Study of Erosion and Accretion of Jamuna River Using GIS and Remote Sensing Technology

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ABSTRACT

The Jamuna River exhibits significant erosion along its banks, resulting in changes to its course and posing challenges for local communities. This study aimed to detect the changes of Jamuna River flow path and to estimate the rate of change of flow area, erosion, and accretion along the Jamuna River for the period of 1990 to 2020. Landsat satellite images of 30 m resolution from 1990 to 2020 at five years interval were collected from USGS website. River flow area and bank lines were detected from raster calculation of MNDWI. The rate of bankline shifting and bankline movement were computed in LRR (m/year) and NSM (m) method respectively. The Jamuna River had consistently lost its water body at an average rate of 4.6 km^2 per year from 1990 to 2000. However, the river's flow area remained relatively stable, with an average annual decrease of 0.35 km^2 during 2000-2020. The upstream areas of Kazipur and downstream areas of Nagarpur and Shahajadpur were identified as the most vulnerable regions. Conversely, the middle segments of Sirajganj Sadar and Bhuapur were relatively stable. The area downstream of Jamuna Bridge has experienced significant land gain, with a maximum width of 4.2 km. On average, the right bank of the river experienced an erosion rate of -11.97 m/year, while the left bank eroded at an average rate of -52.44 m/year. This study advocates for policymakers to mitigate the risk of Jamuna riverbank erosion and implement sustainable management strategies.

1. INTRODUCTION

Bangladesh is known as the land of rivers due to its extensive river network. The rivers in Bangladesh play a vital role in the country's geography, economy and culture. The river system directly or indirectly influences many aspects of the environment and plays a vital role in the livelihood pattern of millions of inhabitants. Bangladesh owns three mighty rivers, the Ganga (Padma), Brahmaputra (Jamuna) and Meghna. The Brahmaputra-Jamuna is a classic example of a braided river and is highly susceptible to channel migration and avulsion, making the river very dynamic and unstable, which is prone to erosion and accretion. The Jamuna is provided to have exquisite bank erosion and highest rate of bank line movement (N. I. Khan & Islam, 2003). It has been evidently observed that changes in the proportion of erosion and accretion differ in different points of Jamuna River. The highest eroded area, spanning over 3.82 km^2, occurred between 1995 and 2005, while the highest accreted area, covering 6.15 km^2, was observed between 1995 and 2015 (M. A. Hassan et al., 2017). During the period of 1973 to 2015, the net erosion along the 220 km long Jamuna River was about 88,462 ha. (Klaassen et al., 1988).

The erosion and accretion of the Jamuna River is a serious problem that is having a significant impact on the people who live along the river. These processes can have far-reaching impacts including the loss of valuable agricultural land damage to infrastructure and settlements changes in river flow patterns and alterations to the ecological balance. The erosion is causing the river to widen and deepen, which is displacing millions of people along river bank. The accretion is causing the river to narrow and become shallower, making it difficult for boats to navigate and leading to huge floods due to water overflow. This case study focused on the erosion and accretion dynamics of the Jamuna River, aiming to understand the patterns, rate of bank line changes, and extents of these processes. By utilizing GIS and remote sensing technology, we can obtain detailed and accurate spatial information, enabling comprehensive analysis of the river's changes over time. It also helps to identify areas at risk of rapid erosion and accretion. This information can be used to develop plans to mitigate the effects of erosion and accretion along the bankline of Jamuna River.

However, the main objectives of this study are as follow:

1. To detect the change of Jamuna River flow path using Landsat Satellite images.
2. To estimate the rate of change of flow area, erosion and accretion along the Jamuna River for the period of 1990 to 2020.

2. DATA COLLECTION AND STUDY AREA

2.1 Study Area

The Brahmaputra originates in the Chemayung-Dung glacier, approximately at 31'30'N and 82'0'E. The total length of the Tsangpo-Brahmaputra-Jamuna River up to its confluence with the Ganges is about 2,700 km. Within Bangladesh territory, Brahmaputra-Jamuna is 276 km long, of which Jamuna is 205 km. The Jamuna River is braided in nature. Within the braided belt of the Jamuna, there are lots of chars of different sizes. An assessment of the 1992 dry season Landsat image showed that the Jamuna contained a total of 56 large island chars, each longer than 3.5 km. The study area for this study is Jamuna River passes through Sirajganj and Tangail District, which is 85 km long started from Kazipur to Shahjadpur. The study area which lies between latitude 24°00'N -24°48'N and longitude 89°38'E-89°52'E.

