Morphological Changes in Deltaic Rivers: A Case Study on the Meghna, Payra and Karnaphuli Rivers in the Coastal Region of Bangladesh

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ABSTRACT: Understanding river dynamics is vital for effective coastal management and conservation. Bangladesh lies mainly in the Bengal Basin, where the major rivers flow into the Bay of Bengal via the Meghna estuary. This study examines riverbank changes along the Meghna, Payra, and Karnaphuli Rivers from 1999 to 2022, using satellite imagery to track erosion and accretion patterns across coastal zones. A 50-kilometer-wide area along each river reveals significant bank dynamics. The Karnaphuli River experienced notable left bank erosion of 41.06 meters between 2019 and 2022. The Meghna River underwent drastic changes, with 1561.34 meters of left bank erosion from 1999 to 2004. The Payra River showed right bank erosion of 95.13 meters over the same period. High-resolution satellite imagery and GIS processing quantified land changes and sinuosity indices, highlighting the rivers' meandering patterns. The findings underscore the dynamic nature of these coastal rivers, shaped by sediment transport, water flow, and human activities. Continuous monitoring and research are essential for understanding river dynamics, managing resources, and mitigating erosion and accretion impacts on vulnerable coastal regions.

Keywords: Accretion; Coast; Erosion; GIS; Morphology; Sinuosity

INTRODUCTION

The extensive river system of Bangladesh, comprising of 700 rivers, underpins vital services such as water transport, fisheries, and sediment deposition, which create new land for its growing population (DoE, 2016; Uddin and Jeong, 2021). However, riverbank erosion and sedimentation cause economic losses, monsoon floods, and harm to agriculture and livelihoods (Rudra, 2018; Islam et al., 2020). Coastal Bangladesh is shaped by a complex interplay of Himalayan sediment supply, monsoon climate, cyclones, and human activity (Milliman, 1991). The coastal zone is categorized into deltaic eastern, central, and stable western regions, each with distinct hydro-morphological traits (Islam, 2001).

Deltas provide essential ecosystem services and support biodiversity but are highly vulnerable to flooding from rainfall and storm surges, disrupting agriculture, infrastructure, and livelihoods (Motsholapheko et al., 2011; Sanchez-Arcilla et al., 2012). These flood impacts hinder economic development, necessitating interventions such as coastal defenses, dredging, and hazard zoning. Understanding delta morphology is critical for flood mitigation, land reclamation, erosion studies, and urban planning (Masria et al., 2015). The coastal regions of Bangladesh, rich in resources, are prone to hazards such as floods, erosion, and salinity intrusion exacerbated by climate change and land use (Dastagir, 2015). The western coast is a flat, semi-active delta, while the central coast receives substantial sediment from the Ganges-Brahmaputra-Meghna Rivers, and the eastern coast includes hilly terrain (Allison et al., 2003). Coastal morphodynamics, influenced by daily water level fluctuations, are essential for understanding the region's challenges and for planning sustainable development (Minar et al., 2013; Brammer, 2014).

Research on morphological changes due to island formation at regional and national scales remains limited. In Bangladesh, efforts to map deltaic morphological

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changes have shown a net land gain of 591 km², with an annual increase of 19.7 km², primarily driven by sediment deposits from the Himalayas (Abdullah et al., 2019; Al et al., 2018; Teka et al., 2020). While new islands emerge along the coast, significant erosion emphasizes the country's vulnerability to coastal changes (Brammer, 2014). Studies have leveraged remote sensing to analyze land cover changes. For example, the changes on Sandwip Island from 1978 to 2014 were studied using Landsat images (Ciavola et al., 2015), and the changes in the coastline of Hatiya Island from 1989 to 2010 were recorded (Ghosh et al., 2015). Remote sensing has also highlighted Bangladesh's coastal changes, revealing a land gain of 87,255 ha between 1973 and 2012 (Sultana et al., 2023). Advanced geospatial tools like Google Earth Engine, ArcGIS, and QGIS have been used to study riverbank migration and land use changes around the Padma River from 1991 to 2021, with projections until 2041 (Ritu et al., 2023). The findings showed differential rates of riverbank change, affecting 11 of 37 upazilas. Similarly, from 2000 to 2022, studies on the Meghna estuary reported a net land gain of 22.1 km², with substantial erosion (667 km²) and accretion (689.1 km²) (Mou et al., 2023). Chairman Ghat in Laxmipur district experienced a notable loss of 92.4 km². Coastal dynamics in Bangladesh exhibit maximum accretion rates of 195.42 m/year and erosion rates of -185.83 m/year, emphasizing the importance of continuous monitoring (Sultana et al., 2023).

The present research takes advantage of Landsat Satellite Imagery to delve into the changes over time along the riverbanks of the Meghna, Payra, and Karnaphuli Rivers. By leveraging a detailed method known as parcel-based geo-processing within GIS, it meticulously measured the extent of land accretion (build-up) and erosion along these riversides. The main purpose behind this study was to conduct a thorough examination of how the shorelines of these three rivers have been eroding or expanding by analyzing satellite images in great detail. The focus extends to understand coastal erosion, its significant socio-economic repercussions, and monitoring the shifts in shoreline positions from 1999 to 2022. Through this process, the study sheds light on how the Meghna, Payra, and Karnaphuli Rivers have transformed by using parcel-based geo-processing in GIS to accurately quantify the changes in land. Focusing on the morphological changes of coastal rivers, the most dynamic landscapes of Bangladesh, this research examines how erosion and accretion shape the nature and behavior of these river systems. Furthermore, this research contributes to the broader scientific field of fluvial geomorphology by enhancing comprehensions of how river landscapes evolve over time.

STUDY AREA

The present study focuses on the coastal morphodynamics and the changes in river courses in three coastal regions of Bangladesh (i.e. western, central, and eastern), which correspond to the three major rivers that flow into the Bay of Bengal: the Ganges, the Meghna, and the Karnaphuli (Fig. 1). The Ganges Tidal Plain, or the Western Coastal Region, stretches from the Bangladesh-India border to the Tetulia River. The Pyra River is located in this deltaic zone. This region is home to the Sundarbans, the largest mangrove forest in the world, which acts as a natural barrier against coastal erosion and storm surges. The region also hosts a diverse range of aquatic life and supports the livelihoods of millions of people. The Meghna Deltaic Plain, or the Central Coastal Region, covers the area from the Feni River estuary to the eastern edge of the Sundarbans. This region is characterized by high erosion and accretion rates, as well as a large amount of silt and sand sediment (Allison et al., 2003). The region is vulnerable to flooding, salinity intrusion, and land subsidence but also offers opportunities for land reclamation and agriculture. The Chittagong Coastal Plain, or the Eastern Coastal Region, extends from Teknaf upazila to Mirsarai upazila along the Feni River estuary. This region is the most stable part of the coast, with less exposure to storm surges and tidal fluctuations (BUET and BIDS, 1993). The region features scenic sandy beaches, such as at Cox's Bazar and Patenga, and the Karnaphuli River, the main water and power source for the port city of Chittagong. The Payra River is located in the Bengal delta, the Meghna River flows through the lower estuary of the Meghna basin, and the Karnaphuli River runs along the coastal plain near the Chittagong hill tract. These rivers have diverse locations that reflect how their morphology is affected by different factors. Three rivers, including the Payra, Meghna, and Karnaphuli, represent the characteristics of the three zones of the coastal region. Investigating the morphological changes of these rivers resonates with the coastal morpho-dynamics in a broader aspect which is crucial for developing effective coastal zone management strategies and predicting future changes in response to natural and anthropogenic factors.

