MAPPING AND MONITORING EROSION-ACCRETION IN AN ALLUVIAL RIVER USING SATELLITE IMAGERY – THE RIVER BANK CHANGES OF THE PADMA RIVER IN BANGLADESH

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Abstract: The Padma river is widely known for its dynamic and disastrous behaviour, and the river has been experiencing intense and frequent bank erosion and deposition leading to the changes and shifting of bank line. In this paper, a time series of Landsat satellite imagery MSS, TM and OLI and TIRS images and are used to detect river bank erosion-accretion and bank line shifting during the study period 1975-2015. This study exhibits a drastic increase of erosion and accretion of land along the Padma river. The results show that from 1975 to 2015, the total amount of river bank erosion is 49,951 ha of land, at a rate of 1,249 ha a^{-1} and the total amount of accretion is 83,333 ha of land, at a rate of 2,083 ha a^{-1}. Throughout the monitoring period, erosion-accretion was more pronounced in the right part of the river and bank line had been shifting towards the southern direction. The paper also reveals that the total area of islands had been increased significantly, in 2015 there was about 50,967 ha of island area increased from 20,533 ha of island area in 1975, and the results evidence consistency of sedimentation in the river bed.

Key words: bank line shifting, geographic information system, remote sensing, river bank erosion-accretion, satellite image

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Introduction

Bangladesh is one of the riverine countries in the world and more than seven percent of its lands are occupied by river systems (Hossain et al. 2008). The Padma is one of the major three rivers in Bangladesh and is morphologically highly dynamic (CEGIS 2010, Yeasmin 2011). The Padma river originates in the Gangotri Glacier of the Himalaya, runs through India and which enters Bangladesh known as Padma (Sarifuzzaman et al. 2010). The bed and banks of the Padma river primarily composed of alluvial materials (CEGIS 2010), the bank materials consist mostly of fine-grained and cohesive sediments (Azuma et al. 2007). Due to fine sand and silty sediments with occasional clay and its banks are highly unstable (Mclean et al. 2012), and frequently occurs continuous erosion-accretion process (Kammu et al. 2008). The Padma river is braided, and form islands or chars between the braiding channels, these chars, of which many are inhabited, move with the flow and are extremely sensitive to changes in the river conditions of erosion and accretion (NPDM 2006). A study showed that bank erosion along the Padma river during 1967–2009 is 66,457 hectares (CEGIS 2005).

Riverbank erosion in the Padma river is a perennial problem and is considered as a natural disaster in Bangladesh, this river causes loss

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of lots of lands and livelihoods. At one side the continuous erosion is endangering human livelihoods near the river bank floodplain; on other side the siltation and deposition in the river bed is leading the formation of permanent sandbars or islands, fish and aquatic biodiversity are reducing significantly. Haque (1985) and Islam (2000) remarked that river bank erosion has an immediate and severe impact on the human population displacement, flood and bank erosion is a key contributor to landlessness and impoverishment of rural population. Such direct social and economic impacts due to rapid riverbank erosion are the significant constraints against further development along the river banks.

In recent decades, various studies had been conducted on the river bank erosion for the Padma river e.g. Sarker et al. (2003) for rivers, chars, and char dwellers, CEGIS (2003) for morphological evolution of Padma. Moreover, a number of studies had been conducted on the Padma River are based on satellite images, such as the river and char (island) dynamics (EGIS 2000). Islam (2009) studied in his thesis about the movement of river channel on Padma and Jamuna using remote sensing (RS) and geographical information systems (GIS). Islam (2009) described that RS and GIS provide tools for quantitative and qualitative river morphological analysis. Hassan and Mahmud-ul-Islam (2016) studied for quantification of riverbank erosion and bar deposition in Sirajganj District and they demonstrated that human settlement, forest, seasonal crops and agriculture features have been decreased, while river coverage has been increased dramatically. Dewan et al. (2016) observed the channel changes of the Ganges–Padma river system and it was showed that both banks of the Ganges–Padma river experienced considerable loss of land.

