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Original Article

Identification of the potential locations for land reclamation in the meghna estuary of Bangladesh using the remote sensing technique

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Abstract

In pace with the continuous population and economic expansion, the land is becoming increasingly saturated with human settlement and industrial and agricultural activities, making it scarce and raising demand. On the other side, there is a real fear in today's climate change discussion that many coastal communities will be forced to flee owing to sea level rise, especially in low-lying coastal countries like Bangladesh. Reclaiming land from the sea might become a viable option considering these challenges. This study aimed to analyze the potential land reclamation sites, sediment transport patterns, accretion, and erosion trends using remote sensing techniques in the Meghna River estuary. The study was carried out to determine the technical context under which land has already been reclaimed on that coast and to devise RS/GIS-assisted methodology to identify potential locations in Meghna Estuary for reclamation of land. Coastal configuration datasets were generated from multi-temporal satellite images from 1972 to 2020 of low tide conditions. Locations with progressive depositional phenomena were identified through a comparison of the coastal configuration datasets. Sedimentation distribution patterns during high tide and low tide were studied to identify potential locations in the Meghna estuary. It has been identified that sediment is transported into the estuary, particularly on the eastern side, by high tide flow, which could be a potential site for land reclamation. The findings indicate the probability of a vast area for reclamation and demonstrate the need for large-scale initiatives for effective land reclamation measures.

Keywords: sediment distribution pattern, accretion, erosion, sea level rise

1. Introduction

Land is one of the most basic natural assets for all countries (Ukhurebor *et al.*, 2022). With the increasing demand for settlement brought about by population growth, the land is becoming increasingly saturated with high-rise structures, making land more and more scarce (Chee, Othman, Sim, Adam, & Firth, 2017). Land reclamation from the sea has frequently been the favored approach to address the growing demand for additional land (Sengupta, Chen, & Meadows, 2018; Wang, Ge, Yuan, & Zhang, 2014). On the other side, there is a serious concern in today's climate change discourse that many coastal communities would have to evacuate due to sea level rise (SLR) (Esteban *et al.*, 2020). Coastal ecosystems may lose some of their habitats and ecosystem services because of SLR in estuarine zones (Palanisamy & Chui, 2013; Wang *et al.*, 2014). Countries with low elevation are extremely sensitive to SLR, which threatens the very lives of communities residing in seaside regions, and have little other option than to force migration (Brown *et al.*,

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2023). The Ganges-Brahmaputra-Meghna (GBM) Delta is vulnerable to SLR impacts because of its low-level terrain (Sarker, Akter, Ferdous, & Noor, 2011). Land reclamation is the process of stretching land surfaces outward over the ocean (Idowu & Home, 2015; Sengupta *et al.,* 2018) by constructing new lands from coastal seas by refilling the region with sand, rock, cement, or other substances and decreasing the water area which could alleviate the impacts of SLR to some extent (Yang & Chui, 2017).

