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Bankline Migration Analysis of Brahmaputra River in Morigaon District, Assam using Automated Method

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Abstract

Objectives: The study examines spatio-temporal changes, forecasts bankline migration and seeks to determine its underlying causes and consequences. **Methods:** Bankline change detection was performed through comprehensive GPS-based field surveys and remote sensing data, validated with ground-based data. The NDWI and MNDWI used to delineate the bankline positions from 1988-2022, with temporal changes estimated using the DSAS model. **Findings:** The left and right riverbank have been divided into three exclusive zones to find out which zone is severely erosion and accretion prone regions for zone-wise exclusive analysis. In the analysis, it has noticed that the left bank experiencing severe bank erosion and the right bank is experiencing an accretion rate increase in the last few decades. The LRR statistics show that the erosion rate in the left bank (81.17 m/y) is significantly high with an accretion rate of 0 m/y in the observed area. On the other hand, in the right bank, the rate of erosion is 83.59 m/y and the rate of accretion is 68.45 m/y. The left bank's erosion is notably high. Additionally, the erosion rate is severe in the zone C (118.22 m/y) of left bank line. In this zone, the erosion rate hiked by 59.58 m/y in 34 years. **Novelty:** This study addresses a significant gap in understanding the riverbank shifting dynamics along with its causes and socio-economic impact of the Brahmaputra River in the Morigaon district. By combining the hydrodynamic modelling and cause-effect analysis, it provides a comprehensive analysis of bankline migration patterns and their causes and consequences. Unlike previous research, which primarily focuses on bankline migration rates and land use changes, this research work uniquely explores the direct impact of riverbank shifting on local communities. The integration of advanced predictive models with detailed primary and secondary data analysis offers novel insights crucial for efficient flood management and policy making practices.

Keywords: Normalised Difference Water Index (NDWI); Modified Normalized Difference Index (MNDWI); Digital Shoreline Analysis System (DSAS); EPR and LRR Model; Bankline Shift

1 Introduction

The flood plains are the largest and most productive ecosystems on the entire planet [1]. In these areas, the river channel migration often takes place. [2] The riverbank shifting poses not only a geomorphological problem but also a significant environmental hazard [3]. Among the various kinds of disasters, riverbank shifting, which includes both erosion and accretion, is a most significant geomorphological process in the floodplain zones. This process impacts both natural and anthropogenic structures [4]. Channel shifting leads to riverbank erosion. [5] Riverbank erosion depends on the factors such as the river's magnitude, the morphology of its bends and the velocity of water [6]. Riverbank erosion is a multifaceted intrinsic interaction between soil and water, which is highly dynamic and constantly changing. Consequently, it is essential to understand its properties and their hydrodynamics [7] and forecasting river's hydrodynamic changes is crucial, which helps in flood management in the changing scenario of climate and intensifying anthropogenic activities. [8]

Research on the Brahmaputra valley has been revealed that the recent rate of riverbank erosion has accelerated significantly and analyse and predict the changes in LULC using CA-Markov model which showing over 85% accuracy in aligning with the actual data [9]. Another study focusing on the middle part of the Brahmaputra River indicating that there is a significant land area erosion, predominantly affecting the southern bank [10]. Though the estimation of bankline shifting rates has been conducted but there is a dearth of information on the causes and effects of bankline migration along with detailed analysis of bankline migration at the district level. Therefore, this study aims to address this research gap by analysing the bank migration patterns of the Brahmaputra River in the Morigaon district and exploring its causes and socio-economic impacts of the riverbank migration.

1.1 Study Area

The Brahmaputra River covers approximately 1,94,413 square kilometres in India, accounting for around 5.9% of the total geographical area of India. The river basin extends across multiple Indian states, including Arunachal Pradesh, Assam, West Bengal, Meghalaya, Nagaland, and the entire state of Sikkim. The boundaries of Brahmaputra River basin are defined by Himalayas to the north, the Patkai Hill ranges along the India-Myanmar boarder to the east, the Assam hills to the south and the Ganga basin area to the west.

The geographical extent of Morigaon district lies between 26° 31' 13.027" North to 26° 3' 48.099" North latitude and 91° 57' 32.469" East to 92° 34' 16.501" East longitude. The total geographical area under study is approximately 1502.69 square kilometres. The district is boarded by the mighty Brahmaputra to the north, Karbi Anglong to the south, Nagaon district to the east, and Kamrup district to the west.