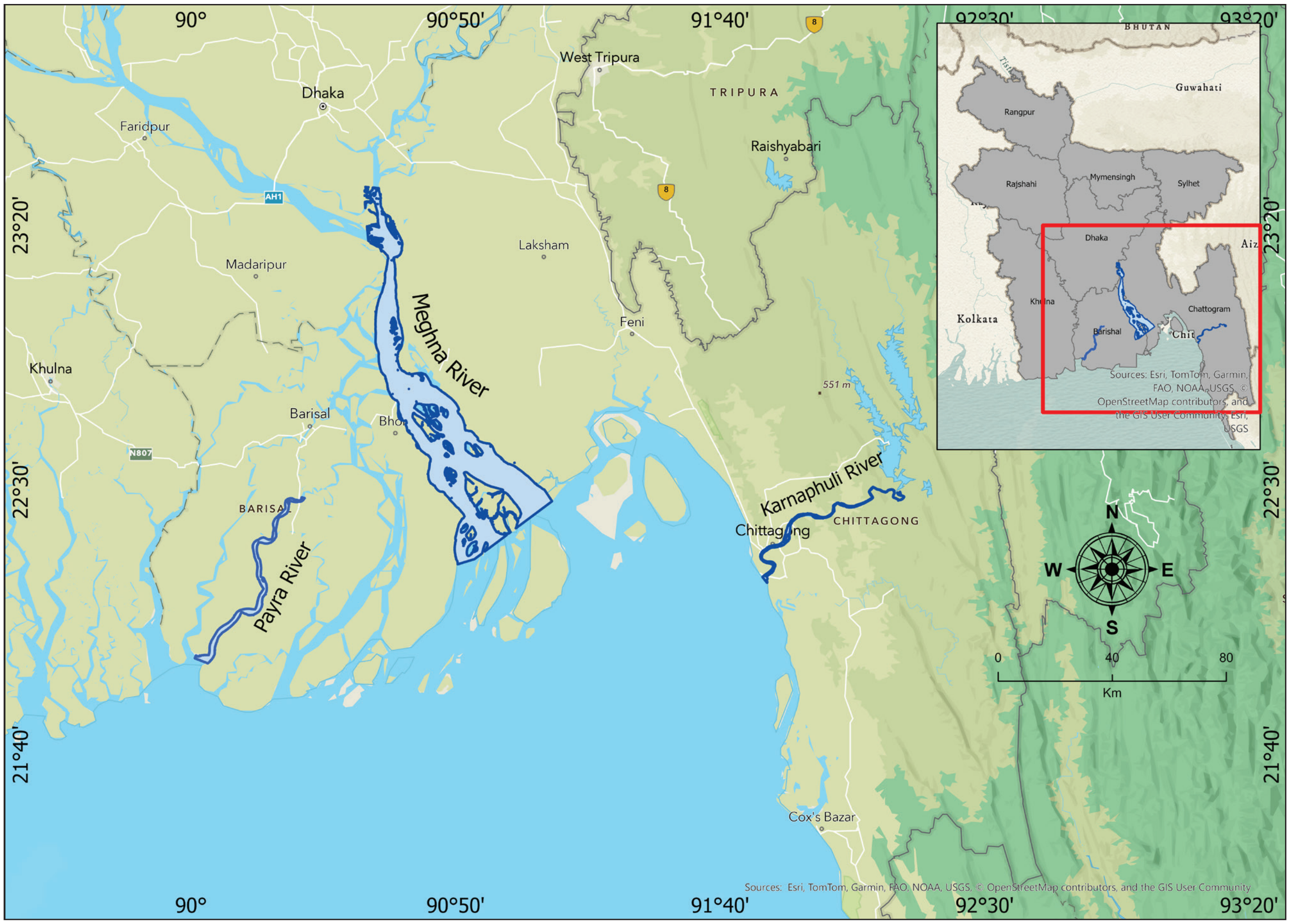

Figure 1: The Locations of the Three Rivers (Meghna, Payra, Karnaphuli) in the Coastal Area of Bangladesh Selected for the Study

MATERIALS AND METHODS

This study identified the rate and extent of erosion and accretion along the Meghna, Payra, and Karnaphuli Rivers using high-resolution, freely available satellite imagery. The analysis spanning from 1999 to 2022, examined an approximately 50-kilometer-wide catchment area along each of these three rivers. In the study, a series of preprocessing and processing steps were applied to the satellite images to identify changes and delineate areas of accretion and erosion across different years (Fig. 2). The extent of land accretion and erosion was estimated through parcel-based geoprocessing within a GIS framework.

Time series Landsat images from 1999, 2004, 2009, 2014, 2019, and 2022 were utilized to examine temporal alterations in river bank positions. With a spatial resolution of 30 meters, Landsat images include the Green Band and Near Infra-Red, enabling the calculation of NDWI to accurately extract riverbank lines at the end of each period. The Karnaphuli River is analyzed via Landsat path 136 and row 044, the Payra River, through Landsat path 137 and row 045 and the Meghna River is studied with Landsat path 137 and row 044 focusing on coastal river shifting.

Image processing in the present study included amalgamating disparate spectral bands within each Landsat image into a unified file through layer stacking. Mosaicking facilitated the seamless integration of Landsat images covering distinct sections of the study area. Furthermore, image enhancement procedures including radiometric correction, pan-sharpening, histogram equalization and filtering were applied to heighten visibility and differentiation of features by augmenting contrast and brightness. Subsequent radiometric correction rectified pixel values for atmospheric conditions, sensor calibration, and sun angle effects (Paolini et al., 2007).

