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Quantifying River Bank Erosion and Accretion Patterns along the Gorai River in Kushtia, Bangladesh: A Geospatial Analysis Utilizing GIS and Remote Sensing Techniques

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Abstract

River bank erosion is a natural process that occurs when the water flow of a river exceeds the bank's ability to withstand it. It is a common phenomenon that causes extensive land damage, displacement of people, loss of crops, and infrastructure damage. The Gorai River, situated on the right bank of the Ganges, is a significant branch of the river that flows into the Bay of Bengal via the Mathumati and Baleswar rivers. The erosion of the banks of the Gorai River in Kushtia district is not a recent occurrence. Local residents have been dealing with this issue for the past hundred years, and according to the elderly members of the community, the erosion has become more severe activities. Therefore, the main objective of this research is to quantify river bank erosion and accretion and bankline shifting from 2003 to 2022 using multi-temporal Landsat images data with GIS and remote sensing technique. Bank-line migration occurs as a result of the interplay and interconnectedness of various factors such as the degree of river-related processes such as erosion, transportation, and deposition, the amount of water in the river during the high season, the geological and soil makeup, and human intervention in the river. The results show that the highest eroded area was 4.6 square kilometers during the period of 2016 to 2019, while the highest accreted area was 7.12 square kilometers during the period of 2013 to 2016. However, the erosion and accretion values fluctuated from year to year.

Keywords

Erosion and Accretion, Geographic Information System (GIS), Remote Sensing, Satellite Image, Bankline Shifting

1. Introduction

The problems of riverbank erosion, accretion, and channel shifting are significant global resource management issues. It is considered to be one of the most hazardous and unpredictable types of disasters, as it is influenced by a variety of factors such as rainfall, soil composition, river morphology, topography of the river and surrounding areas, and floods [1]. The uncontrolled movement of alluvial rivers in Bangladesh, which leads to bank erosion and channel shifting, poses significant challenges to the country's socio-economic and environmental well-being [2]. The Gorai River, situated on the right bank of the Ganges, is a significant branch of the river that flows into the Bay of Bengal via the Madhumati and Baleswar rivers. The erosion of the banks of the Gorai River in Kushtia district is not a recent occurrence. Local residents have been dealing with this issue for the past hundred years, and according to the elderly members of the community, the erosion has become more severe due to certain human activities. A large number of tributaries and distributaries of the powerful Ganges, Brahmaputra, and Meghan River systems pass through Bangladesh, which is a riparian basin. In this nation, river bank erosion and accretion with concomitant channel migration is a highly frequent occurrence and continuous dynamic process [3]. The study of Gorai River bank erosion and accretion using GIS and RS techniques is significant due to its ability to provide detailed and accurate information on the changes occurring in the river channel over time. The use of satellite imagery allows for the detection and monitoring of riverbank dynamics, which can provide valuable insights into the river's hydrological behavior. River bank erosion and accretion are essential natural geomorphological processes that have drawn significant attention from river engineering scientists. This indicates the crucial role that these processes play in shaping river ecosystems and the need for continued study and understanding of their mechanisms [4]. At the same time, GIS can be applied in various fields, [5] such as biodiversity and climate change identification, monitoring of noise pollution and air pollution [6] [7]. River bank shifting usually involves the formation of one bank while the opposite bank is eroding. Therefore, it is important to study the spatiotemporal morpho dynamics of a river to understand its behavior [8]. The study of river bank erosion and accretion, and its position, is a complex and challenging task in the field of geomorphology [9]. River bank erosion is just one aspect of the overall channel system, where it is closely connected to other processes such as sediment transport and deposition [10]. Satellite imagery can readily identify and map land use/land cover changes both locally and over large areas, along with their effects on river processes. This emphasizes the usefulness of satellite imagery in detecting and monitoring changes in land use and cover that affect river systems [11]. GIS and RS are valuable tools for detecting changes in river channels and bank erosion. By using appropriate formulas, these tools can be used to measure bank shifts and determine universal erosion and accretion for any river. This highlights the usefulness of GIS and RS in identifying and monitoring erosion situations in rivers [12]. The Gorai River, which is a crucial watercourse for Bangladesh, has attracted the attention of various national and international researchers and organizations Horeet (2013), under the Centre for Environmental and Geographic Information Services (CEGIS), conducted a study on the morphological development of the Gorai River off-take to restore the river's flow [13]. Objectives of the Study are—To analyze the erosion and accretion patterns of the Gorai River in Kushtia over the period of 2003 to 2022 and also analysis river bankline shifting from 2003 to 2022. The Gorai River is the study's primary emphasis, but a comparative examination with other river systems dealing with comparable issues might improve the findings' generalizability. Provide a comparison study with other river systems in the area or throughout the world that deal with the same problems. This could shed light on recurring patterns or distinctive features of the Gorai River. By utilizing GIS and RS techniques, a study on the erosion and accretion of the Gorai River will be conducted. The aim of the research includes analyzing satellite imagery of the river taken at various times, calculating the regions impacted by erosion and accretion, and analyzing riverbank displacement. The outcome of this study will contribute to understanding the morphological behavior (channel sifting, erosion, and deposition) of the Gorai River.

