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Assessing River Bank Erosion and Accretion Along the Lower Part of the Meghna River Using GIS and Remote Sensing Techniques

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Abstract: The Meghna River, one of Bangladesh's principal rivers, has undergone continuous changes due to significant riverbank erosion and accretion over the past decades. This study assesses the riverbank erosion, accretion, and bank line shifting of the lower Meghna River from 1990 to 2021 using GIS and remote sensing techniques. Landsat TM and OLI images, along with GIS and ERDAS Imagine software, were utilized to quantify these changes. The study found that the most severe erosion occurred between 1990 and 1995, totaling 574.04 sq. km, while the greatest accretion, 448.88 sq. km, occurred between 1995 and 2000. Over the entire study period, approximately 305 sq. km of land was lost. Erosion and deposition patterns fluctuated due to the increasing water discharge downstream from the Padma, the Ganges, and the Meghna. Erosion on the eastern (right) bank was more significant than on the western (left) bank, with the left bank experiencing the highest erosion (339.75 sq. km) between 1990 and 1995. The shifting riverbank has caused severe socio-economic issues, displacing communities and submerging farmland, leading to rural-urban migration. Continuous monitoring, satellite image analysis, planting, and construction of embankments are crucial to protecting the riverbank and reducing the impact of future erosion.

Keywords: *Accretion, Erosion, NDWI, Meghna River, GIS and Remote Sensing*

Introduction: Bangladesh is at ease among the countries that are most vulnerable to the effects of a change in the global climate and atmosphere. This is due to its exceptional geological setting, unparalleled floodplains, proximity to the coast, and alluring reliance on nature. Streambank disintegration is treated as a geomorphic danger. Geomorphic perils delineated as the shakiness of the earth's surface highlight treat that is the danger to human progress [1]. Rivers are somewhat delicate to natural conditions [2], and alluvial channels can react or oblige at a scope of rates to the varieties because of water and silt inputs, dynamic tectonics, and human exercises at a sort of spatial and temporal scales [3]. Waterways, streams, and channels are kinds of regular conduits on the outside of the earth and have become pivotal pieces of topographical components. The waterway channel course industriously moved over space through time and tends to accomplish harmonious conditions to modify itself with the shifting fluvial geomorphic just as a climatic condition [4]. Riverbank erosion and accretion (deposition) are the two key geomorphic processes of a fluvial framework. Bank erosion is averse to riparian zones and has different geomorphic, social, and monetary results [5] whereas accretion can diminish transport capacity [6], making routes possibly more difficult. Although the two procedures are basic in the deltaic fields of South Asia, serious disintegration is identified as one of the significant reasons for arable land loss and population displacement [7]. Riverbank disintegration is a recognizable catastrophic event in Bangladesh and an issue of significant misery. It causes incredible devastation yearly to individuals living close to the banks of waterways in Bangladesh and transforms into risks. It is a powerful fluvial procedure that happens quickly for a brief length during and after floods coming about in wandering of streams just as a change of channel course. Such kind of erosion influences a scope of physical, socio-social, and environmental administration issues in the environmental factors. Again, the disintegration is a component of many interrelated factors like-stream qualities, the composition of bank materials, silt store attributes, channel geometry, and so on, vegetation spread and man-induced factors like human residence close to the stream bank, the expulsion of vegetation cover from the riverbank area and so on. The extraction of waterway assets like sands and rock is a central point of bank disintegration. Disintegration may result from the channel water eroding the higher bank materials during large flood events or from the bank being oversoaked as a result of the formation of the deepest direct channel toward the bank during water dropping stages [8]. The combined discharges from the Ganges, Brahmaputra, and Meghna (GBM) rivers, which average 35 000 m3/s, are drained into the Bay of Bengal [9]. About 85% of water comes to Bangladesh through these three waterways. These are particularly seasonal in variances inflow with outermost discharge in the monsoon. The average yearly silt load conveyed by the GBM Rivers to the Bay of Bengal is around 2 billion tons every year [10]. Massive sediment load originating from GBM and high tidal flow combat the sediment to go directly to the Bay of Bengal may be a factor for accretion of inward waterways of the island. The zone is influenced by semi-diurnal tidal flows, the most extreme tidal range of 5 meters happens in the lower Meghna River which continuously diminishes southeastwards along the Chattogram coast [10]. According to the study [11], the lower portion of the Meghna River which is the main channel for water and sediment discharges from the powerful