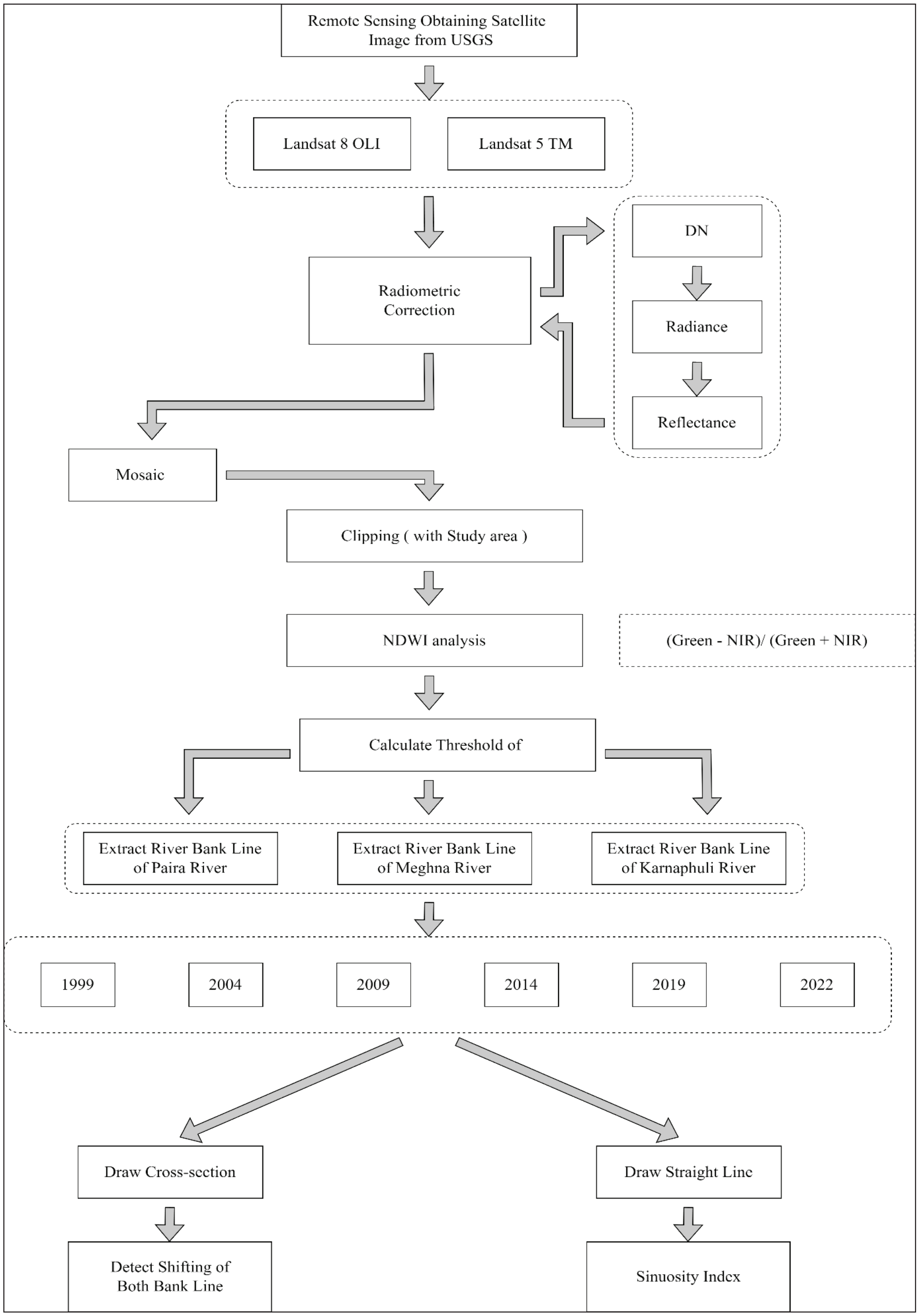

Figure 2: Workflow for River Bank Extraction. USGS (United States Geological Survey) Images from Landsat 8 OLI (Operational Land Imager) and Landsat 5 TM (Thematic Mapper) are Processed Using NDWI (Normalized Difference Water Index) to Extract River Banks (DN – Digital Number, NIR – Near Infrared) and Analyze Changes

To identify and delineate water bodies within the study area, an analysis employing normalized difference water index (NDWI) was conducted (Equation 1). NDWI, a ratio of the green and near-infrared bands, produces values from -1 to 1. Higher values signify increased water content, while lower values denote diminished water or land presence.

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

Assessment of river characteristics involved the creation of cross-sections along the river channel to ascertain width and depth variations across different locales and timeframes. River bank lines, demarcating the boundaries between water and land pixels along the river channel, were extracted from NDWI images using a predefined threshold value ranging from 0.004 to 0.46 (with an average of 0.18) (Laonamsai et al., 2023). Measurements encompassed determining the shortest distance between the two termini of the river channel, established by drawing direct lines. Tracking the migration of bank lines involved comparing their positions in distinct Landsat images, thereby calculating the magnitude and direction of their movement from their 1999 origins. Calculating the sinuosity index for each Landsat image provides insights into the deviation of the river channel from a linear path (Kalantar et al., 2020). Computed by dividing the river channel's length by the length of a straight line between its termini, a sinuosity index of 1 denotes a perfectly straight river. Higher values indicate a more meandering course, reflecting increased channel curvature and deviation from linearity.

River Morphometric Indices

The present study used the braiding index (BI) which represents the mean number of channels observed across multiple transects placed perpendicular to the river's flow within a specified length of the river reach. (Chew & Ashmore, 2001; Rhoads, 2020) (Equation 2).

$$B_i = \frac{\sum N_1}{N_{xs}} \quad \text{..........................(ii)}$$

Where N_1 is a channel location crossed by a transect and N_{xs} is the number of transects.

The study also used sinuosity index which quantifies as the ratio of channel length along the thalweg (the deepest path through successive cross-sections along the channel) to valley length (Wilzbach & Cummins, 2018) (Equation 3).

$$Sinuosity = \frac{Length\ of\ the\ stream\ channel}{Length\ of\ straight\ line\ distance} \quad \text{......(iii)}$$

RESULTS

Dynamics of Karnaphuli River Bank

The present study identified that the river bank of Karnaphuli is constantly changing for the years from 1999 to 2022 due to erosion and accretion processes, which are influenced by natural and human factors.

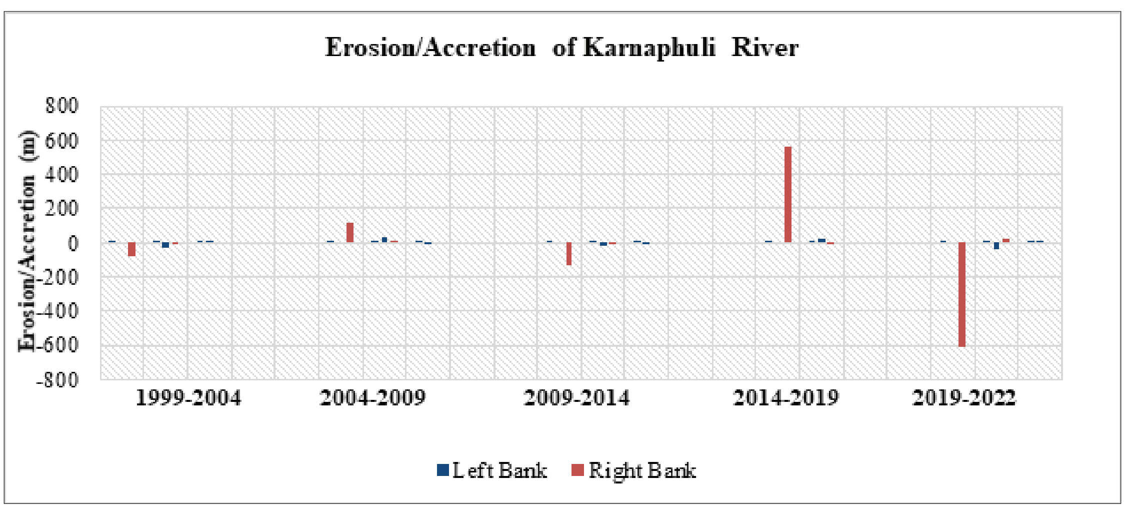

Figure 3: Erosion and Accretion Along the Karnaphuli River (1999–2022) Show Dynamic Shifts, with Major Right Bank Accretion in 2004–2009 (131.61 m) and 2014–2019 (557.32 m), Followed by Intense Erosion in 2019–2022 (595.25 m), Highlighting Significant Morphological Changes

From 1999 to 2022 (Fig. 3), the Karnaphuli River's banks witnessed a dramatic interplay of erosion and growth. From 1999 to 2004, erosion nibbled away 26.48 meters from the left bank and a more pronounced 90.63 meters from the right. Between 2004 and 2009, this trend flipped as both banks flourished, gaining 31.55 meters on the left and 131.61 meters on the right. Yet, the trend turned again from 2009 to 2014, with erosion reclaiming 19.90 meters from the left and 139.16 meters from the right. The following five years until 2019 brought significant growth, especially on the right bank, which expanded by 557.32 meters, while the left also gained 27.32 meters. However, the period from 2019 to 2022 saw both banks erode again, with the left bank shrinking by 24.88 meters and the right bank dramatically by 595.25 meters, highlighting the river's ever-changing landscape.

