected based on the existing vulnerability studies and

Table 1 Description of IPCC (2001) contributing factor, major components and indicators of vulnerability

IPCC contributing factor of vulnerability	Components	Indicators
Exposure	Characteristics of riverbank erosion hazard (frequency and magnitude)	Frequency of riverbank erosion
		Human mortality rate
		Percent of HHs reporting injury of a family member
		Total number of affected people
		Percent of HHs reporting land degradation during last 30 years
		Percent of HHs experienced displacement in last 30 years
		Average number of others natural calamity during last 30 years
Sensitivity	Health sensitivity	Average time to reach nearest health center
		Percent of HHs reported at least one chronically ill member
		Percent of HHs where a family member is infected by a communicable disease
		Percent of HHs who do not have toilet and poor hygiene status
		Inverse of life expectancy
	Food and agricultural sensitivity	Average food insufficient month
		Inverse of land productivity
		Percent of HHs that collect water directly from river, streams, pond
	Demographic sensitivity	Dependency ratio (% of population below 15 and over 65 years of age)
		Percent of female-headed HHs
		Average family member in a HHs
		Population density
Adaptive capacity	Economic capacity	Percent of households dependent solely on agriculture as income source
		Average number of households who have burden of loan
		Percent of HHs who have access to financial services to any financial institution
		Percent of HHs who have a family member working outside the village at relatively developed place
		Household income per month
	Social network and communications	Percent of HHs who have received any kind of support from neighbor in past 1 month
		Percent if HHs who have supported and helped to neighbor in past 1 month
		Percent of HHs where a family member is affiliated with any organization
		Average time to reach nearest vehicle station
		Percent of HHs have communicative devices (TV, radio, mobile etc.) at home
	Education and skill	Education index
		Percentage of households where members had any formal or informal skill

the available information. Adaptive capacity describes the ability of a system to adjust to actual or expected stresses, or to cope with the consequences (Islam and Bhuiyan 2016). It is considered as a function of wealth, technology, education, information, skills, infrastructures, access to resources, and stability and management capabilities (McCarthy et al. 2001). Recent research also indicated that perceptions of social identity by communities played a strong role in adaptive ability (Frank et al. 2011). The present study considered components like; economic capacity, social network and communications, education and skill to estimate adaptive capacity of each union of the study area. Sensitivity refers to the degree of a system which will respond either positively or negatively to any hazard (Islam et al. 2015; Islam and Uddin 2015). The present study calculated three types of sensitivity, i.e., demographic, food and agricultural, and health. Exposure was determined by the extent to which the area faces a hazard or stress. It relates to the degree of stress upon a particular unit of analysis. It may be represented as either long-term changes including the magnitude and frequency of extreme events.

There are two ways to analyze indicators: (i) giving equal weight to each indicator and (ii) assigning a weight to each indicator with the help of expert judgment, principal component analysis, correlation with past disaster events and fuzzy logic (Deressa et al. 2008). The present analysis has given equal weight to each indicator since the appropriateness of giving weights is still dubious as there is no standard weighting method against each method which is tested for precision (Deressa 2010). Because each of the indicators is measured on a different scale, it was first necessary to standardize each as an index. For example, equation used for the conversion was adapted from that used in the Human Development Index (HDI) to calculate the Life Expectancy Index (LEI), which is the ratio of difference of the actual life expectancy and a pre-selected minimum, and the range of pre-determined maximum and minimum life expectancy (UNDP 2007), are calculated by following;

$$\text{LEI} = \frac{\text{Actual value} - \text{Min.value}}{\text{Max.value} - \text{Min.value}}. \quad (2)$$

In case of inverse index, the formula 1/(1 + observed index) were used, which offered value tends to zero. For variables that measure frequencies the minimum value was set at 0 and the maximum at 100. After that, a normalization method was followed in order to aggregate the indicators into a single value (Bahinipati 2014; Islam et al. 2015) which shown in following equation;

$$\text{Index } X_{ij} = \left(X_{ij} - \text{Min } X_i\right)/(\text{Max } X_i - \text{Min } X_i), \quad (3)$$

where, Index X_{ij} is the index value (i.e., 0–1) of the indicator for union *j*, X_{ij} represents the value of the *i*th indicator for each union, and Max X_i and Min X_i manifest the maximum and minimum value of the *i*th indicator among all the unions respectively. After that, all the indicators were indexed, the indicators had been averaged to calculate the value of each components using;

$$M_j = \sum_{i=1}^{n} \text{Index } X_{ij}/n, \quad (4)$$

where, M_j is the components of vulnerability. Index X_{ij} is the index value of the *i*th indicator for union *j* and *n* is the number of indicators in each component. Once values for each of the components were calculated, according to Hahn et al. (2009) following equation was used to determine the contributing factor of vulnerability.

$$\text{CF}_j = \frac{\sum_{i=1}^{n} W_{miM_j}}{\sum_{i=1}^{n} W_{mi}}, \quad (5)$$

where, CF_j is the contributing factor (exposure, sensitivity or adaptive capacity); for the union j, W_{mi}, determined by the number of indicators that make up each component and M_j is the major components for *j* union indexed by *i*. After calculating exposure, sensitivity and adaptive capacity, IPCC-VI was calculated using the following formula pertaining to the IPCC's definition of vulnerability.

$$\text{IPCC} - \text{VI} = (\text{EI} - \text{AI}) \times \text{SI}, \quad (6)$$

where, EI is exposure index, AI is adaptive capacity index and SI is the sensitivity index. Range of IPCC-VI varies from − 1 to + 1, where − 1 denotes least vulnerable (adaptive capacity is more than exposure), 0 denotes moderately vulnerable (exposure and adaptive capacity are equal) and 1 denotes extremely vulnerable (exposure is very high than adaptive capacity).