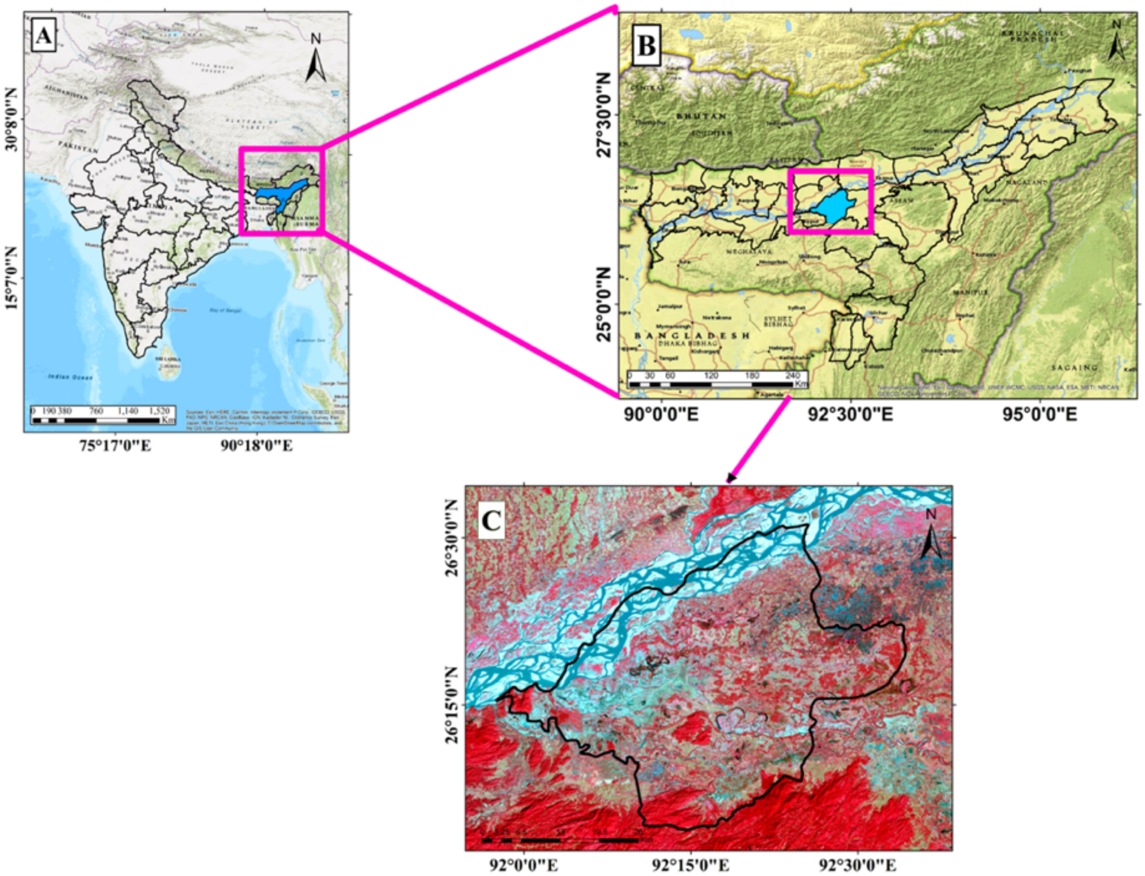

Fig 1. Location maps of the study area, (A) Map of India showing the Assam, (B) Map of Assam showing the Morigaon district (C) Satellite image of Morigaon district

2 Methodology

2.1 Datasets preparation

In this research, Thematic Mapper 1988, Thematic Mapper 1998, Enhanced Thematic Mapper Plus (ETM+) 2006, Enhanced Thematic Mapper Plus (ETM+) 2012, Operational Land Imager (OLI) 2022 were used to demarcate the riverbank line. These years were selected based on the availability of cloud free images have been projected in the UTM projection, Zone 45 North with the WGS84 datum. To enhance the results of the satellite-based analysis, preprocessing steps have been conducted such as noise reduction, contrast enhancement, sharpness enhancement.

Table 1. Details regarding the sources of data used for the study

Serial No.	Satellite	Sensor	Path/Row	Acquisition Date	Spatial Resolution
1	Landsat 5	TM	136/42	26-Nov-1988	30
2	Landsat 5	TM	136/42	24-Dec-1998	30
3	Landsat 7	ETM+	136/42	22-Dec-2006	30
4	Landsat 7	ETM+	136/42	06-Dec-2012	30
5	Landsat 8	OLI/TIRS	136/42	24-Nov-2022	30

