INFLUENCE OF THE PADMA BRIDGE ON RIVER HYDRODYNAMICS AND MORPHOLOGICAL RESPONSE IN THE PADMA RIVER, BANGLADESH

Arafat Kabir*[1], Sanzid Hossain Parag[2] and Nafis Fuad Rifat[3]

[1] *Chittagong University of Engineering and Technology, Bangladesh, e-mail: akrony5221@gmail.com*
[2] *Chittagong University of Engineering and Technology, Bangladesh, e-mail: paragsanzidhossain@gmail.com*
[3] *Chittagong University of Engineering and Technology, Bangladesh, e-mail: nafisrifat07@gmail.com*

***Corresponding Author**

ABSTRACT

The Padma River in Bangladesh is one of the most morphologically dynamic watercourses in the world, as evidenced by frequent and significant shoreline changes that pose long-term challenges to the sustainability of infrastructure. Padma Bridge construction has altered the natural flow regime and process of sediment transport in the river, creating distinct erosion upstream and downstream deposition in local areas, especially at bridge piers. This study analyzed the spatiotemporal patterns of shoreline shifting along a 65 km stretch of the river surrounding the Padma Bridge, including both upstream and downstream reaches between 2005 and 2025, with a focus on understanding the impact of the bridge on these changes. Multi-temporal Landsat satellite imagery was processed using GIS techniques to investigate centerline shifting and to calculate erosion and accretion as well. The centerline shifting and erosion-accretion patterns of the Padma River changed over these 20 years. Centerline shifting and erosion-accretion were calculated in four phases, which were classified as Pre-construction (2005 to 2010 & 2010 to 2015), Construction (2015 to 2020), and Post-construction (2020 to 2025). The centerline shifting along these periods was approximately 403.46 meters (2005 to 2010), 433.58 meters (2010 to 2015), 820.26 meters (2015 to 2020), and 628.38 meters (2020 to 2025). The average erosion for these four phases was respectively 12.84 km²/year, 16.306 km²/year, 27.532 km²/year and 16.88 km²/year and the average accretion for these four phases is 13.57, 15.242, 19.752, and 19.27 km²/year respectively. The average erosion from 2005 to 2025 was 7.78 km²/year, and the average accretion was 6.26 km²/year. These results confirm that shoreline monitoring at high resolutions and in localized areas is necessary to understand the morphodynamic reaction of large rivers to massive infrastructural projects and to help with sustainable river-management plans in the Padma Bridge area.

Keywords: *Centerline Shifting, Erosion-Accretion, Padma River, Padma Bridge, ArcGIS.*

1. INTRODUCTION

The geography of Bangladesh is fundamentally defined by its vast river network, comprising more than 410 rivers (Mondal et al., 2020). A significant portion of this network consists of 57 transboundary rivers that flow in from India and Myanmar (Mondal et al., 2020). The Ganges, the Brahmaputra, and the Meghna (GBM) are internationally known, mighty rivers of the country (Mondal et al., 2020). They originate from the Himalayas and flow through Bangladesh before emptying into the Bay of Bengal (Mondal et al., 2020). Also, the Ganges–Brahmaputra–Meghna (GBM) river system is the third largest freshwater outlet into the world's oceans; it is exceeded only by the Amazon and the Congo rivers (Chowdhury & Ward, 2004). The Brahmaputra-Jamuna and Ganga rivers combine to form the Padma, which carries the third greatest water discharge of all the world's rivers, but is often ranked the highest in terms of sediment discharge (Best et al., 2007). The Padma River is one of the major rivers in Bangladesh, and it is known as the Ganges River in India. The Padma River exhibits highly dynamic morphological characteristics, with frequent channel migration, bank erosion, and bar formation shaping its floodplain landscape. These continuous morphological adjustments significantly influence local hydrology, sediment dynamics, and the stability of surrounding infrastructure and settlements. The river has an average discharge of approximately 30,000 m^3/s, a bank-full discharge of around 75,000 m^3/s, and an estimated flood discharge of about 130,000 m^3/s corresponding to a 100-year return period (Neill et al., 2013). The river system carries nearly 1×10^9 tons of sediment annually, which is widely distributed across the Bangladesh Delta and contributes significantly to its geomorphological evolution (D.G. McLean et al., 2012).

The Padma River is widely known for its dynamic and disastrous behavior, and the river has been experiencing intense and frequent bank erosion and deposition, leading to changes and shifting of the bank line (Billah, 2018). Erosion occurs when water, sediment, and other materials are removed from the river channel, while accretion occurs when sediment and other materials are deposited in the channel, adding to its size and shape (Shu et al., 2019). Between 1975 and 2015, the river experienced a total erosion of 499.51 km^2 and a total accretion of 833.33 km^2 (Billah, 2018). Also, it has shown significant centerline migration over the past decades, reflecting its highly dynamic and unstable nature. Frequent shifting of the river's course causes extensive land loss, disrupts local livelihoods, and poses challenges to the stability of major infrastructures. The construction of major infrastructure, such as the Padma Bridge, inherently reduces a waterway's flow area, significantly impacting river shifting characteristics (Uddin et al., 2022). Therefore, the Padma Bridge has had some significant influence on the river dynamics as well as on the livelihoods of the communities living along the river banks. Despite the river's historical instability, a critical void exists in the literature regarding the specific morphological response to this intervention. No empirical study has yet quantified and compared the distinct patterns of erosion, accretion, and centerline migration across the critical pre-construction, construction, and post-construction phases. This research provides the first detailed, multi-period assessment of the bridge's initial morphological footprint by addressing this crucial gap. The paper focuses on the impact of the Padma Bridge on river flow dynamics, specifically centerline shifting and erosion-accretion in the Padma River. This study utilizes remote sensing and GIS to quantify the patterns, rates, and extent of morphological changes in the Padma River, enabling a detailed analysis of its transformation over time. However, the main objectives of the study are to assess the impact of the Padma Bridge on the morphological changes of the Padma River, to measure and compare the rate of centerline migration of the Padma River in the three different phases, namely Pre-construction (2005 to 2015), Construction (2015 to 2020), and Post-construction (2020 to 2025), and to quantify the spatio-temporal dynamics of erosion and accretion during the same three phases of 20 years.