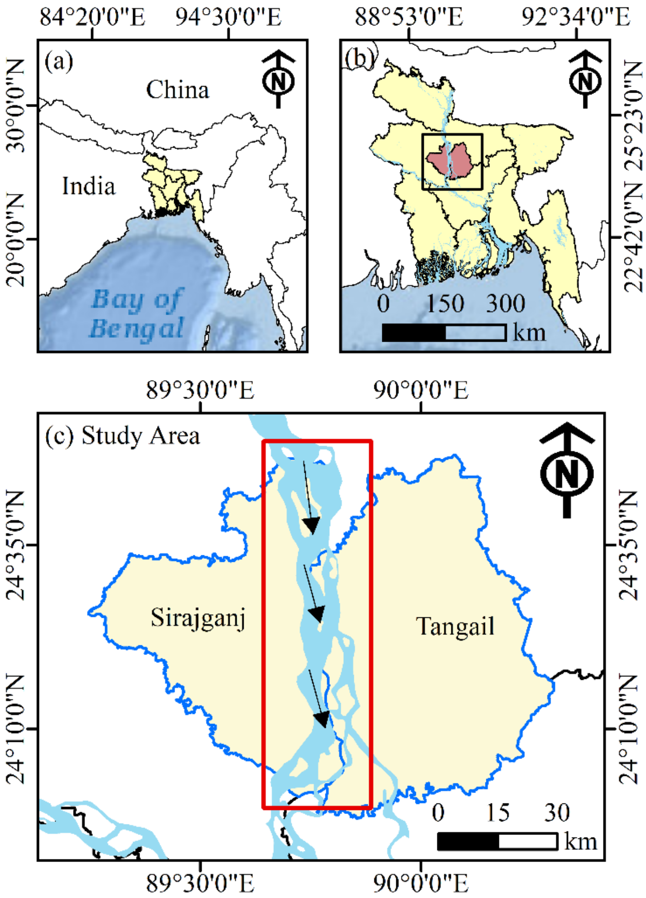

Fig. 1: Map showing (a) World view, (b) Bangladesh, (c) Zoomed view of 85 km long study area of Jamuna River passes through Tangail and Sirajganj district.

The left bank (Sirajganj side) is vulnerable in case of bank erosion than right bank (Tangail side) erosion of the river. Sirajganj and Tangail district were connected through 5 km long Jamuna Bridge which was constructed over the Jamuna River in 1998 (R. Islam et al., 2017). River training structures have been built more than 30 places along the Sirajganj and Tangail Bankline since 1996 (Sarker et al., 2011). Fig. 1 shows the study area in between Tangail and Sirajganj district. Many important places i.e., Kazipur, Sirajganj Sadar, Shahjadpur, and Bhuapur are located along the Bankline of Jamuna River. The density of the population in Sirajganj district along the riverbank is higher than that of the population density in Tangail district. Nagarpur, located in Tangail side, has the highest population density.

2.2 Data Collection

Identification of the river morphology from satellite imagery of different years using GIS and Remote Sensing technology is found to be useful for studying the fluvial geomorphology of a river. The Landsat Program is the longest running exercise in the collection of multispectral, digital data of the earth's surface from space since 1972. In this study, dry season Landsat imagery from 1990 to 2020 was collected from the USGS website archives. The details information of the imagery are listed in Table I.

Table I: Acquisition date of Landsat images and their resolution.

S.L	Image Acquisition Date mm/dd/yyyy	Sensor Type (Landsat)	Image Resolution (m)	Source
1.	11/14/1990	5 TM	30	
2.	01/28/1995	5 TM	30	
3.	01/26/2000	5 TM	30	
4.	01/07/2005	5 TM	30	USGS
5.	01/21/2010	5 TM	30	
6.	02/04/2015	8 OLI	30	
7.	01/17/2020	8 OLI	30	

We primarily collected Landsat dry season cloud-free images available during the January to February months. This choice was made to facilitate the clear detection of the river's main flow path and bar land, as rainwater on the surface of bar land could potentially interfere with the results. All the Images were collected from path 138 and row 43 of Landsat USGS archive. We used three Band images i.e., green, near infrared (NIR), and short-wave infrared (SWIR). The data obtained were in a GeoTIFF format for each individual band. Short-wave infrared is mostly absorbed by water which helped us to detect the river and the land area.

3. METHODOLOGY

3.1 Flow Path Changes of Jamuna River

Remote Sensing (RS), Geographic Information System (GIS) methods, and other statistical data techniques have been employed to assess river erosion and accretion, as well as to identify shifting patterns of Jamuna River. Various methods for extracting the river body from Landsat imagery have been developed using ArcGIS software. The river body was extracted from the image using the MNDWI method, which stands for Modified Normalized Difference Water Index developed by (Xu, 2007). The reflectance of water is higher in the green band and lower in NIR band. Xu (2007) proposed that the MNDWI is suitable for extracting the waterbody from a landmass. The modification of the NDWI using a MIR band instead of a NIR band can considerably improve the enhancement of open water features. The MNDWI is more suitable for enhancement of water with many built-up land areas in the background than the NDWI because it can efficiently reduce and even remove built-up land noise (Xu, 2007).