Source: USGS Earth Explorer

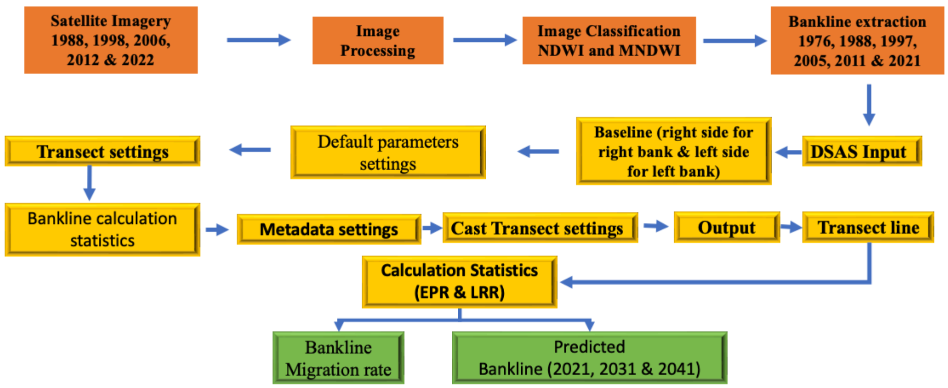

Fig 2. Flow chart showing steps applied in this study

2.2 Delineation of bankline

It is useful for discriminating among broad vegetation classes due to its optimal spectral reflectance from the leaf surface in both dry and wet environments. The spectral value of the green band is highly sensitive to turbid water content. This sensitivity helps in identifying diverse vegetation types due to the optimal spectral reflectance from leaf surfaces in both dry and wet conditions. The near-infrared (NIR) spectral values impact the water surface and are useful for mapping aquatic surfaces, wetlands, soil moisture content, and flood inundated areas. Similarly, the mid infrared (MIR) spectrum for Landsat 7 and the shortwave-infrared (SWIR) spectrum for Landsat 5 and 8, efficiently differentiate between vegetation and water[(11)]. The NDWI values ranges from -1 to 1 and are used to distinguish between water bodies (values above 0) and non-aquatic areas (values below 0)[(12)]. In this study, the Normalized Difference Water Index (NDWI) and the Modified Normalized Difference Index (MNDWI) where used to identify the bank line (Equations (1), (2) and (3)).

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{1}$$

The MNDWI calculation is as follows:

$$NDWI = \frac{Green - SWIR}{Green + SWIR} \tag{2}$$

$$MNDWI = \frac{Green - MIR}{Green + MIR} \tag{3}$$

For the comparison and estimation of riverbank and channel shifting rates, we divided the analysis into four sub-periods: 1988 to 1998, 1998 to 2006, 2006 to 2012, 2012 to 2022. To calculate the bankline shifting, we traced the bankline of the earlier year and then traced the bankline of consequent year. The baseline for the left and right banks were individually produced using a 1000 meter buffer from the composite line. Subsequently, 546 transects were created with a 5 meter uncertainty at an acute angle to the baseline.

2.3 Estimation of erosion-accretion rate

The Digital Shoreline Analysis System (DSAS) estimated changes in the shoreline pattern using Linear Regression Rate (LRR), End Point Rate (EPR), Net Shoreline Movement (NSM) methods[(13)]. The rate of EPR was determined using following equation:

$$EPR = \frac{D1 - D2}{t1 - t2} \tag{4}$$

Where, D_1 - D_2 implies the difference in distance between the earliest and most recent shorelines and t_1 and t_2 implies the dates of these shorelines.

2.4 Bankline Prediction

A set of linear regression rates (LRR) is used to accurately predict the future bankline changes. When projecting bankline migration using Kalman Filter method, the model considers the bankline migration over different time periods: 1988 to 1998, 1998 to 2006, 2006 to 2012 and 2012 to 2022. The following equation is applied to estimate the rate of bankline migration by fitting a regression line to each point along a specific transect.

$$Y = a + bx \tag{5}$$

In this equation, 'y' represents the dependent variable, which is predicted or explained by 'x', 'a' constant, and 'b' is the slope of the regression line. The slope of the regression line illustrates the impact of each unit of 'x' on the shifting of 'y'. Additionally, the correlation coefficient was computed to determine the level of correlation between 'x' and 'y' values [14].

The estimated values of 'y' (which represents the distance from the baseline) are for each shoreline points are calculated by using the 'x' values (the dates of the shoreline) and solving the equation for the best fit regression line:

$$Y = mx + b \tag{6}$$

In this equation, 'y' represents the predicted probable distance from the baseline, 'm' indicates the slope (rate of change), and 'b' denotes the y-intercept (where the line crosses the y-axis).

The standard error of the estimate evaluates how precise the predicted 'y', values are by comparing them to actual values from the shoreline point data. The LSE (Linear Standard Error) and WSE (Weighted Linear Regression) was calculated (Equation (7)).

$$LSE\ or\ WSE = \sqrt{\frac{\sum\left(y - y'\right)^2}{n-2}} \tag{7}$$

Where, 'y' stands for the distance from the baseline of the bank for a shoreline data point; 'y′' represents the distance by the equation of the best-fit regression line, 'n' refers to the number of shoreline used.