Results and discussion

Erosion trends of the Padma River

The total areas, annual rates of erosion and deposition of the left and right banks of the river Padma between 1973 and 2011 are given in Table 2. It shows that during 1973–1977 and 1977–1980 erosion first exceeded and then lowers than accretion. For the next four periods (1980–2000), erosion consistently exceeded accretion, reversing in 2000–2005 and again in 2005–2011. The maximum amount of erosion (58.82 km^2, 11.76 km^2/year) occurred in 1995–2000. Maximum accretion (41.67 km^2, 13.89 km^2/year) was recorded during 1977–1980. Over the whole study period, there was a considerable surplus of erosion on the left bank of the Padma with 189.4 km^2 being eroded and 23.66 km^2 being deposited by accretion, a net loss of 155 km^2. The right bank of the Padma River behaved in the opposite fashion to the left for the first two periods with deposition exceeding erosion in 1973–1977 and erosion exceeding deposition in 1977–1980. This suggests typical meandering as one bank follows the other across the floodplain.

However, for the next four periods (1980–2000), erosion on the right bank exceeded deposition. This parallels the situation on the left bank, suggesting massive loss of material from the banks. However, in the periods of 2000–2005 and 2005–2011, erosion and deposition patterns on the right bank were the opposite from those on the left bank, signifying a return to a more normal regime. Over the 38 years (1973–2011), a total of 166 km^2 land was lost to erosion on the right bank and 134 km^2 gained, a net loss of 28 km^2. Taken together with the loss on the left bank, this signifies a considerable loss of material and land from the channel banks.

Impacts of riverbank erosion hazard

Impact on agricultural land

The impact of erosion on agriculture is enormous. The arable land becomes inerrable. Multi-crop producing land becomes single crop or bare land. The amounts of land of study area for 1-crop, 2-crops, 3-crops were 35–605, 305–1479.9 and 45–979 ha respectively. The amounts of agricultural land of 1-crop, 2- crop, and 3-crop of the unions are shown in Fig. 2.

Table 2 Erosion and accretion areas along banks of the Padma River during 1973–2011. Source: Dewan et al. (2017)

Time period	Bank	Erosion		Accretion	
		Total area (km^2)	Rate (km^2/year)	Total area (km^2)	Rate (km^2/year)
1973–1977	RB	44.31	11.08	91.66	22.91
	LB	36.82	9.20	25.87	6.47
1977–1980	RB	76.96	25.65	34.73	11.58
	LB	15.74	5.25	41.67	13.89
1980–1984	RB	58.25	14.56	19.39	4.85
	LB	30.33	7.58	16.21	4.05
1984–1989	RB	50.57	10.11	39.13	7.83
	LB	41.92	8.38	6.96	1.39
1989–1995	RB	86.39	14.40	49.99	8.33
	LB	50.67	8.45	8.95	1.49
1995–2000	RB	98.00	19.60	45.60	9.12
	LB	58.82	11.76	51.78	10.36
2000–2005	RB	74.81	12.47	20.81	3.47
	LB	33.48	5.58	41.07	6.84
2005–2011	RB	34.50	5.75	105.71	17.62
	LB	56.90	9.48	18.55	3.09
1973–2011	RB	166.53	4.38	134.45	3.54
	LB	189.40	4.98	23.66	0.62