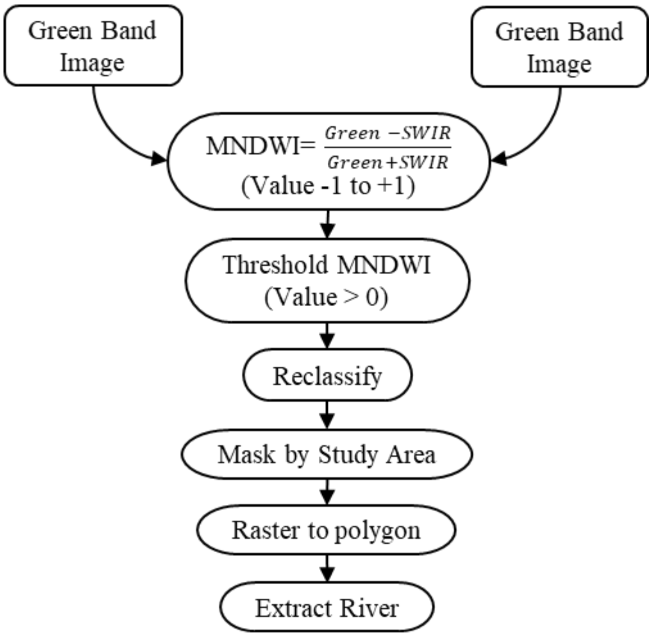

Fig. 2: Methodology flowchart to extract waterbody from satellite images.

Fig. 2 shows the methodology of extracting the river polygon from satellite imagery. The threshold values for the MNDWI to achieve best water extraction result are usually much less than those of the NDWI, suggesting using zero as a default threshold value can produce better water extraction accuracy for the MNDWI than for the NDWI (Xu, 2007).

$$MNDWI = \frac{Green - SWIR}{Green + SWIR} \quad (1)$$

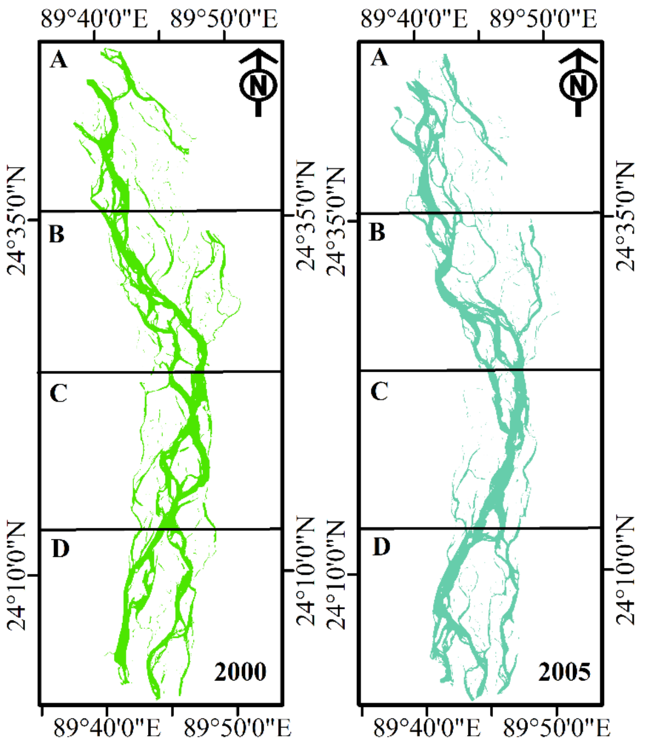

Fig. 3: Extracted River flow area in 2000 (green) and 2005(blue).

The value of MNDWI Ranges from -1 to +1. The higher reflectance of built-up and lower reflectance of water in SWIR band result in negative values of built-up and positive values of water features in the MNDWI-derived image.

Each extracted river polygon from 1990 to 2020 at 5-year interval was divided into 4 rectangular segments i.e., Segment A (22.4km×24.8km), Segment B (20.8km ×24.8km), Segment C (20.6km ×24.8km) and Segment D (22.6km ×24.8km). Fig. 3 represents the detected waterbody from Landsat images of 2000 and 2005. Extracted rivers indicated the waterbody of the river. We measured the total area of each individual segment, and then subtracted the river area to estimate net land area. Thus, we quantified only the land area of each segment throughout the year 1990 to 2020. Comparing consecutive two years images, we estimated net erosion and accretion area of each segment throughout the years 1990-1995.