3 Results and Discussion

3.1 Results

Assam experiences heavy devastation due to natural calamities such as floods including flash floods, riverbank migration, landslides. Among these, riverbank erosion significantly affects the lives and properties [15]. The increasing population and extreme climate events have become major concerns for the river valleys. The rate of vulnerability and risk has increased significantly compared to earlier disasters. [16] Therefore, there is an urgent need to study riverbank shifting in the regions of the Brahmaputra valley that are highly affected by erosion. Various studies have been conducted on riverbank line migration, such as Santos C. et al. (2020) [17] in Brazil, Quang DN, 2021 [18] in the Vietnam, Hossain, S., et al. (2022) [19] in the southeast coast of Bangladesh. Typically, the DSAS model has been used to monitor changes in sea shoreline. However, it is now used to monitor the riverbank line shifting with higher precession after analyzing the right and left banks separately [3,11]. Therefore, the DSAS model has been used in this study to monitor the rate of riverbank shifting. Two main methods were employed to identify the trend of bankline shifting of Brahmaputra riverbank in the Morigaon district. Initially, the EPR method was used to estimate the bankline shifting rate between two banklines. Subsequently, the LRR method was applied to analyse the changes in the bankline using more than two sets of bankline data. Finally, based on the LRR data, future predictions were made for 10 years and 20 years intervals.

3.1.1 Bankline shifting estimation using EPR method

Three zones have been delineated along the riverbank: zone A, zone B and zone C. A total of 573 transect are spread across both the right and left banks, with 191 transects in each zone. The EPR rates of the erosion and deposition have been organized to assist in finding the intensity of erosion and accretion (Figure 3). It is important to note that a positive EPR value indicates accretion and negative EPR value indicates erosion. The EPR and LRR (meter/year) are classified as 0 to 50 means low accretion, 50 to 100 moderate accretions, more than 100 means high accretion, 0 means unchanged, 0 to -50 means low erosion, -50 to -100 means moderate erosion, more than -100 means high erosion.

In the analysis of riverbank shifting from 1988 to 1998, the average rate of left bankline shifting in the zone A, B and C were -54.47 meter/year, -65.71 meter/year and -74.00 meter/year respectively. In the same period, the average rates of right bank shifting in zone A, B and C were 133.61 meter/year, 90.17 meter/year and 29.91 meter/year respectively. During this period, the erosion was severe in left bank while deposition was prominent on the right bank. On the left bank, all zones showed high erosion rates, but in the right bank in the zone A, the rate of accretion compared to zone B and zone C. In the 1998 to 2006, the average rate of left bank line shifting in zone A, B and C were -89.53 meter/year, -59.59 meter/year and -270.98 meter/year respectively. In the same period, the average rates of right bankline shifting in zone A, B and C were -37.61 meter/year, 27.74 meter/year and 604.49 meter/year respectively.

During this period, the average rate of erosion was highly significant in zone C i.e., 270.98 meter/year, while the average rate of accretion was significantly high i.e., 604.49 meter/year. In the 2006 to 2012, the average rates of riverbank shifting in the left bankline in the zone A, B and C were -34.43 meter/year, 8.20 meter/year and -144.89 meter/year respectively. In the same period, the average rate of shifting in the right bankline in zones A, B and C were 296.84 meter/year, -2.37 meter/year and 11.14 meter/year respectively. In this time frame, the rate of bank erosion is high in the left bank's zone C and on the other hand, the rate of accretion is high in the zone A.