Having a coastline of about 710 km Bangladesh is one of the countries with the highest geomorphological activity (Mahmood, Ahmed, Zhang, & Li, 2020). Bangladesh's coastal regions had a net increase of 139 square kilometers of land between 1977 and 2010 (Mentaschi, Vousdoukas, Pekel, Voukouvalas, & Feyen, 2018). According to Mentaschi *et al.* (2018), around 28,000 km^2 was lost permanently in coastal regions between 1984 and 2015. This is about twice as big as the area of newly acquired land (around 14,000 km^2) over the same time frame (Alam & Uddin, 2013). Tidal flow along the coastal lands of Bangladesh makes the detection of coastline difficult from remotely sensed images, as it is difficult to have satellite images matching the required tidal condition. In the context of the Bangladesh coast, this aspect has been elaborated by (Hussain, Tajima, Gunasekara, Rana, & Hasan, 2014). Some studies have focused on the morphological changes of Bangladesh's offshore islands and coastal regions utilizing remote sensing, where tidal conditions were not considered (Mentaschi *et al.,* 2018) deteriorating the merit of the work. The technique of the high tide shoreline has been proposed by Islam (2013) to solve the problem of coastline detection from satellite images. This is an effective way to use satellite images, as the high-tide coastline is obtainable from satellite images acquired at any tidal condition. The same authors incorporated spectral analysis with visual interpretation to identify the high-tide coastline (Ahmed, Drake, Nawaz, & Woulds, 2018). To prepare a map of the coastal areas and islands to measure the accretion and erosion, it is essential to draw the coastline accurately. Misleading statistical information would be obtained about the eroded or accreted areas without accurately detecting the coastline. The area has the highest sediment discharge rate, at about 1 × 10^9 t/yr (Goodbred & Kuehl, 2000; Mukherjee, Fryar, & Thomas, 2009), and the fourth-greatest riverine flow in the world (Milliman & Meade, 1983; Mukherjee *et al.,* 2009). The massive load of sediment carried by the GBM system leads to very high concentrations of suspended sediment in the Meghna estuary, which are fine, cohesive, and prone to flocculation, allowing for deposition and land development in the surrounding area (Alam, 2014). In 1957 and 1964, Bangladesh retrieved 1,000 square kilometers of virgin territory in the Meghna estuary by constructing two dams (Mentaschi *et al.,* 2018). The Meghna estuary has accumulated over 1,700 km^2 of net land area during the past 60 years (Sarker *et al.,* 2011). Moreover, Bangladesh reclaimed 1,000 square kilometers of new land in the Meghna estuary by building two dams in 1957 and 1964 (Alam *et al.,*2013). Very few studies have addressed effective technical aspects and useful insights into the potential for land reclamation in Bangladesh, specifically in the Meghna river estuary, determining potential locations. The current research is intended to investigate the natural potential locations for the reclamation of lands in the Meghna river estuary of Bangladesh employing remote sensing methods. The present study might benefit scientists and policymakers by offering a compelling argument and guiding work for the strategic planning of land reclamation initiatives in response to the dual challenges of population pressure and sea level rise.

2. Materials and Methods

2.1. Study area

The Meghna estuary located in the central coastal area of Bangladesh was chosen as the study site (Figure 1). It is the most prominent estuary in the region covering an area of 9,40,979 hectares. Owing to significant upstream sediment intake and strong tidal energy, the estuary experiences significant erosion and accretion, making it very dynamic (Sarker *et al.,* 2011). The Meghna estuary was selected for the current study due to its dynamic nature and importance. We assumed based on previous studies and literature that there would be potential sites in the Meghna estuary area featured with reclamation suitability.