The results not only describe the sophisticated erosion, accretion, and channel migration processes in relation to the new infrastructure but also provide an important empirical basis for informing policymakers in the development of adaptive and sustainable management policies to deal with this important river. The findings can help to identify the key zones of instability and change within the river system. This understanding can help with better planning for river management along the riverbanks. In addition, this study contributes to future research on the morphological evolution of the Padma River.

2. METHODOLOGY

2.1 Study Area

The Ganges River is a major transboundary river that originates in the glaciers of the Himalayas. It runs a long distance on the Indo-Gangetic plain in India and enters Bangladesh at Shibganj of Chapai Nababganj district, where it is known as the Padma River (Monir et al., 2013). It flows southeast through central Bangladesh, traversing Rajbari, Faridpur, and Munshiganj districts before joining the Jamuna River near Goalundo Ghat. The combined flow continues as the Padma and merges with the Meghna River near Chandpur, ultimately draining into the Bay of Bengal. Within Bangladesh, the river extends about 120 km. This study focuses on the Padma River, a major fluvial system in Bangladesh extending approximately 65 km in length and varying between 1.5 and 10 km in width. Figure 1 shows the study area around the Padma Multipurpose Bridge. It is located between latitude 23°2′ to 23°45′N and longitude 89°56′ to 90°41′E. The Padma River exhibits highly dynamic morphological characteristics, with frequent channel migration, bank erosion, and bar formation shaping its floodplain landscape. These continuous morphological adjustments significantly influence local hydrology, sediment dynamics, and the stability of surrounding infrastructure and settlements. The river has an average discharge of approximately 30,000 m³/s, a bank-full discharge of around 75,000 m³/s, and an estimated flood discharge of about 130,000 m³/s corresponding to a 100-year return period (Neill et al., 2013). The river system carries nearly 1 × 10⁹ tons of sediment annually, which is widely distributed across the Bangladesh Delta and contributes significantly to its geomorphological evolution (D.G. McLean et al., 2012).