However, in the present paper, an attempt has been made to monitor and map the bank erosion and accretion of the Padma river. The better understanding of such erosion-accretion processes, as well as techniques to detect such changes, are very useful for planning and management of the floodplain environment of the Padma river. There is the availability of satellite image data at various spatial and temporal resolutions provides tremendous opportunity to monitor river bank erosion and deposition processes. Here, GIS and RS methods had been used to analyse satellite image data. The main objectives are:

- identify the erosion and accretion along the Padma river,
- delineate the shifting of bank line of the river,
- quantify the changes of islands area in different time periods.

Study area

This study concentrates the Padma river is located in Bangladesh, is 120 km long and its width varies from 4 to 8 km (Chowdhury 2003). The study area (Fig. 1) embraced the confluence points of the Padma-Jamuna at Goalanda, Rajbari and the Padma-Meghna at Matlab, Chandpur. The study area which lies between the latitude 23°50'–23°13'N and longitude 49°43'–90°39'E, and it passes through the Chandpur, Dhaka, Faridpur, Madaripur, Manikganj, Munshiganj, Rajbari and Shariatpur districts. The Padma river is characterized by Ganges river system. The annual average discharge is 35,000 m^3 s^{-1} and the average width of the river is 10.3 km (CEGIS 2010). The velocity ranging from 4–5 m s^{-1}, with depth varying from 20 m to 21 m and annual silt load of 492 t km^{-2}. The average gradient from Goalandaghat to Chandpur is 1:37,700 or 0.000027 degree for a distance of 120 km (ADB 2010). The characteristics of the sediment of the northeast bank is alkaline soil and the southwest bank is peat (CEGIS 2010). The Padma has high water flow in the monsoon and much less in the dry season, erosion and deposition of the Padma riverbank are influenced by the unstable water flow during the monsoon and dry season, and by yearly flood (Islam 2010). The mean annual rainfall is 2,000 mm of which about 70% occurs during the monsoon season; the average temperature is 25.5°C to 26°C (Hassan and Akhtaruzzaman 2010).

Methods

The Remote Sensing (RS) and Geographic Information System (GIS) methods and other statistical data techniques have been used for the assessment of river bank erosion-accretion and identification of bank line shifting pattern of the Padma river. Landsat satellite images from 1975