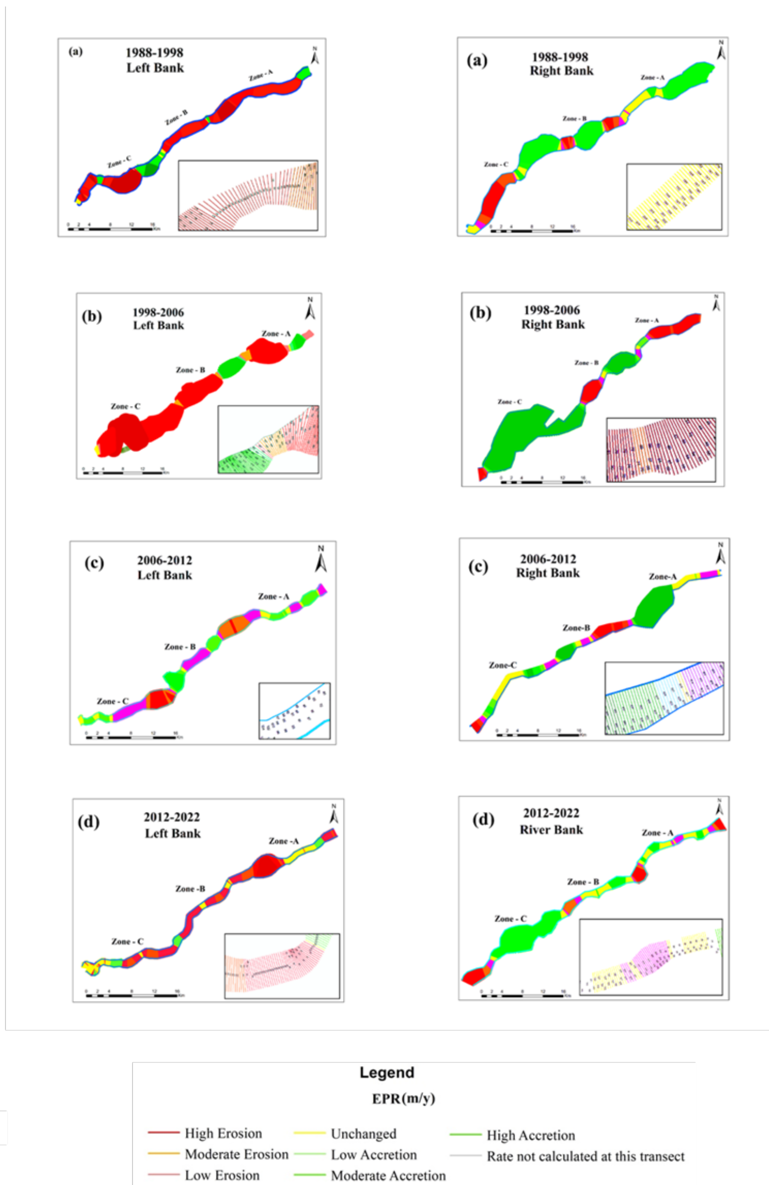

Fig 3. Channel shifting status on the basis of EPR rate during the period of (a) 1988-1998, (b) 1998-2006, (c) 2006-2012, (d) 2012-2022

From 2012 to 2022, the average rate of left bankline shifting in zone A, B and C were -86.57 meter/year, -26.58 meter/year and -18.89 meter/year respectively. In the same period, the average rate of right bank line shifting in zone A, B and C were 8.12 meter/year, -9.85 meter/year and 171.54 meter/year respectively. During this period, the rate of erosion was constant across all the zones of left bank, while the rate of accretion was significant in the zone C.