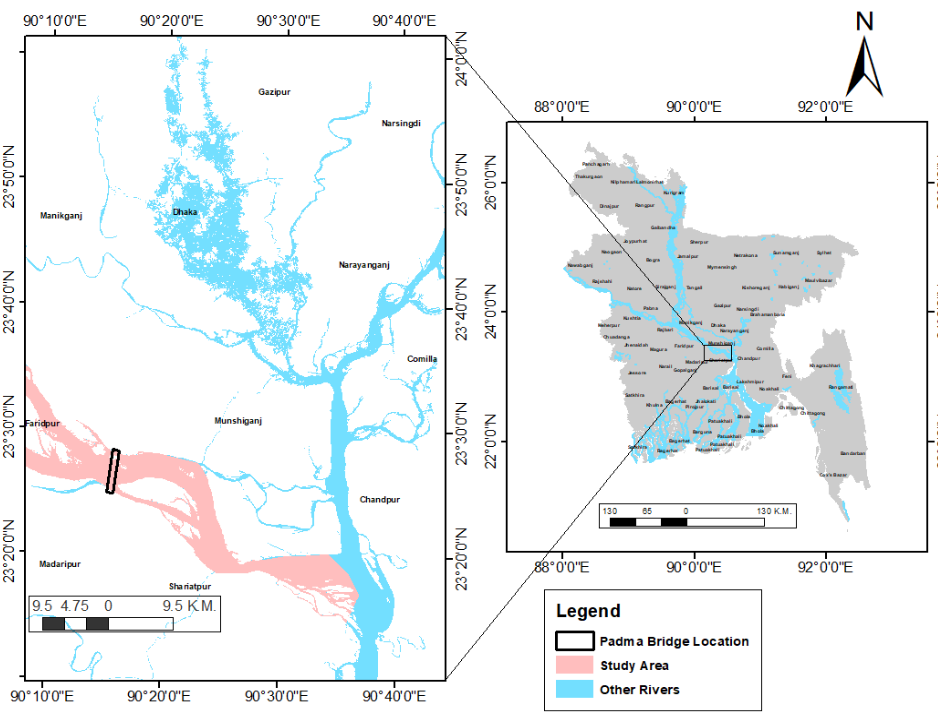

Figure 1: Study Area Location

2.2 Data Collection and Data Processing

In this study, dry-season satellite imagery covering the period from 2005 to 2025 was analyzed using data acquired from the USGS Earth Explorer Landsat Archive. The specific details of these images are outlined in Table 1. Images with minimal cloud cover were selected from the dry season from December to January. This period was chosen to obtain the proper width and accurate landform of the river bars. Due to scanline issues of Landsat 7, Landsat 5 images were used for the years 2005 to 2010. The dynamic nature of river systems, particularly large ones like the Padma, makes them prone to significant changes frequently. As a result, frequent centerline migration and erosion–accretion occur, and hydraulic structures across rivers, such as bridges, significantly influence these processes. Therefore, to quantify the hydro-morphological impact of the Padma Bridge on the river, this study employed a GIS-based change detection analysis. The methodology was designed to compare the river's planform dynamics during the pre-construction, construction, and post-construction periods. The study followed two main stages. First, the river channel was carefully delineated from multi-temporal satellite images using a consistent and systematic approach. Then, two analytical methods were applied to the extracted channel data to assess its morphological changes over time: (1) river centerline migration analysis and (2) quantification of erosion and accretion through spatial overlay techniques.

Table 1: Properties of Landsat satellite images used in the spatio-temporal analysis

Year	Landsat ID	Sensor ID	Acquisition Date	Path/Row	Spatial Resolution (m)	Collection Level	Image Quality	Cloud Cover
2005	Landsat 5	TM	1/16/2005	137/44	30	C2- L1	7	0
2010	Landsat 5	TM	12/16/2010	137/44	30	C2- L1	7	0
2015	Landsat 8	OLI_TIRS	12/30/2015	137/44	30	C2- L1	9	8.14
2020	Landsat 8	OLI_TIRS	12/27/2020	137/44	30	C2- L1	9	0
2025	Landsat 8	OLI_TIRS	1/7/2025	137/44	30	C2- L1	9	8.68

2.2.1 River Channel Extraction and Delineation

GIS-based techniques were employed to extract and monitor the spatiotemporal variations of the Padma River channel. The analysis began with the preprocessing of the Landsat images, including geometric and atmospheric corrections, to ensure spatial and radiometric consistency. Subsequently, the Normalized Difference Water Index (NDWI) was computed for each image to enhance and extract surface water features.

$$\text{NDWI} = \frac{\text{Green - NIR}}{Green + NIR} \quad (1)$$

The NDWI method was applied to both Landsat 5 and Landsat 8 imagery. The NDWI outputs were reclassified into binary values, with water assigned a value of 1 and non-water assigned a value of 0, and the resulting raster layers were converted to vector polygons. The river channel was then isolated from other water features and clipped to the study area boundary, forming the basis for subsequent analyses of river centerline migration and erosion–accretion dynamics.

2.2.2 River Centerline Migration Analysis

Centerlines were generated in ArcGIS 10.8 using the river shapefiles as the source data. All datasets were reprojected to UTM Zone 46N (WGS 84) to maintain spatial consistency. To determine the migration zones of these centerlines were imported into the Channel Migration Toolbox, developed by the Department of Ecology, State of Washington (Nicholas T. Legg, 2014). In this study, the average migration of the channel was calculated, and 22 transects (points and lines) were created by the toolbox. The analysis was conducted for four time intervals: 2005 to 2010, 2010 to 2015, 2015 to 2020, and 2020 to 2025 to find out the trends in channel migration.