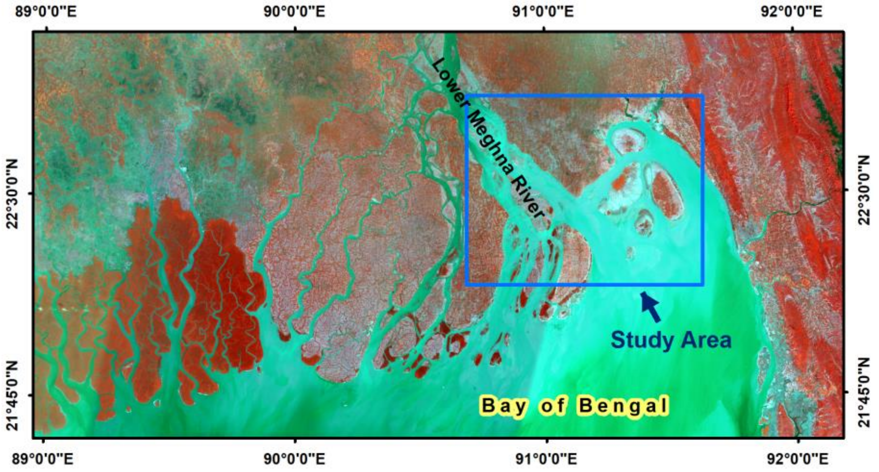

Figure 1. Study area

2.2. Generation of coastal configuration datasets

This dataset of the study area was generated from multi-temporal satellite images. Information on the images is given in Table 1. The datasets were generated using standard image processing and digitization techniques, such as (a) Geo-referencing, (b) Mosaicing, (c) Study area extraction, (d) Interpretation, and (e) Digitization. A decadal digital dataset of the coastal configuration has been generated using the on-screen digitization technique on Landsat images. This technique is applied to generate the landmass data layer in the study area through the visual interpretation of images. The dataset has been generated using visual interpretation and on-screen digitization techniques and no automatic classification techniques have been used. So, no atmospheric correction has been applied to the images. Also, this technique does not require any DN value threshold and depends on the visual skill of the analysts. Geometric distortion in the images has been corrected in the process of georeferencing of the images. In the dataset mentioned in Table 1, the OLI images have a higher geometric accuracy. Taking these images as reference, interactive geo-referencing of the other images has been carried out using the tools of ArcGIS software. The study area belongs to four Landsat frames (137-44, 137-45, 136-44, and 137-45), which were mosaiced, and the study area was extracted from the mosaiced image using a pre-generated Area of Interest (AOI) layer. The AOI layer was generated to include the coastal area in the Meghna estuary where significant geomorphological changes occurred over the study period as visually assessed from the images in Table 1. The generated coastal configuration dataset is shown in Figure 2. The back polygons in this figure show the land areas.

2.3. Analysis of the coastal configuration dataset

An analytical data layer of the study area has been generated from the decadal digital dataset, mentioned in the preceding section, through the ‘Union’ operation of the ArcGIS overlay tools. Before overlay operation, the data layer of each year has been attributed to render its entity in the composite data layer. Based on this entity change class (erosion and accretion) has been populated in the composite data layer on a decadal basis.

The analysis of the coastal configuration dataset was carried out to find out the places where land has already been reclaimed during the study period (1972–2020). The analytical composite data layers on a decadal basis are represented in Figure 3. This figure depicts the morphological changing pattern in the study area with the remarks that, alone with land reclamation through the process of accretion, the study area was also subjected to erosion on a significant scale. The quantitative values of erosion and accretion that occurred in the study area are given in Table 2, and the patterns of the rate of erosion and accretion are presented in Figure 4. It is observed that in the initial decade (1972–1980), accretion was much higher than erosion. During the next decade (1980-1989) the accretion reduced considerably while erosion increased to a dominating magnitude. Afterwards, both accretion and erosion have an increasing pattern but again accretion dominated during the rest of the study period.

3. Results and Discussion

3.1. Sediment dynamics and reclamation pattern

The quantitative values of erosion and accretion that occurred in the study area are given in Table 2, and the pattern of the rate of erosion and accretion is presented in Figure 4. It is observed that in the initial decade (1972–1980), accretion was much higher than erosion. During the next decade (1980-1989) the accretion reduced considerably while erosion increased to a dominating magnitude. Afterwards, both accretion and erosion have an increasing pattern but again accretion dominated during the rest of the study period.

The locations in the research region where land has previously been reclaimed for the whole study period (1972-2020) are depicted in Figure 4 a. Reclamation of land occurs in the study area through the process of natural accretion and is shown in dark green in Figure 4 a. Now, to analyze the sediment distribution pattern, it is imperative to understand the source(s) of sediment and its movement mechanism in the study area. From the literature, it is reported that 2.4 billion tons of sediment pass through the Meghna estuary every year (Goodbred & Kuehl, 2000; Mukherjee, Fryar, & Thomas, 2009), which comes through flows and stream flows (Figure 4 b).

Table 1. Information on satellite images used in the study

Satellite/Sensor	Frame	Image resolution, m	Acquisition date	Cloud coverage in the study area, %	Tide condition at image acquisition time
Landsat/MSS	136-44, 136-45	30	27/12/1972	0.2	Low tide
	137-44, 137-45		28/12/1972	0	
	136-44, 136-45		14/01/1980	0	
	137-44, 137-45		15/01/1980	0	
Landsat/TM	136-44, 136-45		05/01/1989	0	
	137-44, 137-45		28/01/1989	0	
	136-44, 136-45		07/02/2001	0	
	137-44, 137-45		28/02/2000	0	
	136-44, 136-45		08/02/2010	0	
	137-44, 137-45		30/01/2010	0	
Landsat/OLI	136-44, 136-45		19/01/2020	0	
	137-44, 137-45		26/01/2020	0	

