ASSESSMENT OF THE IMPACT OF STRUCTURAL INTERVENTION ON RIVERBANK EROSION-ACCRETION AND BAR DYNAMICS OF THE NORTH-WESTERN PART OF THE GANGES RIVER USING REMOTE SENSING TECHNIQUE

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ABSTRACT

Riverbank erosion and accretion have been a very common occurance in Bangladesh. Excessive erosion and accretion have severely affected many people who either directly or indirectly depend on the river. The bank line migration of rivers may be greatly impacted by lateral hydraulic structures and major flood episodes. Better understanding of river behaviour should help reduce suffering and prevent damage to public infrastructure by the river. Hence this study has analysed the migration pattern, short-term and long-term erosion-accretion rate, rate of change of sinuosity, average width, and bar dynamics due to construction of Lalon Shah Bridge. The analysis has been done on North-Western part of Ganges (around 84 km reach starting from Lalon Shah Bridge upto Ganges-Jamuna confluence) by using multi-temporal satellite images of 37 years (1986 to 2022) from Google Earth and processing them using ArcGIS. The rate of migration of the riverbanks from image to image has been estimated for short term as well as for long term analysis. For the long-term study, the bank migration rates are determined by estimating the difference between the image from 1986 as reference and the following images. For the Ganges river, the average erosion and accretion rates for the short- (and long-term) analysis are 92.91 m/yr and 113.6 m/yr on the left bank (27.43 m/yr and 130 m/yr), and 121.86 m/yr and 120.84 m/yr (51.86 m/yr and 45.72 m/yr) on the right bank.. Both the erosion and the accretion rates decreased after construction of the Lalon Shah bridge for both of the banks of the river. Additionally, during the study period, there has been a slight decrease in the bar area, which could be attributed to the construction of the Lalon Shah Bridge. The sinuosity analysis indicates the meandering nature of river. The sinuosity index increased significantly after the bridge has been constructed indicating that the river became more meandering in nature owing to the influence of the bridge. The decreasing trend in the river width halted after the construction of the bridge, showing a slight increase in width.The findings would help to comprehend the trend of erosion-accretion that occured in the Ganges river after construction of Lalon Shah Bridge, including the impact of flooding events and may prove to be helpful in planning preventive measures to ensure the safety of people living on the river floodplains and also depending on it for their livelihoods.

Keywords: *Structural intervention, erosion-accretion, bar dynamics, sinuosity, ArcGIS*

1. INTRODUCTION

Bangladesh, a country situated at the mouths of three rivers, in the world. Ganges, Brahmaputra and Meghna (Hassan et al., 2017) is known for its lying deltaic geography. Over time these rivers have reached a stage. Meandered or braided as a result. Such movements along the river channels have caused erosion and deposition of sediment along their banks (M. F. Islam & Rashid, 2011). The erosion process is influenced by factors like rainfall soil structure, topography of the river and adjacent areas, river morphology well as floods (Hooke, 1979). On the hand riverbank accretion refers to the process where sediments and other materials carried by the river are deposited or settled (Saha et al., 2021).

The construction of bridges often brings about changes in the dynamics of river systems. One notable consequence is that it can cause shifts in the alignment of the bank line. The bank line acts as an interface between a rivers water and its surrounding land; it plays a role, in maintaining ecosystem balance and providing habitats. When a bridge is built, modifications are frequently made to accommodate its structure which can potentially alter the course of the river and subsequently impact the alignment of its bank line. It is crucial to grasp the significance of this change, in the bank line as it can have an impact on the rivers ecological and geomorphic features. The patterns of erosion and accretion have exhibited differences both prior, to and following the construction of the Lalon Shah Bridge.

Different studies have examined the changes, in erosion, accretion and bankline migration patterns before and after the construction of the Lalon Shah Bridge. The rivers flow pattern underwent alterations after the bridge was built in 2004 leading to transformations

Prior research has extensively investigated topics such as river bank erosion, accretion, channel bar development and bankline migration. For instance, (Khan et al., 2020) analyzed these phenomena while (Rashid, 2020) focused on studying formation of channel bars and bankline movement in the Lower Padma River of Bangladesh. (R. Islam et al., 2017) conducted a study on Jamuna Rivers bar morphology influenced by the Bangabandhu Jamuna Multi-Purpose Bridge. Furthermore, (Nabi et al., 2016) performed a case study utilizing GIS and Remote Sensing techniques to observe shifts in Meghna River since the 1760s. (Baki & Gan, 2012) analyzed riverbank migration and island dynamics of the Jamuna River which is a braided river within the Ganges Brahmaputra basin using temporal Landsat images. To identify migration in Jamuna River specifically (Thorne et al., 1993) compared photographs from the 1950s with Bangladesh survey maps, alongside a 1989 SPOT image. In a vein researchers estimated the shifting of the Jamuna Rivers banks by comparing images captured by Landsat TM between 1990 and 1992 with those, from Landsat MSS spanning from 1973 to 1987. Their findings suggest that the left bank experienced overall movement as it was influenced by a combination of erosion and accretion. On the hand the right bank displayed a susceptibility to erosion.