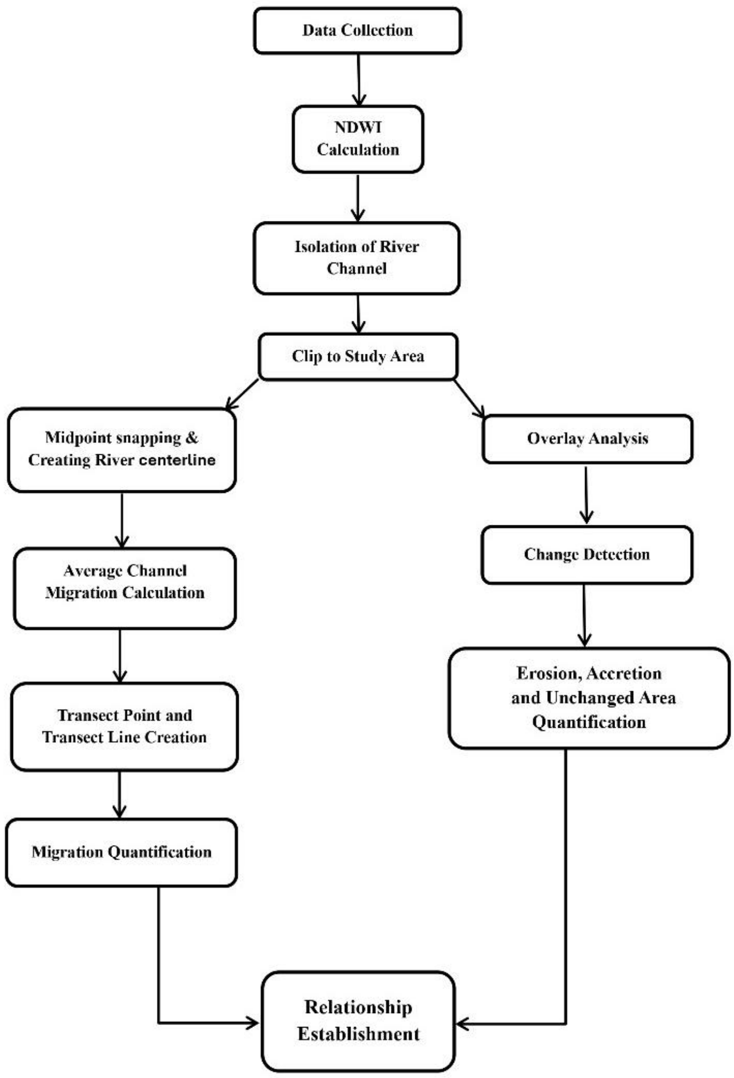

Figure 2: Methodology Flowchart

2.2.3 Quantification of Erosion and Accretion Using a Spatial Overlay

To assess the morphological changes of the Padma River over a 20-year span, a systematic, multi-period change detection analysis was conducted. The core methodology was designed as a repeatable workflow. Then it was applied to the river channel polygons for each consecutive pair of years to measure erosion and accretion across the four 5-year periods.

$$\text{Erosion} = \text{Flow Area}_{\text{next}} - \text{Flow Area}_{\text{unchanged}} \quad (3)$$

$$\text{Accretion} = \text{Flow Area}_{\text{previous}} - \text{Flow Area}_{\text{unchanged}} \quad (4)$$

First, the unchanged portion of the river was identified through geometric intersection of the polygons, and erosion and accretion were then calculated using the above equations. This analytical process was carefully repeated for each of the four 5-year periods: 2005 to 2010, 2010 to 2015, 2015 to 2020, and 2020 to 2025. It produced a clear dataset that showed the erosion and accretion of the river for each interval. These values were used to study how the river's shape, pattern, and behavior changed over time. This allowed for a detailed analysis of the river's hydromorphological activity, which focuses on erosion and accretion of the river.

3. ILLUSTRATIONS

3.1 Spatio-Temporal Pattern of Padma River Centerline Migration

Analysis of the Padma River centerline over the 20 years between 2005 and 2025 indicates noticeable changes in the river's planform over the approximately 65 km stretch, including the Padma Bridge. Strong lateral shifts of the channel are evident by the centerlines, drawn at five-year intervals (2005, 2010, 2015, 2020, and 2025), thus reflecting alternating instances of erosion and accretion on the two banks. Migration rates and directions also differ significantly among 22 transects, highlighting the irregular and dynamic nature of the Padma River's morphology.

3.1.1 Pre-Construction Phase: 2005 to 2010

From 2005 to 2010, the centerline of the Padma River showed irregular migration on both the north and south banks, and the migration in both directions showed the lack of a major directional movement. The average migration distance was 403.46 meters. This non-uniform movement reflected localized erosion and accretion driven by bar formation and variable discharge, suggesting that the river remained in a relatively natural dynamic state.

3.1.2 Pre-Construction Phase: 2010 to 2015

Between 2010 and 2015, the Padma River showed a clearer and more directional migration pattern than in the previous period. The downstream segment moved mainly to the north, and the upstream shifted towards the south. The centerline migration was about 433.58 meters. This uneven movement could have been explained by the irregular sediment layer and local variability of the conditions of flow.

3.1.3 Construction Phase: 2015 to 2020

The Padma River experienced the highest proportional channel displacement of 820.26 meters (average) during the period when the bridge was being constructed. Migration and river flow were enhanced around the bridge and in the downstream reach, which was affected by the construction works and blocked river flow. This sharp increase in movement represents a high instability of the channel and the formation of new sandbars, which is due to the change in flow direction and sediment transportation related to the construction procedure.

3.1.4 Post-Construction Phase: 2020 to 2025

After the Padma Bridge had been completed, a different style of migration was observed on the river. Movements were slower in the upstream part, and some channel stabilization was observed; the downstream part was still moving and creating small meanders along the bridge. The mean migration dropped to about 628.38 meters, which suggested a gradual adjustment of the river to the new hydraulic and sedimentary conditions introduced by the bridge.

Table 2: Centerline Migration Analysis with transect ID

River Centerline Migration Analysis (2005-2010)				**River Centerline Migration Analysis (2010-2015)**			
T. ID	**Migration Direction**	**Migration Distance (m)**	**Average Migration (m)**	**T. ID**	**Migration Direction**	**Migration Distance (m)**	**Average Migration (m)**
1	Northward	62.27	403.46	1	Northward	222.19	433.58
2	Southward	463.63		2	Northward	160.93	
3	Southward	412.09		3	Northward	72.38	
4	Northward	661.42		4	Northward	364.13	
5	Northward	1035.37		5	Northward	134.88	
6	Northward	932.92		6	Northward	193.65	
7	Southward	19.17		7	Northward	114.98	
8	Southward	124.07		8	Northward	284.55	
9	Southward	251.25		9	Northward	700.11	
10	Southward	94.35		10	Northward	396.06	
11	Southward	289.77		11	Northward	127.51	
12	Northward	60.59		12	Northward	0.46	
13	Southward	125.4		13	Southward	91.78	
14	Northward	36.5		14	Southward	134.68	
15	Northward	21.23		15	Southward	297.31	
16	Northward	274.18		16	Southward	82.53	
17	Northward	46.47		17	Southward	62.85	
18	Southward	487.63		18	Southward	1276.16	
19	Southward	867.42		19	Southward	1928.56	
20	Southward	203.26		20	Southward	1733.66	
21	Northward	602.83		21	Southward	851.08	
22	Northward	1804.23		22	Southward	308.3	