Figure 2. Coastal configuration dataset generated for the study

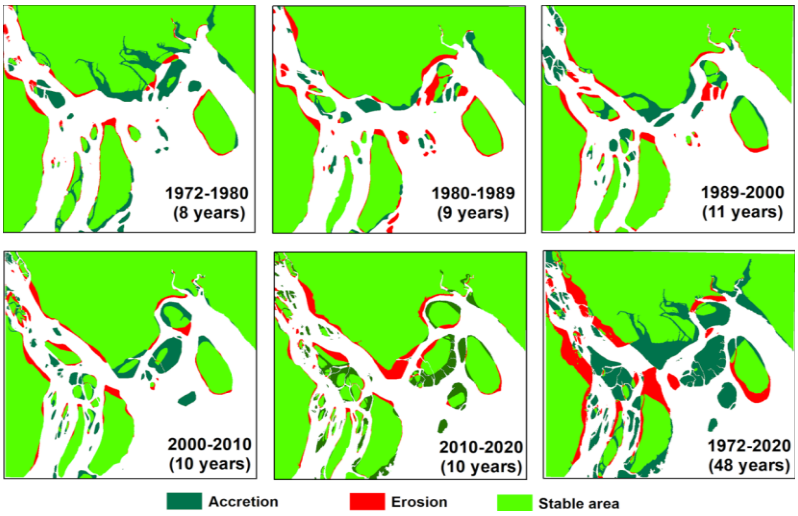

Figure 3. Composition of coastal configuration datasets

Table 2. Quantitative value of erosion and accretion in the study area

Period	Accretion			Erosion		
	Area (ha)	% of area under study	Rate (ha/year)	Area (ha)	% of area under study	Rate (ha/year)
1972-1980	55,089	5.85	6886	20,521	2.18	2565
1980-1989	25,966	2.76	2885	34,461	3.66	3829
1989-2000	38,084	4.05	3462	28,503	3.03	2591
2000-2010	42,223	4.49	4222	25,848	2.75	2585
2010-2020	48,490	5.15	4849	34,205	3.64	3421
1972-2020	1,29,797	13.79	2704	63,483	6.75	1323

The lower Meghna carries the collective waters of the Ganges, the Jamuna, and the upper Meghna which passes through the Meghna estuary and routes into the Swatch of No Ground. Swatch of No Ground connects Ganga–Brahmaputra mouth with the Bengal Fan. The canyon serves as an obstruction to further westward sediment flow and sinks around one-third of the fluvial sediment load (Garzanti *et al.*, 2019). The interplay of the freshwater inflow from upstream via the lower Meghna and the tidal wave determines the pattern of sediment transport while traveling through the Meghna estuary. At ebb tide conditions, the main flows are towards the sea, as shown in Figure 5 a. Due to the high tide flows shown in (Figure 5 b), sediment is transferred into the northeast side of the estuary and settled therein due to the flow equilibrium created as shown in Figure 6. The areas marked by the black rectangles in Figure 6 are the flow equilibrium

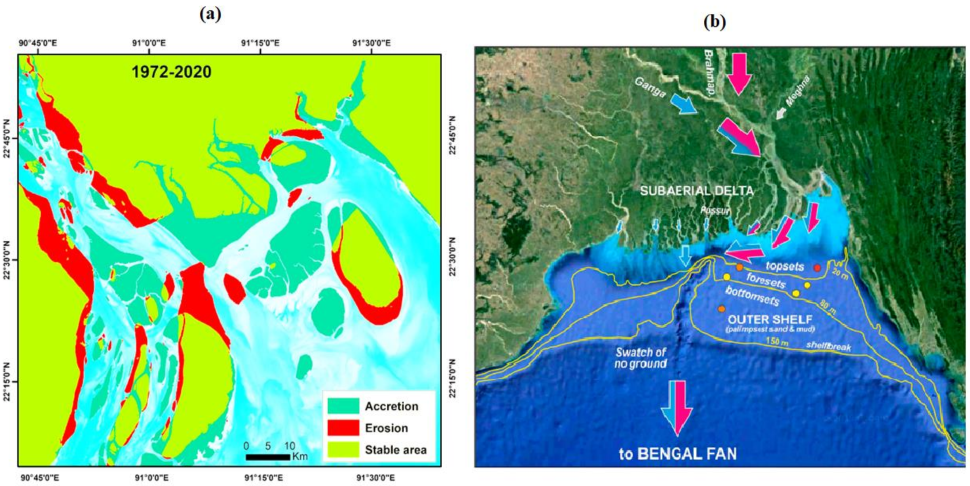

Figure 4. Places where land has already been reclaimed during the whole study duration (1972-2020) (a), and sediment source and its movement pattern through the Meghna estuary (b)