The study has the following goals;

- To evaluate how structural interventions affect the erosion and deposition of riverbanks and the dynamics of bars, in the North part of the Ganges River using a Remote Sensing based techniques.
- To analyze the patterns of migration, the short-term as well as the long-term rates of erosion and accretion.
- To examine changes, in width, sinuosity and bar dynamics caused by the construction of Lalon Shah Bridge.

The Ganges, one of the principal anabranching rivers of the whole world (Kleinhans, 2010) flows in a basin that covers over 1.1 million km^2 and crosses China, Nepal, India, and Bangladesh (Mirza, 2004). The greatest area of the basin belongs to India, accounting for 79%, while Bangladesh and China each contribute approximately 4%. The remaining 13% is attributed to Nepal (Mirza, 2004). The river begins its journey at the Gangotri glacier, located on the southern slope of the Himalayas at a height of about 7010 meters (Adhikary et al., 2000). After there, it flows across India in a south and southeast direction for roughly 2000 km before reaching the border between India and Bangladesh (Adhikary et al., 2000). Prior to its entry into Bangladesh at Farakka, the river divides into the Ganges and Hooghly Bhagirathi streams. Eventually, along separate pathways, each of the branches empties into the Bay of Bengal. The main left branch enters Bangladesh 18 km downstream, from Farakka, flows south-east until it meets the Brahmaputra (Jamuna) River at Aricha (Hossain et al., 2013).

The Lalon Shah Bridge is a road bridge, also known as Pakshey Bridge that spans the Ganges River. Location of the bridge is between Ishwardi upazila in Pabna to the east and Bheramara Upazila in Kushtia to the west. Completed in 2004 this bridge is 1,800 meters long ranking as the third longest road bridge in Bangladesh. It runs parallel and to the south, downstream of the Hardinge Bridge. The total length of the river section along its centerline considered for this study is 84 km with a valley length of 72 km starting from downstream of the Lalon Shah bridge to its convergence with Brahmaputra (Jamuna) River, at Aricha as depicted in Figure 1.

In Bangladesh the Ganges River displays a meandering pattern characterized by broad, sweeping bends. The flow of the river is intricately divided within the meander belt, showcasing variation in planform over both time and space (CEGIS (Center for Environmental and Geographic Information Services), 2003). Coupled with pronounced seasonal fluctuations in discharges, the Ganges River experiences substantial and frequent erosion-accretion, the pattern of which changed significantly after the construction of the Lalon Shah Bridge which will be examined further below.