River Centerline Migration Analysis (2015-2020)				**River Centerline Migration Analysis (2020-2025)**			
T. ID	**Migration Direction**	**Migration Distance (m)**	**Average Migration (m)**	**T. ID**	**Migration Direction**	**Migration Distance (m)**	**Average Migration (m)**
1	Northward	1214.36	820.26	1	Northward	562.52	628.38
2	Northward	1076.15		2	Northward	1287.34	
3	Northward	172.96		3	Northward	1237.1	
4	Southward	298.62		4	Southward	11.03	
5	Southward	32.26		5	Southward	945.31	
6	Southward	210.77		6	Southward	2224.21	
7	Southward	554.24		7	Southward	1979.92	
8	Southward	728.25		8	Southward	446.92	
9	Northward	117.61		9	Northward	266.39	
10	Northward	596.73		10	Northward	701.17	
11	Northward	1587.37		11	Northward	989.81	
12	Northward	1376.44		12	Northward	329.3	
13	Southward	592.62		13	Southward	187.36	
14	Northward	932.64		14	Northward	148.49	
15	Northward	1760.41		15	Northward	221.54	
16	Southward	1969.71		16	Southward	657.68	
17	Southward	1843.91		17	Southward	259.46	
18	Northward	1335.44		18	Northward	632.04	