Net land area of each segment = (Segment Area – River flow area) (2)

Net Area of erosion or accretion in the segment = (land area in 90 – land area in 95) (3)

(Positive value indicates accretion and negative vale indicates erosion)

3.2 Bankline Detection

Bankline is defined as the feature that separates the outer margin of a river channel from the floodplain (Hassan et al., 1997)

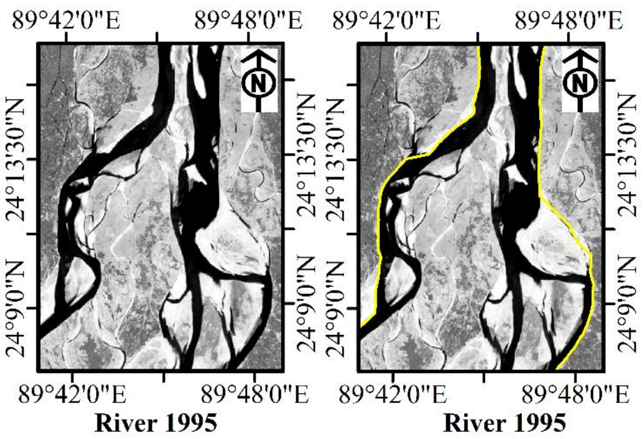

Fig. 4: Landsat SWIR image of 1995, black portion indicate as waterbody and yellow as river Bankline.

The analysis of historical Bankline changes helped us understanding the erosion rate and vulnerable areas near the river Bankline. This study relied on Remote Sensing satellite image for Bankline detection. Water exhibits a high degree of infrared energy absorption, while it is strongly reflected by vegetation and land. The short wavelength band shows significant difference between land and water interface. Hence, we used a single SWIR band for Bankline detection. The water appears black and land surface or vegetation appears grey in Landsat SWIR band. Fig. 4 shows the detection of the Bankline of Jamuna River in the year 1995.

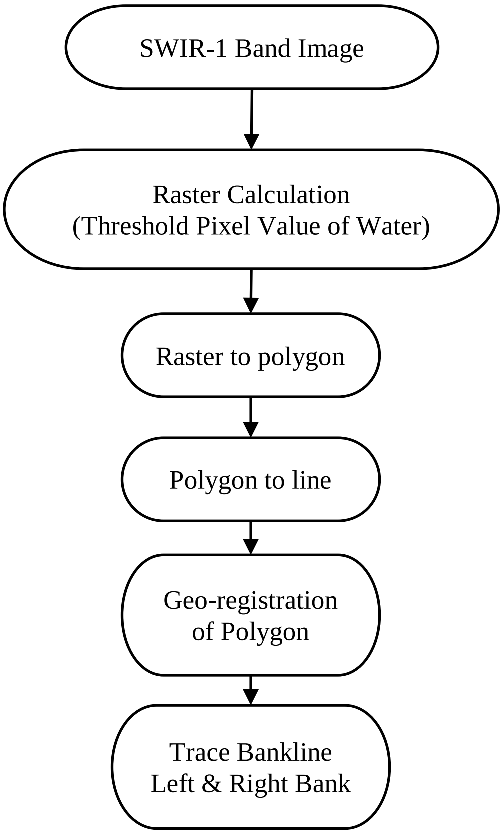

Fig. 5: Methodology flowchart to extract river bankline from satellite images.

In this study, Automatic Bankline detection techniques were employed to detect the Bankline of the Jamuna River for the period 1990 to 2020. First, we performed geo-registration based on the World Geodetic System WGS-84 with projected coordinate system UTM zone 45N to adjust the geographic positions of all images. Raster calculation was then performed from the threshold values of water exhibited pixels. The threshold value for water pixel was selected by trial-and-error method. Then, the riverbank line was traced for both left and right bank from 1990 to 2020 at 5-year interval. Fig. 5 represents the sequential process of river Bankline detection from SWIR image.

3.3 Bankline Change Analysis in DSAS

In this study, we used the Digital Shoreline Analysis System (DSAS) version 5.1, an extension tools of ArcGIS, to compute the rate of Bankline changes. The processes were carried out in four steps i.e., bankline preparation, creating baseline, transects generation and computing the rate of Bankline changes (Raj et al., 2020). DSAS used baseline measurements of a time series of banklines to estimate the rate of Bankline change and it required another shapefile in the same personal geodatabase (Leatherman, 1983). We positioned approximately 15000 m long baseline parallel to the riverbank and cast transects along this baseline at 100 m intervals perpendicular to that baseline. These transects were generated using the cast transects tool in DSAS, with a smoothing distance set at 0.00 m. Overall, 645 transects were created and the data from the transect feature class were used to compute the changes.