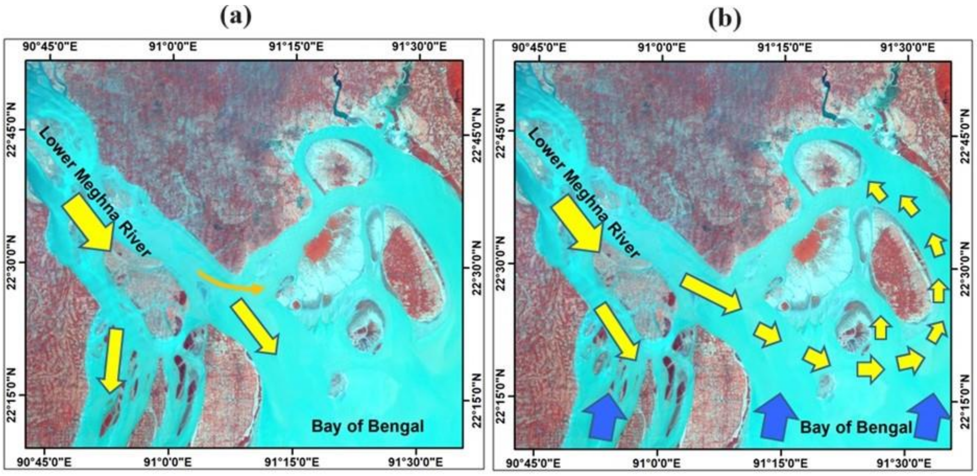

Figure 5. Flow through the Meghna estuary during Ebb tide (a), and high tide (b)

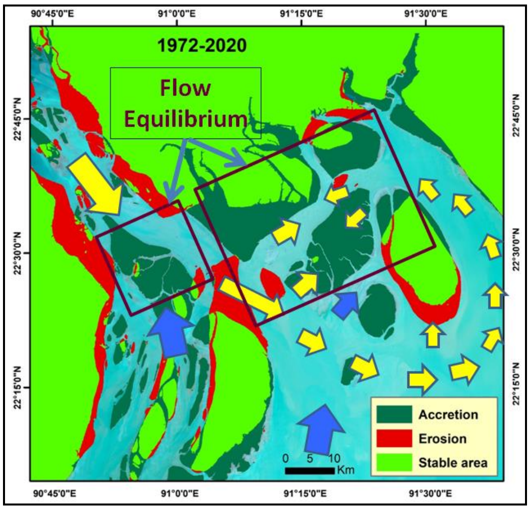

Figure 6. Flow equilibrium in the Meghna estuary. Black rectangles also show the potential land reclamation sites

The accumulation of sediment through the mechanism mentioned above is investigated using satellite images. Figure 7 a, b represents the satellite image used for this analysis. The image in (Figure 7 a) shows sediment distribution at about one hour of high tide flow after starting the high tide cycle (image acquisition date: January 1, 2021; tidal height at Sandwip: low tide level: 0.73 m at 09.37 AM; approximate tide level at image acquisition time: 10.31 AM: 1.32 m; next high tide level: 5.16 m at 04.17 PM). This image shows a uniform distribution of sediment in the offshore, including the Meghna estuary. Figure 7 b shows sediment distribution at about full high tide flow after the start of the high tide cycle (image acquisition date: April 6, 2021; tidal height at Sandwip: Low tide level: 1.94 m at 03.32 AM; approximate tide level at image acquisition time 10.31 AM: 4.177 m; next high tide level: 4.31 m at 10.56 PM). The concentration of sediment on the northeast side of the estuary is obvious from this figure. A spatial profile was drawn on the images to see the distribution and accumulation of sediment in the area. In the profile for (Figure 7 a), an overall uniform distribution of sediment is seen except at the end portion,