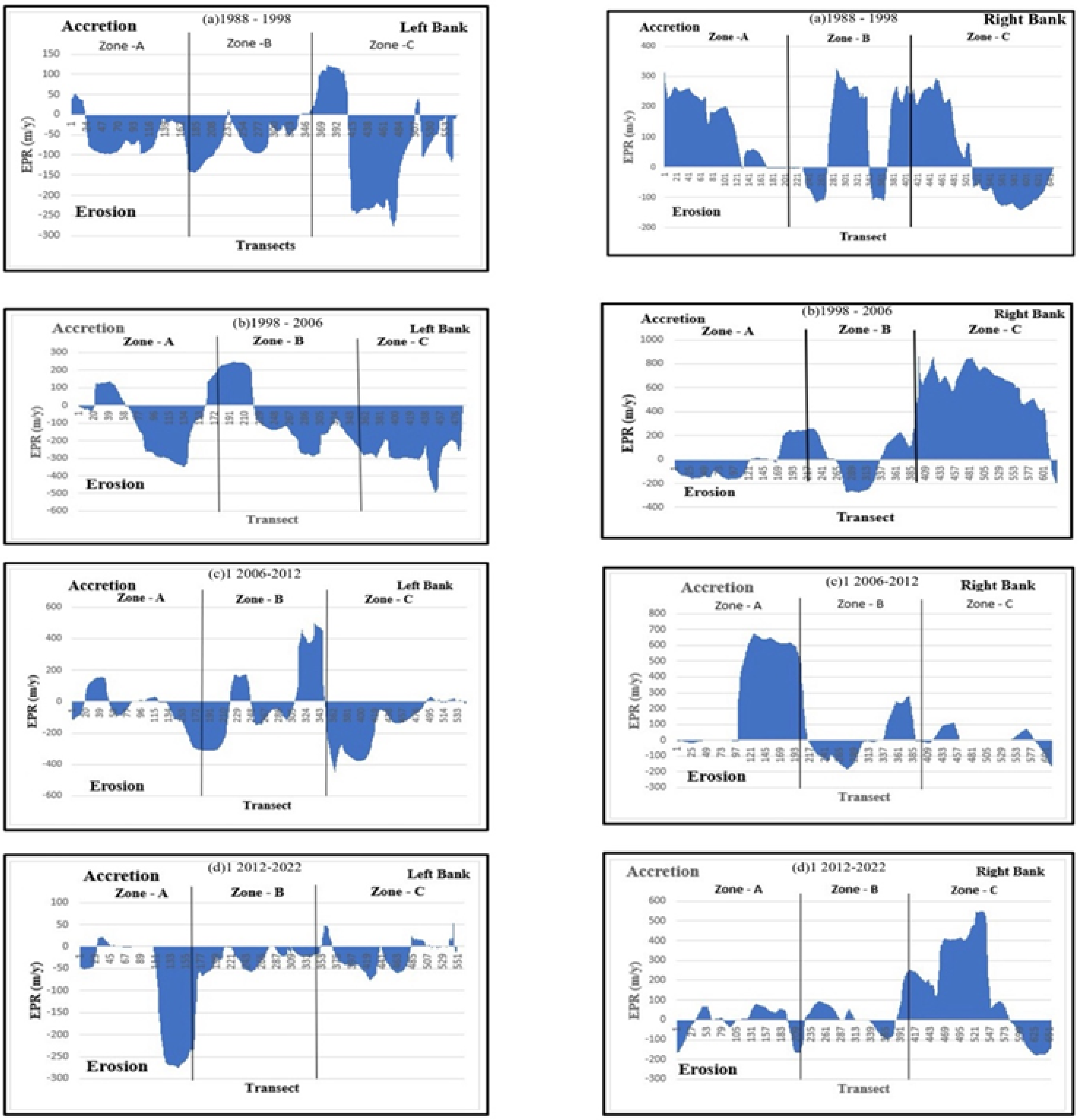

Fig 4. EPR based riverbank channel shifting during the period of (a) 1988-1998, (b) 1998-2006, (c) 2006-2012, (d) 2012-2022

3.1.2 Bankline shifting estimation using LRR method

The linear Regression Rate (LRR) statistics were applied to estimate the slope of the regression line by fitting a least squares regression line across all shoreline points along the transects [20]. The average rate of left bank erosion and accretion from 1988 to 2022 were -81.87 m/y and 0 m/y, respectively. For the right bank, the rates of erosion and accretion were -83.59 m/y and 68.45 m/y respectively. The overall shifting of left bank's zone A, B and C was -81.86 m/y, -48.98 m/y and -118.22 m/y, respectively. In right bank's zone A, B and C, the bankline shifting rates were -44.10 m/y, 68.67 m/y and 27.67 m/y respectively. The overall shifting rates of the right and left riverbank were -81.17 m/y and 17.09 m/y respectively. It is noticeable that a high rate of activity has been observed in the zone C.

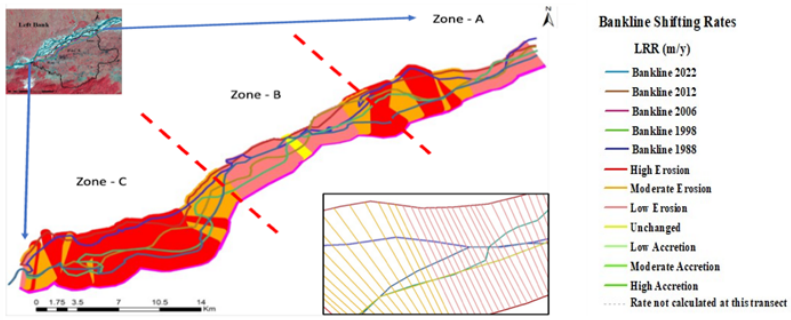

Fig 5. LRR based left riverbank shifting rate

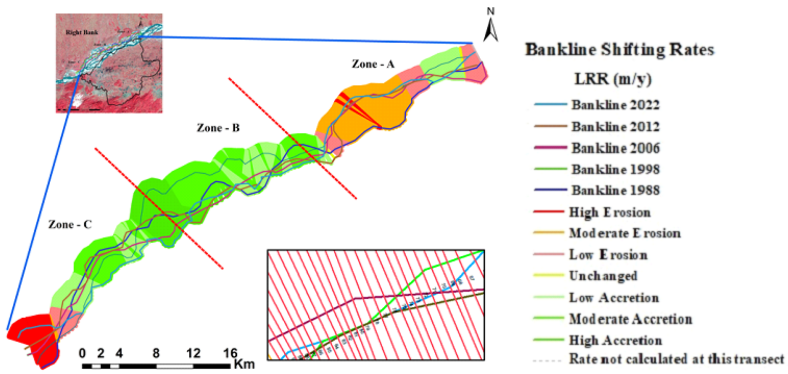

Fig 6. LRR based right riverbank shifting rate

3.1.3 Prediction of riverbank alteration using DSAS model's Kalman Filter Method

Future prediction of riverbank shifting have been considered for 2032 and 2042 (Figure 5). From 2022 to 2032, the average rate of erosion on the left and right banks of the river is expected to be 122.09 m/y and 57.16 m/y respectively. On the other hand, the average rate of accretion on the left and right banks might be 10.23 m/y and 90.16 m/y respectively. The overall shifting during this period is to be -119.66 m/y on the left bank and 16.88 m/y in the right bank. In terms of the erosion, the zone C (left bank) is expected to experience severe erosion as compared to zone A and B, while zone B is predicted to experience the high-rate accretion compared to zone A and C. From 2022 to 2042, the average rate of erosion on the left and right banks is projected to be 115.63 m/y and 63.32 m/y respectively. Conversely, the rate of bank accretion on the left and right bank is expected to be 5.91 m/y and 2.35 m/y respectively. From 2022 to 2032, the overall shifting of the left and right bank would be -119.66 m/y and 16.88 m/y respectively. From 2022 to 2042, the overall shifting of the left and right bank would be -116.75 m/y and 2.35 m/y respectively. During this period, the zone C would be highly erosion prone as compared to zone A and B, while the highest rate of accretion is expected in zone B, followed by zone A and C.