2. Materials and Method

2.1. Study Area

Kushtia Gorai River was selected for the study (in **Figure 1**). Khulna Division's Kushtia District occupies an area of 1608.80 square kilometres and is situated between latitudes 23˚42' and 24˚12' north and longitudes 88˚42' and 89˚22' east. Its borders are that of Rajbari district to the east, West Bengal, India, Rajshahi, Natore, and Pabna districts to the north, Chuadanga and Jhenaidah districts to the south, and Meherpur district to the west (Banglapedia). The Gorai River is the primary right bank distributary of the Ganges River and the primary source of highland freshwater inflows into Bangladesh's southwest [14]. The Gorai River is situated in southwestern Bangladesh, spanning between 21˚30'N to 24˚0'N latitude and 89˚0'E to 90˚0'E longitude. The primary river systems in this region are the Gorai-Modhumati-Baleshwar River system and the Gorai-Bhairab-Pussur river system. The Gorai River forms the upper course of the Gorai-Modhumati—Baleshwar system, which becomes the Baleshwar River in its lower course. The Haringhata River, with a mouth width of 14 km, marks the estuary point. The Baleswar River is 57 km long, while the Nabganga River stretches 29 km from Bardia Point to Gazirhat. The Gorai-Modhumoti-Baleswar rivers run for a total length of 371 km, with sections covering 37 km in Kushtia, 71 km in Faridpur, 92 km in Jashore, 104 km in Khulna, and 67 km in Barisal, located on the eastern border of the Sundarbans [15]. The average temperature of the catchment area is varying between 22˚C —23˚C in winter and 23˚C to 32˚C in the summer. The lowest temperature is 6˚C to 11˚C in winter and 40˚C to 43˚C in the summer. The average annual rainfall is between 1516 mm in the northeast and 2478 mm in the southeast.

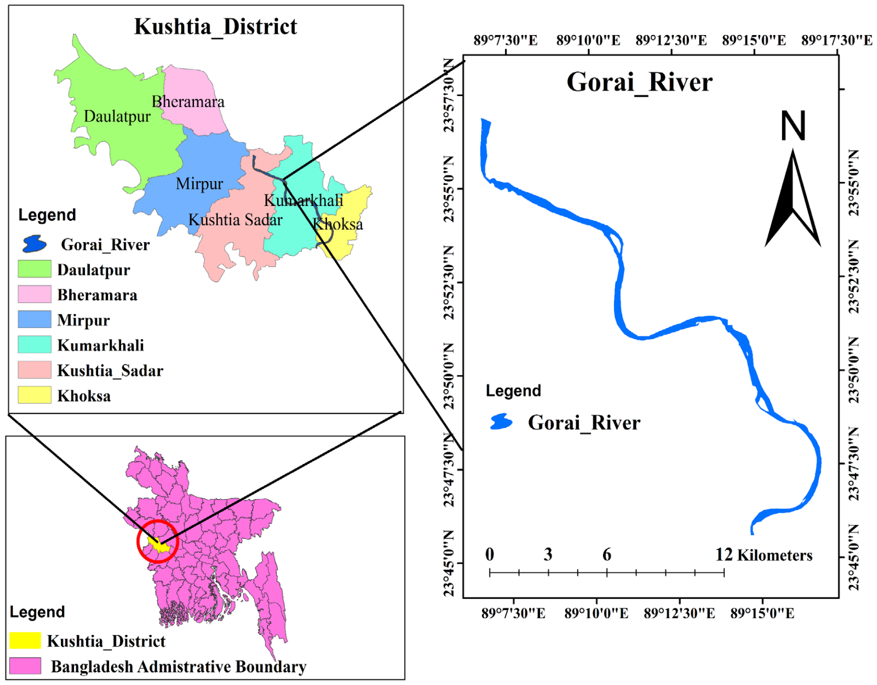


Figure 1. Study area map.

2.2. Data and Its Sources

The satellite images of the Gorai River of seven different years 2003, 2006, 2010, 2013, 2016, 2019 and 2022 in kushtia, Bangladesh are obtained from United States Geological Survey (USGS). The basic data used in this study are seven multi-date Landsat imageries, e.g., 2003 (TM), 2006 (TM), 2010 (TM), 2013 (ETM), 2016 (ETM), and 2019 (OLI) and 2022 (OLI). Table 1 presents all the information about the satellite images used in the present study.