3.3.1 Linear Regression Rate (LRR)

Linear Regression Rate (LRR) estimates the rate of variation by fitting the least squares regression line to all the Bankline points of a transect (Himmelstoss et al., 2021).

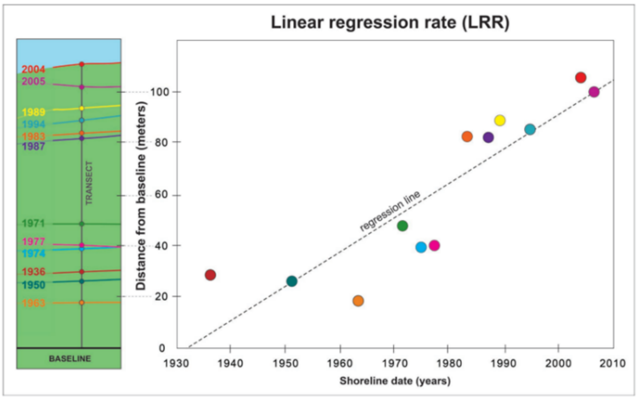

Fig. 6: Shoreline distance vs shoreline date graph represents Linear Regression Rate of a single transect. The slope of the equation describing the line is the rate (Himmelstoss et al., 2021)

The regression line is placed (Fig. 6) so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression is the slope of the line. This method includes all the data regardless of modifications in trend or accuracy. The entire computation was carried out on the accepted and widely demonstrated statistical concepts of LRR (Dolan et al., 1991; Crowell et al., 1997).

3.3.2 Net Bankline Movement (NBM)

Net Bankline Movement (NBM) is another statistical parameter that enumerates the actual distance between the oldest and the youngest shoreline for each transect laid perpendicular to the shorelines (Himmelstoss et al., 2021). In this study, we quantified the net Bankline movement of the study area.

Fig. 7: A Bankline dataset including baseline (black), transect (gray), and shoreline and intersect data (multicolor) to illustrate the relationship between net Bankline movement

However, it was calculated using the following formula:

$$\text{Net Bankline Movement} = \{d_{\text{newest bank}} - d_{\text{oldest bank}}\}\ \text{m} \qquad (4)$$

4. RESULT AND DISCUSSION

4.1 Variation of River Flow Area

The net area of extracted river water body was calculated by ArcGIS software.

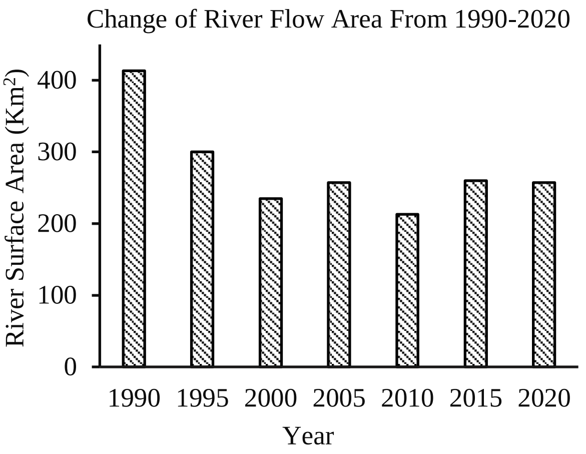

Fig. 8: Area of river net waterbody from 1990-2020.

The area includes all the area of major and minor channel of Jamuna River in this study. As the most of the images were collected in the dry season, the result was not affected by precipitation water. Fig. 8 shows net flow area of Jamuna River for different periods from 1990 to 2020. The flow path was maximum in the year 1990. The river net area decreased in the period from 1990 to 2000, which is because of char land accretion. After the year 2000 change of flow path area was mostly stabilized.

Table II: Jamuna River flow path area from 1990 to 2020.

Year	River Net Flow Area (Km^2)
1990	413
1995	300
2000	235
2005	257
2010	213
2015	260
2020	257

Table II reveals that the maximum river flow area of the Jamuna River was detected in 1990, while the minimum flow area was observed in 2010. Subsequently, after the year 2000, the river's flow area remained predominantly stable. The flow area for the years 2005, 2015, and 2020 is almost the same. Increase in flow area occurred in the period of 2000-2005 and 2010-2015 respectively. An increase in flow area corresponds to a decrease in the land area of the riverbank and instability in the bar land. As the Jamuna River is of the alluvial type, its flow path is inherently unstable and subjected to change over time. Reduced river velocity and a higher sediment settling within the river influence a decrease in flow during the dry season. The sediment load of the Jamuna was 555 Mt/year during the early-1960s (Coleman, 1969).