Dynamics of Meghna River Bank

The changes in the Meghna River's left and right bank positions in Bangladesh occurred over five periods.

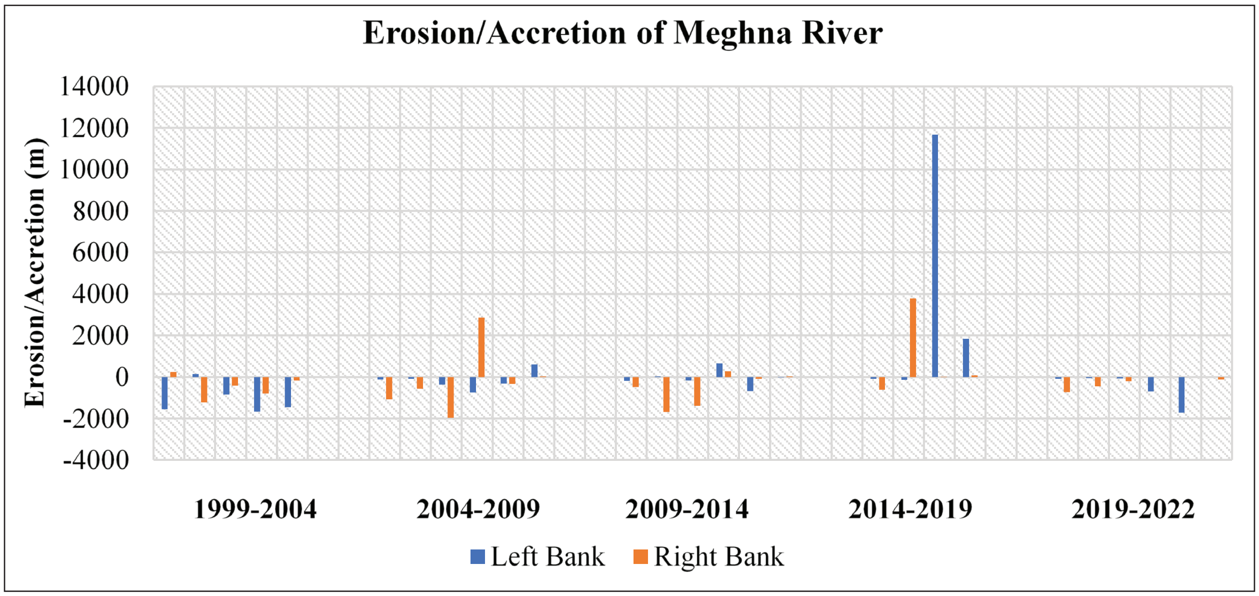

Figure 4: Erosion and Accretion Along the Meghna River (1999–2022) Reveal Major Fluctuations, with Severe Erosion in 1999–2004 (left: 5,389.70 m; right: 2,379.19 m), a Sharp Accretion Phase in 2014–2019 (left: 12,816.97 m; right: 2,157.04 m), and Renewed Erosion from 2019–2022, Reflecting the River's Highly Dynamic Behavior

From 1999 to 2022, the Meghna River's banks underwent dramatic changes, starting with significant erosion in the initial period (1999-2004), where the left bank lost 5389.70 meters and the right bank 2379.19 meters within 5 years (Fig. 4). The erosion continued into the next period (2004-2009), albeit at a reduced rate, with both banks losing approximately 1050 meters each. The trend of erosion persisted from 2009 to 2014, with a notable increase in erosion on the right bank by 3365.34 meters, indicating a potential shift in erosive forces or river dynamics. However, a remarkable turnaround occurred between 2014 and 2019, with the left bank gaining 12816.97 meters and the right bank 2157.04 meters, marking a period of significant accretion. Yet, this trend reversed between 2019 and 2022, as both banks again faced erosion, losing 2637.60 meters on the left and 1499.59 meters on the right, showcasing the river's dynamic and fluctuating landscape over the two decades.

The morphological pattern of Meghna River from 1999 to 2022 shows that both banks of the Meghna River have experienced more erosion than accretion over the years, resulting in a net loss of land area and a widening of the river channel (Fig. 4). The left bank has eroded more than the right bank in every time period, except for 2004-2009, when the right bank had a higher erosion rate. The largest erosion occurred in the left bank from 1999 to 2004, when it retreated by 1561.34 meters at one location. The largest accretion occurred in the right bank from 2009 to 2014, when it advanced by 3788.48 meters at one location.

Dynamics of Payra River Bank

The Payra River is a tidal river that flows into the Bay of Bengal. The tidal dynamics, the sediment transport, and the changes in human activities such as embankments, bridges, and land use influence the river bank erosion and accretion.

The left bank of the Payra River has experienced both erosion and accretion over the years, but the net change is positive (Fig. 5). The largest erosion occurred in the left bank from 1999 to 2004, when it retreated by 139.76 meters at one location. The largest accretion occurred in the left bank from 2014 to 2019, when it advanced by 701.72 meters at one location.

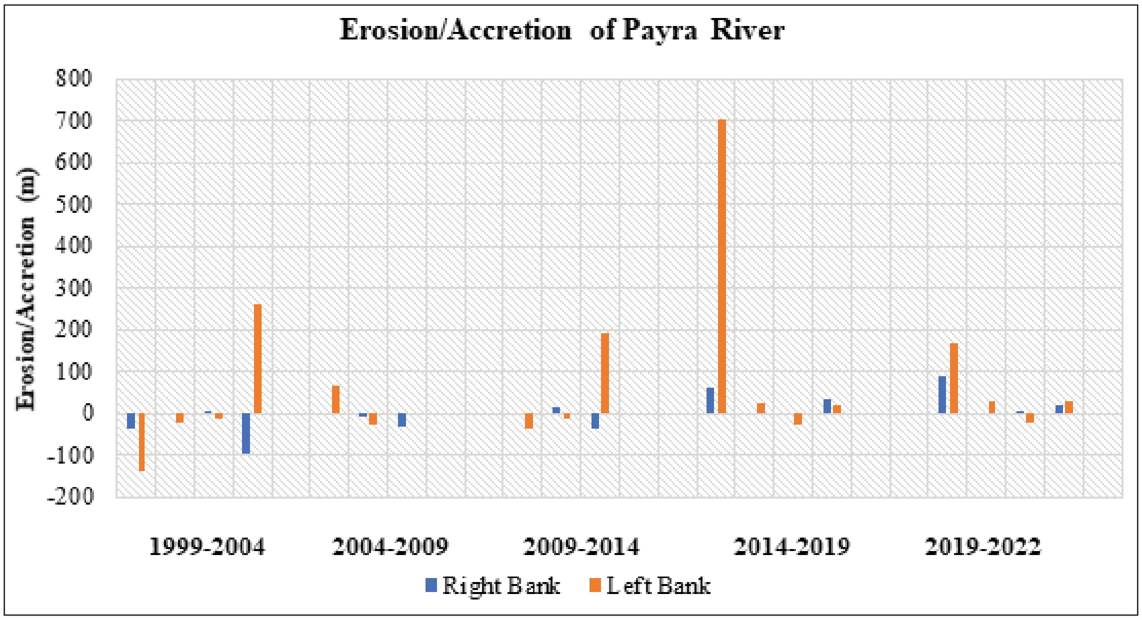

Figure 5: Erosion and Accretion Trends along the Payra River from 1999 to 2022. The Blue Bars Represent Changes along the Right Bank,While the Orange Bars Denote Changes along the Left Bank. Notably, the Most Extreme Left Bank Erosion Occurred between 2014 and 2019, Exceeding 700 Meters, While Periods Such as 1999–2004 and 2009–2014 also Show Distinct Left Bank Accretion