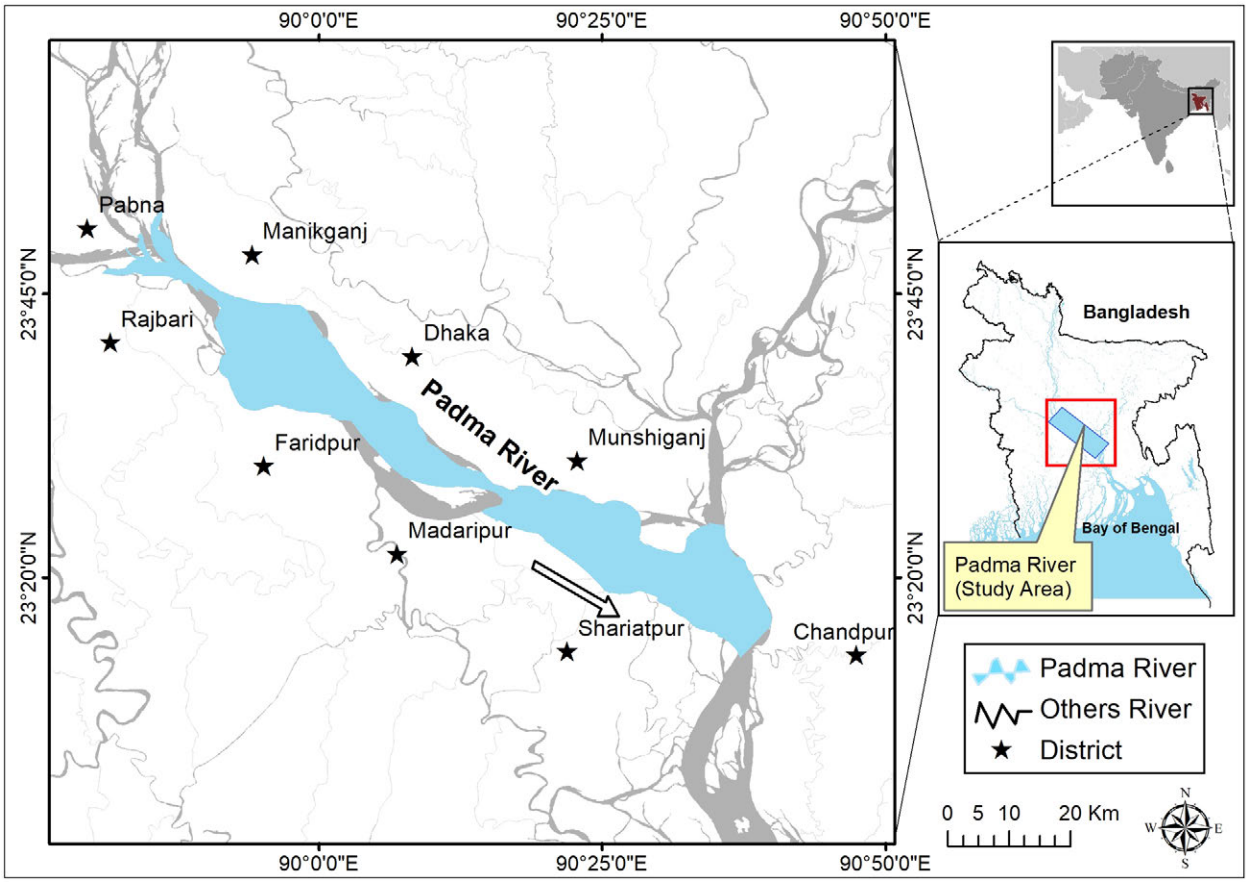

Fig. 1. Location of the study area.

to 2015 of five different time periods during the dry season from Bangladesh have been considered in this study, dry season was taken place in order to avoid overestimation of the river expanse which is common with the images taken during high stages of flow or monsoon and flooding seasons. The satellite image data selected was cloud free. The data obtained was in a GeoTIFF format for each individual band. The satellite image of Landsat 2 MSS of 1975, Landsat 5 TM of 1988, 1994, 2005, and Landsat 8 OLI and TIRS of 2015 were obtained from the United States Geological Survey (USGS) Earth Explorer as a georeferenced dataset (Earth Explorer 2015). The details of the data are given in Table 1.

Table 1. Landsat satellite images utilized in the study.

Sensor	Band numbers	Date of acquisition	Spatial resolution [m]
MSS	1,2,3	March 10, 1975	60
TM	1,2,3,4	November 01, 1988	30
TM	1,2,3,4	October 10, 1994	30
TM	1,2,3,4	January 16, 2005	30
OLI and TIRS	1,2,3,4,5	January 28, 2015	30

In the first step of image processing, layer stack has been processed in ERDAS Imagine 2010 software. Then the images were corrected for radiometric and atmospheric distortions. After then, the layers stacked IMG format image data of five years have been processed to subset image. The bank line and islands of the river of these five years images were extracted with help of on-screen digitization in ArcGIS 10 software at a scale of 1:50,000 and then the bank lines were overlaid. In the ArcGIS software, was created a continuous polygon (vector format) to represent the river channel in each year using the image data and the statistics were generated. The overlaid bank line gave the overall the rate of erosion and accretion, islands area and bank line shifting pattern of the Padma river from 1975 to 2015. Comparing the image vector data from different periods, were defined the changes of the river channel position over different time series. The results revealed the places where erosion and accretion occurred during each period and outputs were mapped. Bankline shifting was measured taking 10 cross-sections (A–K) at 11.5 km intervals along the river (Fig. 5).

