Malaysian
Journal Of Civil
Engineering

Full Paper

FORMATION AND EVOLUTION OF SANDBARS IN THE PADMA RIVER, BANGLADESH

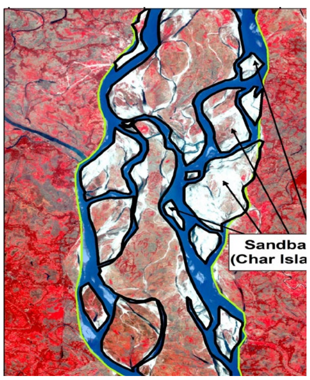
Md Sakib Hossain Talukder[a*] Md Sameer Hossain Talukder[b], Md. Tarequl Islam[b]

[a]Department of Civil Engineering, Military Institute of Science and Technology, Mirpur Cantonment, Dhaka, Bangladesh
[b]Department of Civil Engineering, Bangladesh University of Engineering and Technology, Azimpur, Dhaka, Bangladesh

Article history
Received
16 February 2024
Received in revised form
06 June 2024
Accepted
07 June 2024
Published online
01 August 2024

*Corresponding author
skn@iwmbd.org

Graphical abstract



Abstract

Sandbars are natural formations in river channels, typically composed of sand and other sedimentary particles, created by river flow and erosion-deposition The shapes, sizes, and types of these sandbars exhibit diversity depending on factors such as river flow, sediment composition, hydrological conditions, and erosion-deposition processes. These sandbars are an integral part of the river ecosystem and influence the water flow patterns, navigation routes, aquatic habitats and even provide shelter to humans and habitats. In the context of Bangladesh, there is a considerable size of population that dwell in these sandbars. The process of sandbar formation and recession is quite dynamic, and its complexity is further accentuated within the confluence zones. The Ganges, the Brahmaputra, and the Meghna River systems together form the largest delta (GBM Delta) in the world which is characterized by numerous interlaced rivers, canals, and streams. These river systems contain numerous sandbars which contribute to its complex river morphology. These sandbars are home to many people, animals, and wildlife. However, the dynamic nature of sandbars, high monsoon discharge, flooding and erratic erosion-deposition patterns make the sandbar formation and recession process quite unpredictable and puts the lives of people living on it in danger. This paper aims to study the morphological changes in sandbars, the erosion-deposition patterns within these river systems causing the sandbar formations, compare the sandbar formations in the two confluence zones of the Padma River, determine the changes in water-sandbar surface area ratio, visualize the evolution of sandbars, and quantify the movements of sandbars. The study revealed that over the past two decades (1990-2010), the main channel of the river was dominated by sandbar area. In contrast, in the past 7 years (2016-2022), the average surface area of water within the main channel of the Padma River was approximately 73,387 ha while the sandbars covered an area of around 51,274 ha, highlighting the recent dominance of water in the main channel. Conversely, in a similar time frame (2016-2022), at the two confluence zones of the Padma River, the average surface area of sandbar was greater than that of water within a 30km radial distance from each confluence node. At the upstream confluence (Padma-Jamuna-Ganges), the average surface area of sandbars was approximately 40150 ha while water covered an area of around 28531 ha. Similarly, at the downstream confluence (Padma-Meghna), sandbars covered an area of 43696 ha on an average while water covered an area of around 40889 ha. This showed that sandbars have been rapidly accumulating at the two confluence zones. It is also observed that the sandbars are very dynamic as both lateral and longitudinal migrations are observed. It is however evident that the littoral sandbars are more stable compared to the medial sandbars and therefore more suitable for habitation. From visual inspection it is evident that the bankline of the medial sandbar (Amirabad) shifts more rapidly compared to the littoral sandbar (Harirampur within the period from 2016 to 2022. Additionally, the coefficient of variation of area for the littoral sandbar and the medial sandbar are approximately 2.11% and 5.37% respectively. This indicates that the area of the littoral sandbar is more stable over the years compared to the medial sandbar as it has a lower coefficient of variation and therefore is less active. Over the years, the confluence nodes on either side of the Padma River have constantly shifted due to rapid sandbar accumulation. Between 1990 and 2022, the maximum shifting of the upstream and downstream confluences reached approximately 7500 meters and 18000 meters respectively, both in the southeast direction.

Keywords: Sandbar, Padma River, confluence, erosion-deposition processes, migration

1.0 INTRODUCTION

The Ganges, the Brahmaputra, and the Meghna River systems together form the largest delta (GBM Delta) in the world which is characterized by numerous interlaced rivers, canals and streams alongside a relatively flat terrain (Ullah et al., 2010). The Padma and Jamuna rivers are two of the most important rivers of Bangladesh due to their significance in water navigation, crop irrigation, fishing, and freshwater supply in the downstream areas (Islam, 2009). The Padma River is about 100km long and flows in the southeast direction from the Jamuna-Ganges confluence and joins the Upper Meghna River at Chandpur (Rafi et al., 2018). The GBM Delta (Bangladesh and India) is home to more than 130 million people making it one of the most populous deltas (Rahmanet al., 2020). This rapidly growing population is one of the major problems in Bangladesh as the growth in resources struggle to keep pace with the growth in population (Haqueet al., 2012). This population strain has led to the migration of people to the sandbar or char islands which are common features in Bangladesh (Sarker et al., 2003). Owing to the erosion-accretion process, medial sandbars are formed in the braided rivers like the Brahmaputra and Jamuna as well as the meandering rivers within the main river (Ullah et al., 2010). These sandbars are the result of high sediment load of the rivers, and these riverine and silt landmasses are known as char in Bengali (Kelly& Chowdhury, 2002). Sarker et al. (2003) further revealed that around 600,000 people live on these sandbars that have been created by the erosion-accretion process of the braided rivers like the Jamuna. The Padma which is a braided river by nature creates sandbars within its channels due to variations in the erosion and deposition patterns along its banks (Billah, 2018). Both the Jamuna and the Padma Rivers are susceptible to riverbank erosion which leads to the deposition of sandbanks (char islands) (Islam, 2009). The incessant erosion and deposition process leads to the formation of new lands that are not geographically attached to the mainland which make them vulnerable to floods, drought, and river erosion (Kabir, R. D. 2006). The study by (Sarker et al., 2003) also states that these chars are loosely connected to the mainland and are susceptible to erosion-accretion and flooding which make the inhabitants feel vulnerable.

The accumulation and recession of sediment particles are especially important in the confluence zones since it has been observed that sediment particles have been rapidly accumulating in the upstream channels of both the confluences of the GBM delta (the Padma–Meghna and Ganges–Jamuna confluence) (Gazi et al., 2020). The formation of these char islands might be a result of a range of characteristic confluence zone sedimentology (Dixon et.al. 2018). These confluences form very complex fluvial networks formed by the combination of water and sediment with flow strength of the rivers (Shit& Maiti, 2013). The upstream-downstream movement of these confluences are influenced by the deposition of sediment wedges (sandbars) from the sediment laden tributaries (Dixon et al., 2018).

River water is a vital resource for this char-land life and ecosystem, governs the economic growth, cultural exchanges, and environmental development plans. (S. N., Singh, S., Shaheed, H., & Wei, S., 2010). The study by (Kabir, M. H et.al. 2020) further expressed concern regarding the scarcity of both the quantity and quality of surface water in Bangladesh.

1.1 Objectives of the Study

The aim of this research is to quantify the sandbars formed in the Padma River and its confluence zones, compare the changes in surface area of water and sandbar, visualize the evolution of sandbars, and observe the movements of sandbars. To achieve the aforementioned goals, the following efforts have been made in his paper:

- To estimate the surface area of sandbars formed in the Padma River
- To estimate the amount of surface area of sandbars formed within a radial distance of 30 km from the two confluence nodes namely the Padma–Meghna confluence and the Ganges–Jamuna confluence
- To determine the water-sandbar surface area ratio of the Padma River and its confluence zones over the years
- To visualize the evolution of sandbar formation
- To compare migration and land area change between a medial and littoral sandbar
- To analyze the shifting of the confluence points due to sandbar formation and recession at the confluence zones.

2.0 METHODOLOGY

2.1 Study Area

The study area for this research lies within a part of the GBM (Ganges-Brahmaputra-Meghna) delta with primary focus on the Padma River and the confluence zones which it shares with the Jamuna and Ganges rivers upstream and the Meghna River downstream. The Jamuna River flowing through the Pabna and Tangail districts, is highly braided with numerous char lands or sandbars and meets the Ganges River which enters Bangladesh through the western international boundary from India (Rahman, 2023). The Ganges flows through Chapai-Nawabganj, Rajshahi, and Pabna districts and meets the Jamuna River at the upstream confluence zone of the Padma River (Arefin et al., 2021).

The Padma River flows through the districts of Rajbari, Faridpur, Madaripur, Shariatpur, Chandpur, Munshiganj, Dhaka and Manikganj and ultimately meets the Meghna River at Chandpur. Here the Padma at the downstream confluence zone meets the Upper Meghna and falls into the Lower Meghna River which flows into the Bay of Bengal (Ritu et al., 2023). The general flow direction of these rivers is from the north to south. The estimated length of the Padma River is about 120 km, and its width varies from 4 km to 8 km along its course. The study area is located between latitude 22°0'0''–25°0'0''N and longitude 88°0'0''–92°0'0''E as seen from Figure 1.