LB left bank, *RB* right bank

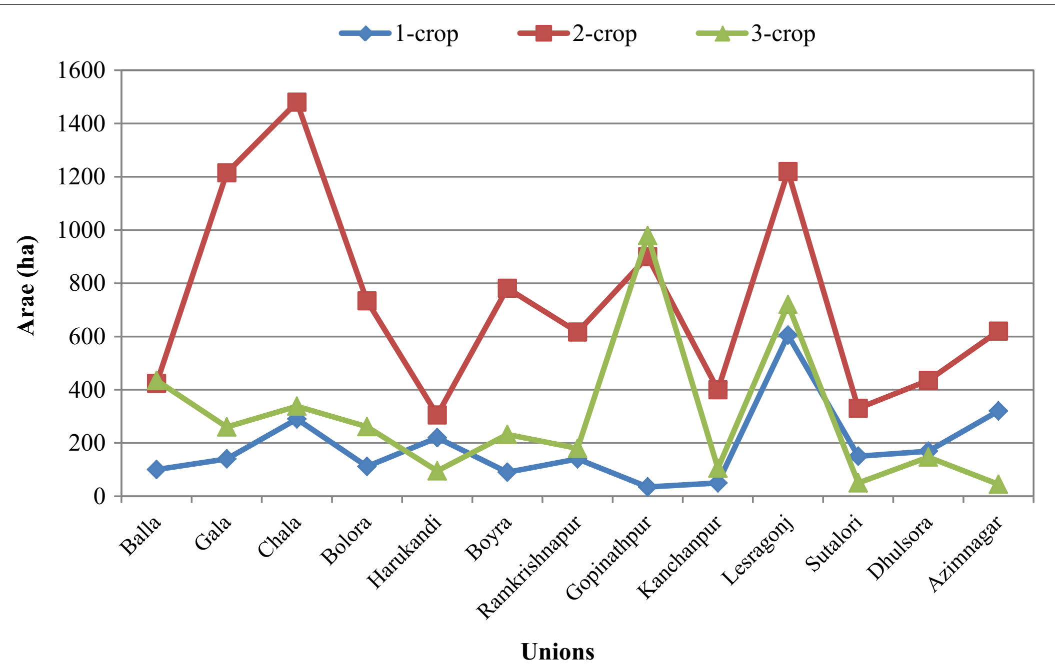

Fig. 2 Agricultural lands with respective unions

The 1-crop land is the highest in Lesragonj union and the lowest in Gopinathpur union. The 2-crops land is the highest in Chala and the lowest in Harukandi, 3-crops land is the highest in Gopinathpur and the lowest in Azimnagar. The earlier settlement or mature char land has the 3-crops land but the immature one has the capacity of 1-crop or 2-crops (Fig. 2). The change in agriculture land create impacts on crop production. There is a huge irregularity and changing pattern in agriculture land by erosion in study area is shown in Table 3.

Impact on local economy

The frequent changes of land types severely effect on local economic condition. The value of original stable agriculture land is very high and is suitable for multiple uses. Whereas the newly accreted land (sand char) has a low economic value because of its low fertility and its use is limited. According to the field survey, the values of wetland, charland agricultural land, residential and settlement areas per Bigha were 10,000 (123.17 $), 20,000 (246.37 $), 50,000 (615.94 $) and 2,500,000 (30,795.15 $) BDT (1 Bigha = 0.1349 ha), respectively. The total calculated land of the study area is 22,469 ha. Among them 13,227 ha (59% of the total) are cultivable, 7040 ha (31% of the total) are wetland, 1588 ha (7% of the total) are fallow land and 714 ha (3% of the total) are settlement. According to the current local market price the value of the total land of the study area is approximately 6865.2 million BDT (84,576,876.63 $). Nine out of 13 unions have been fully or partially eroded. The newly accreted lands of the unions have a lower economic value compare to the original lands. Because, this char lands produce mostly one or two crops and inundate by the flood in every year. This newly developed land is only used for some landless people, marginal farmers and migrated people temporarily. The price of 6362 ha of stable cultivable land is 2358.02 million BDT (29,043,930.39 $), whereas the same amount of char land is only 943.21 million BDT (11,618,693.52 $) only. The detailed prices of the existing char land in the study area is given in Table 4. Being eroded there is huge value difference between the charland and mainland. Therefore, the erosion of original land from 1973 to 1998 caused a great economic loss to the community of the area. Most of the land of Harirampur upazila is more or less eroded by the river. Some of them are developed very early and some of them are deposited recently. The early deposited land supports a good agriculture production whereas the newly deposited lands possess a little agriculture practices.

Table 3 Change in cropland in study area from 1973 to 2014. Source: Agriculture office (2015)

Years	1-crop	2-crop	3-crop
1973–1977	128	1227	679
1977–1980	198	2481	452
1980–1984	98	3847	486
1984–1988	1008	5487	894
1988–1990	1105	1198	679
1990–1995	1478	8769	1563
1995–1998	2165	9658	1187
1998–2000	1670	10,258	1253
2005–2006	3057	9050	1150
2009–2014	1500	10,757	1350

Table 4 Price of the existing char lands in study area

Union	Char land (ha)	Value (million BDT)
Harukandi	442	65.53
Boyra	552	81.83
Ramkrishnapur	233	34.54
Gopinathpur	289	42.84
kanchanpur	356	52.77
Lesragong	2595	384.72
Sutalori	530	79.02
Dhulsonra	250	37.06
Azimnagar	1115	165.30
Total	6362	943.21 (11,618,693.52 $) (approx.)

Agricultural loss

The erosional process of land has a great impact on agriculture. Agriculture practice and crop production is different between char land and main land. The losses of agricultural land result the reduction of total crop production. The production rate and market price of different crops of main land and char lands are in Table 5.

In case of char lands, the scenario is different, where only three or four types of crops were yielded in Robi and Kharip-1 seasons. But, in rainy seasons i.e. Kharip-2 the whole char lands were under water and people were needed to collect food from other place. Comparing to the monetary value of charland and mainland it was found that the price of crops in charland (low fertile) is only 77,975 BDT (961.031 $) ha/year; whereas the price of crops in the original mainland (high fertile) is 4,85,445 BDT (5982.85 $) ha/year. Hence the economic loss at every hector per year is 407,470 BDT (5022.08 $) and the net loss is 2592.33 million BDT (31.95 $) per year.

Cropland pattern change

According to the Department of Agricultural Extension (DAE), 13,257 ha agricultural lands of Harirumpur upazila were classified into four main types based on their elevation and duration of standing water. The crop productivity of high, medium to high land is higher where; the medium to low, low and extreme low land has lower productivity (Table 6).