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Ganges-Brahmaputra-Meghna river system to the Bay of Bengal undergoes frequent morphological changes that have a substantial impact on the local ecology and socioeconomic situation. Moreover, during monsoon, the collapse of the banks of the river causes drastic erosion of land which is a frequent phenomenon [12]. Bangladesh finds that throughout the monsoon season, the mean monthly temperature and mean rainfall are trending upward at a significance level of $p > 0.10$ [13]. Negative effects on agriculture and human life are caused by both excessive (flooding) rain during the monsoon season (June-September) and insufficient rain during the pre-monsoon (March-May) and winter (December-February) seasons. This is the main cause of river bank erosion and accretion along the lower part of Meghna River over the study period [14]. The substantial seasonal variance in rainfall causes frequent changes in flow and water level in the Meghna River. These differences are amplified by the effects of climate change[13]. Downstream of Chandpur, the west bank saw considerable erosion between 1984 and 1993, with rates occasionally reaching as high as 824 meters per year. The average rate of bank erosion along the right and left banks at that time was 182 and 66 meters per year, respectively. The sum of these rates (248 meters per year) is larger than Jamuna's pace of widening during that time (184 meters per year), according to a report by the Flood Plan Coordination Organization (FPCO) [15]. The erosion of the river causes several socio-economic losses and the misery goes uncounted. Therefore, the study aims to evaluate the spatial and temporal (1990 to 2021) dynamics of erosion and accretion of land downstream of the Meghna River. Moreover, it discusses the socio-economic impact of riverbank erosion in the last few decades with some critical recommendations. Therefore, it will be significant to take policy measures against the frequent riverbank erosion in reducing massive socio-economic losses in the future.

Materials and Methods:

Study Area: The Meghna is one of the principal rivers on the south side of Bangladesh. It is a highly alluvial meandering river Chanel and its downstream marge on the Bay of Bengal [16], especially great for the extraordinary estuary that discharges the huge volume water flows of the Ganges-Padma, the Brahmaputra-Jamuna, and the Meghna itself. The Meghna is a flood-inclined waterway. It has two particular parts. The Upper Meghna from Kuliarchar to Shatnol is a similarly little waterway. The Lower Meghna beneath Shatnol is perhaps the biggest water Channel on the earth because of its wide estuary mouth. The Lower Meghna is now and again rewarded as a separate waterway.

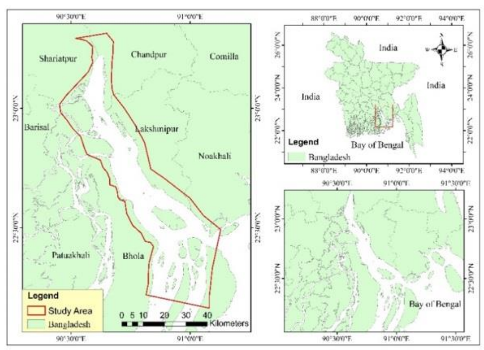

Fig. 1: Study Area Map Showing the Lower Portion of the Meghna River.

The study area covers Chandpur (23°13.768'N, 90°38.58'E), Barisal (22°41.962'N, 90°22.524'E), Bhola (22°37.153'N, 91°07.013'E), Hatiya (22°24.459'N, 91°07.013'E) and Sandwip (22°29.319'N, 91°25.668'E) districts of the country. Fig. 1 depicts the Meghna River Estuary which is considered the study area. The selected portion of the Meghna River is the lower or downstream which is 113.12 km in length.

Data: Landsat satellite images of various years from 1990 to 2021 were collected from USGS. The study area was covered by two scenes from the Landsat archive (path/row: 147/44 of Landsat 5 TM; path/row 137/44 of Landsat 8 OLI). United States Geological Survey (USGS) provides TM, MSS, ETM+, AND OLI images. The information was in the GeoTIFF format for every individual band. All satellite images were taken during dry seasons because the river is a portable framework and significant changes during the rainy season (June to September), cloud-free images post-monsoon were required every year to catch the yearly fluctuation in the framework, and a common resolution of 30m.