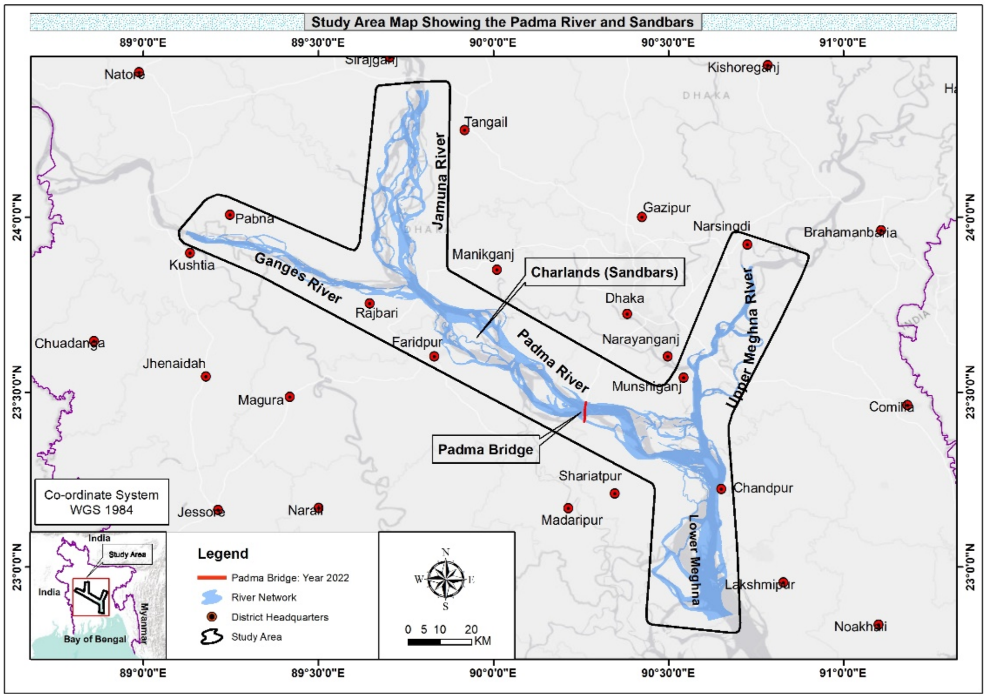


Figure 1 Map of the study area showing the Padma River and its confluence zones

2.2 Rainfall, Discharge and Climatic Condition of the Study Area

Characterized by the Ganges River System, the average annual discharge of the Padma River is estimated to be around 35,000 m^3/s with the depth of the river varying from anywhere between 20 m to 21 m and annual silt load of around 492 tons/km^2 (Billah, 2018). As expected, the discharge is maximum during the monsoon and the average discharge might decrease by as much as 76.3% and 75.7% during the pre-monsoon and post-monsoon periods respectively in the Baruria Transit Station (Mahmud et al. 2018). In terms of precipitation, the Padma River experiences a mean annual rainfall of about 2000 mm and

About 70% of which occur during the monsoon period accompanied by an average temperature which ranges from 25.5°C to 26°C in the area (Hassan and Akhtaruzzaman, 2010).

2.3 Data Collection Methods and Data Specifications

The research was carried out using secondary data. Data was collected from United States Geological Survey (USGS), WorldPop, and Bangladesh Bureau of Statistics (BBS). To analyze the data, Geographic Information System (GIS) and Remote Sensing Techniques were used. High resolution satellite images are free to download from USGS for research purposes. Both Landsat-8 and Sentinel-2 Satellite images were downloaded from USGS. To ensure detailed analysis of data, a total of 11 images were downloaded for the years 1990, 2000, 2010, 2020, 2016, 2017, 2018, 2019, 2020, 2021, 2022. Landsat-8 images are produced through the collaboration of NASA (National Aeronautics and Space Administration) and USGS. Landsat-8 uses 2 sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The spatial resolution of Landsat-8 images varies between 15 m panchromatic images (Sensitive to all the visible colors of the spectrum) and the 30 m multi-spectral images. For this research, Landsat-8 images of 30 m spatial resolution were used. On the other hand, Sentinel-2 images provide a good balance between spectral bands and the optimal resolution. The sensor used by Sentinel-2 images is the Multispectral Imager (MSI) whose spatial resolution varies between 10 m and 60 m. For this research, however, Sentinel-2 images of 30 m spatial resolution were used.

Multiple images for the same year were downloaded in some cases to account for the fluctuating water levels. The images were checked for distortion before processing. It was ensured that the selected images were mostly cloud free so that the terrain and the geographical features were clearly visible. All the images used for this research were collected during the dry season between the months of December and February. This helped to delineate the bank lines of the river and sandbars (char islands) with accuracy which otherwise would be quite perplexing if images during rainy season were used when the water level increases, and the river swells up leading to the overestimation of the overall surface area of the river. The images obtained from USGS were in the GeoTIFF format. These GeoTIFF files were directly added to the ArcGIS software and subjected to post processing. The individual bands of the images were made composite using the ArcGIS software and the best possible combinations were chosen ensuring best terrain visibility. The detailed specifications of the used data have been tabulated below in Table 1 and the sources of population data have been tabulated below in Table 2.

2.4 Delineation of the Bank Lines of the Sandbars and Rivers

Using the ArcGIS software, the riverbank lines and the sandbars were delineated keeping the processed images on the background (Figure 2). The on-screen digital zoom used in the ArcGIS software was 1:30,000. The Bankline of the rivers was delineated beyond the two confluence zones of the Padma River (Figure 3). Both the vegetative islands (Reddish color) and the non-vegetative islands (Whitish color) were delineated as seen from Figure 2. Hence, the Sandbar (Char Island) estimation will include both the vegetative islands and the non-vegetative islands.

2.5 Choice of The Co-ordinate System

Some of the popular co-ordinate systems in the world are the World Geodetic System (WGS) and the Universal Transverse Mercator (UTM). The former system (WGS) uses Degrees as its unit while the latter (UTM) uses meters as its unit. However, Bangladesh falls between two UTM zones namely UTM 45 North and UTM 46 North. Thus, to avoid complexity, the projected co-ordinate system Bangladesh Transverse Mercator (BTM) has been used here. BTM co-ordinate system eliminates the issue of having to deal with multiple zones while measurement unit remains in meters which is convenient and easy to understand.

2.6 Determination of the Confluence Node and Selection of Area of Analysis Around the Confluence Node

In a multi-channel river like the Ganges-Jamuna-Meghna River system, channel migration, bifurcation or avulsion within a braided belt may lead to confluence migration. Both the Padma-Jamuna-Ganges confluence and the Padma-Meghna confluence are highly dynamic due to the morpho-dynamic processes and the formation and recession of sandbars at these confluences which according to (Yuan et al., 2022) happens due to the convergence of streams which produces complex mechanism of flow momentum and mass mixing six (6) times the width the respective channels and allows for investigation of sandbars around the surrounding districts.

.

Table 1 Detailed specification of the Landsat and Sentinel Images used for the study

Type of Image	Scale	Spatial resolution (m)	Image Sensor	Date of collection
Sentinel-2	1: 30,000	30	MSI	January 1990
Sentinel-2			MSI	January 2000
Sentinel-2			MSI	March 2010
Landsat-8			OLI	December 2016
Landsat-8			OLI	October 2017
Landsat-8			OLI	December 2018
Landsat-8			OLI	November 2019
Sentinel-2			MSI	November 2020
Landsat-8			OLI	December 2021
Landsat-8			OLI	December 2022

Table 2 Sources of Population Data

Data Type	Sources	Description	Website
Population	WorldPop	Population Count	https://www.worldpop.org/
Population	The Bangladesh Bureau of Statistics (BBS)	Population Count	http://www.bbs.gov.bd/

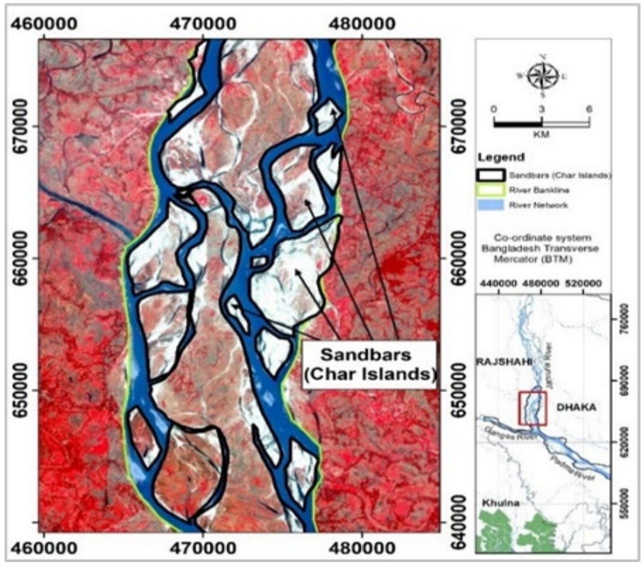


Figure 2 Map Showing the Delineation of Sandbar and River Banklines from Close Proximity

The confluence node is the point which the center lines of the rivers meet. Center Lines were drawn through the mid channels of all the rivers and the point at which the center lines of these rivers met were regarded as the confluence nodes. In order to draw the center lines, a series of channel width measurements were taken at an interval of 50 m until distance of 3 channel width (W) upstream of the junction (Jamuna River for upstream confluence and Upper Meghna River for downstream confluence) is reached (Hackney & Carling, 2011). A distance of 3W ensures that the changes near the confluences are taken into account. (Miori, S., Repetto, R., & Tubino, M. (2006)). However, for braided rivers like the Jamuna or Ganges, it is very difficult to identify the main channel due to the prominence of sandbars. As a result, the widest channel leading to the confluence node has been chosen as the main channel. As seen from Figure 3, the position of the widest channel in the Padma River shifts with time. The widest channel in 1990 occupies the northern side of the Padma-Meghna confluence while it occupies the southern part of the confluence in the year 2010 (Figure 3).