The types of land distributions regarding crop productivity at every union are showing in Fig. 3. It is found that the amount of high, medium to high, medium to low and low land is 0–505, 40–647, 90–690 and 30–515 ha, respectively. According to DAE from 2005, the amount of

Table 5 Crop production in main lands and the char lands with money value in local market. Source: Agriculture office (2015)

Crop	Market price (BDT)	Main land		Char land	
		Production MT/ha/year	Value of crop (BDT)	Production MT/ha/year	Value of crop (BDT)
Boro (total)	15/kg	3.65	5475	–	–
Wheat	22/kg	2.4	5280	15	15,000
Mustard	38/kg	1	3800	–	–
Potato (total)	12/kg	16.5	19,800	–	–
Sweet potato	10/kg	–	–	–	–
Vegetable (winter)	20/kg	15	30,000	16	32,000
Corn	18/kg	16	28,800	6.5	11,700
Onion	30/kg	6.5	19,500	–	–
Garlic	80/kg	6.5	52,000	–	–
Chilli (winter)	20/kg	6	1200	1.5	3000
Sugarcane	50/kg	48	24,000	–	–
Peanut	30/kg	–	–	1.8	5400
Dhonia	80/kg	1.23	9840	–	–
Maskolai dal	50/kg	1	5000	–	–
Mugdal	65/kg	1	6500	1	6500
Musur dal	70/kg	1	7000	–	–
Khesari dal	28/kg	1	2800	–	–
Motor dal	70/kg	1	7000	–	–
Aush dan	15/kg	3.65	5475	–	–
Aman, Bona	15/kg	3.65	5475	–	–
Jute (total)	50/kg	1.2	240,000	–	–
Vegetable (summer)	20/kg	8.8	17,600	–	–
Til	35/kg	–	–	0.85	2975
Kaon	20/kg	–	–	0.7	1400
Dhoncha	–	–	–	–	–
Chilli (summer)	20/kg	1.13	2260	–	–
Chola	75/kg	1	7500	–	–

[1 BDT = 0.0123255 $]

Table 6 Land types with agricultural activity in study area. Source: DAE (2014)

Land type	Character of the land	Cropping pattern	Productivity
High	Never flooded by water	3-crop or 2-crop land	High
Medium high	90 cm standing water for 2–5 days	3-crop, 2 crop or 1-crop land	High
Medium low	180–270 cm standing water in rainy season	2 crop or 1-crop land	Low
Low	270–360 cm or more standing water in rainy season	1-crop or fallow land	Low

high land and medium land have increased about 4 and 11%, respectively whereas, medium to low land and low land have decreased 18 and 3%, respectively. The high land dominating areas are Lesragong, Chala, Azimnagar and low land dominating are Harukandi, Sutalori, Balla unions (Fig. 3). From the field survey it was found that due to surface erosion the area height of land decrease i.e. the high land became medium or medium low land; medium land became low land. It was also found that the newly accreted land is mostly medium to low land. That is why the eroded areas (unions) have the low land compare to others.

Changes in livelihood pattern

Riverbank erosion has enormous impacts on livelihood pattern. Due to having the risk of erosion there is no developmental or industrial setup in this area. The livelihood of the people mostly depends on agriculture or

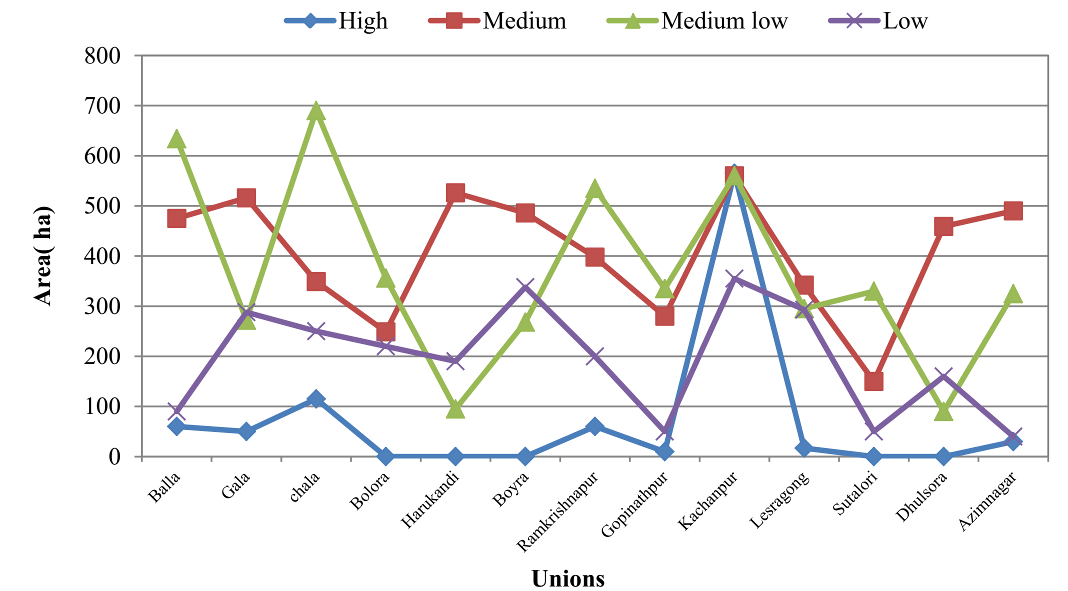

Fig. 3 Croplands of respective unions (Source: UNO office, 2015)

agricultural labor. Besides a limited number of fishing, agro-industry, agro-farming, rural commerce, service, wage labor is also followed. Among them agro-farming is the dominating sector among the occupations. Figure 4 shows the sources of income of the people at pre- and post-erosion periods. It was found that income source of the people of the study area being changed significantly during pre- and post-erosion periods and the remarkable changes was found in agriculture sector. The numbers of cultivable land proprietors were decreased with time due to erosion; consequently, the numbers of shared cultivation were increased. However, the numbers of engagement of labor in agriculture sector was also reduced. The reasons behind this scenario