2.3. Geo-Referencing of Satellite Image

Before beginning the analysis, the study's data must be geo-referencing. Every Landsat picture used as a guide was captured. Geo-referencing uses Arc GIS (version 10.8) software. In this work, traditional georeferencing and a high-resolution feature matching approach were employed. Geo-referencing is one of the primary mistakes of multi-resolution satellite pictures. In order to correct the WGS 1984 UTM Zone 45N projection system picture, image processing was used to accomplish geometric rectification.

2.4. Data Analysis Process

Seven images of Gorai River of 2003, 2006, 2010, 2013, 2016, 2019 and 2022 were downloaded from United States of Geological Survey (USGS) website (in Figure 2).

The erosion and accretion analysis were conducted using Remote Sensing (RS) and Geographic Information Systems (GIS) technology. ArcGIS image processing tool was used to process the images, while ArcGIS version 10.8 was

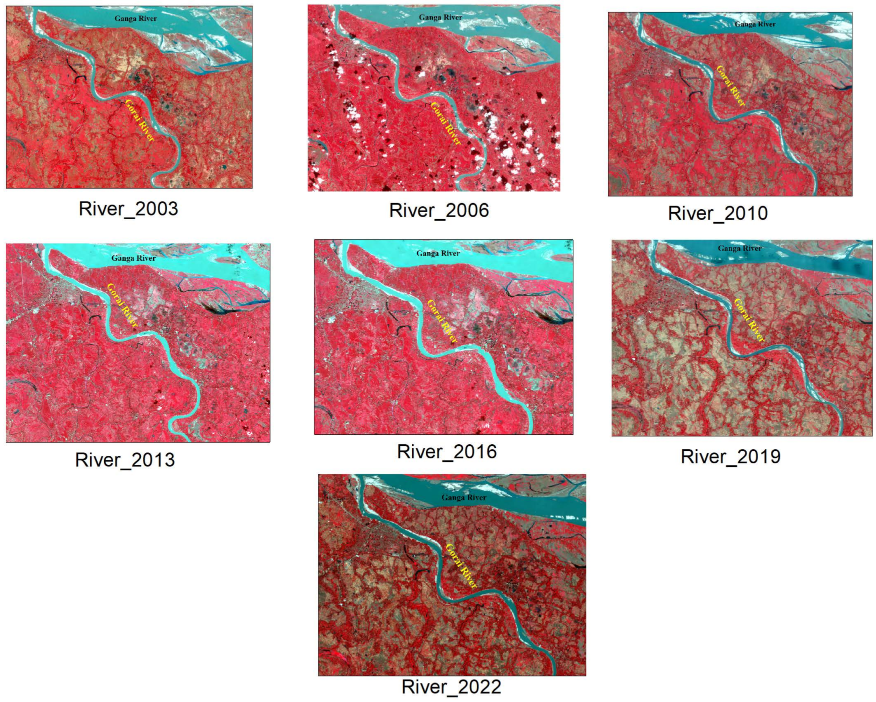


Figure 2. Satellite image of Gorai River at different time period.

Table 1. List of Landsat satellite images information (Source: USGS).

Image year	Satellite	Sensor	Path/Raw	Acquisition Date	Sources
2003	LANDSAT 4	TM	138/42	12—Oct 2003	USGS
2006	LANDSAT 5	TM	138/42	25-Oct-2006	USGS
2010	LANDSAT 5	TM	138/42	22-Nov-2010	USGS
2013	LANDSAT 7	ETM	138/42	18-Sep-2013	USGS
2016	LANDSAT 7	ETM	138/42	13-Oct-2016	USGS
2019	LANDSAT 8	OLI	138/42	10-Dec-2019	USGS
2022	LANDSAT 8	OLI	138/42	22-Nov-2022	USGS

used for the GIS analysis. Additionally, Microsoft Excel was utilized for data analysis and graphing. The study utilized Landsat satellite images to analyze river bank erosion and accretion during seven time periods from 2003 to 2022. To obtain cloud-free surface reflectance images during the pre-monsoon dry period, data was downloaded from the USGS Earth Explorer website.