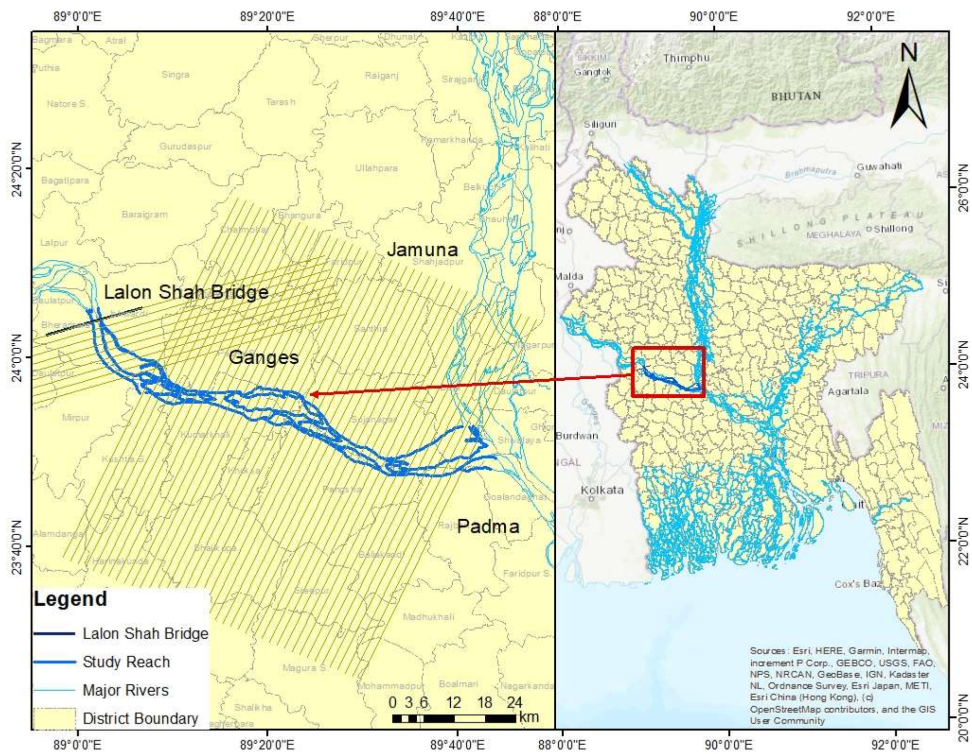


Figure 1: Study Area

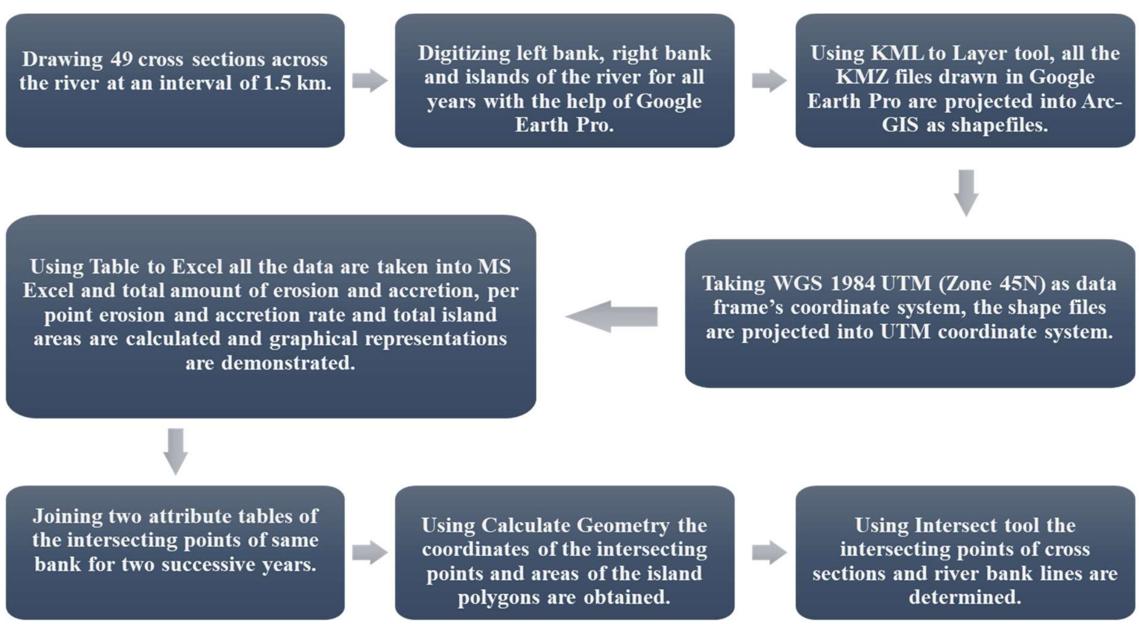
2. METHODOLOGY

2.1 Data Collection

For this research, georeferenced Landsat images from Google Earth were selected that cover the Ganges River, in Bangladesh. These images were chosen specifically for the time span, between 1986 and 2022. These images were taken around the last week of December which is considered as the dry season. The goal was to maintain consistency, in reference stage levels as possible aligning the river bank boundaries based on similar stage levels across the multi-temporal Landsat images. This approach aimed to reduce biases when estimating variation in the rates of erosion and deposition along the river banks. Images collected during the dry period are also ideal for analyzing land-water boundaries, statistics of channel islands, braiding and sinuosity indices.

2.2 Analysis of Satellite Images

The banklines were digitized and forty-nine cross sections were delineated at intervals of 1.5 km as shown in Figure 1. The points where these cross-sections intersect with riverbank lines were isolated, and their coordinates were computed using ArcGIS. This process was employed to analyze riverbank shifting and variations in river width. A negative value indicated erosion signifying a decrease in riverbank dimensions while a positive value was considered as accretion indicating an increase in the area of the riverbank. The width of the river was determined by measuring distances between two coordinates at points intersecting with the cross-section lines. The water areas and islands could be easily distinguished and so all islands were digitized in order to calculate their areas, locations and shapes. This method enabled to study the dynamics of islands in response to the changes in river morphology over time. The analysis involved examining both short-term and long-term migrations of the left river bank, as well as the right bank. For short-term analysis, the movement rate was determined by comparing consecutive images for the following periods: 1986-1987, 1987-1988, 1988-1989, and so forth, up to 2021-2022. In contrast, the migration rate in the long-term was estimated using the image from 1986 as reference. The rate of migration for the river banks was computed for various periods, such as 1986-1988, 1986-1989, 1986-1990, and continuing through 1986-2022. In order to study the dynamics of the bars, the river's bars were delineated on Google Earth and subsequently projected onto ArcGIS for analysis. By calculating the area of the islands, changes of these bars over time were examine. Additionally, by obtaining points along the length of the river channel, sinuosity index was calculated. This was done by dividing the Channel Length by the Valley Length and measuring distances using ArcGIS. A self-explanatory framework for the overall workflow is given below-



3. ILLUSTRATIONS

3.1 Bank Line Shifting

To acquire a comprehensive understanding of the patterns of erosion and accretion for the Ganges River before and after construction of the Lalon Shah bridge, two distinct time periods, namely 1986-2004

(19 years) and 2004-2022 (19 years), overlay maps were generated depicting riverbank erosion-accretion are depicted in

Figure 2. Also, the bank movement rates along the river, depicting both the left and right banks, are graphically represented in Figure 3 for the 1986-2004 and 2004-2022 time periods. In summary, the Ganges River experienced greater accretion rate on the both banks before the completion of the bridge in 2004. However, after the construction, there was a shift, with more erosion occurring on both banks. The maximum accretion rate before 2004 reached nearly 260 m/yr, primarily on the left bank, while the maximum rate of erosion after the construction was approximately 94 m/yr on the right bank. Furthermore, the left bank exhibited a tendency for accretion, whereas the right bank was susceptible to erosion. Interestingly, during the construction of the bridge, there was an increase in the accretion rate on both banks.