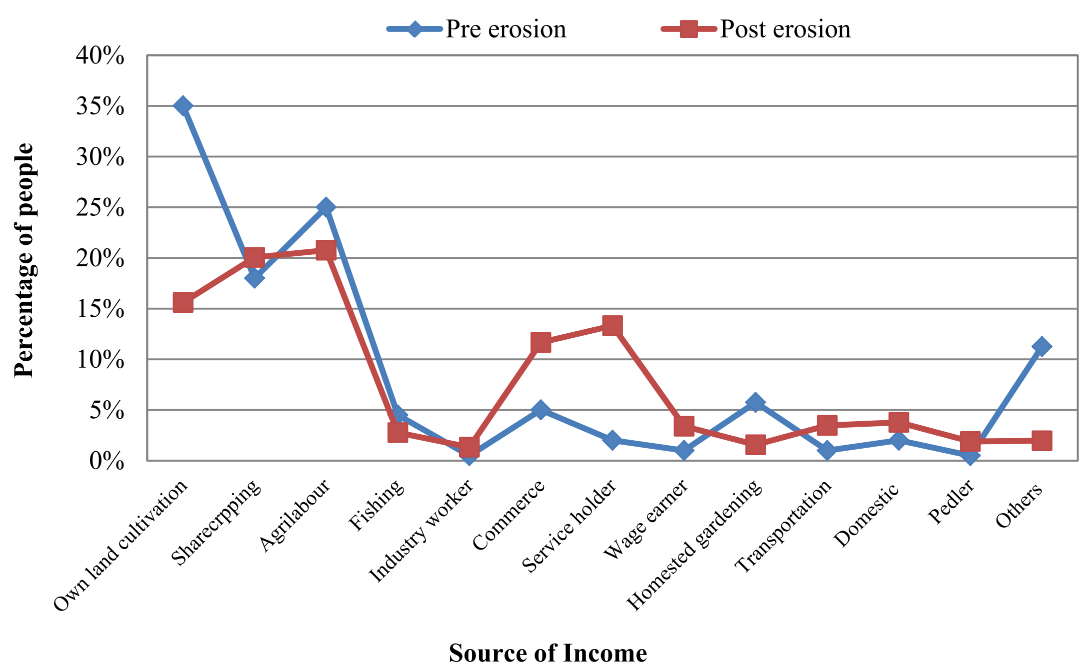

Fig. 4 Source of income in study area at pre-and-post erosion period

are that the agriculture sector is the most vulnerable sector affected by erosion.

According to the concern of DAE, there are five different types of farmers according to the distribution of land owners in study area, such as; landless farmer (0.0–0.049 acre), marginal farmer (0.05–1.49 acre), small farmer (1.50–2.49 acre), medium farmer (2.50–7.49 acre) and large farmer (≥ 7.50 acre). Due to river bank erosion many rich farmers have now become a marginal or landless farmer. There is a common scenario at the char land in Bangladesh. When the new char developed at the river corridor it is occupied by the influential group due to lack of proper government administrative monitoring system. It is a common picture that the legal owner (marginal farmer) is depriving from getting back his lost land. In Lesragonj, Sutalori, Dhulsonra, Harukandi unions the number of marginal farmers is getting high for this reason. The landless and marginal farmers frequently like to change their occupation and have to migrate urban areas in different parts of Bangladesh. After being eroded of Patgram and Andharmanik Bazar, the large traders currently become poor and survive in a miserable condition. Therefore, the people of the study area are like to change their occupation and also have to migrate urban areas for their livelihood. From the questionnaire survey it was found that both male and female of these areas are migrating to Manikgonj district sadar, Savar and Gazipur industrial areas and capital city Dhaka for their shelter and livelihood.

Infrastructural losses

Harirampur upazila has experienced erosion severely from early 70 s to date. The actual statistics of infrastructural losses are not available at the local office data base because of proper monitoring systems. But a rough estimation was made from local people, government and non-government offices. The losses of infrastructures have huge stress on the local economy, education, culture, social development and strategic impact of the inhabitants of the study area. The major infrastructural losses are local government office, roads, embankment, market, educational institutions, mosque, temple and graveyard.