The images were analyzed through an unsupervised classification algorithm and post-classification change employing skills in Geographic Information System are performed to evaluate spatial and temporal dynamics of erosion and accretion for different points of Gorai River using Bangladesh. shape files of each year were created from the histogram equalized unsupervised Landsat images using ArcGIS 10.8 through manual digitization to extract river boundaries. The method by which every image in a dataset is determined to belong to one of the intrinsic categories included in the image collection all without the need of tagged training samples is known as unsupervised image classification. Unsupervised machine learning methods are used to accomplish unsupervised picture categorization. The two primary classes of unsupervised machine learning algorithms required for unsupervised image categorization are clustering algorithms and dimension reduction algorithms [16].

First of all, An Iso Cluster unsupervised image classification approach is employed to generate LULC maps, which are reclassified based on river value. The resulting raster image is transformed into a polygon shape file for analysis. then extracted AOI and calculated erosion, accretion, and river bank line shifting using the ArcGIS 10.8 version tool and MS Excel. Conceptual Data Processing and Analysis are shown in Figures 3-5.

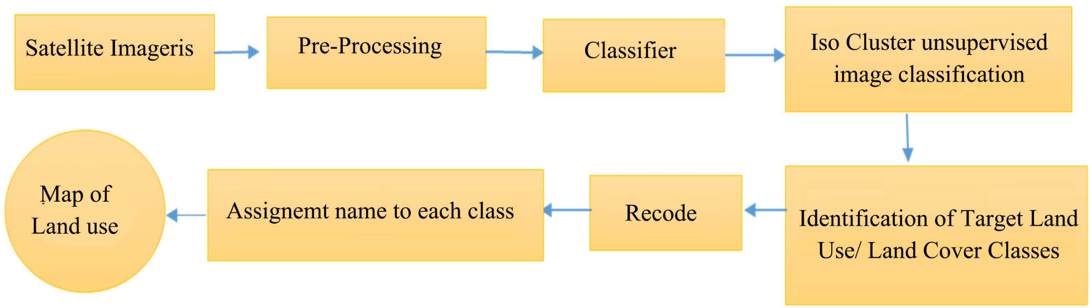


Figure 3. Flow chart of ISO cluster unsupervised image classification.

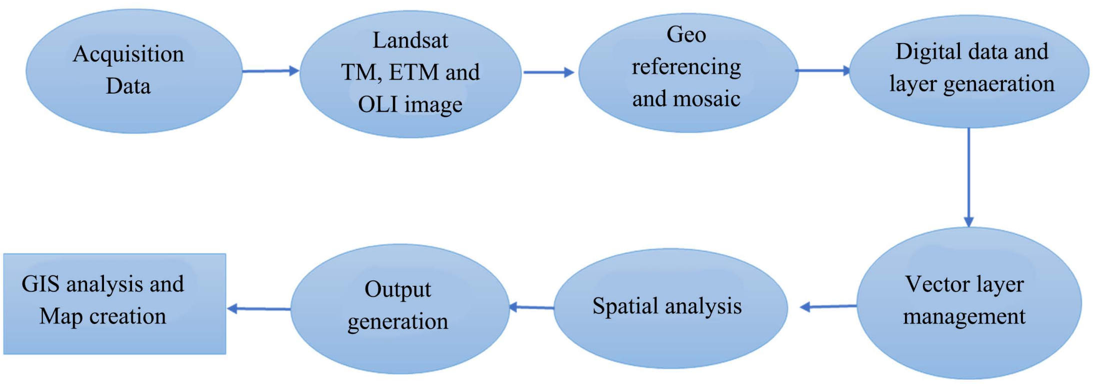


Figure 4. Conceptual framework.

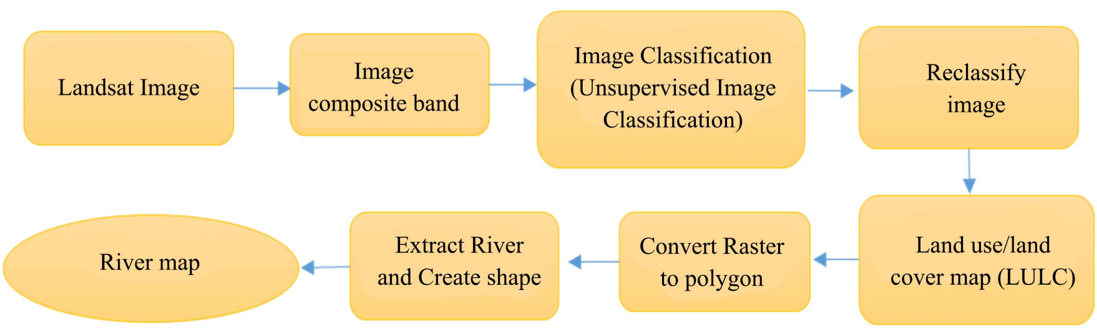


Figure 5. GIS Image analysis framework.