4.2 Segment Wise Flow Area Changes

We divided study area into four different rectangular segments i.e., A, B, C, and D to understand the change pattern of Jamuna River flow area throughout the entire study period. After measuring the area of each segment, we compared the flow area of each segment in different periods.

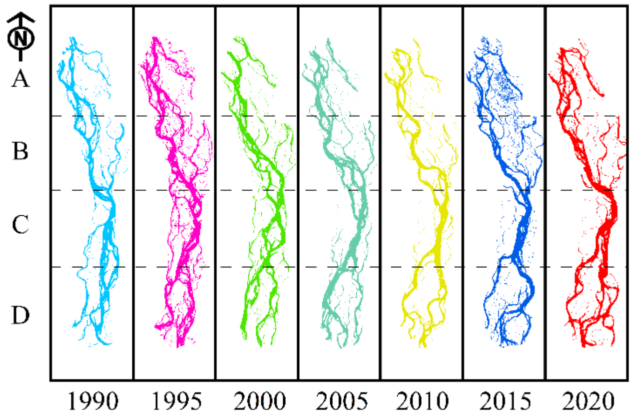

Fig. 9: Rate of change of net river flow area from 1990-2020.

Fig. 9 shows the segmented river of different year. It can be perceptible from the figure that the upstream river sifted slightly towards west and main channel became narrow in the middle, which was because of the construction of Jamuna Bridge in 1998.

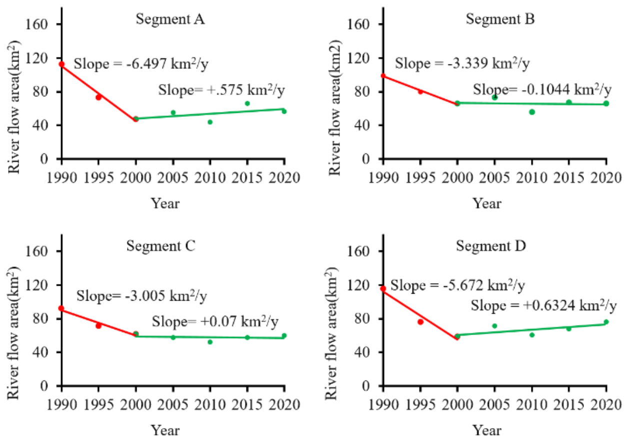

Fig. 10: Distribution of segment-wise changes of river flow path from 1990 to 2020.

Fig. 10 illustrates that segment A experienced a reduction in its flow area from 1990 to 2000. The rate of waterbody loss in the upstream segment was the highest of all segments, standing at -6.497 km^2/year. After 2000, the river started gaining flow area, signifying an increase in land area upstream, amounting to +0.577 km^2/year. Several river protection works were undertaken between 1998 and 2000 on the right bank of this segment, including Meghna spur- 1, 2 & 3, Shingrabari spur- 1 & 2, and Subagacha spur-1 & 2

(Sarker et al., 2011). These efforts contributed to the stabilization of the river's flow area after 2000.

Table III: Segment-wise change of flow area in five years interval from 1990 to 2020.

Time	Net Changes of Jamuna River Flow Area (km^2)			
	A 554.3 (km^2)	B 515.02 (km^2)	C 511.09 (km^2)	D 566.13 (km^2)
1990-1995	39.52	19.43	20.54	39.67
1995-2000	25.45	13.96	9.51	17.05
2000-2005	-7.59	-7.36	4.1	-12.28
2005-2010	11.18	17.13	5.57	10.31
2010-2015	-22.11	-11.11	-5.44	-7.25
2015-2020	9.61	0.94	-2.45	-8.12

In segment B, the river's waterbody declined at a rate of -3.339 km^2/year from 1990 to 2000. Subsequently, from 2000 to 2020, the rate of change in waterbody was +0.1044 km^2/year, indicating a relatively stable condition in that area. This stability can be attributed to riverbank protection measures upstream of the Jamuna Bridge and surrounding river training works.

In segment C the rate of change of waterbody was +0.07 km^2/year from the year 2000 to 2020. In this segment Jamuna bridge was constructed in 1998, before that the area was eroded at -3.337 km^2/y from the year 1990-2000. The construction of guide banks at the Jamuna Bridge in segment C has led to a reduction in the rate of flow area change in this particular segment, resulting in a minimal rate of change.