Another interesting finding after analyzing the satellite images was that it seems that sandbar formation and recession process is more pronounced around the confluence zones of the Padma River as also found by the study of (Yuan et al., 2022). To analyze this observation, a circle with a radius of 30 km is drawn from the confluence nodes of the respective years (Figure 3). A radial distance of 30 km has been chosen which is approximately equal to six

For the Padma-Ganges-Jamuna confluence, Rajbari, Manikganj and Faridpur districts fall within the range of 30 km while for the Padma-Meghna confluence, Shariatpur, Chandpur and Munishuganj districts fall within the range of 30 km (Figure 3). For both the confluences, a common radial distance of 30 km has been chosen to maintain harmony and for the sake of comparison between the two confluences. Then, the surface area of the sandbars is estimated within that radial distance of 30 km after delineating the sandbar banklines and it is stacked up against the surface area of water within the same extent. The process is repeated for both the confluences (Padma-Ganges-Jamuna and Padma-Meghna confluence) and the two are compared to investigate the accumulation and recession of sandbars at these confluences. 30 km radial distance from the confluence node seems to strike an ideal balance between investigation of confluence zone effects and the number of districts affected due to the phenomenon.

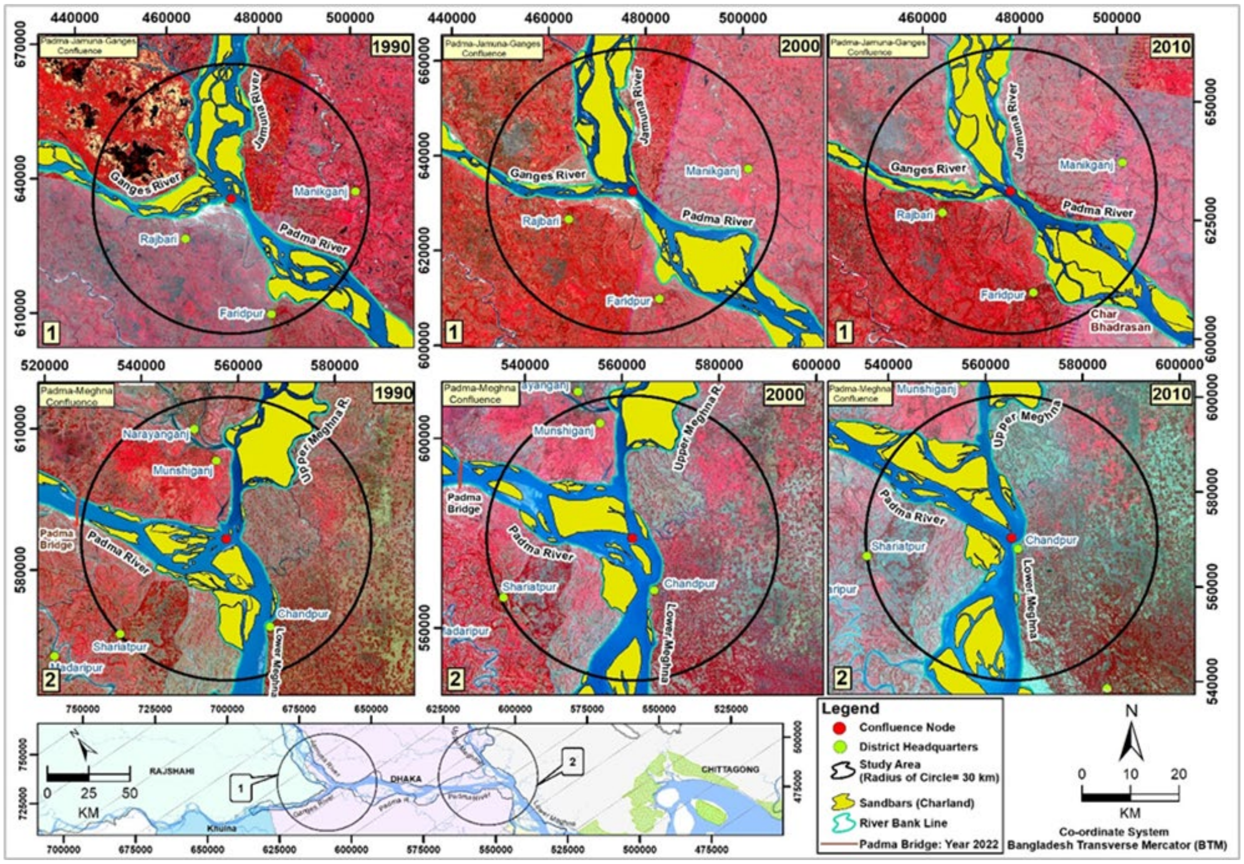


Figure 3 Sediment accumulation & recession within 30 km radial distance from two confluence nodes

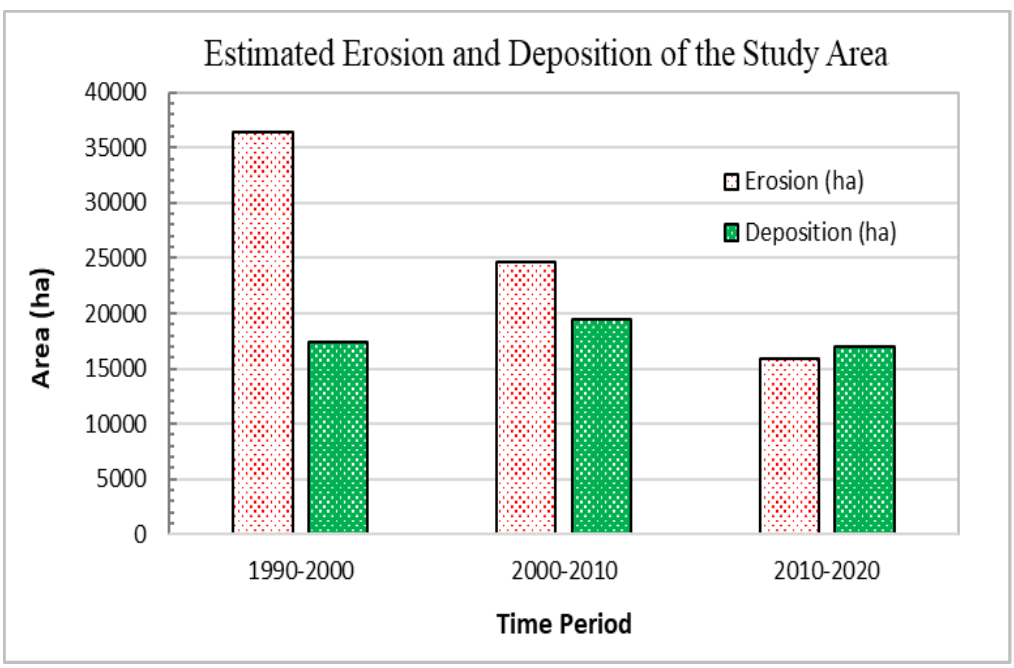


Figure 4 Erosion and Deposition in the past 30 years within the Study Area

3.0 RESULTS AND DISCUSSION

3.1 Estimation of Erosion-Deposition Within the Study Area that Leads to Sandbar Formation

As mentioned earlier, the sandbars are formed due to the erosion-deposition process of the riverbank lines. The Jamuna and Padma are braided (Contains network of many channels) rivers due to their high sediment loads owing to the deposition of sandbanks. These rivers are susceptible to riverbank erosion and deposition which leads to the formation of new lands that are not geographically attached to the mainland (Figure 2) and are known as Chars in Bengali (Sarker et al., 2003).

The estimated amount of erosion-deposition within the study area (Figure 4) at an interval of 10 years ranging from 1990 to 2020 is presented in a tabular form below in Table 3.