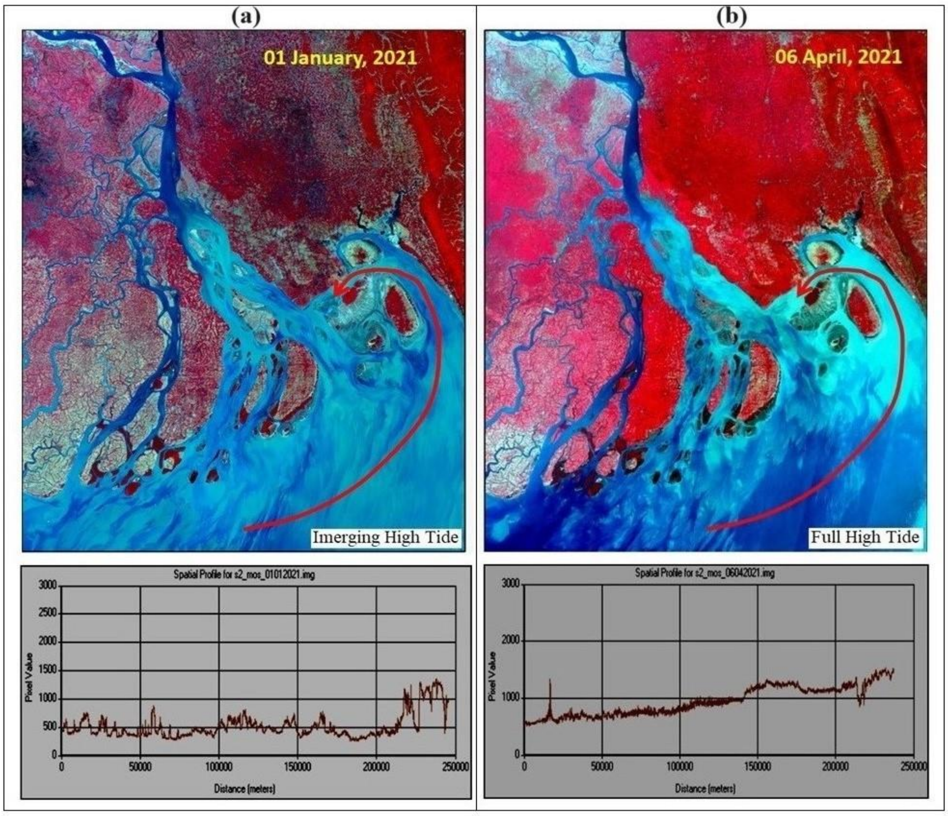

Figure 7. Sediment distribution and accumulation around the estuary at emerging high tide condition (a), and at full high tide condition (b)

where much higher sediment accumulation is found. In the profile for (Figure 7 b), an increasing distribution of sediment is seen, with higher accumulation on the north-east side of the estuary.

This result implies a huge potential for land reclamation in the Meghna River estuary region. It is known for the world's greatest sediment discharge rate, which is around 1,109 t/yr (Goodbred & Kuehl, 2000; Mukherjee *et al.*, 2009). Islam, Begum, Yamaguchi, & Ogawa (2002) reported that the sediment suspended in the estuary and throughout the coastal water, off the river mouth, reaches 1,050 mg/l, although in the zone of greatest turbidity in the coastal sea, typically within 5-10 m of water, it climbs to 1,700 mg/l. Nonetheless, the average concentration of suspended sediment in the vicinity of the Meghna estuary could be as much as 9,740 mg/l, as reported at 0.5 meters above the channel floor north of Urir Char (Ahmed & Louters, 1997). Akter, Roelvink, & van der Wegen (2021) calculated the total amount of sediment deposition in the GBM estuary system to be 1,150 million tons/year and the floodplains and tidal plains acquire around 22% of the entire sediment entering the network. Anwar and Rahman (2021) examined the shoreline at east Bhola Island in the Meghna estuary from 1989 to 2018 and observed a remarkable decrease in the erosion rate to 41 m/year in the most recent period of 2005–2018, after significant erosion from 1989 to 2005. In the Meghna estuary, significant erosion and accretion happened concurrently at Hatiya Island, where maximum shoreline shift rates were 138.5 m/year seaward and 285.4 m/year landward (Kabir *et al.*, 2020). Kabir *et al.* (2020) noted that the tidal flats surrounding this island are mostly accumulating sediment and are rather active. The combined size of Urir Char, Sandwip, and Jahajir Char islands in the eastern Meghna estuary expanded by around 120 km^2 between 2007 and 2013 (Hussain, *et al.*, 2014). Brammer (2014) discovered that although 451 km^2 of overall accretion occurred in the Meghna estuary between 1984 and 2007, almost 40% of Sandwip Island's eastern side had been destroyed. Ali, Mynett, & Azam (2007) demonstrated that the land reclamation dams were effective in accelerating accretion in the area around these structures. It was observed that accretion was the predominant process from Chandpur to Sandwip channel in the Meghna estuary from 1978 to 2008 (Hasan, 2011). Crawford *et al.* (2020) reported that the lower Meghna estuary region has experienced erosion from 2011 to 2019; however, the pace has slowed since 2013.