Segment D, located downstream of the Jamuna River where it converges with the Ganges-Padma River, experiences sediment deposition due to suspended sediment in the water. The rate of change in flow area from 1990 to 2000 was computed at -5.672 km^2/year, which is equivalent to the changes observed upstream during that period. In this segment, river training works, including PIRDP bank protection, Betil Spur-1, and Enayetpur spur-2, were constructed between 2001 and 2006 (Sarker et al., 2011). In recent years, this segment continues to be susceptible to erosion, with an erosion rate of +0.63 km^2/year. However, a detailed segment-wise analysis of flow area changes over five-year intervals from 1990 to 2020 is presented in Table III. A prior study indicated that in the years 2004, 2006, and 2007, there were instances of significantly higher water discharge, exceeding 12,000 m^3/s, during a span of 34 years. Conversely, the lowest discharge was recorded in the years 2012 and 2013, spanning the period from 1982 to 2016 (Khan et al., 2020). This recent decline in discharge has had a considerable impact on the river's flow area. Additionally, this study observes a reduction in the river's flow path after the year 2000.

4.3 Bankline Changes

Fig. 11 shows rate of Bankline changes Jamuna River for the Periods of 1990–2000 (brown), and 2000-2020 (blue) along different vertical transects.

Table IV: Rates of Bankline changes of Sirajganj side for the different segments of Jamuna River in the study period of 1990-2020.

Years	Rate of Bankline change right bank in each segment (m/y)				
	P 15Km	Q 10km	R 9Km	S 16Km	T 5Km
1990-2000	-69	-152	+177	-90	-37
2000-2020	-43	+3.4	-5	+170	-48
Average	**-11.965 m/year (Sirajganj Side)**				

The rates of changes in Bankline position were calculated for the different designated segments P, Q, R, S and T located at right bank (Sirajganj side) and I, J, K and L for left bank (Tangail side) of the river.

Table V: Rates of Bankline changes of Tangail side for the different segments of Jamuna River in the study period of 1990-2020.

Years	Rate of Bankline change left bank in each segment (m/y)			
	I 15Km	**J 10km**	**K 9Km**	**L 16Km**
1990-2000	+47	-185	-118	-107
2000-2020	+13	-31	+99	-101
Average	**-52.44 m/year (Tangail Side)**			

At the right bank erosion was maximum at Q (152 m/year) section (Table IV) and at the left bank was at J (185 m/year) section (Table V) for the period of 1990-2000. For the period of 2000-2020 erosion was dominating along the bank line of segment P and T at Sirajganj side and in Tangail side segment L is the most eroded (101 m/year) area. In that period at right bank S segment is the area of accretion at a rate of 170 m/year.

Table VI: Shifting of Jamuna riverbank line of Sirajganj and Tangail side for the different segments in the study period of 1990-2020.

Bank Position	Segment	Net Bankline Movement (m)	
		1990-2000	**2000-2020**
Left Bank (Sirajganj Side)	P (15 Km)	-674	-870
	Q (10 Km)	-1525	-121
	R (9 Km)	1773	-359
	S (16 Km)	-902	4200
	T (15 Km)	-366	-704
Right Bank (Tangail Side)	I (15 Km)	475	346
	J (25 Km)	-1860	-446
	K (15 Km)	-1186	1612
	L (10 Km)	-1068	-1813

Erosion was reduced in period of 2000-2020 at 10 km of Q and 9 Km of R segment (Table VI) because of construction of various river training works along the river. In segment I, Bankline moves towards west direction at a rate of +13