a. *Roads and embankment* Harirampur is the worst affected upazila of Manikgong district due to severe riverbank erosion. According to the Local Government Engineering Department (LGED), the length of lost Pacca road is 27 km; Semi-pacca is 8 km and Mud road is 177 km. Every erosion attacks the roads, bridge, and culvert among mud road are most affected. Therefore, the unions Lesragonj, Sutalori, Azimnagar, Dhulsonra and Kanchanpur have no pacca road. During 2000 twenty villages with 13 culverts, 4 bridges and 100 houses has been eroded in Dhulsonra union, where monetary value was minimum 28 million USD (UNB 2001). The embankment of Harirampur town and Ichamoti River has highly vulnerable nowadays for example thousands of eroded people live on the embankment.
b. *Market* There are many famous markets/bazar in Harirampur upazila which situated on the bank of Padma River such as; Patgram Bazar, Andharmanik Bazar, Jitka Hat, Daskandi Bazar etc. Hundreds of vendors were active at upazila sadar; and thousands of small vendor are depending their livelihood in the entire upazila. The Patgram Bazar was eroded in early 1980s with the loss of at least 150 shops, 25 Godowns making thousands of vendor's capitals. The local people said that during that period the biggest Andharmanik Hat had been disappeared within half an hour where 70 people were died at the spot and 200 shops and 1000 boats were lost at that disaster.
c. *Educational institutions* The educational status of the char land is comparatively lower than the mainland. The educational institutions of the affected unions were mostly relocated due to riverbank erosion. This causes a big problem for distributing the educational institutions according to the rules of population census. Therefore, the char land areas have a limited number of schools than the mainland. In 1915 due to severe erosion famous Patgram Anathbondhu High School, had been relocated to Harirampur upazila sadar. Now Harirampur upazila has three colleges, one government high school, fifteen non-government high schools, seven madrasas, sixty-eight government primary schools, eleven non-government primary schools and fifty-two NGO's operated schools with the total of 31,408 students which are in main land. In 2000, five schools of Dhulsonra unions had been washed away. There is no high school and college in char land areas like; Lesragonj, Sutalori, Azimnagar and Kanchanpur. The student of that region are struggling a lot to attend their school in main land though a limited number of elementary NGO's schools are located in the char land area. The numbers of student per institution in the char land is 140.1 where for mainland 302. For the students of char land areas there are not sufficient infrastructures and other facilities for their proper education, whereas the students of main land have enough infrastructures and other facilities like library, computer and multimedia classrooms.
d. *Religious institutions status* As the study area has 84.4% Muslims and 14.04% Hindu community; it has 161 mosques and 71 temples at present. The old

mosque and temples were washed away due to erosion. It is found that about 24 mosques and 11 temples have been eroded from different unions from 1973 to 2002. Some of them were rebuilt, but the aesthetic and strategic value is beyond the measurement. The kindness of the people is high for their lost. The monetary value estimated for that lost at present local market prices is about 10.6 million BDT (130,996.71 $). At least 29 graveyard of capacity 1450 dead bodies have been eroded. Many people losses their parent's and loving people graves. It is an emotional hazard among that rural community to the eroded area.

Environmental losses

Erosion of an area not only destroys its land or infrastructure but also effects on the environment of the area for short term or long term. The erosion of the river Padma at Harirumpur upazila has some adverse environmental consequences on flora, fauna and fisheries sector. The homestead tree plantation is very common and regular practice in the study area. Every house has huge indigenous trees around the corridor. But due to severe erosion the trees are disappeared. Many people sold their immature trees when they understand the land will be eroded. As the erosion is continuing the amount of land loss is getting high with the loss of agriculture and forestry. The newly developed char land takes huge time to develop sufficient soil layers for plantation. However, the most affected sector of the environment is the fisheries sector. The amount of fish harvest is going down day by day. The bank erosion and the risen char land at middle of the river decreased the river depth and also changed the flow pattern of spawning area of fishes. This siltation process also impacts the navigation of river is decreasing rapidly and also the number of fishes.

Changes in soil fertility

Soil fertility of the eroded area shows a tremendous change. Due to siltation the top soil layer in the agriculture fields is overlain by thin sheet of fine sands which is less fertile. By losing the top soil the potential agriculture lands become barren. The newly accreted char land is sandy and dynamic in nature therefore the crop production is very low with limited crop species. Sometime only peanuts, pumpkin, Kaon is harvested in the char lands.

Losses of aesthetic beauty

The aesthetic losses cannot express directly in monetary value. From the local people interview it is observed that once there was an endless paddy field but now it is a sandy char land. Due to relocation the lost the lost village is now at the middle of the river. There was a beautiful layer of indigenous plant species recorded from the local forest office are now absent from study area. As the market is disappeared the people change their occupation and are migrated another places. There are some unplanned road and embankment based in the study area which shows the miserable situation of the people. This huge changes of river planform create stress on the aesthetic issues of the study area. The barren place of at present; once was a beautiful village, or a productive cropland or a market places.

Population displacement and migration

Population displacement of the erosion prone area is very common phenomenon. It was found that 65% people of the study area has experiences to change their settlement at least one time. The people of the study area have been categorized into four sub-groups in Harirampur upazila are: char people, main land people, and people on the riverbank, embankment and street dwellers. The relocation status among the inhabitants of Lesragonj, Sutalori, Azimnagar, Dhulsonra and Knachanpur unions most significant. Almost 90% people of the study areas have the experiences of relocation at least one time and highest relocation was 14 times. The number of relocated people is relatively high in the study area comparing to the non-eroded and less affected areas. From the study it was found that, 55% respondents identify the cause for migration is lack of agricultural lands, 25% told as for lack of job opportunity, 17% told about for better living and remaining 3% identified the others causes. For migration the people are choosing those areas where they have easy access, get land to cultivate, have necessary support from their relatives, scope of job opportunities, better life guarantees, have educational opportunity and access of basic needs.

Vulnerability assessment

The concept of vulnerability is a descriptor of the status of a society or community with respect to an imposed hazard or threat. Vulnerability to impacts is a multidimensional concept, encompassing bio-geophysical, economic, institutional and socio-cultural factors (Islam et al. 2015). It usually considered as a function of a system's ability to cope with stress and shock (Smith 1992; Islam and Bhuiyan 2016). Table 7 represents the vulnerability scores for all the unions of study area.