The Payra River's bank changes from 1999 to 2022 show a dynamic interplay between erosion and deposition (Fig. 5). The early years (1999-2004) faced a net loss, with erosion outpacing deposition by 36.38 meters. The situation nearly balanced out between 2004 and 2009, with a minimal net gain. However, a significant shift occurred post-2009, as deposition began to dominate. The period from 2014 to 2019 saw the largest increase, with the river banks gaining 806.57 meters due to sediment accumulation. This trend of growth continued through 2019 to 2022, albeit at a slower rate, adding another 313.56 meters. These fluctuations underscore the river's evolving landscape, shaped by ongoing natural forces.

Width Cross-Sectional Change of the Karnaphuli River

Over the years, the right bank of the Karnaphuli River, especially at Section 2, has seen its share of ups and downs with erosion and accretion (Fig. 6). Despite these fluctuations, the overall trend has been one of growth, with the bank edging closer to the river's channel. This trend became particularly evident between 2019 and 2022 when the bank gained a significant 18.45 meters, marking a stark contrast to its earlier phase from 1999 to 2004, during which it receded by 9.62 meters. However, a period of recovery was noted between 2004 and 2009, with the bank regaining 15.59 meters. These changes reflect a dynamic environment where the bank has alternately retreated and advanced, with recent years favoring expansion.

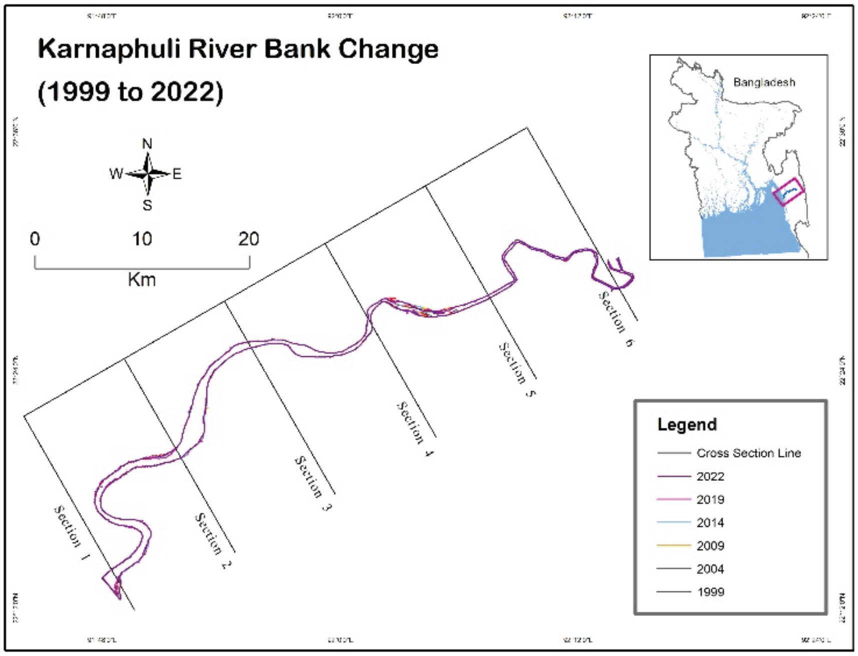

Figure 6: Cross-Sectional Changes of Both the Banks of Karnaphuli River (1999-2022)

Similarly, the left bank at Section 6 of the Karnaphuli River has experienced its cycles of erosion and accretion, ultimately resulting in a net positive change that suggests an overall growth towards the river. The most dramatic change occurred recently, from 2019 to 2022, when the bank expanded 1, outpacing its growth in earlier years. From 1999 to 2004, the bank had a modest accretion of 7.04 meters, followed by a slight setback between 2004 and 2009, losing 3.33 meters due to erosion. Despite these variances, the general direction has been towards accretion, with the bank steadily growing larger, particularly in the latest period. This pattern underscores a broader trend of the river's banks gradually moving towards each other, with the most significant growth observed in recent times, apart from an exceptional surge in accretion from 2014 to 2019 for Section 1.

Width Cross-Sectional Change of the Meghna River

On the left bank, the landscape tells a story of significant transformation. The most dramatic change occurred in Section 1, where the river gnawed away over 1500 meters of land, a vivid testament to the power of erosion. Conversely, Section 2 presents a contrasting tale of sediment gathering, gaining 142.4 meters of ground, a rare instance of the river's generosity. Section 3, too, succumbed to erosion, losing 838.68 meters, further illustrating the river's relentless reshaping of its banks. Amidst these changes, Section 4 remained silent, unchanged, marking a serene pause in the river's otherwise turbulent interactions with its banks.

The right bank mirrors this dynamic interplay, albeit with its own unique chapters (Fig. 7). Section 1 flourished, gaining 238.65 meters, perhaps a nod to the cyclical nature of loss and gain that defines riverine landscapes. Yet, this gain is overshadowed by the stark erosion in Section 2, where a significant 1223.7 meters of land was eroded away, highlighting the river's capacity for both creation and destruction. Section 3's loss of 425 meters further underscores the ongoing battle between land and water. Like its counterpart across the water, Section 4 on the right bank remained static, a bastion of stability amidst the ever-changing geography of the Meghna River banks.

Width Cross-Sectional Change of the Payra River

The changes in the right bank of the Payra River show erosion in some sections, with negative values indicating the extent of erosion. For instance, in Section 1, during the 1999-2004 period, the right bank experienced an erosion of 38.16 meters. In other sections, there are instances with no change (indicated by 0), suggesting stability in those areas of the right bank during the observed periods.

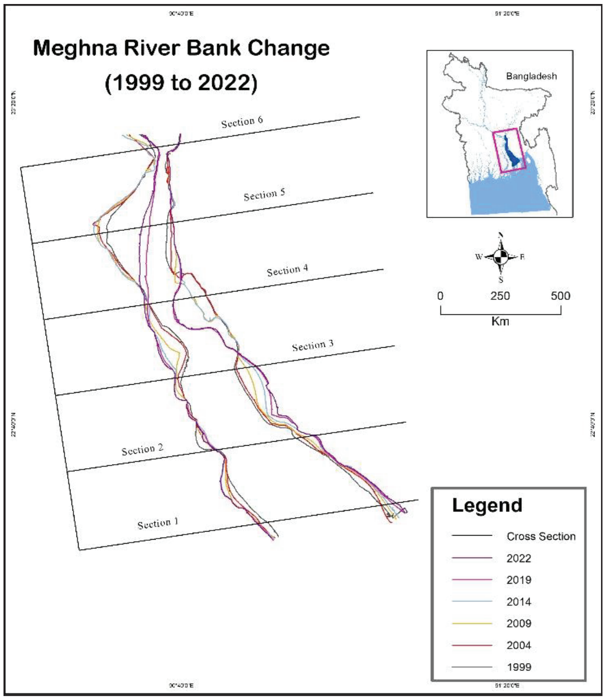

Figure 7: Cross-Sectional Changes of Both the Banks of Meghna River Bank (1999-2022)