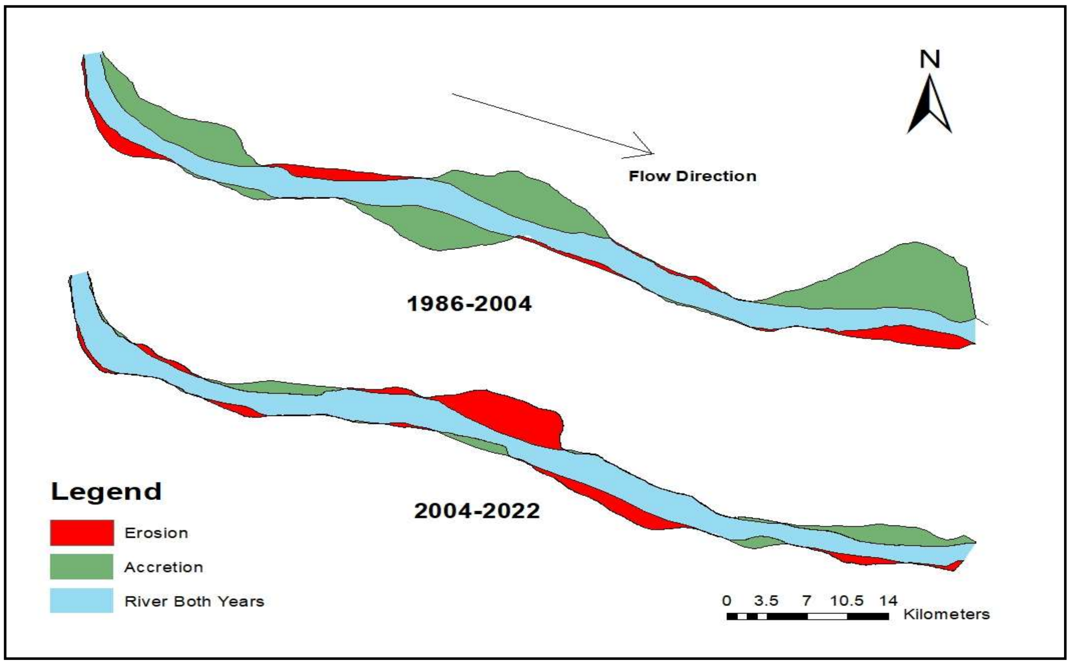
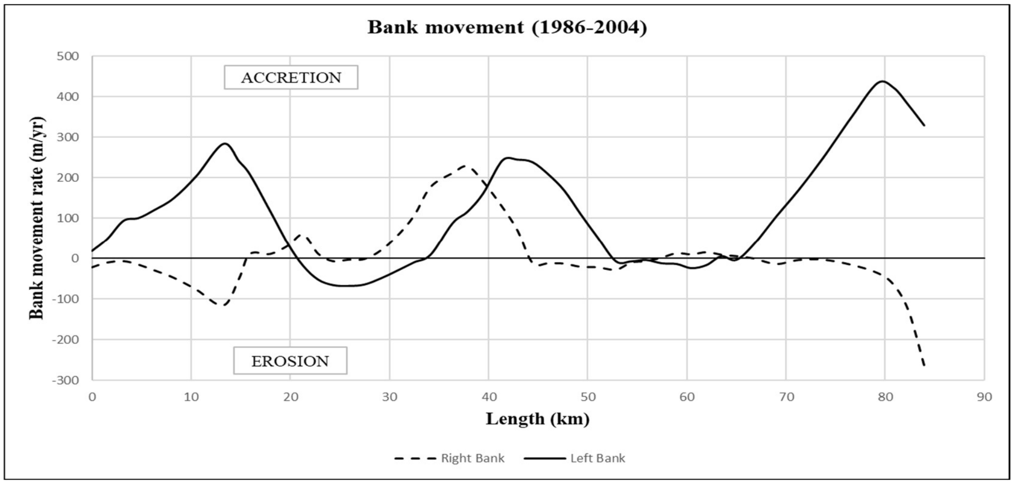


Figure 2: Erosion and accretion of the Ganges River banks between 2004 and 1986 and between 2022 and 1986.

Figure 2 suggests significant accretion in expansive areas of the Ganges River bank, especially in the upstream, mid-reach, and downstream stretches near the confluence with Jamuna, primarily along the left bank before 2004. Nevertheless, considerable erosion took place in the mid-reach of the river, predominantly on the left bank.

Significant bank accretion was noted on the left bank in specific segments, namely the 0-20 km, 32-52 km, and 65-84 km reaches, during the period from 1986 to 2004 and the maximum erosion rate was around 440 m/yr at a 78 km distance from the Lalon Shah bridge. Conversely, a lower erosion rate was detected on the left bank in the remaining portions of the reach during the same time frame as can be seen in Figure 3(a) The highest erosion rate was observed at a distance of 25 km, with a value approximately around 80 m/yr. On the right bank, an opposite trend can be observed to that of the left bank in Figure 3(a) with highest accretion and erosion rates of 220 m/yr and 150 m/yr respectively at 38 km and 84 km from the bridge location. During the period from 2004 to 2022, there was a reversal in the erosion-accretion pattern on the left bank. Areas that were previously prone to accretion became governed by erosion, and vice versa, up to the 70 km reach. Beyond that point, the reach followed the earlier accretion pattern up to the confluence as shown in Figure 3(b). The maximum erosion and accretion rates in this case were 230 m/yr and 150 m/yr that occurred at distances 47 km and 82 km respectively. On the right bank, the erosion-accretion pattern remained largely consistent with the period from 1986 to 2004, albeit with an increased rate of erosion and a decreased rate of accretion during the subsequent years. as can be observed from Figure 3(b). In this scenario, the maximum erosion rate reached 90 m/yr at a distance of 59 km, while the maximum accretion rate was 80 m/yr at a distance of 69 km.