Table 1. Information on Landsat images

Year	Acquired date	Sensor	Cloud cover	Path/Row	Spatial Resolution
1990	1990-01-07	LANDSAT 5 TM	0.00	137/44	30m
1995	1995-12-23	LANDSAT 5 TM	0.00	137/44	30m
2000	2000-01-19	LANDSAT 5 TM	0.00	137/44	30m
2005	2005-01-16	LANDSAT 5 TM	0.00	137/44	30m
2011	2011-01-01	LANDSAT 5 TM	0.00	137/44	30m
2016	2016-11-14	LANDSAT 8 OLI	0.03	137/44	30m
2021	2021-02-13	LANDSAT 8 OLI	3.17	137/44	30m

Methodology: Geographic Information System (GIS), Remote Sensing (RS) software, and other statistical data management systems have been utilized for the appraisal of riverbank erosion, deposition, and identification of bank line shifting patterns of the Meghna River. For image processing, the layer stack tool has been done using ERDAS Imagine 2014 software. Again, the accuracy of the data that was retrieved from several Landsat images was corrected for atmospheric effects. Each image was corrected geometrically to fit the UTM-46N projection.

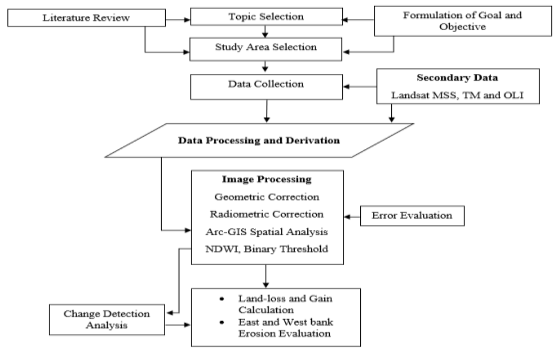

Fig. 2: Flowchart of Methodology.

Because of the flat land, the symmetrical change was not performed. All images were sampled with the nearest neighbor method to a common resolution of 30m. A subset of the study area from the layer staked image even though the Landsat image. Multispectral Scanner (TM, OLI) picture information initially utilized for NDWI (McFeeters), is relevant for other sensors to discover expanding vast water.

$$NDWI = \frac{Green - NIR}{Green + NIR} \qquad \text{eq. 1}$$

A study [17] focused on the NDWI values that are more than zero as water surfaces, whereas those that are less than zero are non-water surfaces. The NDWI images of several years depicted the erosion and accretion at various locations of the Meghna River Estuary. Eq. 1 was used to visualize the NDWI maps of the river for several years. Again, the accretion and erosion rates were also calculated and the areas were also defined. Fig. 2 visualizes the flowchart of the methodology followed to perform the study.

Erosion and Accretion at the Meghna River Estuary: The temporal changes of the Meghna River for several periods are detected to depict the accretion and erosion taking place in those years. The changes in the river for around 30 years (1990-2021) due to accretion and erosion are analyzed. Several Landsat images are taken and required data are extracted using the Normalized Difference Water Index (NDWI) at ERDAS Imagine software.

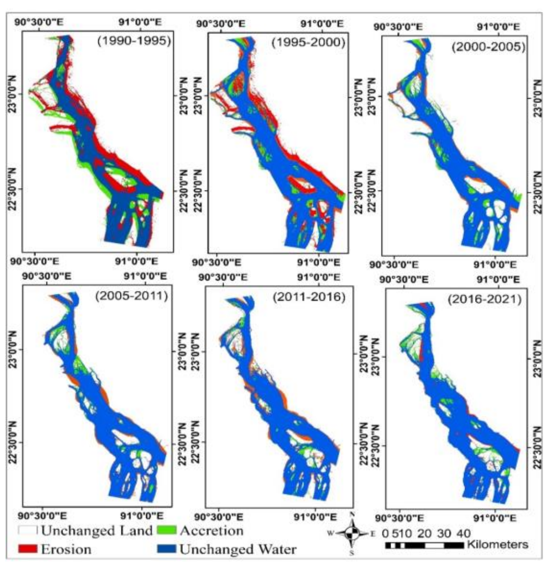

Fig. 3: Temporal Changes of Meghna River Estuary from 1990 to 2021.