Table 3 Estimated erosion-deposition within the study area

Duration	Erosion (ha)	Deposition (ha)	Net Land Loss/Gain (ha)
1990-2000	36461	17343	-19118
2000-2010	24607	19513	-5094
2010-2020	15848	16979	1131

Note: Positive sign (+ve) indicates accretion or land gain and negative sign (-ve) indicates erosion or land loss

It is observed that the features of the Padma River and some reaches of the Jamuna, Ganges and Meghna River suffers from severe erosion and deposition process (Table 3). It is further observed that, during the last 30 years (1990-2020), severe erosion and deposition has taken place within the study area. The least amount of erosion amounted to approximately 15800 ha while the highest erosion amounted to approximately 36400 ha. Even though the amount of deposition was lower compared to the amount of erosion in the same time frame, a significant amount of deposition was observed with the value maxing out at approximately 19500 ha and a minimum of approximately 17000 ha (Figure 4). Hence, it can be concluded that the rivers suffer from huge amounts of erosion and deposition. Another major finding happened to be that erosion and deposition was prominent along both banks of the river as seen in Figure 5 below. It is further observed that the erosion process follows a decreasing trend whereas the deposition process follows no such trend. The amount of land deposited at first increases between 2000 and 2010 and then decreases within the next decade between 2010-2020 (Figure-5). It is also seen from Figure 5, that the erosion-deposition process is prominent throughout the entire reach of the study area. (Dewan et al., 2017). This might explain the formation of numerous sandbars (char islands) within these rivers and their braided nature. This is because in alluvial channels, sandbars are formed by a cyclic process of sedimentation and scouring and are continuously modified by eolian and fluvial processes. (Moteki et al., 2023) (Sweeney et al., 2019).

3.2 Comparison of Water and Sandbar Surface Area of the Padma River

The main channel of the Padma River is blocked by numerous sandbars known as chars (Reza et al., n.d.). The sandbars consist of both stable islands with human settlement that always remain above water and islands that go under water during high stage of the river (Islam et al., n.d.) . Hence, a long-term statistical analysis of the amount of surface area of sandbar and water of the Padma River is required to understand the trend of accumulation or recession of sandbar surface and its proportion to the water surface area. Hence, the entire reach of only the Padma River was delineated as seen Figure 5. It is observed that, the total amount of sandbars (Both stable islands and those submerged during high stage of river) has decreased over the years from 1990 to 2022 (Figure 5) and the extent of which is shown in Figure 6.

The surface area of sandbars (measured in hectares) was the highest in 1990 amounting to approximately 71,000 ha. The value decreases in the year 2000 to approximately 61,500 ha and again increases in 2010 reaching approximately 68,200 ha. From 2010 to the year 2016, the surface area of sandbar experiences a significant drop to approximately 51,000 down from 61,500 ha of 2010. Then, between 2016 and 2022, the surface area of sandbars remains steady (Figure 7). The average surface area of sandbars between 2016 and 2022 was approximately 51,200 ha. However, it is observed that the amount of water surface area actually increases within the similar time frame. The water surface area was approximately 54,600 ha in 1990. The value increased to approximately 58,800 ha in the year 2000 and again decreased to approximately 53,500 ha in 2010. From 2010 to the year 2016, the water surface area increased significantly reaching approximately 70,000 ha (Figure-7). Between 2016 and 2022, the water surface area remains steady. The average water surface area between 2016 and 2022 was approximately 73,400 ha.

The water-Sandbar surface area ratio (Surface area of water/Surface area of sandbar) increased within the study period. The value of the ratio was 0.77 in 1990 but since 2016, the value has constantly exceeded 1.00 with the highest value observed in 2022 (1.61) and the lowest value of 1.29 observed in 2020 (Figure 8). It shows that the water-sandbar surface area ratio has been following an increasing trend in the Padma River within the study period signifying the dominance of water surface area over the sandbar surface area in recent years. The separation of land and water surface is possible utilizing the multispectral band data where the riverbanks are manually digitized to effectively display the river channels at normal water level (Dewan et al., 2017).

3.3 Water-Sandbar Surface Area at the Confluence Zones

As mentioned earlier, the water and sandbar surface area has been estimated within a radial distance of 30 km with the confluence node at its center (Figure 3).

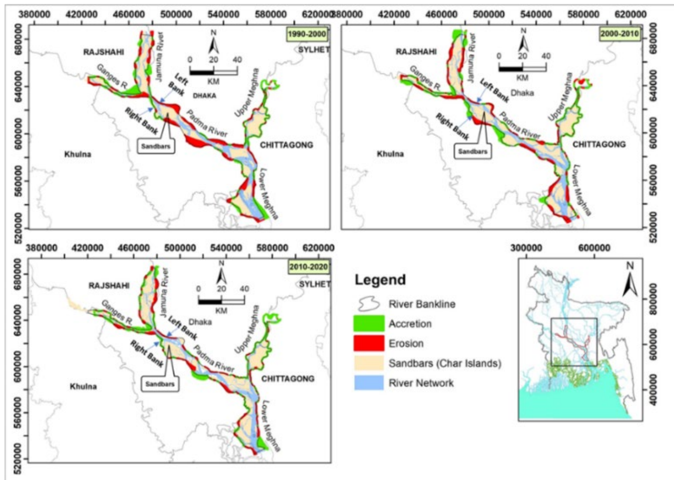


Figure 5 Map Showing the Severe Erosion-Deposition Process of the River Systems within the Study Area

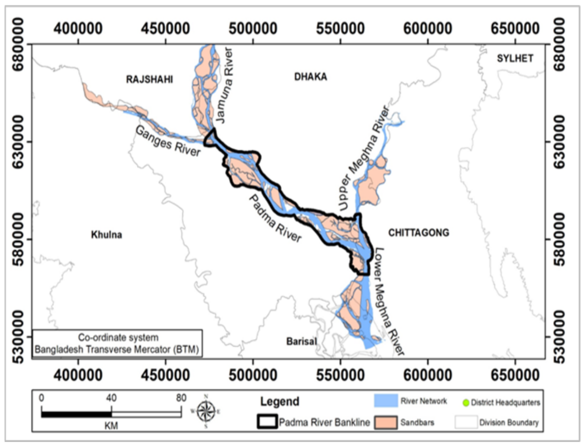


Figure 6 Map Showing the Extent of the Padma River

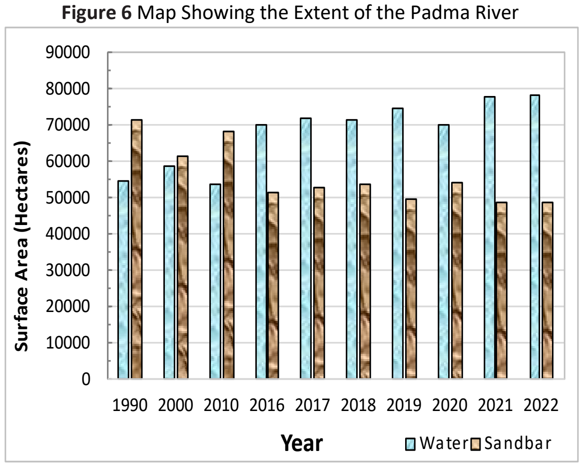


Figure 7 Estimated Water and Sandbar Surface Area within the Padma River

It is observed that, for the Padma-Jamuna-Ganges Confluence node, the sandbar surface area dominates the water surface area across the entire study period (Figure 8) except the year 1990 where the water and sandbar surface area are almost equal. For the Padma-Jamuna-Ganges Confluence, the estimated sandbar surface area within a radial distance of 30 km from the confluence is shown in Figure 9.

It is quite clear from Figure 9; the sandbar surface area dominates water surface area. At the same time, rapid accumulation of sandbars is observed at the upstream confluence of the Padma River (Figure 3). As for the Padma-Meghna Confluence, the estimated sandbar surface area for the years within a radial distance of 30 km from the confluence node are shown in Figure 10. Unlike the Padma-Jamuna-Ganges confluence, the water and sandbar surface area are quite close to each other in the Padma-Meghna confluence as seen from Figure 10.

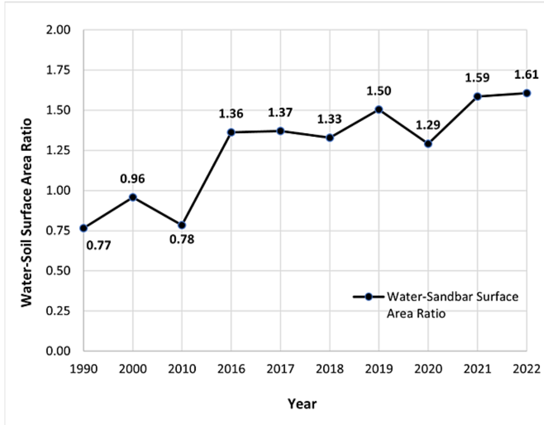


Figure 8 Water-Sandbar Surface Area Ratio of the Padma River over the years

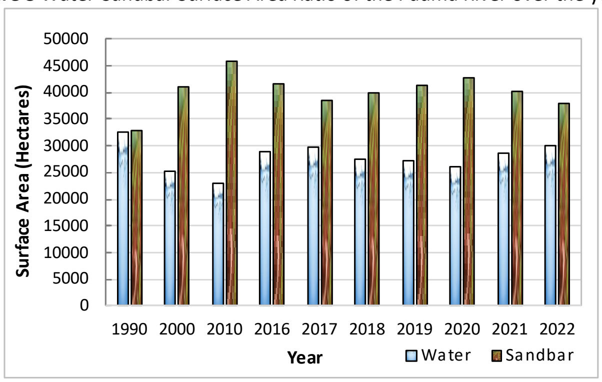


Figure 9 Estimated Water and Sandbar Surface Area within 30 km radial distance from the Padma-Jamuna-Ganges Confluence Node between 1990 and 2022

This shows a clear divide between the water and sandbar surface area between the two confluences. The conclusion is corroborated when the water-sandbar surface area ratio is compared between the two confluences (Figure 11). The upstream confluence (Padma-Jamuna-Ganges Confluence) maintains a water-sandbar ratio that is close to 1.00 over the years (1990-2022) which indicates that the amount of water and sandbar surface area are almost equal within the aforementioned extent (Figure 11). However, at the downstream confluence (Padma-Meghna Confluence), the water-sandbar ratio is constantly below 1.00 within the same time period which indicates that the estimated amount of sandbar surface area significantly exceeds the water surface area within the chosen extent as mentioned earlier. Hence, it can be concluded that there are significant differences between the water-soil interactions and proportions between the two confluences.