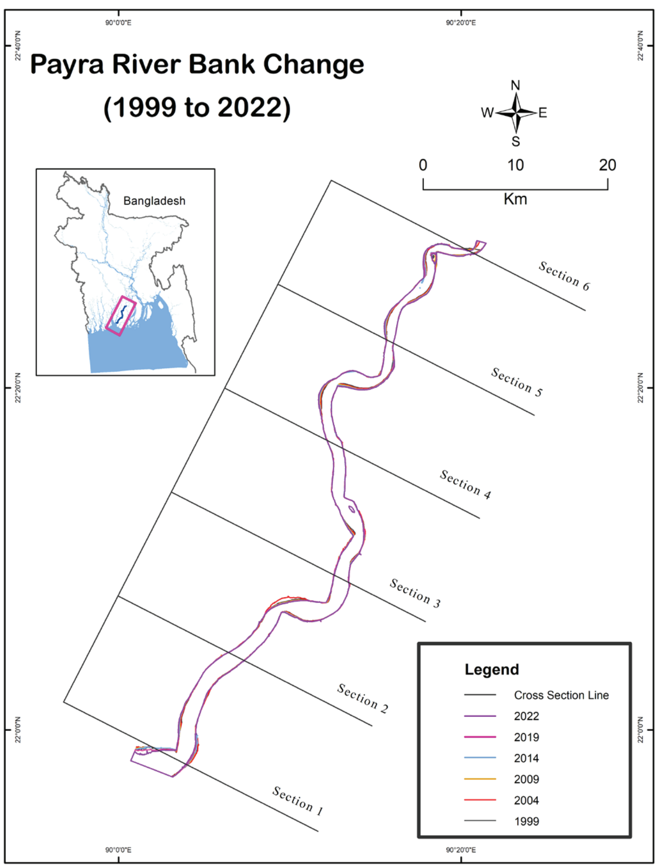

Figure 8: Cross-Sectional Changes of Both the Banks of Payra River Bank (1999-2022)

The left bank also shows signs of erosion in specific sections (Fig.8). During 1999-2004, Section 1 on the left bank underwent significant erosion, measured at 139.76 meters. Other sections, such as Section 3, experienced less severe erosion (23.1 meters), while some sections reported no change, indicating areas of the left bank remained unaffected by erosion during the measured intervals.

Correlation Analysis of Accretion and Erosion Dynamics

The correlation analysis of accretion and erosion between the right and left banks of three rivers—Meghna, Karnaphuli, and Payra—reveals distinct patterns of bank stability and sediment dynamics. The Meghna River shows a strong positive correlation ($r = 0.768$) for accretion, indicating a significant synchronization in sediment deposition on both banks. Conversely, the negative correlation for erosion ($r = -0.163$) suggests that when one bank experiences erosion, the other implies a compensatory dynamic. The Karnaphuli River, with a weak positive correlation for both accretion ($r = 0.186$) and erosion ($r = 0.084$), shows minimal interdependence between the banks, suggesting more localized and independent sedimentary processes. In contrast, the Payra River exhibits a weak positive correlation for accretion ($r = 0.18$) but a moderate positive correlation for erosion ($r = 0.524$), indicating a tendency for simultaneous erosion on both banks. These findings highlight the varied geomorphological behaviors of the rivers, influenced by factors such as hydrodynamics, sediment supply, and anthropogenic activities, which are crucial for formulating effective river management and erosion control strategies.

Meandering and Braiding Dynamics

The present study shows (Table 1) that the Payra River has a sinuosity index of 1.21, which is slightly meandering. However, the Karnaphuli River has a sinuosity index of 1.504, which is moderately meandering. The braided index (BI) of the Meghna River has shown a progressive increase from 1999 to 2022, indicating a notable trend in its geomorphological characteristics. In 1999, the BI was 1.978, which rose slightly to 2.065 in 2004. This upward trajectory continued more markedly over the following years, reaching 2.498 in 2009 and 2.594 in 2014. The index further increased to 2.641 in 2019 and 2.694 in 2022.

Table 1: Sinuosity Index of Karnaphuli, Payra and Meghna River

River Name	Stream Channel Length (SC)	Straight Line Length (SL)	Sinuosity Index (SI = SC / SL)
Payra River	80.10 km	65.77 km	1.22
Meghna River	133.75 km	128.01 km	1.04
Karnaphuli River	79.79 km	53.04 km	1.50

DISCUSSION

The morphological dynamics of the Karnaphuli, Meghna, and Payra Rivers, as observed from 1999 to 2022, offer intriguing insights into the interplay of natural processes and human interventions that shape deltaic riverbanks. In the context of Bangladesh's coastal region, these rivers exhibit distinct erosion and accretion patterns, which are influenced by both hydrodynamic forces and anthropogenic activities (Hassan et al., 2017). The results of the study reveal that the Karnaphuli River displays cyclical shifts between erosion and accretion, influenced by both natural sediment transport and human-driven modifications (Alam and Matin, 2013). From 1999 to 2004, the right bank eroded significantly, but this was followed by accretion between 2004 and 2009, as the right bank gained 131.61 meters. However, erosion again dominated between 2009 and 2014, and the trend of expansion resumed between 2014 and 2019, particularly on the right bank. This fluctuating pattern is consistent with studies on deltaic rivers, where sediment dynamics are often governed by seasonal and hydrological variability, as well as human interventions such as embankments and land reclamation (Sarker et al., 2011; Sultan et al., 2025). The weak correlations between accretion and erosion on both banks ($r = 0.186$ and $r = 0.084$ for accretion and erosion, respectively) indicate that sedimentary processes on the left and right banks are largely independent, reflecting localized factors (Alam & Matin, 2013).

In contrast, the Meghna River, with its significant erosion, showcases a more persistent trend of land loss (khatun et al., 2025), especially on the left bank. The erosion between 1999 and 2004, where the left bank lost over 5,000 meters, is a stark example of the aggressive erosional forces at play. Such severe erosion has been extensively documented in the literature, as the Meghna River's sediment transport is influenced by high discharge and sediment load from the upstream Ganges-Brahmaputra basin (Sarker et al., 2011). However, the Meghna also saw significant periods of accretion, particularly between 2014 and 2019, where both banks gained considerable land, including an expansion of over 12,000 meters on the left bank. Despite this, the river experienced net erosion over the long term, suggesting that even during accretion phases, the river's overall morphology is shifting toward greater channel widening and land loss (Hassan et al., 2017). The strong positive correlation for accretion ($r = 0.768$) indicates that when sediment is deposited on one bank, it is likely deposited on the other as well, contributing to more synchronized sediment dynamics (Khatun et al., 2025).

The Payra River, a tidal river, shows a distinctly different behavior from the Meghna and Karnaphuli (Sifa et al., 2024). The tidal influences play a major role in the Payra's sediment dynamics, with the left bank showing substantial accretion, particularly between 2009 and 2019. The significant growth of 701.72 meters during this period contrasts sharply with the erosion observed on both the Karnaphuli and Meghna. The correlation between erosion and accretion in the Payra River, though weak for accretion ($r = 0.18$), reveals a more pronounced trend of simultaneous erosion across both banks ($r = 0.524$). This suggests that tidal forces and anthropogenic activities, such as embankments, have shaped the Payra's morphology to a greater extent than in the Meghna or Karnaphuli (Sifa et al., 2024). The balanced interplay of erosion and accretion in the Payra River is likely a result of the river's tidal nature, which facilitates regular sediment deposition, although human activities might still influence local patterns of erosion and sediment retention (Sifa et al., 2024).