According to eq. 1, the study [17] on the indices of sensor images emphasized the values of NDWI that are more than zero as water surfaces, whose values are less than those described to be non-water surfaces. Only the pixels with the greatest NDWI value were chosen to reduce the errors of the selected feature to mottled pixels that are nearest to water bodies and other low-reflectance features. The sorted pixels were then converted into one of the proposed classes (signature) using a mathematically established decision mechanism (maximum likelihood). The land uses that each suggested class matched were then identified. Fig. 3 depicts the temporal changes at the lower part of the Meghna River estuary using the NDWI tool. The changes are gradual throughout the years. So, the period taken for the study is vast enough to visualize the change of the river over time.

Due to the meandering effect of the river, the rivers seem to change their directions in a regular manner. Water flowing through a curving channel and the underlying river bed interact to form meanders. Helicoidal flow results from this, in which water flows from the outer to the inner bank down the riverbed, then flows back to the outer bank close to the river's surface. As a result, the inner bank's carrying capacity for sediments decreases while the outer bank's carrying capacity increases, causing sediments to erode from the outer bank and be redeposited on the inner bank of the following downstream meander [18]. Between 1990 and 2000, the accreted lands were visible at most of the places of the Meghna River estuary. But the rate of eroded land was lesser than the accreted land. However, the accreted lands started decreasing and the lands were eroded at a considerable rate during 2000-2021. Still, the erosion of lands was found maximum in the 1990-1995 period. Similarly, the eroded lands later moved down the river. From 2000, the river width increased and the accreted lands decreased. During 2016-2021, the scenario started changing, and the expansion of the land was noticed in a few places. The rate of accretion of lands has also increased than in previous years.

Table 2. Accreted and Eroded Land at the Meghna River Estuary.

Year	Erosion (sq. km)	Accretion (sq. km)	Net Gain/Loss (sq. km)	Cumulative Gain/Loss
1990-1995	574.0371	325.1574	-248.8797	-248.8797
1995-2000	499.0986	448.8867	-50.2119	-299.0916
2000-2005	147.2562	212.3163	65.0601	-234.0315
2005-2011	214.9686	127.6479	-87.3207	-321.3522
2011-2016	249.5997	100.2465	-149.3532	-470.7054
2016-2021	111.6621	177.8661	66.204	-404.5014
1990-2021	641.2797	355.6055	-305.6742	

Table 2 shows the amount of accreted and eroded land at the Meghna River estuary where a higher amount of land (around 450 sq. km) was accreted during 1995-2000. However, the amount of accretion has decreased from the 2011 to 2016 period. On the contrary, the river witnessed a larger amount of erosion of land during 1990-1995.

Table 3. East and West Bank Erosion at the Meghna River Estuary.

Year	West (Left) Bank Erosion (sq. km)	East (Right) Bank Erosion (sq. km)
1990-1995	124.534	339.751
1995-2000	79.384	249.146
2000-2005	54.887	50.557
2005-2011	73.9	73.06
2011-2016	82.93	83.05
2016-2021	31.93	34.17

Again, the erosion of the riverbank has decreased recently (2016-2021). In the last five years, only around 111 sq. km of lands were eroded at the estuary. Fig. 4(a) also shows the accreted and eroded land amount (sq. km) at the estuary of the river where a larger area was accreted from 1995 to 2000. But the number of eroded lands was less during that period. But in the next decade, the erosion rate got higher and a huge amount of accreted lands were eroded and gone under the river water. Due to the meandering and discharge from the river, the river water increased and the accreted lands were inundated. The erosion generally takes place on both banks of the river. Considering the east and west banks of the Meghna River estuary, most of the land was eroded from 1990 to 1995, again, the west (left) bank of the river was affected due to the regular erosion of land.