3.4 Comparison of Sandbar Surface Area between the Two Confluence Zones

Despite the significant differences in the water-sandbar surface area ratio between the two confluences, it is seen that the estimated amount of surface area of the two confluences is comparable within the same extent (within 30 km radial distance from their respective confluence nodes) as seen from the Figure 12.

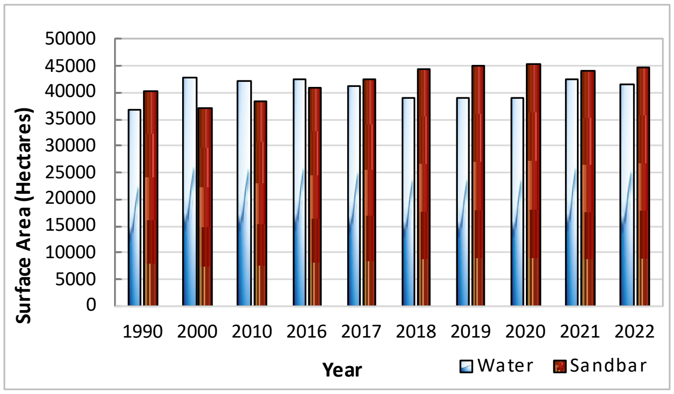


Figure 10 Estimated Water and Sandbar Surface Area within 30 km radial distance from the Padma-Meghna Confluence Node between 1990 and 2022

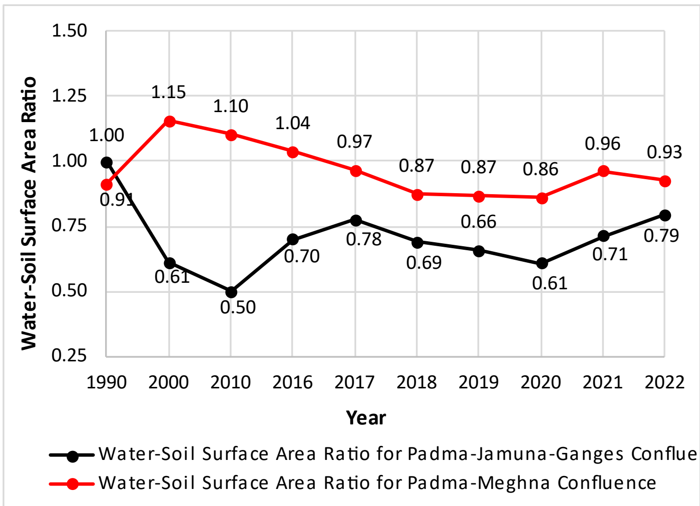


Figure 11 Comparison of Water-Sandbar Surface Area Ratio between the two Confluence Zones of the Padma River

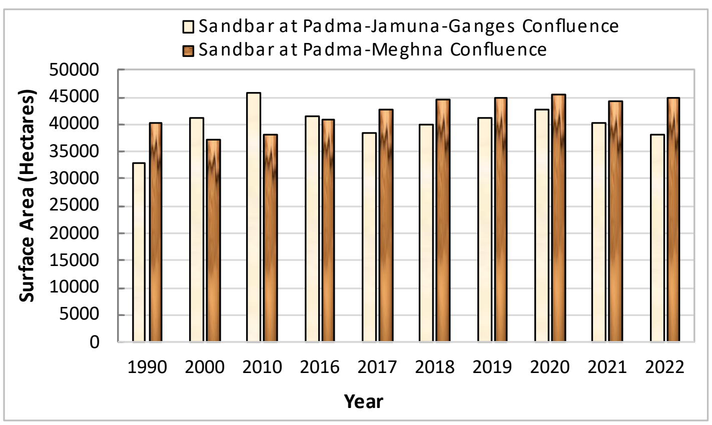


Figure 12 Comparison of the Estimated Amount of Sandbar Surface Area within 30 km Radial Distance from either Confluence Nodes of the Padma River

3.5 Visual changes of Sandbar Shifting Near the Confluence Zones of the Padma River

The Padma, being a braided river, undergoes frequent changes in its planform almost every year. As the river erodes one bank, it deposits silt on the other, facilitating this dynamic process of erosion and accretion. The movement of char-lands can take place gradually, but it can also take place in the form of avulsion, which is the sudden change in the location of a channel that can occur during a single flood event. Chars are dynamic features that may undergo movement both spatially and temporally. Also, the height of char-lands above low or normal water levels is influenced by the variation in water levels depending on the season such as the chars may go underwater during monsoon (Islam et al., n.d.).

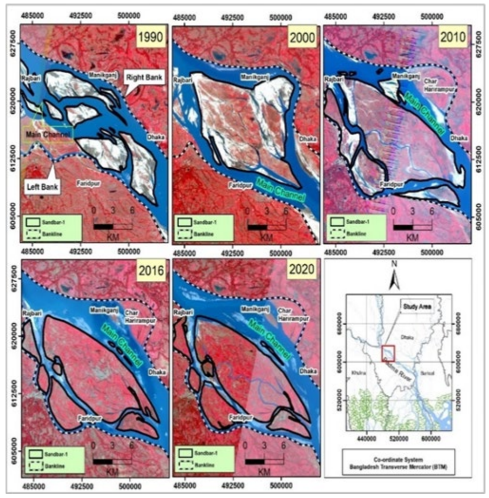


Figure 13 Formation and Evolution of Sandbars at the Upstream of Padma River

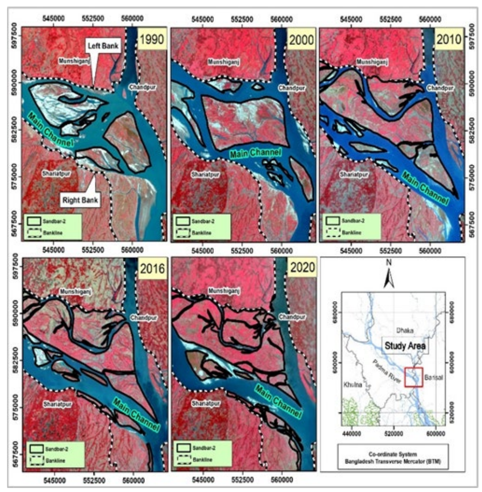


Figure 14 Formation and Evolution of Sandbars at the Downstream of Padma River

In this study, the formation processes, and visual changes of the sandbars in two locations are studied. The sandbars located just downstream of the Padma-Jamuna-Ganges confluence in the Faridpur, Dhaka and, Manikganj districts are designated as "Sandbar-1" as shown in Figure 13 and the sandbars located just upstream of the Padma-Meghna confluence located in the Faridpur, Dhaka and Manikganj districts are designated as "Sandbar-2". Settlements are found in both of these sandbars.

Figure 13 depicts the planform change of Sandbar-1 using Landsat images of the years 1990, 2010, 2016, and 2017. Only a portion of discreet sandy chars is seen in 1990. However, the chars became much more prominent between 2000 and 2010 during which, char formation process accelerated to form char-lands of larger areas. Further changes of the shape can be observed in Sandbar-1 from the satellite images of 2016 and 2020. Moreover, the main channel of the Padma River within this study area was seen to flow along the Right Bank of Padma River (Faridpur district) in 1990 and 2010 (Figure 13). The main channel, however, seems to have shifted towards the Left Bank of the river (Manikganj district) as seen from the satellite image of 2010.

For Sandbar-2, Figure 14 demonstrates the planform change of Sandbar-2 using Landsat images of the years 1990, 2010, 2016, and 2017. Only discreet sandy chars are seen in 1990. With time, char formation process accelerated to form charlands of larger areas as seen from the image of 2010. Further changes of the shape can be observed in Sandbar-2 from the satellite images of 2016 and 2020 where, the charlands have become much more prominent with further increase in surface areas. In this case, the main channel of the Padma River has not shifted its location and is seen to flow along the Right Bank of Padma River (Shariatpur district) from 1990 to 2020 (Figure 14).

3.6 Longitudinal and Lateral migration of Sandbars

To perceive the dynamics of such large-scale sandbars, two important large sandbars containing settlements have been chosen for investigation. Satellite images have been used to calculate both longitudinal and lateral migration of the sandbars between 2016 and 2022. Char Bhadrasan near upstream confluence and Char Amirabad in the middle of the main channel has been assessed in this study. The longitudinal migration was measured from the head end of 2016 sandbar towards the downstream direction while the lateral migration was measured from the center line of 2016 sandbar towards the western direction. Lateral migration was calculated from the midpoint of the center line of 2016 sandbar. The distance between the mid points of the sandbars in their respective years from the reference sandbar 2016 gave the estimated lateral migration of sandbars. A schematic diagram has been provided below in Figure 15 to demonstrate the longitudinal and lateral movements of both sandbars.