3. Results

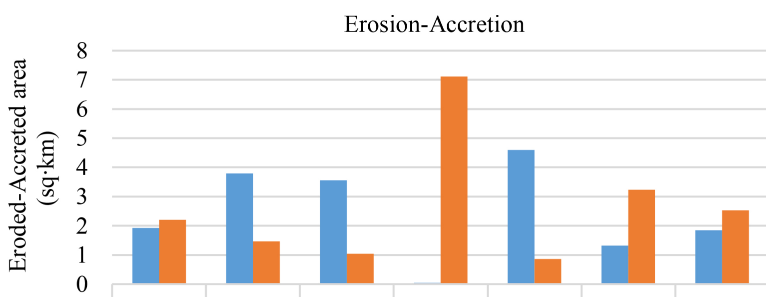
3.1. Erosion and Accretion Analysis

By analyzing Landsat images from 2003 to 2022, the Riverbank line has been identified and established. The analysis provides insight into the rate of erosion and accretion in the active channel of the Gorai River over a period of seven years (in **Figure 6**) and we have calculated eroded and accreted area at a square kilometer scale (in **Figure 7**).

The Riverbank line has been identified and established at Landsat image of 2003, 2006, 2010, 2013, 2016, 2019, and 2022. Histogram Equalized unsupervised image is meaningful for identifying the Riverbank line. By analyzing seven distinct Landsat images from 2003 to 2022, it has been observed erosion and accretion of the active channel of Gorai River. The period spanning from 2013 to 2016 showed the most significant increase in accretion, with 7.12 square kilometers (km^2) gained, while only 0.04 square kilometers (km^2) were lost due to erosion. Conversely, the period between 2016 to 2019 had the highest level of erosion, with 4.60 square kilometers (km^2) lost, while only 0.86 square kilometers (km^2) were gained through accretion. The smallest amount of erosion was observed between 2013 to 2016, with only 0.04 square kilometers (km^2) lost, while 7.12 square kilometers (km^2) were gained through accretion. Similarly, the smallest amount of accretion was observed between 2016 to 2019, with only 0.86 square kilometers (km^2) gained, while 4.60 square kilometers (km^2) were lost due to erosion. The erosion and accretion values fluctuated from place to place. The fluctuation of erosion and accretion values is shown on a graph in **Figure 6**.

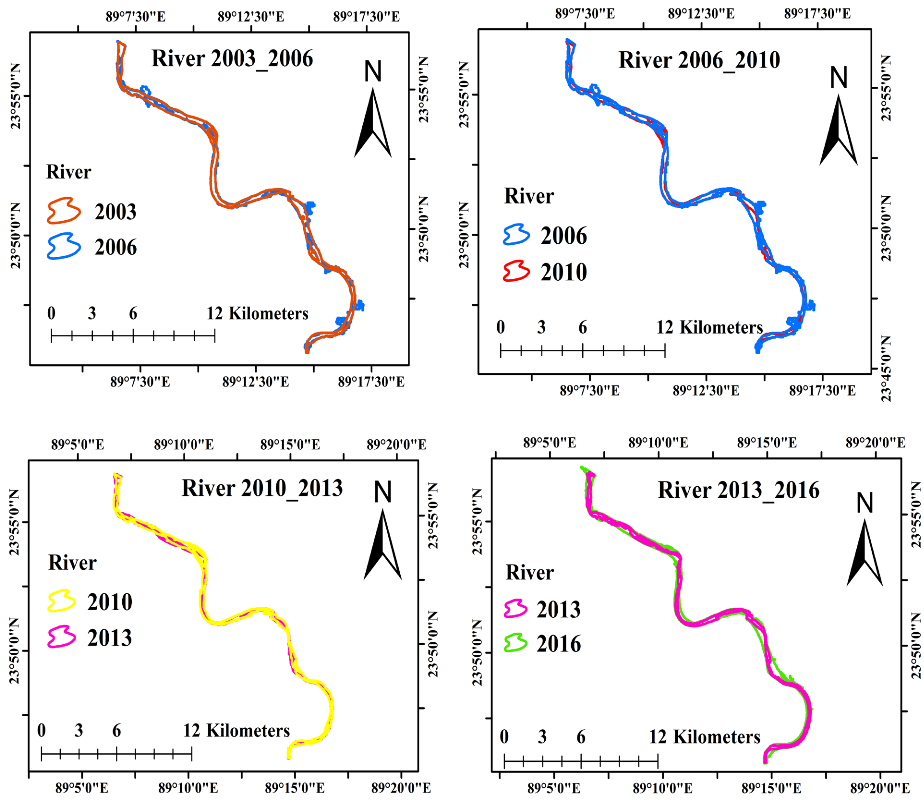
3.2. River Bankline Shifting

Bank-line shifting occurs as a result of the interplay and interconnectedness of various factors such as the degree of river-related processes such as erosion, transportation, and deposition, the amount of water in the river during the high season, the geological and soil makeup, and human intervention in the river. The current investigation has assessed the movement of the river channel from