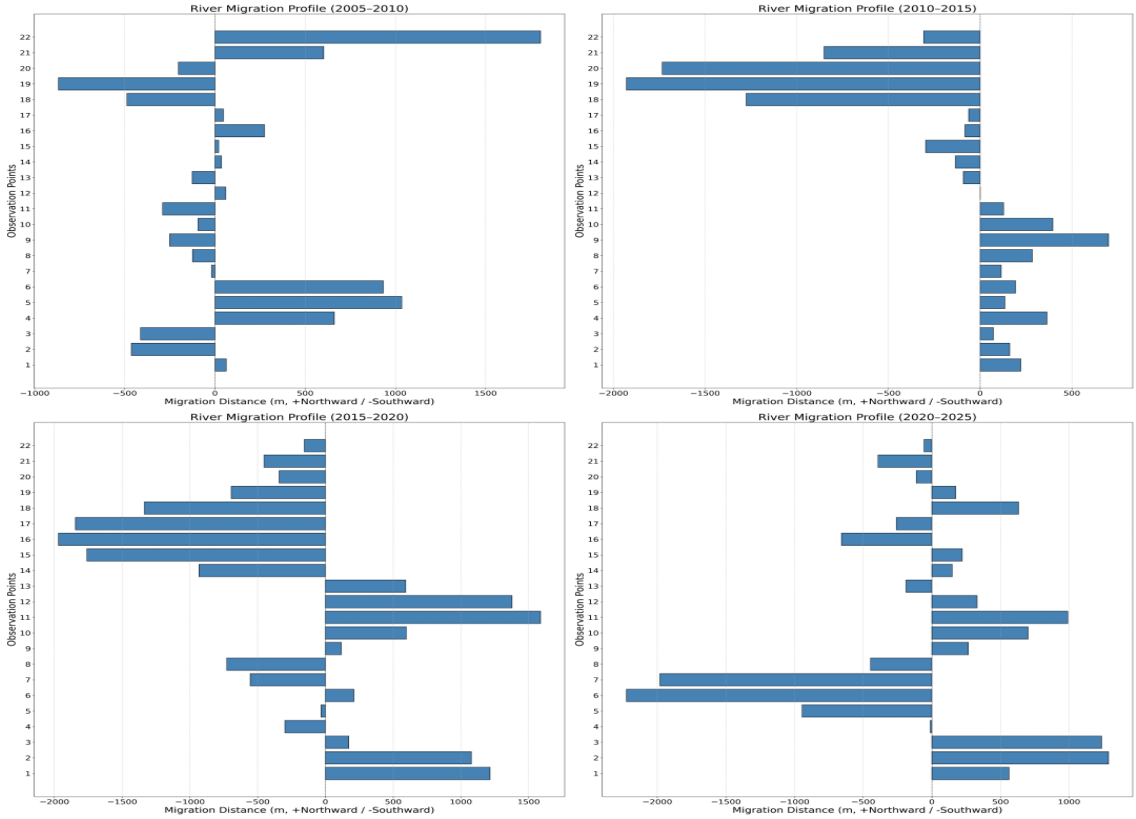

Figure 3: River Centerline Migration Profiles

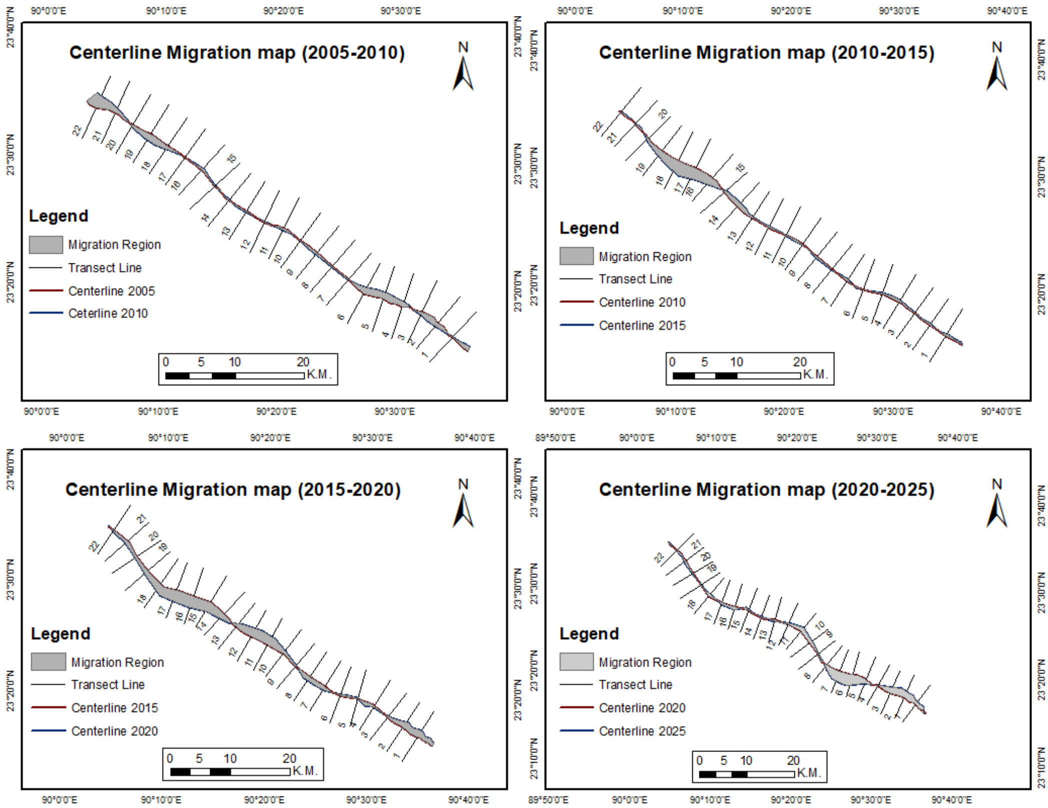

Figure 4: Centerline Shifting for 2005-2010, 2010-2015, 2015-2020, 2020-2025

3.2 Spatio-temporal Dynamics of Erosion and Accretion

The spatio-temporal analysis of the Padma River from 2005 to 2025 showed some specific changes in its morphological behavior, with the most significant changes coinciding with the construction of the Padma Bridge. Approximately a 65 km stretch of the river, including Padma Bridge, was considered for the analysis of erosion-accretion. The analysis shows the influence of the four phases, including pre-construction, construction, and post-construction, on the river. The corresponding spatial patterns of erosion, accretion, and unchanged flow area are illustrated in Figure 5. This analysis also shows the irregular and dynamic nature of the Padma River.

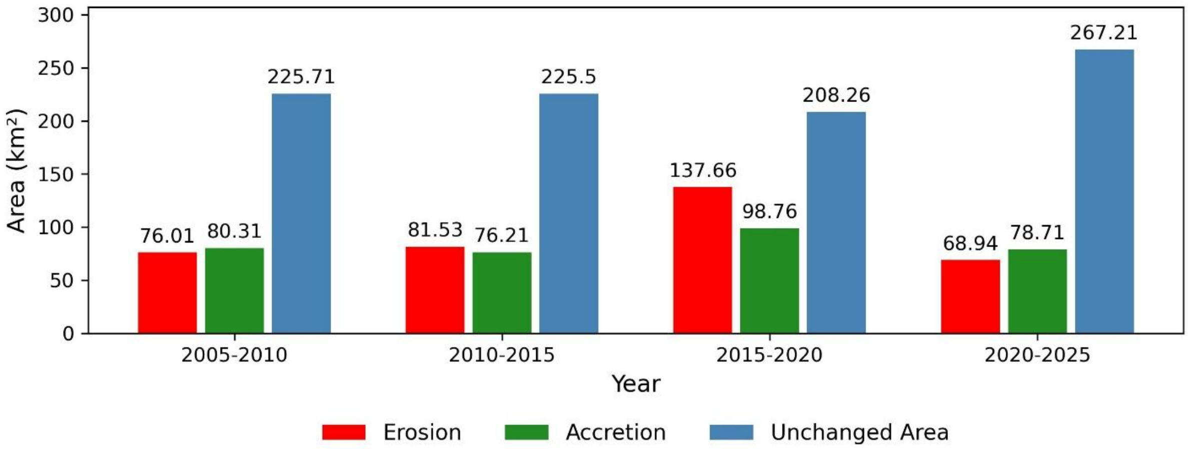

Figure 5: Comparison of Erosion, Accretion, and Unchanged Area.

3.2.1 Pre-Construction Phase: 2005 to 2010

The pre-construction phase was characterized by a net accretional state. Accretion (80.31 km²) was slightly greater than erosion (76.01 km²), which resulted in a net reduction of 4.3 km² in the river's flow area. The unchanged portion of the river during this period was 225.71 km².

3.2.2 Pre-Construction Phase: 2010 to 2015

The previous trend reversed during this period because the erosional processes became dominant. An erosional loss of 81.53 km² surpassed the 76.21 km² of accretion, and the net effect was a 5.32 km² increase in the river's flow area. The extent of the unchanged channel remained consistent at 225.50 km².