It is observed that the sandbars are moving longitudinally towards the downstream direction. The distance travelled by the head end of the sandbar is used to calculate the longitudinal movement in the downward direction between the consecutive years. The estimated longitudinal migration of both sandbars is tabulated in Table 4.

Between 2016 and 2022, the longitudinal migration of sandbars Bhadrasan and Amirabad are tabulated In Table 4 and Table 5 respectively. While it is observed that initially sandbar Amirabad had the lead in longitudinal migration, sandbar Bhadrasan is significantly more active in the later stages which leads to a higher overall rate of year-on-year movement. The range of movement is also higher for sandbar Bhadrasan compared to sandbar Amriabad. Sandbar Amirabad is in the middle of the Padma River and as seen in Figure 15, Amriabad is closer to the Padma multipurpose bridge and bank protection works were carried out in the vicinity of this sandbar along the western coast. Over the past decade, erosion dominates deposition near sandbar Bhadrasan while deposition dominates erosion in the vicinity of sandbar Amirabad (Figure 15)(Dewan et al., 2017).

Distinct differences are found between the longitudinal migration patterns of sandbar Bhadrasan and Amirabad from 2016 to 2022 as shown in Figure 16. Bhadrasan exhibited more dramatic movements with significant increases in the year 2018 and 2021 with an increase of approximately 1125% (245 meters) and 194.74% (2016 meters) from their respective pervious years averaging 358 meters of downward movement annually. In contrast, Amirabad showed more consistent changes with an increase in downward movements of 171.38% (729 meters) in 2018 and 66.93% (1721 meters) in 2021 from their respective prior years averaging an annual rate of 292 meters of longitudinal downward movement per year. However, Bhadrasan has a wider range of annual movements, from 20 to 1332 meters compared to Amirabad's 30 to 690 meters from 2016 and 2022. These differences are crucial as it demonstrates the sandbars near the confluence are exhibiting erratic longitudinal downward migrations compared to the sandbars in the middle of the main channel. As for the lateral migrations (Table 6), while both sandbars exhibit annual variations in lateral movements, greater fluctuations are observed in the movement of Bhadrasan with significant percentage changes of 146.88% increase in 2020 and a -49.36% decrease in 2018 from their respective previous years. In contrast, Amirabad follows a more consistent pattern with major increases in 2018 (36.53%) and 2021 (30.56%) but also experiencing a substantial decrease in 2020 (-38.62%) which indicates overall greater stability in terms of lateral shifts. The comparison of Lateral migration between Bhadrasan and Amirabad Sandbar is shown in Figure 17.

Therefore, in both cases it is found that the sandbar near the upstream confluence (Bhadrasan) is more active and less stable compared to the sandbar in the middle of the Padma River (Amirabad). These findings are in conformity with the findings of (Dewan et al., 2017) where they found that the movement of these sandbars is a common phenomenon and the bank lines even shift in the range of a few kilometers per year.

3.7 Comparison between a peripheral sandbar (Char Harirampur) and a medial sandbar (Char Amirabad)

Char Amirabad is a medial sandbar located in the center of the channel of the Padma River and Char Harirampur is a peripheral sandbar located near the channel bank. A comparison is made between these two types of sandbars to compare the morpho-dynamics of the sandbars in relation to their positions within the channel. Settlements are found on both sandbars.

Charland boundaries for the years 2016 to 2022 have been delineated using ArcGIS software and superimposed to observe the shifting of char-lands (Figure 18). From the figure, it is seen that the Medial Sandbar (Char Amirabad) has undergone frequent morphological changes compared to the Littoral Sandbar (Char Harirampur) which is comparatively much more stable within the time period of analysis (2016-2022). Char Amirabad is seen to have experienced greater morphological changes such as erosion-deposition and migration movements. This is further validated by the change in areas of the charlands. The changes in areas of the charlands over the years are represented in a tabular form in Table 7 and graphically represented in Figure 19. Also, the coefficient of variation (CV) of char area was calculated using the formula:

$$CV = \frac{\sigma}{\mu} \quad (1)$$

σ = Standard deviation, μ = mean;
for the littoral sandbar and the medial sandbar are approximately 2.11% and 5.37% respectively which shows greater stability of the littoral sandbar.

Table 4 Changes in the Longitudinal migration of Bhadrasan Sandbar

Sandbar Bhadrasan				
Year	Longitudinal migration of Sandbar (m)	Year on Year Movement (m)	Range of Movement (m)	Rate of Movement (m/year)
2016	0	-		
2017	20	20		
2018	245	225		
2019	650	405	20 to 1332	358
2020	684	34		
2021	2016	1332		
2022	2151	135		

Table 5 Changes in the Longitudinal migration Amirabad Sandbar

Sandbar Amirabad				
Year	*Longitudinal migration of Sandbar (m)*	*Year on Year Movement (m)*	*Range of Movement between years (m)*	*Rate of Movement (m/year)*
2016	-	-		
2017	*269*	*269*		
2018	*729*	*460*	*30 to 690*	*292.*
2019	1001	272		
2020	1031	30		
2021	1721	690		
2022	1755	34		

Table 6 Changes in the Lateral migration of Sandbars

Sandbar Bhadrasan				Sandbar Amirabad			
Year	Lateral migration of Sandbar (m)	Range of Movement between years (m)	Average migration per year (m)	Year	Lateral migration of Sandbar (m)	Range of Movement between years (m)	Average migration per year (m)
2016	0			2016	0		
2017	543			2017	841		
2018	275			2018	1148		
2019	160	91 to 543	463	2019	1274	27 to 841	1019
2020	395			2020	782		
2021	749			2021	1020		
2022	658			2022	1047		

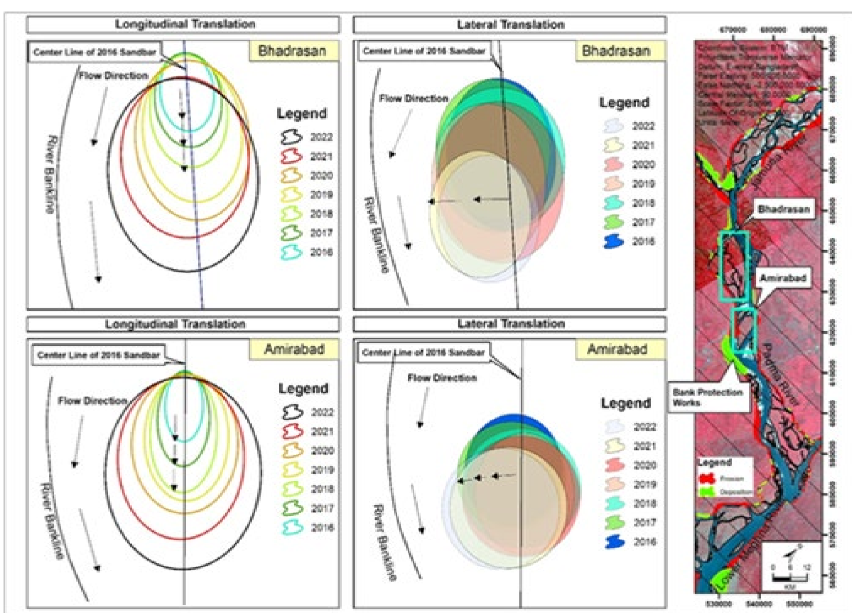


Figure 15 Schematic Diagrams Showing Longitudinal and Lateral migration of Bhadrasan and Amirabad Sandbars

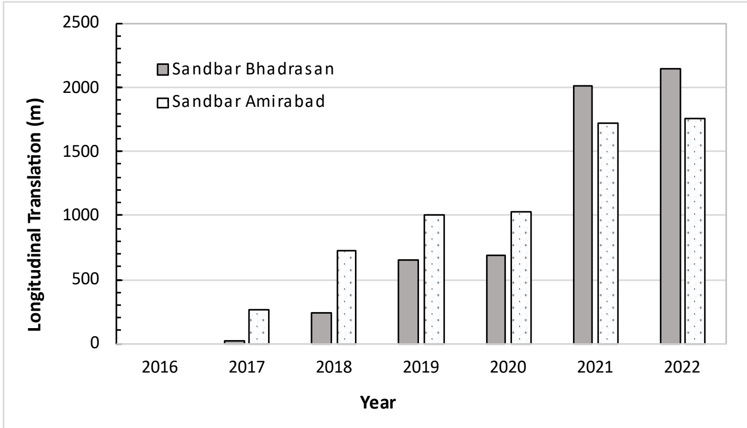


Figure 16 Comparison of Longitudinal migration between Bhadrasan and Amirabad Sandbar