Results

The total amount of erosion and accretion during the study period from 1975–2015 along both banks of the river are 49,951 ha and 83,333 ha, respectively. During this time period, the overall rate of erosion and accretion on both banks are 1,249 ha a^{-1} and 2,083 ha a^{-1}, respectively. Table 2 shows that there has been significant accretion in the Padma river during a period of 40 years as compared to erosion. In addition, erosion and accretion are more pronounced in the right bank than that of the left bank. From 1975 to 2015, in the left bank, the overall erosion and accretion are 24,387 ha at a rate of 610 ha a^{-1} and 36,037 ha at a rate of 901 ha a^{-1}, respectively. During this time span, in the right bank, the overall erosion and accretion are 25,564 ha at a rate of 639 ha a^{-1} and 47,297 ha at a rate of 1,142 ha a^{-1}, respectively.

From 1975 to 1988, the entire reach of Padma (both left and right banks) eroded 7,740 ha but accreted 26,216 ha, with a net gain of 18,476 ha of new land. Similarly, from 1988 to 1994, accretion was more dominant than erosion on both banks of the river. The total amount of erosion during this period was about 9,392 ha compared to accretion about 18,207 ha and there was a net loss of 8,815 ha of land. Between 1994 and 2005 erosion was more pronounced than accretion. The total amount of erosion and accretion in this period were 26,830 ha and 17,206 ha, respectively. For 2005 to 2015, the total amount of bank erosion is 5,988 ha and the total amount of bank accretion is 21,705 ha, which shows the trend of gradual increase of erosion. But over the forty years of the study period, the overall river bank erosion is less than the amount of accretion. However, the result of erosion and accretion is influenced by some natural factors like water discharge

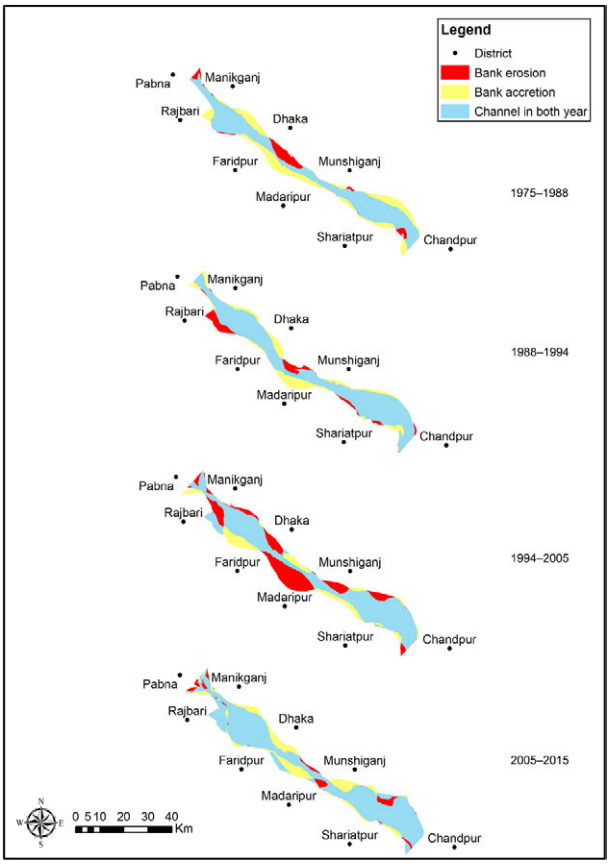

Fig. 2. Riverbank erosion-accretion along the Padma river for four periods.

Table 2. Erosion-accretion net along the Padma river.