Table 3: Summary of River Erosion and Accretion Statistics (2005 to 2025)

Year period	**Erosion (km²)**	**Average Erosion (km²/year)**	**Accretion (km²)**	**Average Accretion (km²/year)**	**Unchanged River (km²)**	**Changed River (km²)**	**Remarks**
Jan 2005 to Dec 2010	76.01	12.84	80.31	13.57	225.71	-4.3	Accretion
Dec 2010 to Dec 2015	81.53	16.306	76.21	15.242	225.50	5.32	Erosion
Dec 2015 to Dec 2020	137.66	27.532	98.76	19.752	208.26	38.9	Erosion
Dec 2020 to Jan 2025	68.94	16.88	78.71	19.27	267.21	-9.77	Accretion

3.2.3 Construction Phase: 2015 to 2020

The construction period of the Padma Bridge was the most dynamic among the four phases. The highest erosional loss of the study occurred during this period, at 137.66 km². Accretion was 98.76 km², which was lower than the corresponding erosion, but the highest amount recorded across the four phases. This difference between erosion and accretion resulted in the river's flow area increasing by 38.9 km². In contrast to the fragmented patterns seen before, this period was characterized by large, continuous zones of spatial change. The instability is also shown by the unchanged portion of the river, which shrank to a 20-year low of 208.26 km².

3.2.4 Post-Construction Phase: 2020 to 2025

The trend again reversed during this period as the river re-entered a strongly accretional state. There was more accretion (78.71 km²) than erosion (68.94 km²). The most significant finding was the expansion of the river's unchanged flow area, which reached a 20-year maximum of 267.21 km².

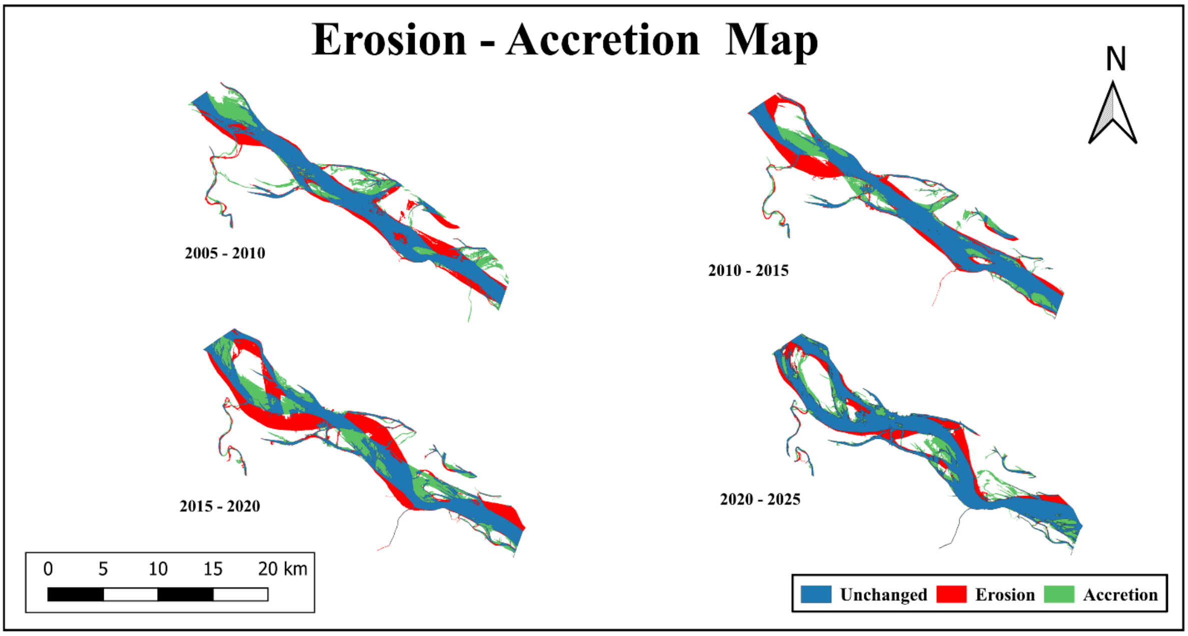

Figure 6: Erosion Accretion and Unchanged Area map for 2005-2010, 2010-2015, 2015-2020, 2020-2025

3.2.5 Downstream Morphological Divergence

In order to measure the spatial distribution of hydromorphological effects, two 15-km-long sections of the 30-km downstream of the bridge were studied. The proximal area is the region of the river that extends from Shibchar Upazila to Zajira. During the construction phase, this proximal region was dominated by accretion, which was 33.82 km². It means the river lost 33.82 km² of its flow area. The distal section continues from Zajira to Bhedarganj. During the same time, this portion was dominated by erosion. 26.01 km² of land eroded during this time.

3.3 Discussion

The analysis explains a vivid connection between the migration of the centerlines and the erosion and accretion processes of the Padma River. From 2005 to 2025, the average centerline migration was 1564.57 m. For the same time interval, the average erosion and accretion rates were 7.78 km²/year and 6.26 km²/year, respectively. Figure 7 shows that in areas where erosion occurs, meaning where the river expands, the 2025 centerline shifts in the same direction. This indicates a strong relationship between the centerline movement and the erosion-accretion of the Padma River. During the pre-construction period (2005 to 2015), the channel was in a relative equilibrium state, with moderate shifting and almost equal erosion and deposition. Migration rates more than doubled during the construction phase (2015 to 2020), due to the constriction of flows caused by bridging piers and guide bunds and the redistribution of the sediment. During the post-construction period (2020 to 2025), the upstream reaches became partially stable, but the downstream parts were still adapting to altered hydrodynamics. These findings indicate that large river infrastructures like the Padma Bridge can temporarily intensify channel instability but eventually lead to a steady morphological balance as the system adjusts.