The sinuosity indices (SI) of the rivers also provide insight into their geomorphological characteristics. The Payra River's low sinuosity index of 1.22 indicates that it is only slightly meandering, while the Karnaphuli's higher SI of 1.50 indicates moderate meandering. The Meghna River, on the other hand, is increasingly braiding, as evidenced by the progressive increase in its braided index (BI) from 1999 to 2022. This suggests that the Meghna River is undergoing a more complex transformation compared to the other two rivers, with the increasing BI highlighting a tendency toward channel fragmentation and a more intricate flow pattern over time (Sultan et al., 2025).

The comparison of these rivers reveals that while the Meghna River is primarily dominated by erosion, the Karnaphuli and Payra Rivers exhibit more localized, fluctuating dynamics, heavily influenced by tidal forces and human interventions. These findings align with previous studies on deltaic river systems, which emphasize the importance of understanding the interplay between natural hydrodynamics and human activities for managing river morphology and mitigating the impacts of erosion. Moreover, the contrasting behaviors of these rivers suggest that each requires tailored management strategies that account for the specific geomorphological and hydrological conditions at play, such as tidal influence in the Payra and the intense erosion in the Meghna (Islam and Rahman, 2024; Hassan et al., 2017).

CONCLUSIONS

This study provides a comprehensive analysis of riverbank changes in the Karnaphuli, Meghna, and Payra Rivers from 1999 to 2022, emphasizing the significant morphological transformations resulting from erosion and deposition processes. By quantifying land changes and sinuosity indices using high-resolution satellite imagery and GIS tools, the research identified unique dynamics in each river system. The Karnaphuli River, exhibiting moderate meandering, experienced pronounced left-bank erosion of 41.06 meters from 2019 to 2022. These shifts underline the role of moderate sinuosity in influencing erosion and accretion patterns. In contrast, the Meghna River, with its near-linear morphology, underwent the most drastic changes, including extensive left-bank erosion of 1561.34 meters between 1999 and 2004, followed by significant accretion. This pattern underscores the critical impact of sediment transport and hydrodynamic forces in shaping nearly straight rivers. The Payra River, with slight meandering, demonstrated a dual trend: an initial phase of net land loss, evidenced by right-bank erosion of 95.13 meters over the same period, transitioning into subsequent land gain, highlighting its evolving dynamics. The findings underscore the intricate relationship between sinuosity, sediment dynamics, water flow, and human interventions in shaping riverbank morphologies. These processes create diverse outcomes across the three river systems, each with distinct ecological and socio-economic implications. The study stresses the necessity for ongoing, high-resolution monitoring and integrative research approaches to predict and mitigate erosion and accretion impacts effectively. Such understanding is vital for sustainable river management, particularly in vulnerable coastal regions like Bangladesh, where rivers play a critical role in ecological balance, resource management, and disaster risk reduction.

REFERENCES

Abdullah, H. M., Muraduzzaman, M., Islam, I., Miah, M. G., Rahman, M. M., Rahman, A., Ahmed, N., Ahmed, Z., 2019. Spatiotemporal dynamics of new land development in Bangladesh coast and its potential uses. Remote Sensing Applications: Society and Environment 14, 191–199.

Al, M. A., Alam, M. D., Akhtar, A., Xu, H., Islam, M. S., Kamal, A. H. M., Uddin, M. M., Alam, M. W., 2018. Annual pattern of zooplankton communities and their environmental response in a subtropical maritime channel system in the northern bay of bengal, Bangladesh. Acta Oceanologica Sinica 37, 65–73.

Alam, S., Matin, M. A., 2013. Application of 2D morphological model to assess the response of Karnaphuli river due to capital dredging. Journal of Water Resources and Ocean Science 2(3), 40–48. https://doi.org/10.11648/j.wros.20130203.13.

Allison, M. A., Khan, S. R., Goodbred, S. L., Kuehl, S. A., 2003. Stratigraphic evolution of the late holocene Ganges-Brahmaputra lower delta plain. Sedimentary Geology 155, 317–342.

Anwar, M. S., Hasan, M. Z., Rahman, K., 2020. Salinity variation of south-western coastal region of Bangladesh in response to discharge from an upstream river. International Journal of Advanced Geosciences 8(2), 173. https://doi.org/10.14419/ijag.v8i2.31048.

BBS, 2011. Population and housing census 2011, Zilla series. Bangladesh Bureau of Statistics, Ministry of

Planning, Government of the People's Republic of Bangladesh.

Bendsen, H., Meyer, T., 2002. The dynamics of land use systems in Ngamiland: Changing livelihood options and strategies. In Environmental Monitoring of Tropical Wetlands: Proceedings of a Wetland Conference, Maun, Botswana (pp. 278–304).

Brammer, H., 2014. Bangladesh's dynamic coastal regions and sea-level rise. Climate Risk Management 1, 51–62.

BUET, BIDS, 1993. Multi-purpose cyclone shelter project (MCSP), Summary Report. Bangladesh University of Engineering and Technology and Bangladesh Institute of Development Studies.

Chew, L. C., Ashmore, P. E., 2001. Channel adjustment and a test of rational regime theory in a proglacial braided stream. Geomorphology 37(1–2), 43–63.

Ciavola, P., Uddin, M., Duo, E., Lee, B., Fakhruddin, S., 2015. Vulnerability of Bangladesh coastline to inundation under cyclone activity: Past records and DRR strategies at Sandwip island. In E-proceedings of the 36th IAHR World Congress (pp. 45–46).

Dastagir, M. R., 2015. Modeling recent climate change induced extreme events in Bangladesh: A review. Weather and Climate Extremes 7, 49–60. https://doi.org/10.1016/j.wace.2014.10.003.

Department of Environment (DoE), 2016. River water quality report 2015. Ministry of Environment and Forest, Government of the People's Republic of Bangladesh.

Ghosh, M. K., Kumar, L., Roy, C., 2015. Monitoring the coastline change of Hatiya island in Bangladesh using remote sensing techniques. ISPRS Journal of Photogrammetry and Remote Sensing 101, 137–144.

Hassan, S. T., Syed, M. A., Mamnun, N., 2017. Estimating erosion and accretion in the coast of Ganges-Brahmaputra-Meghna delta in Bangladesh. In Proceedings of the 6th International Conference on Water & Flood Management (pp. 115–124).

Hou, J., van Dijk, A. I., Renzullo, L. J., Vertessy, R. A., Mueller, N., 2019. Hydromorphological attributes for all Australian river reaches derived from Landsat dynamic inundation remote sensing. https://doi.org/10.5194/essd-11-1003-2019.

Islam, A. R. M. T., Islam, H. M. T., Mia, M. U., Khan, R., Habib, M. A., Bodrud-Doza, M., Siddique, M. A. B., Chu, R., 2020. Co-distribution, possible origins, status, and potential health risk of trace elements in surface water sources from six major river basins, Bangladesh. Chemosphere 249. https://doi.org/10.1016/j.chemosphere.2020.126195.