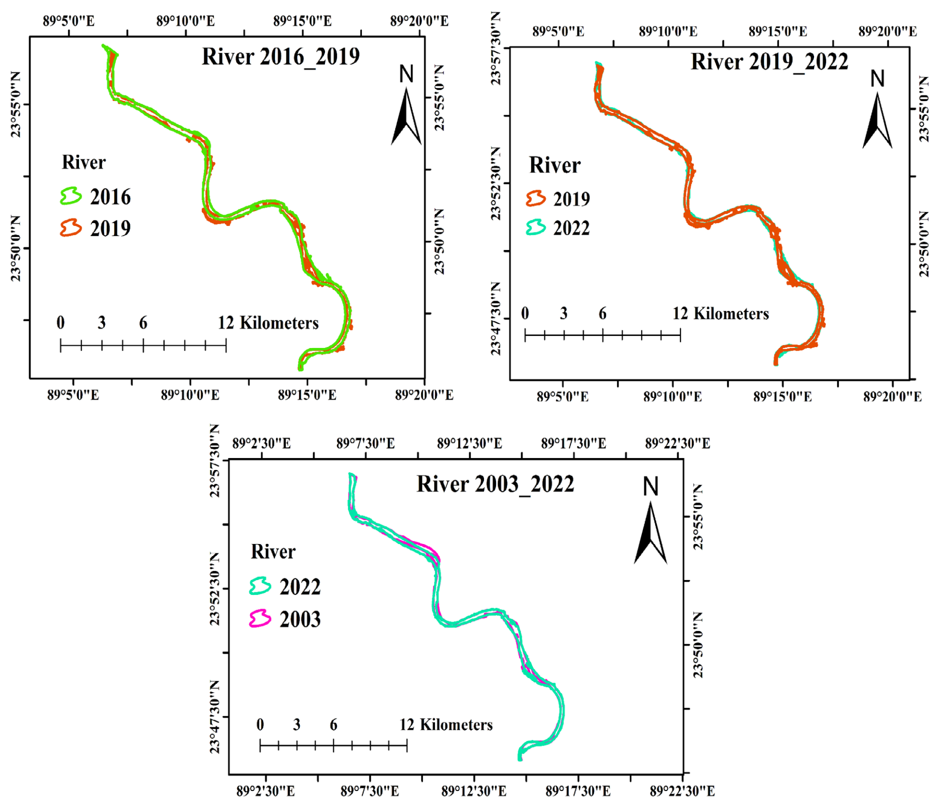


	2003-2006	2006-2010	2010-2013	2013-2016	2016-2019	2019-2022	2003-2022
Erosion (sq·km)	1.93	3.79	3.56	0.04	4.6	1.32	1.85
Accretion (sq·km)	2.2	1.47	1.04	7.12	0.86	3.23	2.53

Figure 6. Erosion and accretion analysis of Gorai River at Kushtia.



(a)



(b)

Figure 7. (a) and (b) represent the erosion and accretion map of the Gorai River at Kushtia.

the 2003 to 2022. To analyze river bankline shifting, we created six cross-sections with uneven distances (as shown in Figure 8), and showing the river bank shifting (in Figures 9-15).

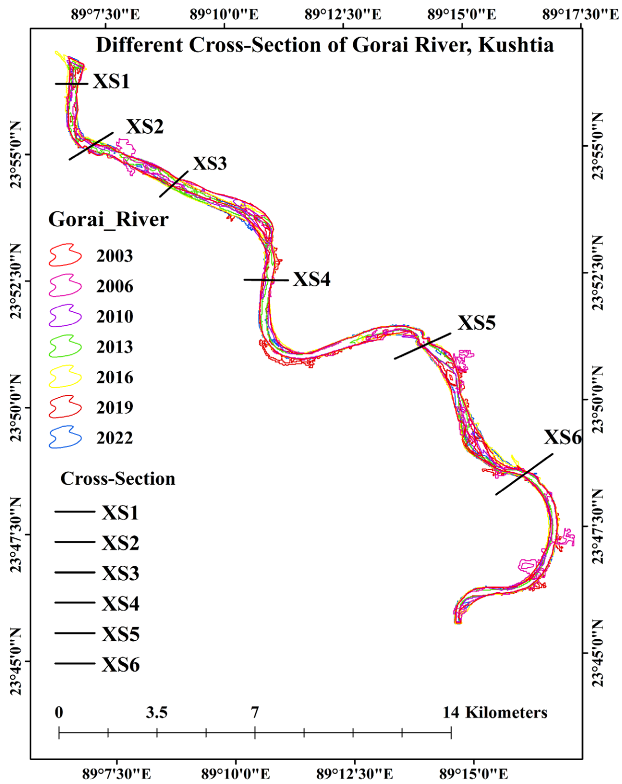


Figure 8. Different cross section of Gorai River.