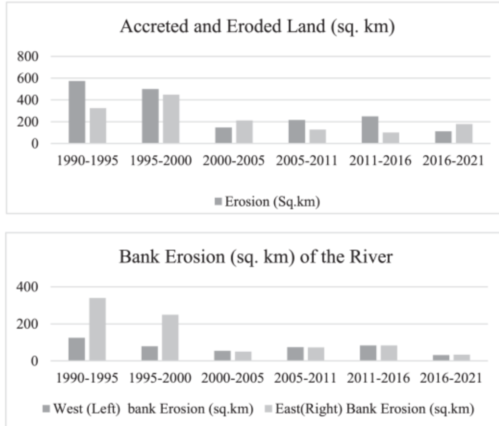

Fig. 4: (a) Temporal Analysis of Accreted and Eroded Land (sq. km) and (b) Erosion at Both Banks of Meghna River Estuary from 1990 to 2021.

Similarly, fig. 5 shows the erosion of lands that took place at different places on both banks of the estuary. The erosion at the riverbank was minor in 2016-2021 in comparison with other years. Moreover, fewer lands were eroded during 2000 to 2005. But the major amount of land was eroded from 1990 to 1995 which changed the scenario drastically, especially on the west bank of the river. Again, the amount of erosion of lands was almost similar during 2005-2011 and 2011-2016 on both banks of the river. Table 3 also shows that the erosion of land has decreased during the past few years (2016-2021).

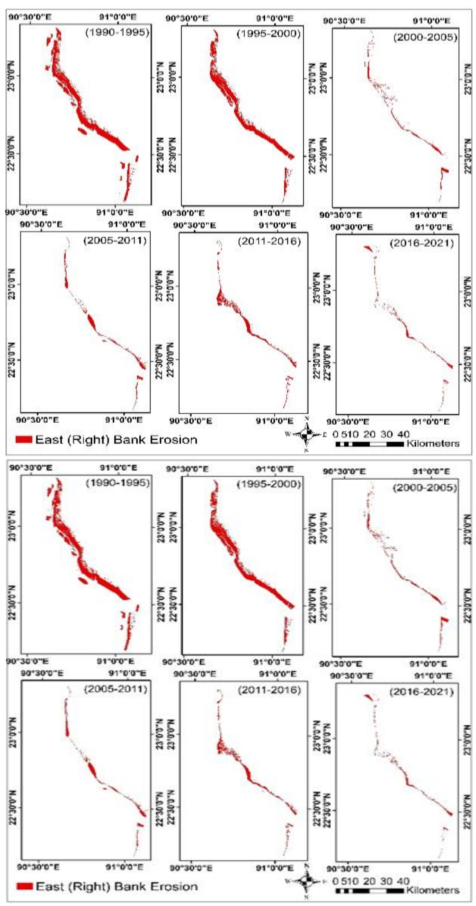

Fig. 5: Temporal Changes of Meghna River Estuary at Both Banks from 1990 to 2021.

Fig. 4(b) also depicted the amount of eroded land at the east and west banks of the Meghna bank estuary. According to the graph, the east (right) bank eroded substantially during 1990-1995. The west (left) bank was comparatively less disintegrated. A lower rate of bank erosion was discovered than in the previous 30 years. Though the erosion of lands has decreased, the rate of erosion isn't constant. The pace of erosion at both banks varies depending on the meandering of the river and the discharge from the upper part of the river.

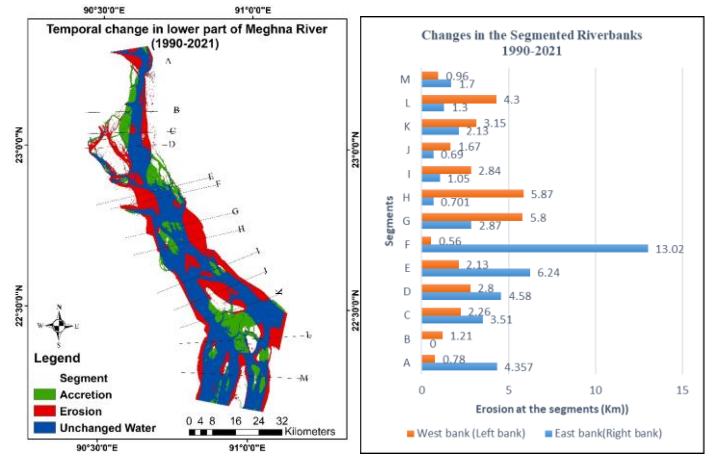

Fig. 6: (a) Temporal Changes at Different Segments of the River and (b) Erosion on the Selected Segments (km) at Both Banks from 1990 to 2021.