In the comparative scenario of bank line shifting from 2022 to 2032 and from 2022 to 2042, a significant erosion rate has been observed in zone C in both images, highlighting an urgent need for mitigation measures to reduce the erosion rate in zone B and C. In terms of accretion, the zone B and C on the right bank show significant changes. There is clear indication that various natural and anthropogenic factors are responsible for the leftward migration of the riverbank leading to significant erosion in the Morigaon district. This will result in human displacement and social disruption.

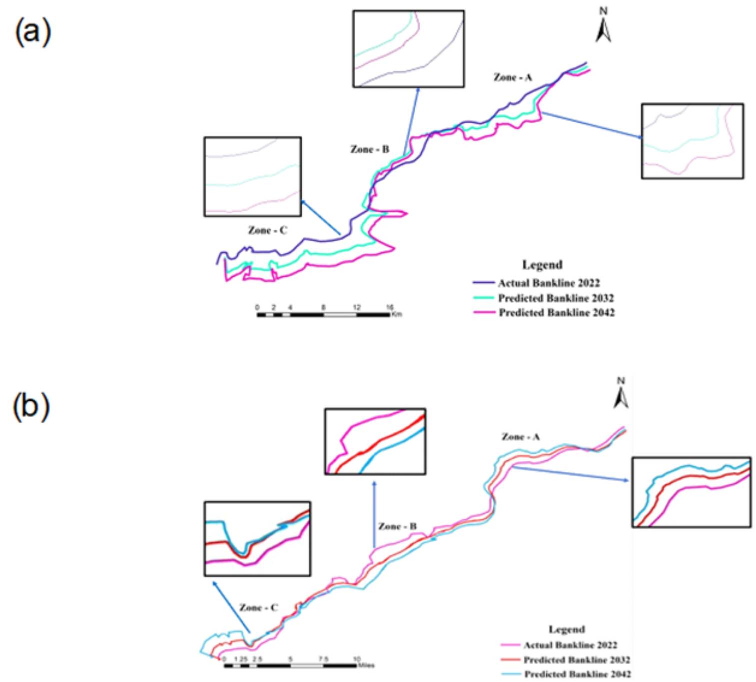

Fig 7. Bankline prediction of riverbank in the study area (a) left bankline future prediction, (b) right bankline prediction

3.1.4 Standard Error Graph

The technique is used for precise analysis of bankline alternation estimation using transects [21]. This analysis reveals that the rate of erosion and accretion detection is high, and uncertainty is insignificant in the WLR approach as compare to LRR approach.

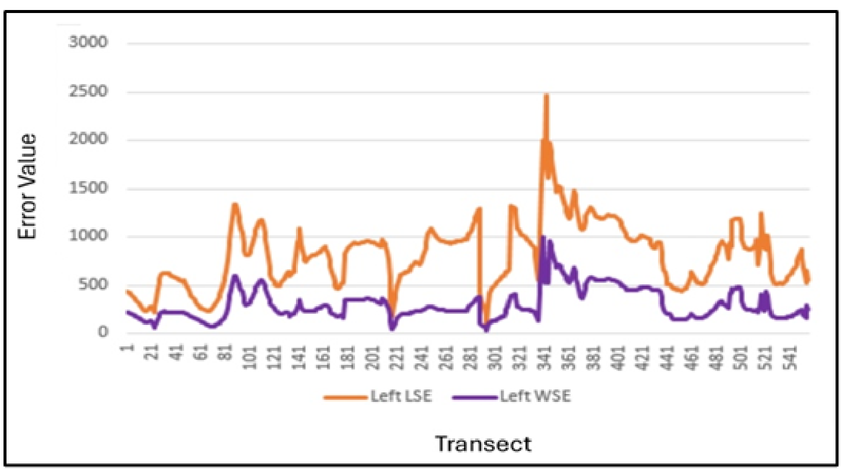

Fig 8. Standard error for LRR and WLR

3.2 Discussion

Channel migration and riverbank erosion are indispensable processes in the dynamic behavior of rivers [22]. Riverbank erosion is the natural mechanism of material attrition along the riverbank, stimulating the formation of various land forms such as river valleys, flood plains, river terraces, cliffs and bluffs. However, riverbank erosion can become a significant threat when the intensity of flood increases, leading to land loss.[23]

The Morigaon district has been facing severe erosion for a long time. The erosion leads to several socio-economic problems including the displacement of communities, loss of agricultural land, degradation of biodiversity, habitat destruction, infrastructural damage, water quality degradation. In this study, erosion, and deposition along the Morigaon district has been studied from 1988 to 2022. Multispectral satellite images have been used to understand the trend of bank erosion. The study area has been divided into three zones: zone A, zone B and zone C. On the left bank, the intensity of erosion is significantly high in all the zones. However, zones B and C are relatively more erosion prone across all the time frames.