Duration	Location (Padma River)	Erosion		Accretion	
		Total (ha)	Rate (ha a^{-1})	Total (ha)	Rate (ha a^{-1})
1975–1988 (13 years)	Left bank	6,258.03	481.38	10,937.18	841.32
	Right bank	1,482.38	114.02	15,278.44	1,175.26
	Total reach	7,740.41	595.41	26,215.62	2,016.58
1988–1994 (6 years)	Left bank	3,680.80	613.46	7,818.39	1,303.06
	Right bank	5,711.33	951.88	10,388.79	1,731.46
	Total reach	9,392.13	1,565.35	18,207.18	3,034.53
1994–2005 (11 years)	Left bank	11,223.93	1,020.35	5,678.95	516.26
	Right bank	15,606.18	1,418.74	11,526.76	1,047.88
	Total reach	26,830.11	2,439.10	17,205.71	1,564.15
2005–2015 (10 years)	Left bank	3,224.44	322.44	11,602.08	1,160.20
	Right bank	2,763.86	276.38	10,102.62	1,010.26
	Total reach	5,988.30	598.83	21,704.70	2,170.47
1975–2015 (40 years)	Total (Left bank)	24,387.20	609.68	36,036.60	900.92
	Total (Right bank)	25,563.75	639.09	47,296.61	1,182.42
	Total (Both bank)	49,950.95	1,248.77	83,333.21	2,083.33

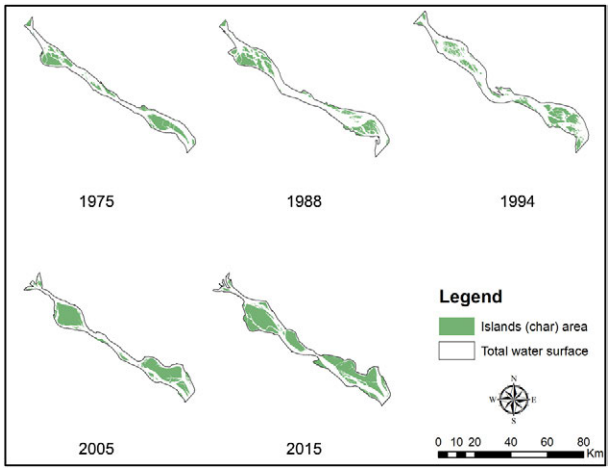

Fig. 3. Changes of Islands (Char) of the Padma River 1975–2015.

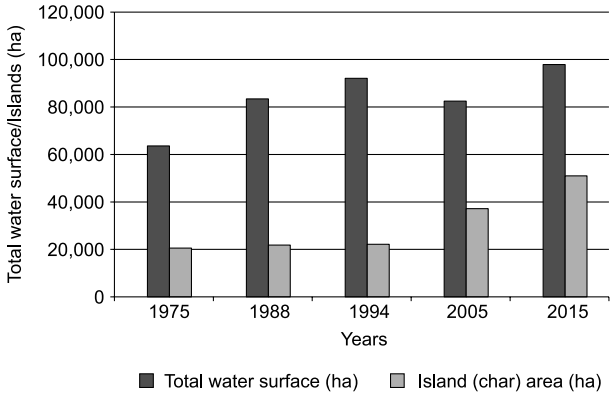

Fig. 4. Islands (char) area in Padma river in different periods.

or water level, climate etc. These factors create the fluctuation of erosion-accretion in the river. Summary statistics and graphical representation of river bank changes of the Padma river, due to erosion and accretion for 1975 to 2015 are presented in the following Figure 2.

The channel through the Padma river is blocked by many sandbars named Islands or Char land. This channel usually disappears during winter and gets activated by water flow only during flood season. These are occurred due to the influence of active erosion and accretion. The statistical results, summarized in Figures 3 and 4 reveal the total water surface and islands area. The char area has increased significantly over time for the year of 1975, 1988, 1994, 2005 and 2015. The analysis of data reveals the changes that the total amount of island was about 20,533 ha in 1975, 21,861 ha in 1988, 22,168 ha in 1994, 37,155 ha in 2005 and 50,966 ha in 2015.