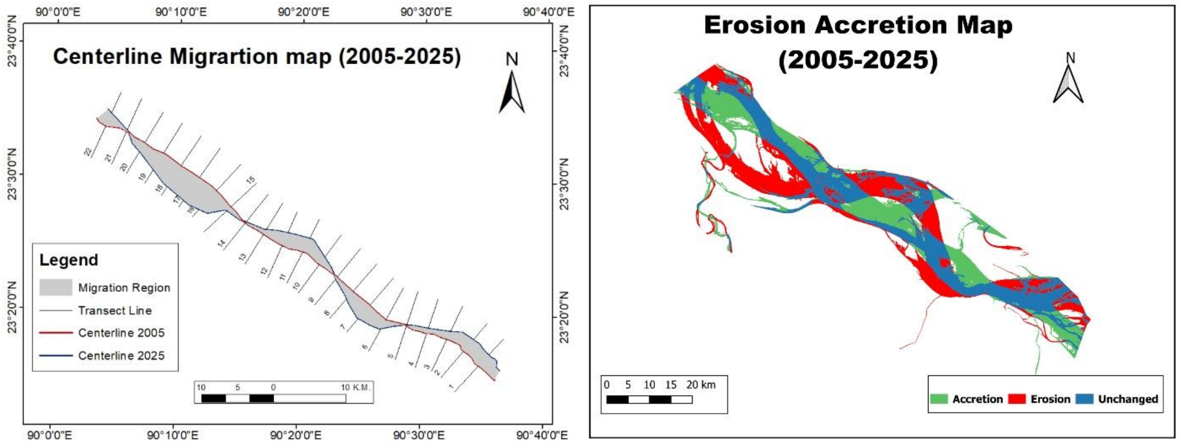

Figure 7: Total Centerline Migration and Erosion- Accretion Map

4. CONCLUSIONS

Monitoring of the Padma River over the last 20 years recorded a clear shift toward increased channel dynamism during construction, followed by gradual stabilization after the completion of the Padma Bridge. Morphological measures of centerline migration, erosion, and accretion indicate that bridge construction increased channel activity, followed by the establishment, an apparent equilibrium was established, where the upstream reaches have been relatively stable, and the downstream parts continued to adjust, particularly between Shibchar Upazila and Zajira, and between Zajira and Bhedarganj. These observations highlighted the dual nature of the large river's infrastructural role in building up and upsetting local stability. As only a few years have passed since the bridge became fully functional, long-term monitoring and analysis are essential to obtain a comprehensive understanding of the changing flow regimes, as well as future morphological alterations. Continued monitoring will enable dynamic management and protect the long-term sustainability of this important river system.

ACKNOWLEDGEMENTS

The authors thank the Department of Water Resources Engineering, Chittagong University of Engineering & Technology, for its valuable support.

DECLARATION OF USE OF AI

The research methodology, analysis, and production of scientific material did not make use of any artificial intelligence. AI tools were used solely for language editing and grammatical correction. The presented work is original, and it is full of Authors.

REFERENCES

Best, J. L., Ashworth, P. J., Sarker, M. H., & Roden, J. E. (2007). The Brahmaputra-Jamuna River, Bangladesh.

Billah, M. M. (2018). Mapping and monitoring erosion-accretion in an alluvial river using satellite imagery - The river bank changes of the Padma River in Bangladesh. Quaestiones Geographical, 37(3), 87–95. https://doi.org/10.2478/quageo-2018-0027

Chowdhury, R., & Ward, N. (2004). Hydro-meteorological variability in the greater Ganges-Brahmaputra-Meghna basins. International Journal of Climatology, 24(12), 1495–1508. https://doi.org/10.1002/joc.1076

D.G. McLean, J. A. V. & K. O. (2012). Padma River morphodynamics near Padma Bridge. CRC Press/Balkema.

Mondal, M. S., Kumar Bala, S., & Haque, A. (2020). Hydromorphology of Bangladesh rivers: Reflections from a large study. www.iabse-bd.org426

Monir, M. U., Khan, Y. A., & Hossain, H. M. Z. (2013). Investigation of Water Quality in the Ganges River, Bangladesh: Implications for Drinking and Household Purposes. In Int. j. econ. Env. Geol (Vol. 2, Issue 2). https://www.researchgate.net/publication/259713574

Neill, C., Hotopp, D., & Hunter, B. (2013). Some hydrotechnical features of the Padma River, Bangladesh.

Nicholas T. Legg, C. H. B. D. C., and P. L. O. (2014). The Channel Migration Toolbox ArcGIS® Tools for Measuring Stream Channel Migration. www.ecy.wa.gov

Shu, A., Duan, G., Rubinato, M., Tian, L., Wang, M., & Wang, S. (2019). An experimental study on mechanisms for sediment transformation due to riverbank collapse. Water (Switzerland), 11(3). https://doi.org/10.3390/w11030529

Uddin, M. J., Haque, M. N., Fayshal, M. A., & Dakua, D. (2022). Assessing the bridge construction effect on river shifting characteristics through a geo-spatial lens: A case study on Dharla River, Bangladesh. Heliyon, 8(8). https://doi.org/10.1016/j.heliyon.2022.e10334