Islam, M. K., Rahman, M. M., 2024. Establishing morpho-dynamic baseline for flow-sediment management of a tidal river in the Ganges–Brahmaputra–Meghna delta system through field measurement. Environmental Fluid Mechanics 24(2), 265–286. https://doi.org/10.1007/s10652-024-09985-x.

Islam, M. M., Rahman, M. S., Kabir, A., Islam, M. N., Chowdhury, R. M., 2020. Predictive assessment on landscape and coastal erosion of Bangladesh using geospatial techniques. Remote Sensing Applications: Society and Environment 17(1), 100277. DOI: 10.1016/j.rsase.2019.100277.

Islam, M. S., 2001. Sea-level changes in Bangladesh: The last ten thousand years. Asiatic Society of Bangladesh.

Kalantar, B., Ameen, M., Jumaah, H., Jumaah, S., Abdul Halin, A., 2020. Zab river (Iraq) sinuosity and meandering analysis based on the remote sensing data. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIII-B3-2020, 91–95. https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-91-2020.

Khatun, F., Saha, O. R., Matin, N., 2025. Morphological changes in the offshore islands of Meghna estuary: Analysis of the erosion and accretion dynamics. HydroResearch 8, 294–306. https://doi.org/10.1016/j.hydres.2024.12.006.

Laonamsai, J., Julphunthong, P., Saprathet, T., Kimmany, B., Ganchanasuragit, T., Chomcheawchan, P., Tomun, N., 2023. Utilizing NDWI, MNDWI, SAVI, WRI, and AWEI for estimating erosion and deposition in ping River in Thailand. Hydrology 10(3), 70. https://doi.org/10.3390/hydrology10030070.

Masria, A., Nadaoka, K., Negm, A., Iskander, M., 2015. Detection of shoreline and land cover changes around Rosetta promontory, Egypt, based on remote sensing analysis. Land 4(1), 216–230. https://doi.org/10.3390/land4010216.

Milliman, J. D., 1991. Flux and fate of fluvial sediment and water in coastal seas. In R. F. C. Montoura, J. M. Martin, & R. Wallast (Eds.), Ocean margin processes in global change (pp. 69–89). John Wiley & Sons Ltd.

Minar, M., Hossain, M. B., & Shamsuddin, M. (2013). Climate change and coastal zone of Bangladesh: Vulnerability, resilience and adaptability. Middle-East Journal of Scientific Research, 13, 114–120.

Mou, M. A., Tusar, M. K., Haque, M. R., Chakraborty, S., Ahmed, S., 2023. Assessment of riverbank erosion and accretion and its impact on the people of Chairman Ghat, Noakhali, Bangladesh. Journal of Sustainability and Environmental Management 2(4), 220–230.

Motsholapheko, M. R., Kgathi, D. L., Vanderpost, C., 2011. Rural livelihoods and household adaptation to extreme flooding in the Okavango Delta, Botswana. Physics and Chemistry of the Earth 36(14–15), 984–995. https://doi.org/10.1016/j.pce.2011.08.004.

Munasinghe, D., Cohen, S., Gadiraju, K., 2021. A review of satellite remote sensing techniques of river delta morphology change. Remote Sensing in Earth Systems Sciences. https://doi.org/10.1007/s41976-021-00044-3.

Ollero, A. (2010). Channel changes and floodplain management in the meandering middle Ebro river, Spain. Geomorphology, 117(3–4), 247–260. https://doi.org/10.1016/j.geomorph.2009.01.015.

Paolini, L., Grings, F., Sobrino, J. A., Jiménez Muñoz, J. C., Karszenbaum, H., 2007. Radiometric correction effects in landsat multi-date/multi-sensor change detection studies. International Journal of Remote Sensing 28(3), 685–704. https://doi.org/10.1080/01431160500183057.

Rhoads, B. L., 2020. River dynamics: Geomorphology to support management. Cambridge University Press.

Ritu, S. M., Sarkar, S. K., Zonaed, H., 2023. Prediction of Padma river bank shifting and its consequences on LULC changes. Ecological Indicators 156, 111104. https://doi.org/10.1016/j.ecolind.2023.111104.

Rudra, K., 2018. Rivers of the Ganga-Brahmaputra-Meghna Delta: A fluvial account of Bengal. Springer Nature. http://www.springer.com/series/15117.

Sanchez-Arcilla, A., Jimenez, J. A., Valdemoro, H. I., 2012. The ebro delta: Morphodynamics and vulnerability. Journal of Coastal Research 14(3).

Sarker, M. H., Akhand, M. R., Rahman, S. M. M., Molla, F., 2013. Mapping of coastal morphological changes of Bangladesh using RS, GIS, and GNSS technology. Journal of Remote Sensing and GIS.

Sarker, M. H., Akter, J., Ferdous, M. R., Noor, F., 2011. Sediment dispersal and land formation processes in the Meghna estuary. In Sediment Problems and Sediment Management in Asian River Basins (pp. 175–183). IAHS Publ. 349.

Sifa, N. J., Jerin, T., Salman, M. A., Asaduzzaman, M., Hossen, M. S., 2024. Assessment of riverbank erosion and its societal impacts along the Payra river in Mirzaganj upazila, Bangladesh. Journal of Clean Water 8(1), 38–44.

Sium, S. M., Ahmed, R., Haq, K. F., 2023. A geospatial analysis on river dynamics in upper active Brahmaputra-Jamuna floodplain region, Bangladesh. International Journal of Business, Society and Science Research 11(2), 15–22. http://doi.org/10.55706/ijbssr11204.

Sultana, T., Islam, M. T., Rahman, M. S., Siddique, A. B., Huda, A. N. M. S., Sarker, S., 2023. Evaluating the long-term geomorphic process in relation to hydrodynamics in the central coastal zone of Bangladesh. Heliyon 9(6). https://doi.org/10.1016/j.heliyon.2023.e17368.

Sultan, N., Al Mahmud, A., Tusar, K., Habib, M. E., Chowdhury, S. A., 2025. Identification of the most dynamic river estuarine system in Bangladesh over the last fifty years (1973–2023) using landsat images. PREPRINT (Version 1). Research Square. https://doi.org/10.21203/rs.3.rs-5130695/v1.

Teka, K., Haftu, M., Ostwald, M., Cederberg, C., 2020. Can integrated watershed management reduce soil erosion and improve livelihoods? A study from northern Ethiopia. International Soil and Water Conservation Research 8, 266–276.

Uddin, K., Khanal, N., Chaudhary, S., Maharjan, S., Thapa, R. B., 2020. Coastal morphological changes: Assessing long-term ecological transformations across the northern bay of bengal. Environmental Challenges.

Uddin, M. J., Jeong, Y.-K., 2021. Urban river pollution in Bangladesh during the last 40 years: Potential public health and ecological risk, present policy, and future prospects toward smart water management. Heliyon 7(2). https://doi.org/10.1016/j.heliyon.2021.e06107.

Wang, S., Li, L., Ran, L., Yan, Y., 2016. Spatial and temporal variations of channel lateral migration rates in the inner Mongolian reach of the upper yellow river. Environmental Earth Sciences 75, 1255.

Wilzbach, M. A., Cummins, K. W., 2018. Rivers and streams: Physical setting and adapted biota. In reference module in earth systems and environmental sciences. Elsevier. https://doi.org/10.1016/b978-0-12-409548-9.11093-0.