The shifting of bank line from 1975 to 2015 on both banks along the Padma river was measured through 10 cross- sections at an interval of 11.5 km along the river and the results are presented in Figure 5 and Table 3. Analysis of the satellite images of the research area showed that the highest amount of erosion of land observed in the left bank along the section G (4.1 km) from 1994–2005 near Munshiganj district and in the right bank along the section F (4.4 km) from 2005–2015 near Faridpur and Madaripur districts. The maximum

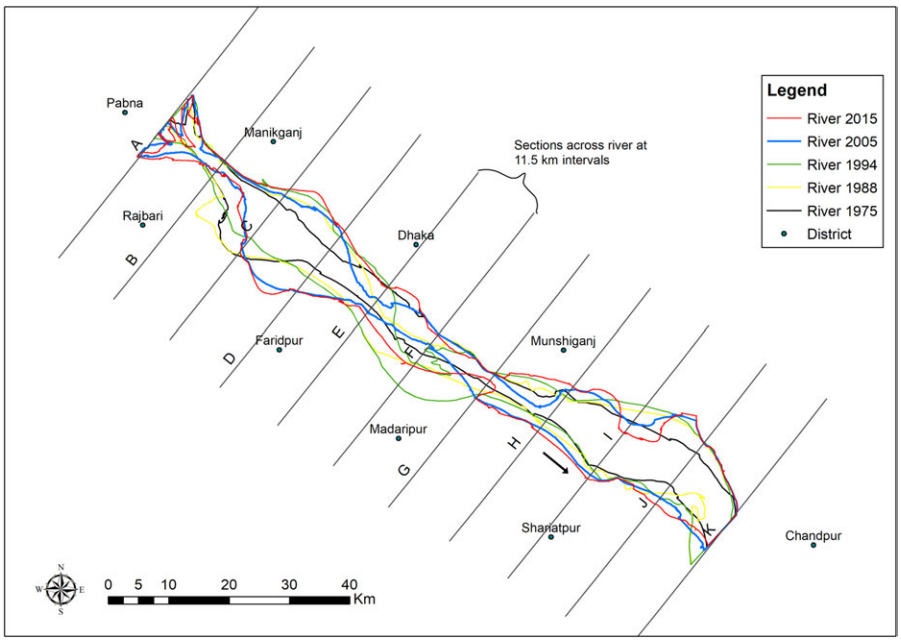

Fig. 5. A schematic diagram of bank line shifting from 1975–2015.

Table 3. Bankline shifting due to erosion and accretion 1975-2015.

Sections	1975–1988		1988–1994		1994–2005		2005–2015		1975–2015	
	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank
A	+1.2	+0.1	–1.2	–2.9	–0.2	–3.7	+0.1	–0.3	–0.15	–6.80
B	+0.2	–0.1	–0.3	–0.4	–0.2	+1.5	–0.1	+0.3	+0.32	+1.35
C	–1.3	+0.3	–1.1	+3.3	+1.0	–2.2	–1.3	+0.5	–2.70	+1.90
D	–2.7	–1.2	+0.1	–0.6	–0.3	–3.0	–0.7	+1.7	+3.68	–3.10
E	+3.1	–3.4	–3.4	–0.1	+2.9	+2.5	–2.5	–0.7	+0.10	–1.61
F	+2.0	–2.1	+3.9	–4.4	–6.0	–3.7	+0.3	–4.4	+0.20	–14.63
G	+0.1	–1.2	–0.1	–0.6	–4.1	–0.7	–0.2	+3.5	–4.30	+1.00
H	+0.7	–1.3	–0.1	+0.8	–1.2	–1.4	+0.7	±0.7	+0.10	–2.60
I	–2.2	–0.8	–1.1	–0.6	+3.6	–0.8	+2.0	–0.7	+2.30	–2.39
J	–2.0	–1.7	–1.1	–0.9	+0.2	–0.1	+0.1	+1.2	–2.85	–1.47
K	–0.3	–3.8	+1.5	+1.5	–1.5	+3.5	–0.1	+1.0	–0.31	+2.20