3.2. Potential impacts of land reclamation

Despite being a solution to increased land demand and climate change adaptation, land reclamation in the coastal region might have some negative impacts on estuarine hydrodynamics, the coastal ecosystem, biodiversity, and socioeconomic conditions. Reclamation of land alters the dynamics of suspended sediments affecting estuarine sedimentation and sediment dynamics (Cheng, Jalon-Rójas, Wang, & Liu, 2020). Reclamation heavily influences sediment stratigraphy and the overall sedimentary environment in a coastal plain (Ouchaou *et al.,* 2024). Land reclamation led to a decrease in the effective dispersion of wastewater discharged into the sea, degrading the water quality, by decreasing and redirecting the ocean circulation (Lecart *et al.,* 2024). Lewis *et al.* (2019) found that the reclamation of tidal marshes results in around 70% loss of sediment carbon stocks; even "New" carbon in reclaimed areas degrades more quickly than in virgin tidal marshes. Reclamation raises the danger of collapse owing to terrain subsidence, with the primary subsidence source being the erection of buildings on artificial ground reclaimed to the sea (Erten & Rossi, 2019). In the areas where such developments were made, land reclamation has affected not just ecological conditions but also the social and cultural lives of the local people (Zeballos & Yamaguchi, 2011). Therefore, although land reclamation offers a practical option to cope with climate change and SLR, before taking any reclamation policy or practical application it is important to take into account the social, ecological, engineering, and economic issues (Brown *et al.,* 2023).

4. Conclusions

We investigated the potential land reclamation sites, sediment transport patterns, accretion, and erosion behavior in the Meghna River estuary utilizing remote sensing techniques. Satellite observation and remotely sensed data provide invaluable information on sediment transportation and, thereby, help identify potential locations for land reclamation. Based on remote sensing data, the study depicts the source of sediment, its transportation, and its accumulation in the Meghna estuary and thereby reveals the context under which land reclamation occurred in the estuary. Coastal configuration datasets are generated from multi-temporal satellite images from 1972 to 2020 of low tide conditions and locations with progressive depositional phenomena identified through a comparison of the coastal configuration datasets. It is observed that sediment is transported into the estuary, particularly on the eastern side through high tide flow, so this could be a potential location for land reclamation. A potential location for land reclamation can be identified based on an assessment of the sediment source, sediment transport, and flow equilibrium. As mentioned in the introduction, Bangladesh reclaimed 1,000 square kilometers of new land in the Meghna estuary by building two dams in 1957 and 1964 (Alam *et al.,* 2013), but despite the success, the reclamation process was halted due to a lack of donor financing and awareness. This study will provide direction and awareness to adopt effective policy and plan for land reclamation in the Meghna estuary. Moreover, the researchers and engineers will be motivated to work more on the Meghna estuary for more precise identification of the potential locations and probability of establishment of physical structure to speed up land reclamation. Based on all factors considered and the findings, it can be concluded that the northeast portion of the Meghna estuary is undergoing a natural reclamation process.

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