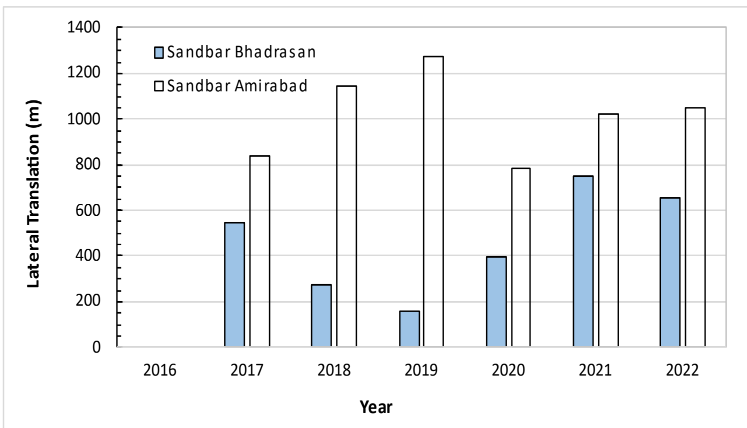


Figure 17 Comparison of Lateral migration between Bhadrasan and Amirabad Sandbar

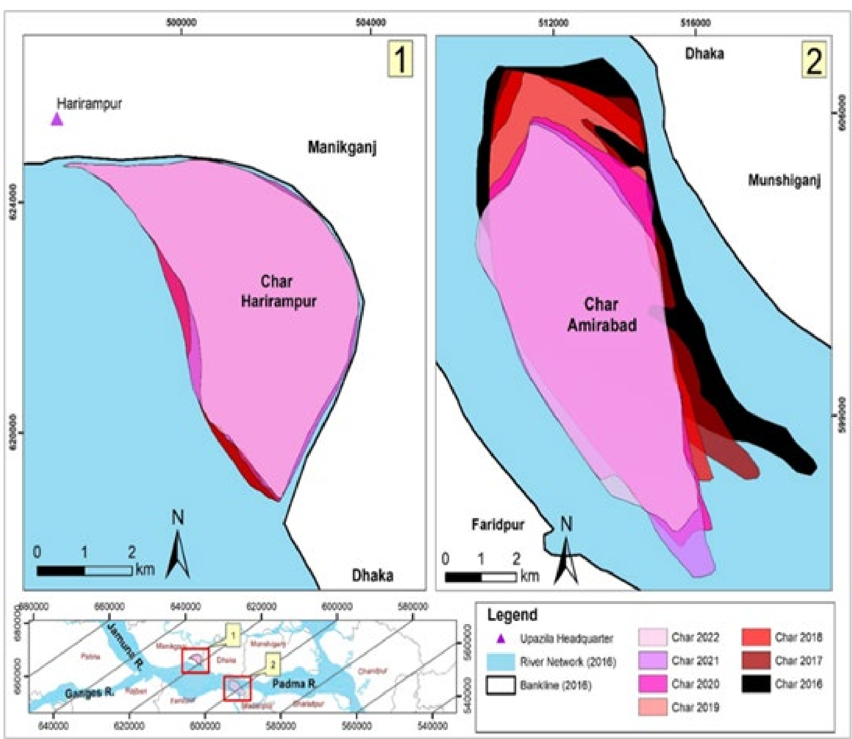


Figure 18 Bankline Shifting of Char Harirampur and Char Amirabad

Table 7: Areas of Char Harirampur and Char Amirabad over the years

Year	Area of Char Harirampur (ha)	Area of Char Amirabad (ha)
2016	1763	3608
2017	1762	3241
2018	1762	3584
2019	1743	3595
2020	1764	3276
2021	1721	3330
2022	1665	3200

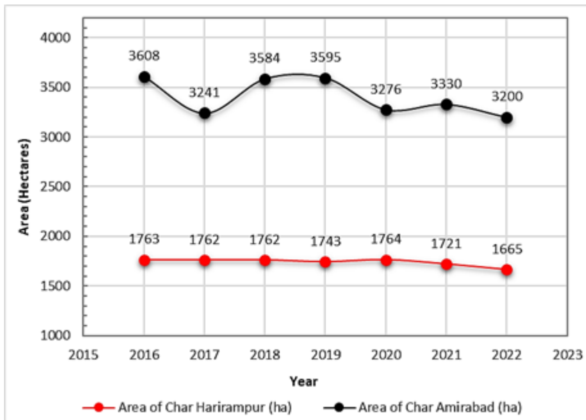


Figure 19 Comparison between the Changes in Land Area between Char Harirampur and Char Amirabad

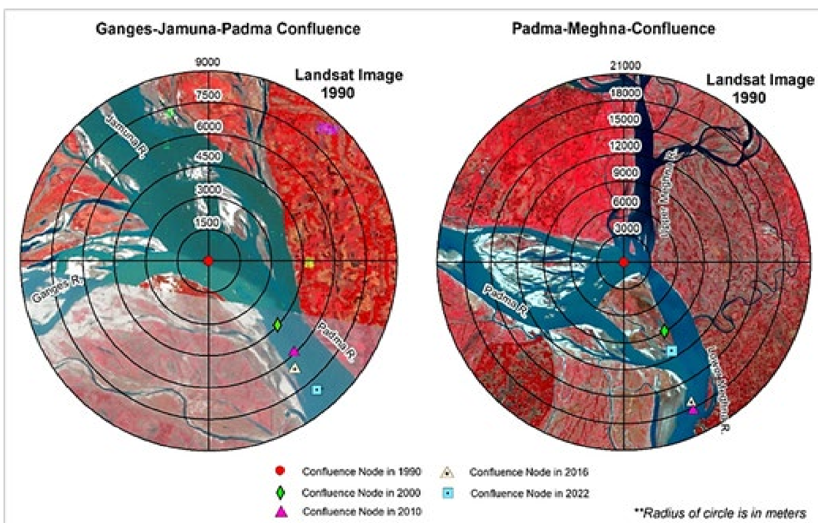


Figure 20 the Confluence Node Migration between 1990 and 2022 for both the Upstream and Downstream Confluence Nodes

Figure 19 shows that the area of Char Harirampur has not changed much over time, contrasting with Char Amirabad whose area has varied significantly over the same time period. This demonstrates the stability of Char Harirampur compared to Char Amirabad.

3.8 Shifting of the Confluence Zones Upstream and Downstream of the Padma River Owing to Sandbar Accumulation and Recession

The confluence nodes upstream and downstream of the Padma River has experienced significant shifting over the years. There are several reasons for the shifting of confluence node. It depends on the confluence zone sedimentology (Dixon et.al. 2018). The movement of the confluence is also influenced by the deposition of sediment wedges (Dixon et.al. 2018). The sediment laden tributaries form numerous sandbars at these confluence zones as evidenced by Figure-3. Hence, it is important to visualize the shifting of the confluence zones over the rivers owing to the sandbar formation and recession process and it is presented in Figure 20.

For the upstream confluence (Padma-Jamuna-Ganges Confluence), it is observed that in the year 2000, the confluence node migrated approximately 4500 m in the south-east direction from its initial position in 1990 (Figure-15). The confluence nodes further migrated about 1500 m in the same south-east direction from 2000 to 2010. Between 2010 and 2016, the confluence node further moves about 600 m south. During the next six years (2016-2022), the confluence node follows a similar trajectory as it drifts further approximately 1900 m in the south-east direction. Hence, a common trend of confluence node migration is observed in the south-east direction from 1990 to 2022 where the confluence node has migrated more than 7500 m from its initial position in 1990 to its final position in 2022 (Figure 20).

As for the downstream confluence (Padma-Meghna Confluence), it is observed that in the year 2000, the confluence node migrated approximately 9000 m in the south-east direction from its initial position in 1990 (Figure 20) which is about double the distance of the upstream confluence node had migrated over the same period. The reason for this drastic movement can be explained when the pattern of sandbar formation is observed in this confluence during that period. It is seen that the rapid accumulation and recession of sandbars at the vicinity of the confluence node in that time period has resulted in the shifting of the main channel which has led to the change in the position of the confluence node as seen from Figure 3. For the next six years, the shifting pattern continues as between 2010-2016, the Padma-Meghna confluence node drifts further south-east migrating approximately 9000 m and reaches near the headquarters of Chandpur district. Between 2016 and 2022, however, the confluence node moves in the north-west direction (Deviation from the previously experienced south-east movement) migrating approximately 6000 m.

Hence, it can be concluded that the confluence nodes in either of the confluence zones has shifted rapidly over the years which supports the findings of the study conducted by (Roy & Sinha, 2007) in Ganga-Ramganga Valley, India. However, a clear contrast was observed while analyzing the two movements as the upstream confluence (Padma-Jamuna-Ganges Confluence), exhibited a common movement is south-east direction while the downstream confluence (Padma-Meghna Confluence) is more dynamic as it moves in both south-east and north-west directions from its initial position in 1990 and exhibits greater migration within the same time period.

4.0 CONCLUSIONS

Sandbar formation is a complex and dynamic process that shapes up the river landscapes, provides habitats for humans and diverse species, and influences flow patterns of the rivers. To cope with the growing challenges such as climate change and human interventions, a deeper understanding of the process of sandbar formation is needed for the preservation of the riverine ecosystem.

The study has revealed that the Padma River experienced severe erosion and deposition between 1990 and 2020 with erosion and deposition of approximately 25639 ha and 17945 ha respectively over the last 30 years. This rapid erosion-deposition process has led to the formation of numerous sandbars across the reaches of the Padma, Jamuna, and Ganges rivers. It is further observed from the study that sandbars have been rapidly accumulating in the vicinity of the two confluence zones of the Padma River. The determination of the water-sandbar surface area ratio of the Padma River supports this finding since the ratio was consistently at 1.00 or below since 2016 at the confluence zones, indicating a close match between sandbar and water surface areas. However, the ratio has consistently exceeded 1.29 in the main channel during the same period.