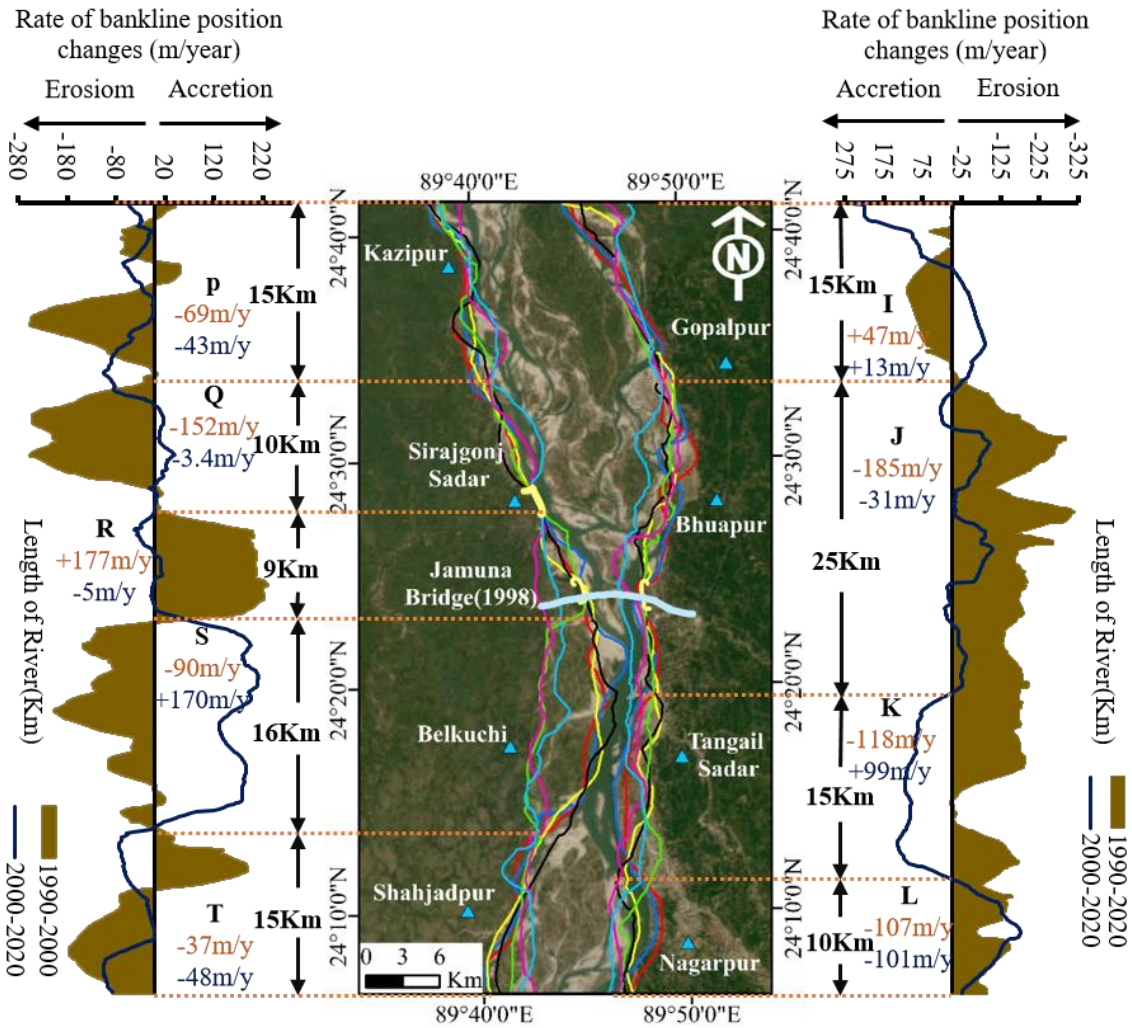

Fig. 11: Bankline change rates along Jamuna River for the periods of 1990–2000 (brown) and 2000-2020(blue), negative values indicate erosion (landward movement of bank line).

m/year, which indicates shifting of upstream river towards west side. The Tangail side was maximum eroded from 1990-2000 and Nagarpur was very vulnerable zone prone to erosion. We observed that the river shifted towards west side (Right bank) from 1990 to 2020. From this study we find westward migration of right bank at a rate of 63.4 m/year, and left bank at a rate of 53 m/year. Westward shifting of the centerline resulted from westward migration of the west (right) bank at an average rate of 90 m/year, combined with westward migration of the east (left) bank at average rates of 48 m/year for westward migration between 1953 and 1989 (Sarker et al., 2014).

A study conducted on the Kazipur riverbank revealed that the mean eastward shift of the riverbank from 1972 to 1988 was 0.55 km, while the west bank exhibited a shift of approximately 0.77 km (Islam et al., 2019). In this study, we observed a riverbank shift of 0.797 km on the right bank of Kazipur and a shift of 0.410 km on the east bank. This is consistent with the previous movement observed in that segment. Average rate of Bankline movement in Sirajganj side was -11.965 m/year, while average rate of Bankline movement in Tangail side is -52.44 m/year. Which means both banks were still prone to erosion.

5. CONCLUSION

The study of the Jamuna River reveals diverse morphological characteristics, including changes in flow patterns, shifts in riverbanks, sandbar formation, channel migration, erosion, and sediment deposition. However, this paper sincerely focuses on erosion, sedimentation, and bank shifting between Kazipur and Shahjadpur during 1990-2000 using the Landsat images collected from United States Geological Survey (USGS). The research indicates that during the year 1990, the river's maximum flow area was 413 km², gradually decreasing until 2000. During the year 2000 to 2020, the flow area remained relatively stable, with a minimum of 213 km² observed in the year 2010. In contrast, Segments Q (Sirajganj), J (Bhuapur), K (Tangail Sadar), and L (Nagarpur) experienced the highest erosion rates, averaging -184 m/year in between the year 1990-2000. However, in the recent years between 2000 and 2020, the areas around Kazipur (15 km) upstream, Nagarpur (10 km), and Shahajadpur (15 km) downstream faced the most severe bank erosion. Furthermore, the downstream of the Jamuna Bridge, a significant land gain of 4.2 km on the right bank and 1.6 km on the left bank was witnessed due to sediment settlement resulting from Jamuna bridge construction.

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