Considering the overall transformation, the downstream of the Meghna River was segmented into several portions to observe the change over the period (1990-2021) and the change in the banks due to the erosion. Fig. 6(a) depicted the segmentation of the lower portion of the river and the temporal analysis of the changes where some lands were accreted and a huge portion of land was eroded at several segments. Again, fig. 6(b) indicated the changes to the segments due to the erosion of the river over a period (1990-2021). A maximum of around 13 km of erosion (Segment F) was observed on the east bank of the river during this period. However, a negligible amount of land was eroded at the west bank (Segment B). The erosion was higher on the west bank than on the east bank almost in all the segments at the Meghna River estuary.

Socio-Economic Impact of Meghna River Erosion: The result of the disintegration of the river bank isn't just human uprooting yet additionally constant disintegration destroys roads, firm land, and other communication facilities decreasing the chances of getting relief rapidly. Various temporary and permanent settlements grew up in the accreted lands and the erosion of river banks affected the settlements with a destructive effect. For their survival, the afflicted individuals who had no other choice moved from rural to urban regions and began living in squatter settlements, slums, and open spaces, beside rail lines, and some of them began residing in the Khash Land of the city. Eventually, slum and squatter populations are growing within several urban regions every year, and the majority of the residents arrived in the urban areas as a result of river erosion.

Social amenities like food, shelter, healthcare services, and career opportunities are severely disrupted in these slums. The majority of those impacted are illiterate, unskilled, and unqualified, and as a result of their unemployment, their suffering gets escalated. They hardly get employment opportunities and places to reside, and as a result, poverty becomes more severe. The accreted lands are generally fertile and agricultural activities grow on those lands, but due to the erosion, the agricultural lands get eroded. A study [19] on the Meghna riverbank erosion shows that 98% of the respondents had changes in social lives due to river erosion. Again, according to that survey taken in 2020 at the 14 Upazilas of Chandpur district, around 91% of the habitats were fully damaged, and the rest of them were partially damaged. Considering the loss of assets, 72% of agricultural lands, 68% of crops, 17% of livestock, 93% of homesteads, and 89% of vegetation were destroyed. Therefore, riverbank erosion causes vital effects on the livelihood, social lives of the people, and the surroundings as well.

Conclusion: Meghna River bank typically shifts periodically every year. The continuous river bank destruction and accretion process caused huge land to go underwater and also the formulation of land. Due to the meandering effect of the river, the Meghna River changes its natural movement by changing its riverbank and bar area. The study demonstrated different rates of erosion and accretion of the river estuary in the past 30 years, and the net change is 305.67 sq km loss of land. The outcome of the study will assist in the future projection of the study area and identify what changes are taking place in the river basin. Again, it will be helpful for the policymakers to find the proper solution and whether the protection measures are required or not. Though the study is performed by only taking the estuary of the Meghna River, the researcher may make applications of this study to other rivers to have a comparative idea about bank erosion and accretion. Again, the erosion and accretion in the riverbank under different circumstances may impact the social, and economic lives and livelihood of the surroundings of the river. Therefore, continuous monitoring of the riverbank by using satellite images (Ikonos, resolution less than 1m) which will give clear information on banking shifting and eroding patterns needs to be done. This information will assist policymakers in taking relevant protections. Besides, planting and replanting of seedlings in the river bade of Meghna River, hard protection measures like (embankments, concrete blocks, and banging) at both sides of the river bade where the area is more vulnerable, and soft protection measures like (tree plantation, increasing vegetation cover) where the area is less vulnerable will protect the riverbank of the Meghna from being excessively eroded and to save lives and properties.

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