According to the IPCC-VI the most vulnerable unions in the study area are Boyra (0.061), Kanchanpur (0.062), Lesragonj (0.064), Azimnagar (0.067), Sutalori (0.071) and Dhulsonra (0.076) because of more sensitivity and less adaptive capacity. Whilst Balara (− 0.017) and Balla (− 0.019) is least vulnerable (Fig. 5a), because of better adaptive strategy and less sensitivity. Among the

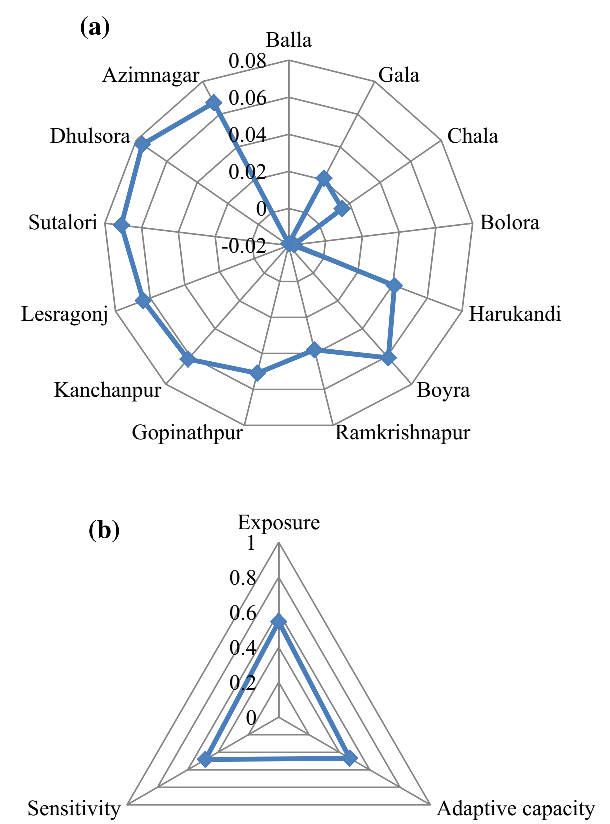

Fig. 5 **a** Spider diagram showing the union-wise vulnerability index, and **b** triangular diagram showing the contributing factors of the IPCC-VI of the study area

vulnerability indices and their contributing factors, a higher standard deviation (SD) is found in the case of vulnerability (0.101) compared to exposure (0.046), sensitivity (0.064) and adaptation (0.061) (Table 7). But the average score of vulnerability (0.101) is less than exposure (0.046), sensitivity (0.064) and adaptation (0.061) which suggests that the variation exist of vulnerability level across all the unions of the study area, compared to the exposure, and hence most of the unions are becoming vulnerable because of high sensitivity and low adaptive capacity (Fig. 5b).

Based on the union level vulnerability index of study area six unions have vulnerability level of more than 0.06, namely Boyra, Kanchanpur, Lesragonj, Sutalori, Dhulsonra and Azimnagar (Fig. 6). Maximum of them are char area and faces several time to riverbank erosion. Further, four unions have vulnerability level between 0.02 and 0.06, and three unions have vulnerability level less than 0.02 are shown in Fig. 6.

However, in all the unions' peoples still depend on natural capital for maintaining their livelihood. Unskilled workers are left with no opportunities to earn and hence, migrate to other areas. Social ties facilitate the process of migration (Deshingkar et al. 2006) but for the poorest people it is difficult to migrate without any network or support (De Haan 2002; Islam et al. 2015). Hence they survive in worse situation by struggling with various natural calamities.

Conclusions

The riverbank erosion causes a severe damage to the affected communities in the study area. Huge amount of fertile agricultural land is eroded every year. The cropping pattern of the agriculture land has been changed enormously and sometimes becomes barren land. The infrastructural losses are also high in the area. The local people frequently change their settlement. From 1973 to 2011 the total eroded land was 155 km^2 in the left bank and 32.08 km^2 in the right bank which create a great loss

Table 7 Vulnerability index for different union of the study area

Name of union	Exposure index (EI)	Rank	Sensitivity index (SI)	Rank	Adaptive capacity index (AI)	Rank	IPCC-VI	Rank
Balla	0.465	12	0.330	13	0.522	13	− 0.019	12
Gala	0.556	7	0.450	11	0.510	11	0.021	10
Chala	0.534	10	0.468	10	0.501	9	0.015	11
Balara	0.456	13	0.381	12	0.502	10	− 0.017	13
Harukandi	0.523	11	0.491	8	0.438	4	0.041	8
Boyra	0.551	8	0.516	5	0.431	3	0.061	6
Ramkrishnapur	0.559	5	0.557	2	0.500	8	0.038	9
Gopinathpur	0.537	9	0.469	9	0.427	1	0.051	7
Kanchanpur	0.558	6	0.523	4	0.441	6	0.062	5
Lesragonj	0.569	4	0.560	1	0.456	7	0.064	4
Sutalori	0.571	3	0.532	3	0.439	5	0.071	2
Dhulsonra	0.583	2	0.498	7	0.429	2	0.076	1
Azimnagar	0.643	1	0.512	6	0.513	12	0.067	3