Note: Minus sign (–) indicates shifting (in km) due to erosion and plus sign (+) indicates shifting (in km) due to accretion.

amount of accretion of land was established in the left bank along the section I (3.6 km) near Munshiganj district and in the right bank along the section G (3.5 km) near Madaripur district from 1994–2005 and along the section K (3.5 km) near Chandpur district. The line diagram in Figure 5 indicates the direction and rate of shifting of bank line.

Discussion

Bangladesh is predominantly a riverine country where river bank erosion is an annual disastrous phenomenon, especially in the Padma river, erosion-accretion is a common and very frequent event. The channel and bank line pattern of the Padma river changes continuously. Obtained results demonstrated that from 1975 to 2015 during 40 years, the total amount of river bank erosion was 49,951 ha of land, and the total amount of accretion was 83,333 ha of land including Islands. In Padma river from 1973–2011 over 38 years, Dewan et al. (2016) found 35,540 ha of eroded land and 15,766 ha of accreted land. Erosion is mainly attributed to the instability of the river in this region. It is also experienced that the erosion pattern is quite irregular and it is very common that a location under attack of severe bank erosion during one flood may or may not experience the similar attack during next season. The change in river bank line causing erosion is taking place during receding stage of floods when excess sediments are deposited as sand bars within the channel resulting into the change of flow direction and migration of sand bars thereupon and also due to flowage failure of the silty materials of the banks.

This study results revealed that erosion along the right bank, in particular, is the major threat to the Faridpur and Madaripur district. Similarly, Rahman and Islam (2017) showed that during the 1980–84 period, the maximum amount of erosion had occurred along the right at Gharishar of Shariatpur district was about 1,800 m, and the highest amount of erosion on the left bank at Harirampur of Manikganj district was about 2,200 m during years 2000–2001.

It was found that erosion and accretion was more dominant in the middle part of the river what is similar to the study by Khan and Islam (2003) who showed frequent and rapid erosion and fast rates of bank line retreat along the Brahmaputra-Jamuna river, and study analysis showed that the erosion rates in the Brahmaputra-Jamuna River were 160 m between 1972 and 1992-year period and accretion has taken place in the middle and lower reaches north of the east bank and in the extreme north of the west bank which indicates the severity of erosion hazard. Study and analysis using satellite and Google image revealed that deposition in the recent decade from 2002–2010, was higher in Chandpur district near Padma river but erosion rate was higher in the previous decade from 1980–1990 (Nath et al. 2013).

Results of this study revealed that erosion and accretion were more pronounced in the right bank than that of the left bank. Similarly, Rahman and Islam (2017) showed the river bank erosion

pattern of the Padma river during 1967–2009 by using remote sensing and field survey data, and that study figured out the total erosion along both banks of the Padma River was 66,457 ha and erosion along the right bank was 43,541 ha, and along the left bank 22,916 ha during that period, and erosion along the right bank was about 50% higher than along the left bank. In another study by it is showed by Islam (2009) that the movement of river channel on Padma and Jamuna using RS and GIS from 1977 to 2000 and demonstrated that during this period, there was more erosion than deposition, indicated the rivers were getting wider, river channels moved due to erosion and deposition following their direction, also distinguished that the general trend of channel movement of the Padma is towards the south. Besides, Hossain et al. (2013) assessed morphological changes of the Ganges river using satellite images within Bangladesh, results indicated that both the left and the right banks of Ganges have changed significantly due to varying erosion and accretion rates that had occurred. On a whole, the left bank was more prone to accretion while the right bank to erosion. The presence of cohesive material is not continuous along both banks of the river. On the left bank, cohesive material which includes consolidated and weathered Pleistocene aged sediments (natural barrier) are common and more resistant to erosion but they are sparse in right bank (Sarker 2004).