(a)



(b)

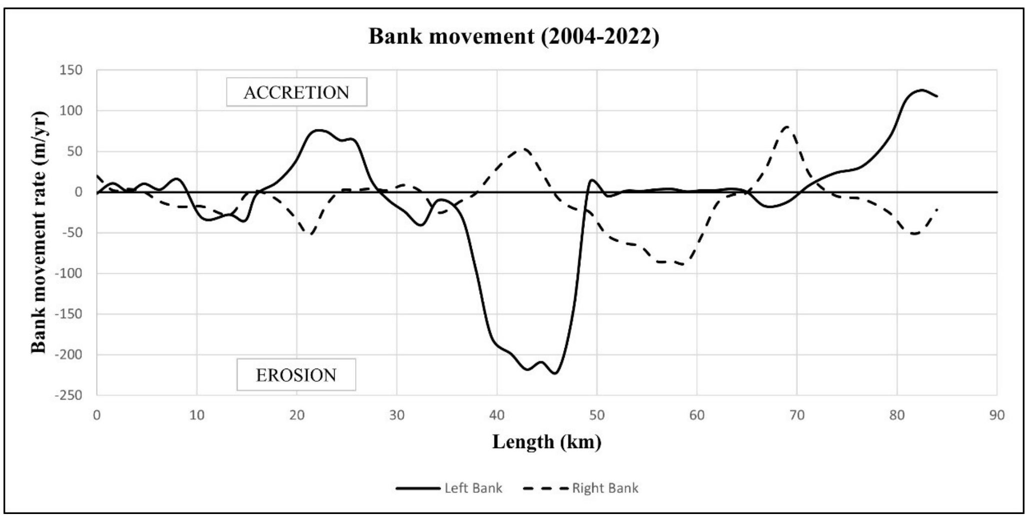
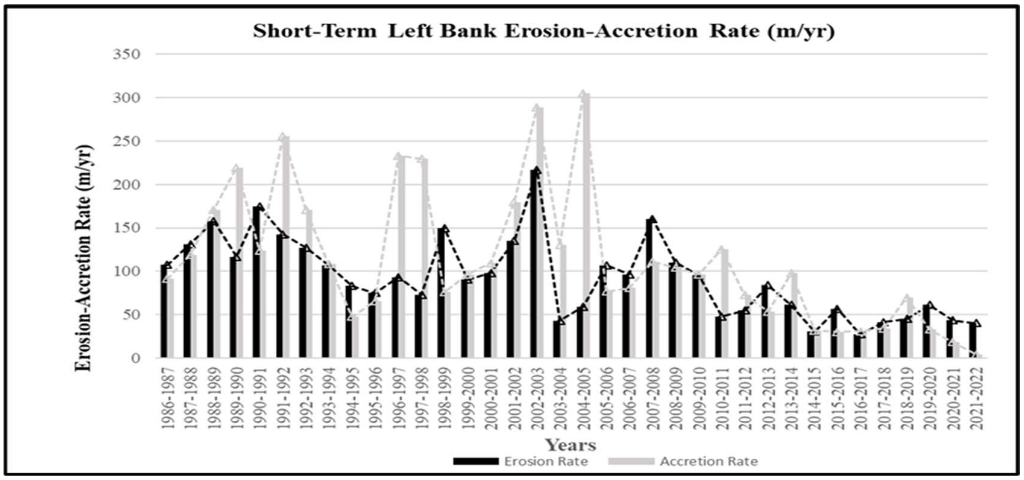


Figure 3: The rates of bank movement (m/year) along the Ganges River (length indicates the distance from the downstream point of Lalon Shah Bridge) for both the left and the right banks, between (a) 1986 and 2004, and (b) 2004 and 2022

3.2 Short Term Changes of Bank Lines

This study was conducted to examine the shifting of the river banks in the short-term demonstrating annual shifts in river banks with respect to the previous year. Bar charts showing erosion and adepositionn rates of the right and the left banks are developed and are included here in Figure 4. These statistics show that during 2002 and 2003, the left bank's maximum erosion rate was 216.75 m/yr, whereas the right bank's greatest erosion rate was 558.89 m/yr for the same period. The minimum erosion rate at the left bank was 27.26 m/yr which occurred during 2014-2015 whereas it was 31.1 m/yr for the right bank during 2016-2017. In terms of accretion rates the left bank had a rate of 304.9 m/yr during 2004-2005 immediately after the construction of Lalon Shah Bridge which is the highest accretion rate throughout all years examined in this study. For the right bank, it reached as high as 668.8 m/yr making it the highest accretion rate among both banks during the period of study.

The minimum accretion rate for the left bank is 4.2 m/yr which was observed during 2021-2022 and for the right bank, the value is 27.3 m/yr during the period of 2017-2018.