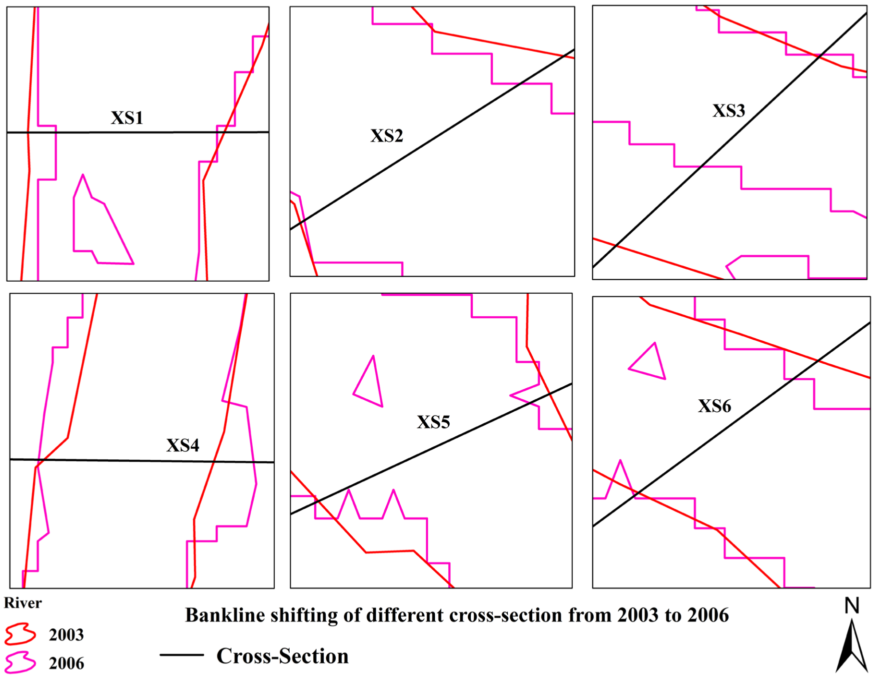


Figure 9. Bankline shifting of different cross-section from 2003 to 2006.

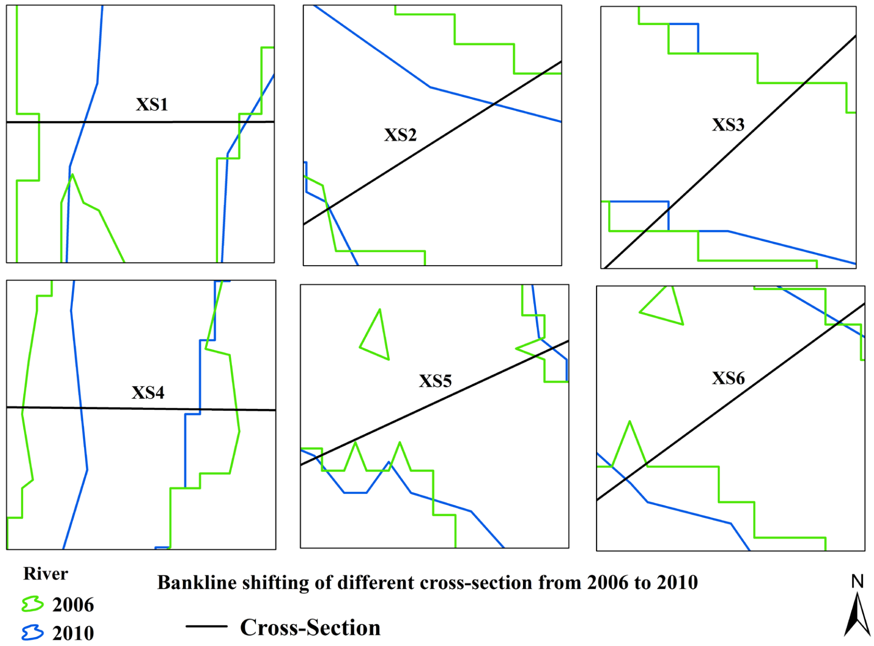


Figure 10. Bankline shifting of different cross-section from 2006 to 2010.