This study further revealed that the changes of water surfaces and increasing of islands in different time periods from 1975 to 2015. The sedimentation behaviour depends on the water velocity, water level and discharge are found minimum during dry season but maximum in monsoon time. Therefore, decrease in flow during dry season leads to the deposition of river bed or increasing of Islands and high velocity results high sediment transport rate and ultimately contributes in erosion in the Padma river (Mahmud et al. 2018).

In this study, analysis from the satellite images showed that the highest shifting of channel observed in the left bank was about 4.1 km from 1994–2005 near Munshiganj district and in the right bank the highest shifting of the channel was about 4.4 km from 2005–2015 near Faridpur and Madaripur districts. Alam and Hoque (1998) illustrated that the major rivers of Bangladesh show different channel pattern with dynamic characteristics, for example, Padma (Ganges) shows a meandering pattern characterized by a high sinuosity single channel.

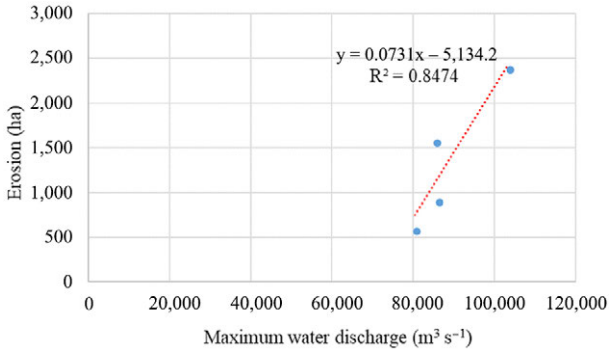

Fig. 6. Relationship between maximum water discharge and erosion (data source: BWDB 2013, CEGIS 2010).

Erosion has been defined as the mechanism of detachment of sediment particles and other materials by the action of flow, waves, tidal fluctuations and other hydrological factors governing the flow condition of a channel (Ahmed 1989). The fluvial geomorphic process is very much active in Bangladesh and most of the river channels are shifting in nature (Hossain 1984). In Padma river, erosion is correlative and sensible to discharge, for instances, in 1994 at Mawa water level measurement station in Munshiganj district, the maximum water discharge of Padma river was 100,555 $m^3 s^{-1}$ where erosion was 2,393 ha and in 2005 the maximum water discharge of Padma river was 86,075 $m^3 s^{-1}$ and where erosion was 908 ha. A relationship between maximum water discharge and erosion of Padma river is shown in Figure 6. The relationship between annual erosion (E) and maximum water discharge (Qmax) has found as:

$$E = 0.0731 \times Qmax - 5,134.2.$$

The coefficient of determination (R^2) value equals 0.8474 indicates substantial relationship of maximum water discharge with sediment erosion in different years. The limit for axis X axis (erosion in ha) is 7,000–110,000 $m^3 s^{-1}$ and for Y axis (maximum water discharge in $m^3 s^{-1}$) is 500–2,500.

Conclusion

The present study shows that satellite data like Landsat can be successfully used to monitor

river bank erosion-accretion using the application of RS and GIS with multi-temporal satellite images. It has been revealed that sharp changes in river channel erosion/accretion in recent years resulting in considerable formation and loss of lands and represents the retrospective scenario of the Padma river. Analysis of multi-date satellite data has indicated that in future erosion and accretion is likely to be more in the Padma river. The riverbank areas which are likely to continuous erosion, natural embankments, and eco-friendly materials would be effective to control the erosion and plan for the development of the Padma river. Furthermore, the information which is generated through this study compiling with other supportive data will facilitate towards taking up long-term flood/erosion protection measures along the Padma river.

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