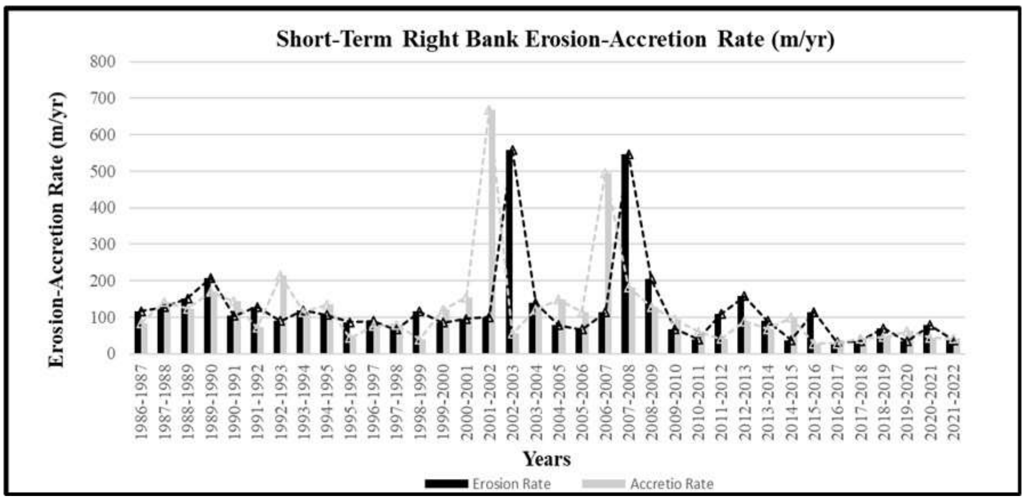
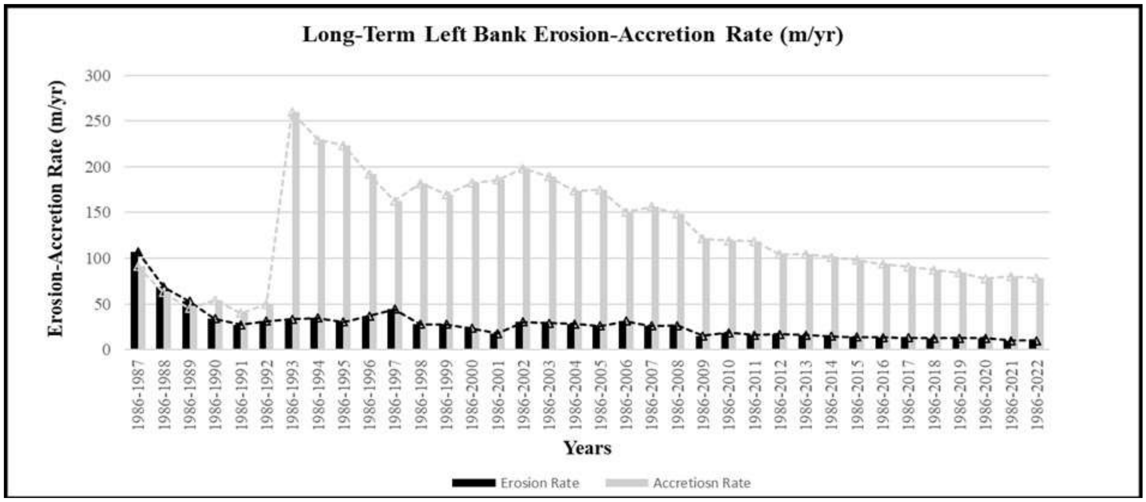


Figure 4: Short Term Left Bank and Right Bank shifting of the river

Upon further examination it becomes evident that the average erosion rate on the left bank (122 m/yr) is lower than that of the left bank (93 m/yr) whereas the average accretion at the left bank (114 m/yr) is lower compared to the accretion rate on the right bank (121 m/yr).

3.3 Long Term Changes of Bank Lines

Shifting of river banks for each year with respect to the bank line of the year 1986 as reference is estimated for analysing long-term bankline movement of the Ganges river. Figure 5 shows the two bar charts developed to demonstrate erosion and accretion of the both banks as included here in. The bar graphs indicate that the left bank experiences the erosion rate of 107.25 m/yr at the highest during 1986-1987 while the right bank shows a higher value of 116.41 m/yr for the same timeframe and it is also the highest rate of erosion for the right bank in long term. For the left bank, the minimum erosion rate is 9.74 m/yr during 1986-2021, while on the right bank, it is 33.05 m/yr during 1986-2006. The maximum accretion rate at the left bank is 259.65 m/yr and the maximum accretion rate for the right bank is 103.10 m/yr which are observed to occur during the period of 1986-1993 and 1986-2002 respectively. As for minimum accretion rate, the left bank experienced 39.96 m/yr during 1986-1991 while for the right bank, it was 9.74 m/yr during the period of 1986-2022.