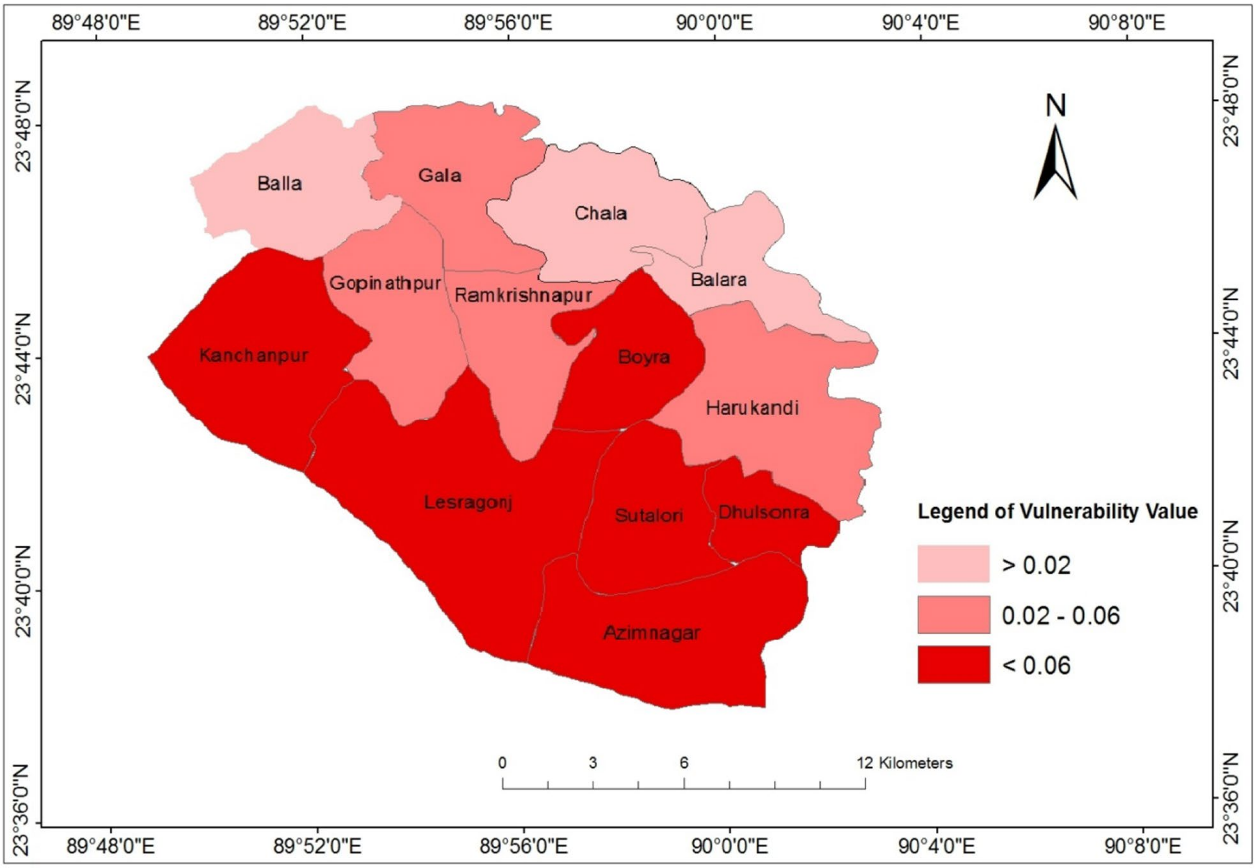

Fig. 6 Vulnerability map of the study area

in local economy. The statuses of farmers were decreased where the rich and medium farmers became marginal farmer and landless. The frequent changing status of farmer's livelihood generates social crisis. The general practice observed in the study area is most of the landless people migrates urban areas for their livelihood. According to the results of vulnerability index, the most vulnerable unions are Boyra, Kanchanpur, Lesragonj, Azimnagar, Sutalori and Dhulsonra, whilst Balara and Balla are least vulnerable. As riverbank erosion is one of the most hazardous processes in study area and creates long term effect, appropriate policies and program should accommodate to improve the livelihood status of the vulnerable areas.

Abbreviations

AI: adaptability index; BBS: Bangladesh Bureau of Statistics; BDT: Bangladeshi Taka; BWDB: Bangladesh Water Development Board; DAE: Department of Agriculture Extension; DPHE: Department of Public Health and Engineering; EI: exposure index; FGD: Focused Group Discussion; GBM: Ganges–Brahmaputra–Meghna; IPCC: Intergovernmental Panel on Climate Change; LGED: Local Government and Engineering Department; SI: sensitivity index; UNO: Upazila Nirbahi Officer; VI: vulnerability index.

Authors' contributions

MAHB: Overall management and planning, financial assistance, data collection and analysis, and reviewing the manuscript. SMDI: Field survey, data collection, data analysis and manuscript preparation. GA: Data analysis, preparing maps and reviewing the manuscript. All authors read and approved the final manuscript.

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Acknowledgements
Authors are thankful to local people and NGO's for their cooperation during field survey. Authors are also thankful to the anonymous reviewers for their valuable contribution to develop the paper in current shape.

Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
Data were collected by field survey by authors.

Consent for publication
Not applicable.

Ethics approval and consent to participate
Not applicable.

Funding
This research was done by authors own interest and financial contributions.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 20 March 2017 Accepted: 24 November 2017
Published online: 21 December 2017

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