Satellite image analysis has also provided fascinating insights into sandbar formation and evolution process where it is observed that sandbars near the upstream confluence followed a continuous cycle of fragmentation and reformation. In contrast, the sandbars at the downstream confluence exhibited a distinct trend towards the formation of larger, more stable islands. Finally, the study found that a medial sandbar (Amirabad) exhibited more longitudinal and lateral migrations compared to a littoral sandbar (Harirampur) which was mostly stable.

The study proves that satellite imagery data can be successfully used to monitor erosion-deposition and sandbar formation. The information obtained from this study will help evaluate risks involved in human settlement in these sandbars. Furthermore, the study will help provide useful information to maintain navigable waterways. The Padma bridge is a landmark project in Bangladesh and this study will provide useful information regarding sandbar formation patterns since sandbars can pose risks to infrastructures such as bridges. The study provides valuable information about the water surface area of the Padma River which according to (Dewan et al., 2017) is important to maintain the balance between freshwater and saline water. Finally, the study will provide important information regarding the erosion-accretion patterns of the Padma River which can be used to identify locations of bank protection and river training works.

In the light of the above study, the author recommends the following investigations to further improve the study:

- To get more detailed results, it is recommended to lengthen the study period and decrease the interval between selected years
- It is highly recommended to determine the age of sandbars to identify the stable islands
- To evaluate the impacts of sandbar formation and recession on the population, it is recommended to study the population of these sandbars
- This paper has investigated the sandbar accumulation and recession within 30 km radial distance from the confluence nodes of the Padma River and it is therefore recommended to increase or decrease the radial distance and compare the findings
- It is recommended to develop a sediment transport model to better understand sandbar formation and evolution

Acknowledgements

The authors acknowledge the satellite data provided by United States Geological Survey (USGS) for research purposes. The authors would like to thank the Department of Civil Engineering of Uttara University, Institute of Water Modeling (IWM), and The Center for Environmental and Geographic Information Services (CEGIS) for providing invaluable experience and insights gained through working with them which greatly contributed to this paper.

References

[1] Tomasello, S. D., Costanzo, L., & Galassi, A. R. 2011. Quantitative coronary angiography in the interventional cardiology. *Advances in the Diagnosis of Coronary Atherosclerosis*, [Bifurcation]

[2] Ullah, H., Islam, M. N., & Malak, M. A. 2010. Charland dynamics of the Brahmaputra-Jamuna River in Bangladesh. *The Jahangirnagar Review*, *34*: 165-182.

[3] Islam, S. N., Singh, S., Shaheed, H., & Wei, S. 2010. Settlement relocations in the char-lands of Padma River basin in Ganges delta, Bangladesh. *Frontiers of Earth Science*, 4(4): 393.

[4] Rafi, A. S. M. M., Tasnim, U. F., & Rahman, M. S. 2018, October. Quantification and qualification of silica sand extracted from Padma River sand. In *IOP Conference Series: Materials Science and Engineering* (Vol. 438, No. 1, p. 012037). IOP Publishing.

[5] Rahman, M. M., Ghosh, T., Salehin, M., Ghosh, A., Haque, A., Hossain, M. A., ... & Hutton, C. W. 2020. Ganges-Brahmaputra-Meghna delta, Bangladesh and India: a transnational mega-delta. *Deltas in the Anthropocene*, 23-51.

[6] Haque, M., Ahmed, F., Anam, S., & Kabir, R. 2012. Future population projection of Bangladesh by growth rate modeling using logistic population model. *Annals of Pure and Applied Mathematics*, 1(2): 192-202.

[7] Sarker, M. H., Huque, I., Alam, M., & Koudstaal, R. 2003. Rivers, chars and char dwellers of Bangladesh. *International Journal of River Basin Management*, 1(1): 61-80.

[8] Gazi, M. Y., Roy, H., Mia, M. B., & Akhter, S. H. 2020. Assessment of morpho-dynamics through geospatial techniques within the Padma-Meghna and Ganges-Jamuna river confluences, Bangladesh. *KN-Journal of Cartography and Geographic Information*, 70: 127-139.

[9] Dixon, S. J., Smith, G. H. S., Best, J. L., Nicholas, A. P., Bull, J. M., Vardy, M. E., ... & Goodbred, S. 2018. The planform mobility of river channel confluences: Insights from analysis of remotely sensed imagery. *Earth-Science Reviews*, 176: 1-18.

[10] 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 Geographicae*, 37(3): 87-95.

[11] Shit, P. K., & Maiti, R. 2013. Confluence dynamics in an ephemeral gully basin (A case study at Rangamati, Paschim Medinipur, West Bengal, India). *Research Journal of Applied Sciences, Engineering and Technology*, 15(5): 3895-3911.

[12] Islam, M. T. 2009. Bank erosion and movement of river channel: A study of Padma and Jamuna Rivers in Bangladesh using remote sensing and GIS. Division of Geoinformatics, Royal Institute of Technology, Stockholm, Sweden.

[13] Kabir, R. D. 2006. The state of char education in Bangladesh: focus on selected chars of Gaibandha district. *Asian Affairs*, 28(3): 5-24.

[14] Rahman, M. R. 2023. River dynamics – a geospatial analysis of Jamuna (Brahmaputra) River in Bangladesh during 1973–2019 using Landsat satellite remote sensing data and GIS. *Environmental Monitoring and Assessment*, 195(1): 96.

[15] Arefin, R., Meshram, S. G., & Seker, D. Z. 2021. River channel migration and land-use/land-cover change for Padma River at Bangladesh: a RS- and GIS-based approach. *International Journal of Environmental Science and Technology*, 1-18.

[16] 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.

[17] Hassan, S., & Akhtaruzzaman, A. F. M. 2010, September. Environmental change detection of the Padma river in the North-Western part of Bangladesh using multi-date Landsat data. In *Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10)*, Japan.

[18] Yuan, S. Y., Xu, L., Tang, H. W., Xiao, Y., & Gualtieri, C. 2022. The dynamics of river confluences and their effects on the ecology of aquatic environment: A review. *Journal of Hydrodynamics*, 34(1): 1-14.

[19] Hackney, C., & Carling, P. 2011. The occurrence of obtuse junction angles and changes in channel width below tributaries along the Mekong River, south-east Asia. *Earth Surface Processes and Landforms*, 36(12): 1563-1576.

[20] Dewan, A., Corner, R., Saleem, A., Rahman, M. M., Haider, M. R., Rahman, M. M., & Sarker, M. H. 2017. Assessing channel changes of the Ganges-Padma River system in Bangladesh using Landsat and hydrological data. *Geomorphology*, 276: 257–279.

[21] Moteki, D., Seki, S., Muramatsu, S., Hayasaka, K., & Yasuda, H. 2023. On the occurrence of sandbars. *Physics of Fluids*, 35(1).

[22] Rahman, M. R. 2023. River dynamics – a geospatial analysis of Jamuna (Brahmaputra) River in Bangladesh during 1973–2019 using Landsat satellite remote sensing data and GIS. *Environmental Monitoring and Assessment*, 195(1): 96.

[23] Coleman, J. M. 1969. Brahmaputra River: channel processes and sedimentation. *Sedimentary Geology*, 3(2-3): 129-239.

[24] Kelly, C., & Chowdhury, M. K. 2002. Poverty, disasters and the environment in Bangladesh: a quantitative and qualitative assessment of causal linkages. *Bangladesh Issues Paper*. UK Department for International Development, Dhaka.

[25] Faruque, M. H., & Ahsan, D. A. 2014. Socio-economic status of the Hilsa (Tenualosa ilisha) fishermen of Padma River, Bangladesh. *World Applied Sciences Journal*, 32(5): 857-864.

[26] Kabir, M. H., Tusher, T. R., Hossain, M. S., Islam, M. S., Shammi, R. S., Kormoker, T., ... & Islam, M. 2020. Evaluation of spatio-temporal variations in water quality and suitability of an ecologically critical urban river employing water quality index and multivariate statistical approaches: a study on Shitalakhya river, Bangladesh. *Human and Ecological Risk Assessment: An International Journal*, 27(5): 1388-1415.

[27] Mahmud, I. H., Pal, P. K., Rahman, A., & Yunus, A. 2018. A study on seasonal variation of hydrodynamic parameters of Padma River. *Journal of Modern Science and Technology*, 5(1): 1-10.

[28] Sweeney, M. R., Fischer, B., Wermers, K., & Cowman, T. 2019. Eolian and fluvial modification of Missouri River sandbars deposited by the 2011 flood, USA. *Geomorphology*, 327: 111–125.

[29] Reza, A. S., Rony, N. K., Saud, N. E., Islam, M. N., & Hasan, M. K. A checklist of birds of Padma River and charlands of Chapai Nawabgonj and Rajshahi District of Bangladesh.

[30] Roy, N., & Sinha, R. 2007. Understanding confluence dynamics in the alluvial Ganga–Ramganga valley, India: an integrated approach using geomorphology and hydrology. *Geomorphology*, 92(3-4): 182-197.