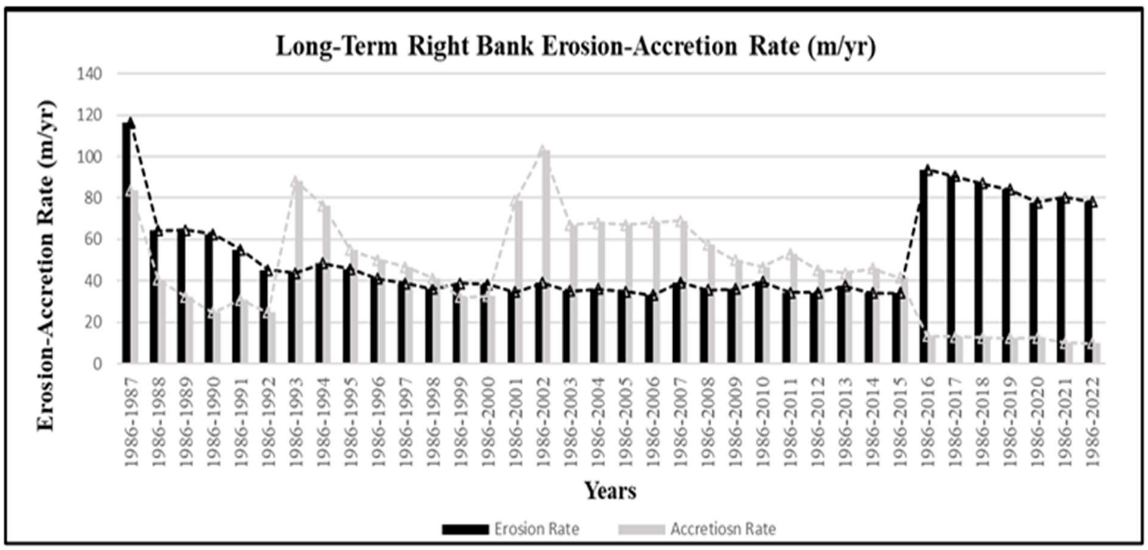


Figure 5: Long Term Left Bank and Right Bank shifting of the river

A closer examination of this bar chart reveals that although the right bank's average erosion rate (52 m/yr) is higher than the left bank's average (28 m/yr), the left bank's average rate of accretion (130 m/yr) is higher than the right bank's (46 m/yr).

3.4 Sinuosity Index

The sinuosity index is calculated at 6 years interval of the river and the results are shown in the graph in Figure 6. The value of the index ranges from 1.15 to 1.27 highlighting the meandering characteristics of the river. 1.27 was the highest value of the sinuosity index which can be observed in 2022 and the lowest value was 1.15 in 1992. Moreover, the sinuosity curve shows a rising trend after the construction of the bridge in 2004 which indicates the dynamic behaviour of the river.

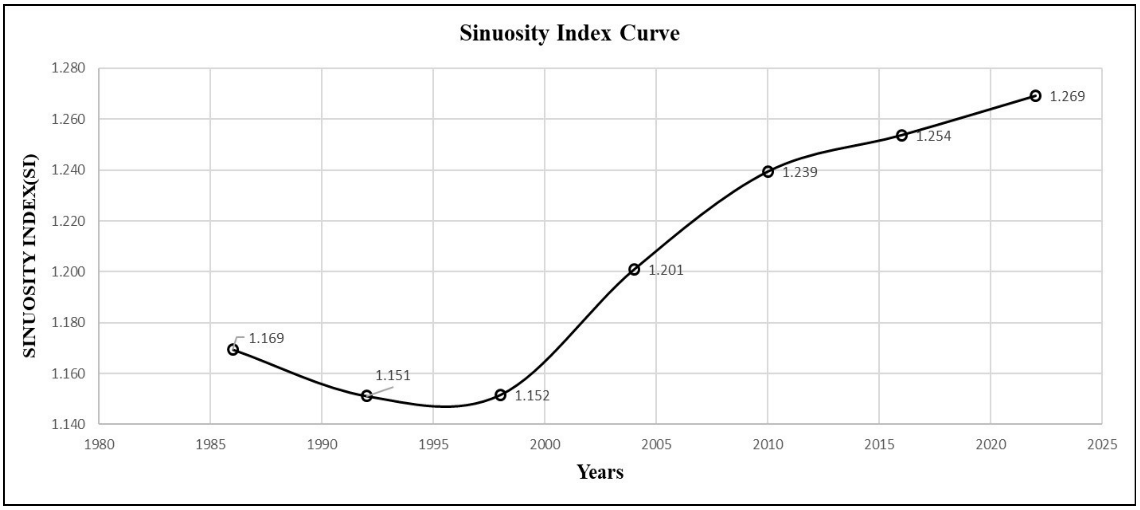


Figure 6: Plot for Sinuosity Index Vs Years

3.5 Average Width of the River

The average width of Ganges river for the selected reach was determined at an interval of six years within the study duration. The average width was observed to be the highest in 1992 (4.97 km) as shown in

Figure *7*. The lowest value for the same was found in 2004 (2.84 km). Hence, the average width of the river was decreasing at a high rate before construction of Lalon Shah Bridge but began to increase at a slow rate after completion of the construction.