From 1988 to 2006, the rate of bank erosion in zone A was found to be moderate to high. Highly erosion prone regions include areas adjacent to Roumari, Harangtoli, Dakhin Chenimari, Pambori, Sunarugaon. Moderate to low erosion prone regions were adjacent to Leruamukh, Garaimari Pathar, Sitolmari Pathar. Some portion showed unchanged and moderate accretion. Between 2006 and 2012, the region experienced low erosion and accretion rates. From 2012 to 2022, some regions adjacent to Kapurpura, Tulsibori, Halowkandha experienced high erosion prone area. The eastern part of the zone indicated unchanged and low erosion and accretion rates.

On the right bank, from 1988 to 2022, the rate of bank accretion was significantly high across all the zones. In zone B on the left bank, from 1988 to 2006, most of the regions adjacent to 2 no. Borkur, Barukati, Bordooba Toop, Dighali Aati, Kupatimari experienced moderate to high rate of bank erosion. However, a significant variation was noticed from 2006 to 2012, the intensity of high erosion was not observed, and most areas experience moderate to low erosion. From 2012 to 2022, the region experienced low erosion rate. On the right bank, the rate of erosion and accretion fluctuated from 1988 to 2022. From 1988 to 1998, most region experienced high deposition rate across the zone, while from 1998 to 2006, the western part of the riverbank experience high erosion rate while the eastern part experienced high deposition rate.

The high rate of erosion was noticed from 2006 to 2012, but the rate accretion decreased from 1998 to 2006. In zone C, in the left bank, from 1988 to 2006, the moderate to high rate of erosion prone area was adjacent to Bahakajari, Betani Kasarigaon, Barunguri Beel, Haibor Pathar, Betani. From 2006 to 2022, there is low rate of erosion has been noticed. In right bank, the rate of bank erosion from 1988 to 1998, the rate of erosion has been noticed but again from 1998 to 2006, the rate of accretion become significant in this region. From 2006 to 2022, the rate of bank erosion increased.

Several natural and human-induced factors are responsible for the riverbank erosion in the Morigaon district. Natural factors include high rainfall intensity, geology, geomorphological setup. The anthropogenic factors include deforestation, human encroachment, human interference on channel (sandbar stabilization and construction of bridges). According to the data from the Indian Metrological Department, the average monthly rainfall in the month of July 2008 is 3.70 mm and in the month of July 2020, it was 6.73 mm, indicating an abrupt increase in the intensity of rainfall. Topographically, most of Morigaon district lies in a low-lying area. Anthropogenic activates also enhances bank erosion such as deforestation has been occurring in the Brahmaputra and Kopili river catchment area and it enhances the surface runoff and vegetation loss has been noticed in the satellite imageries. In 1991, 26.34% of the geographical area covered by natural and semi natural vegetation, which decreased to 15.86% in 2021. Moreover, there has been a significant reduction in wetlands in the study area.

This research significantly contributes to the scientific understanding of fluvial dynamics and the management of riverbank erosion. The study meticulously analyses the rate, pattern and underlying causes of riverbank erosion in the Brahmaputra River in the Morigaon district. This analysis also sheds light on the complex interplay between natural and anthropogenic factors that influencing riverbank erosion. The evidence-based insights provide guidance for the implementation of mitigation measures and the development of sustainable solutions to address the bank erosion in Morigaon district.

4 Conclusion

The application of geospatial technology in evaluating riverbank migration is one of the most effective methods for assessing the riverbank of the Morigaon district. The changing status of riverbank migration has been estimated using statistical parameters such as EPR and LRR. The study reveals that, based on LRR statistics, the rate of erosion on the left bank (81.17 m/y) is significantly high, while the rate of accretion is 0 m/y in the observed area. Conversely, on the right bank, the rate of erosion is 83.59 m/y, and the rate of accretion is 68.45 m/y. Notably, erosion is more severe in the zone C (118.22 m/y) of left bank. Therefore, there is an urgent need to implement necessary measures to address riverbank migration on the left bank. This assessment is limited to a comprehensive analysis of bankline shifting using multitemporal analysis. Further analysis of different parameters, such as shear stress distribution, bank material cohesiveness, channel sinuosity, stream power index, overlay analysis, drainage network analysis, soil moisture content could be conducted. Various hydrological models can be added to understand the changing trends of bankline and the reasons for its shifting. Therefore, more research is needed to understand the changing pattern of bankline, its causes and potential solutions. Finally, the data obtained from this analysis will assist land managers and policy-makers in designing more efficient riverbank erosion mitigation strategies.

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