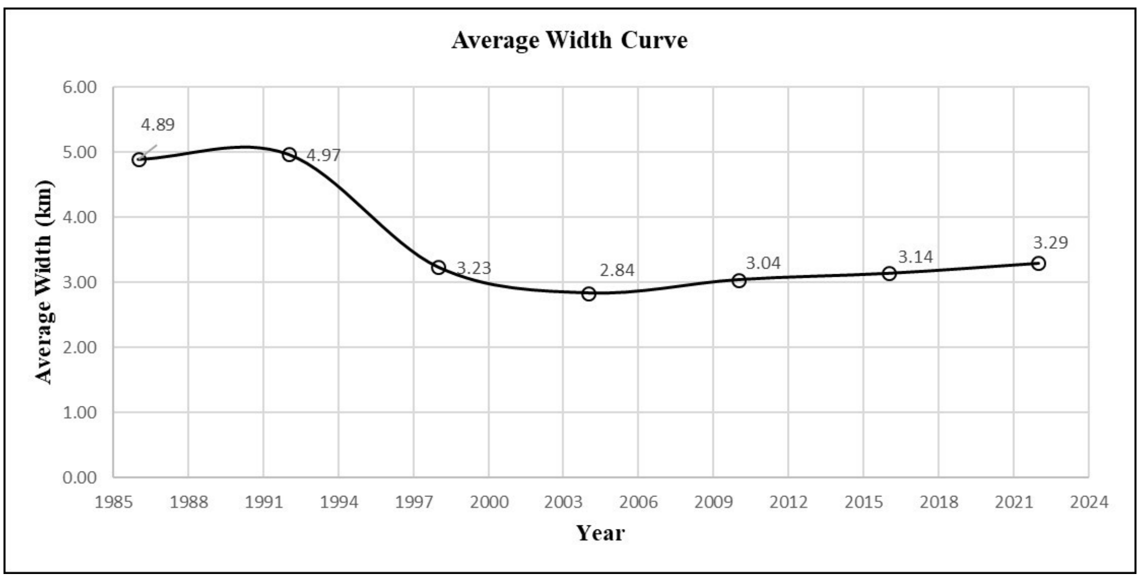


Figure 7: Average Width over the years

3.6 Bar Dynamics

The area of the islands was estimated and shown in the following

Figure *8* at six years interval during the study period. The maximum bar area was found in 1992 (164.53 km2) and the minimum in 2022 (97.11 km^2). The average bar area was found to be 119.46 km2. From the figure below, the trend line shows the linear variation in the island areas, which represents the decreasing trend for the area of bars over the years.

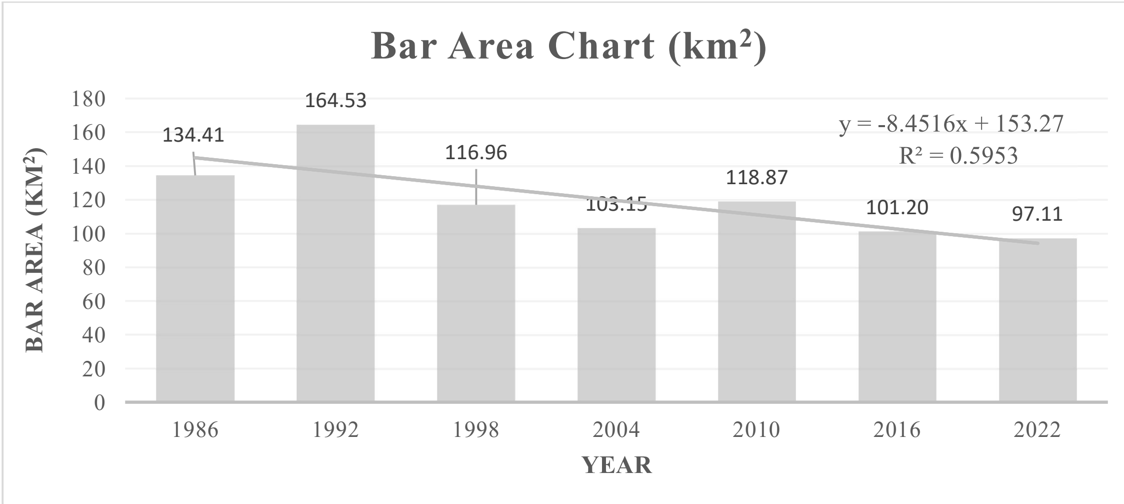


Figure 8: Bar Area after every six years

4. CONCLUSIONS

The study analysed the impact of the Lalon Shah Bridge on the patterns in erosion and accretion situation of the Ganges River banks. It revealed that both erosion and accretion rates decreased following the bridge's construction, as observed in both short-term and long-term analyses for the left bank. In the long-term analysis, the average erosion rate decreased from 38 m/y to 17 m/y, while the average accretion rate decreased from 149 m/y to 110 m/y. For the right bank, the long-term analysis revealed that the average erosion rate increased from 49 m/y to 55 m/y, while the average accretion rate decreased from 54 m/y to 37 m/y. However, in case of short-term analysis, both average erosion and accretion rate decreased to some extent. The Sinuosity Index for the river exhibited a notable increase after 2004, suggesting that the meandering condition of the river increased following the construction of the bridge. Regarding the river width, there was a decreasing trend before the construction of the bridge. However, in the years following the construction, the width showed a slight increase. The river width decreased from 4.89 km to 2.84 km from 1986 to 2004 and then again increased to 3.29 km in 2022. The total area of islands remained more or less the same, with lower areas observed just before and after the construction of the Lalon Shah Bridge. This research has demonstrated the effectiveness of remote-sensing based applications in identifying the structural impact on riverbank erosion-accretion rates. The newly discovered insights into riverbank migration and changes to the islands in the Ganges River will prove valuable for implementing plans regarding erosion or accretion management in the future and measures for protecting the banks of the river against erosion.

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