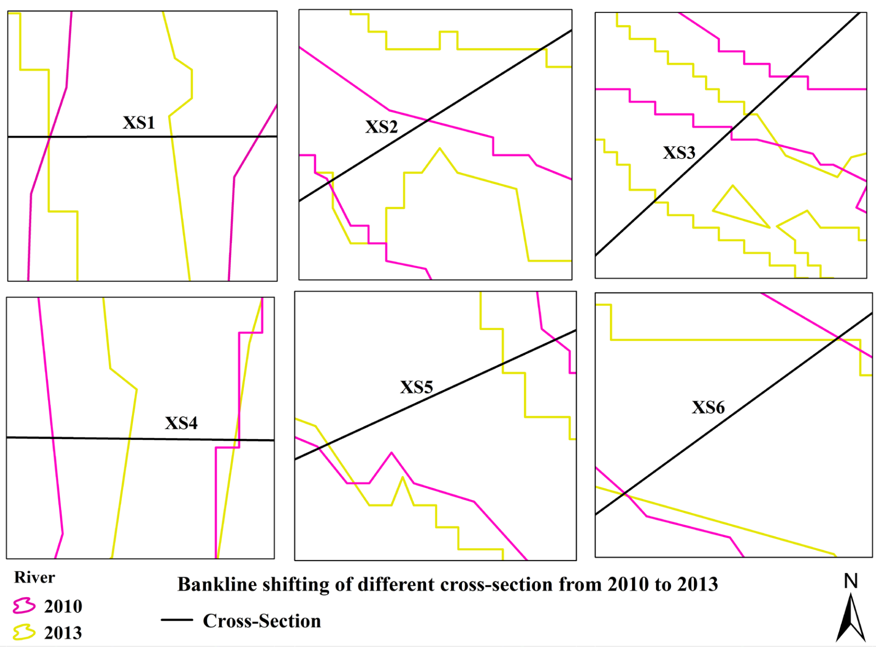


Figure 11. Bankline shifting of different cross-section from 2010 to 2013.

When river cross sections from 2003 to 2006 (Table 2) were analyzed, it was found that the river's left bank moved from left to right, causing accretion in cross Sections 1, 2, and 3. On the other hand, erosion was evident in cross Sections 4, 5, and 6, where the left bank shifted from right to left. During this same time frame, the river's right bankline changed. In particular, accretion was shown by cross Sections 1, 2, 5, and 6 which showed a shift in the right bank from right to left. On the other hand, erosion was caused by the right bank

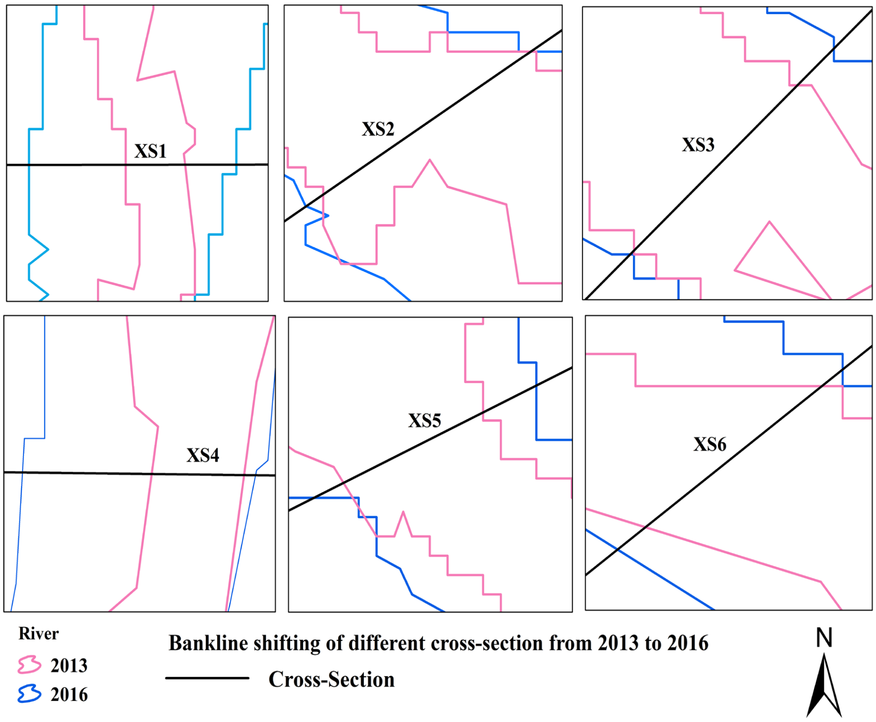


Figure 12. Bankline shifting of different cross-section from 2013 to 2016.

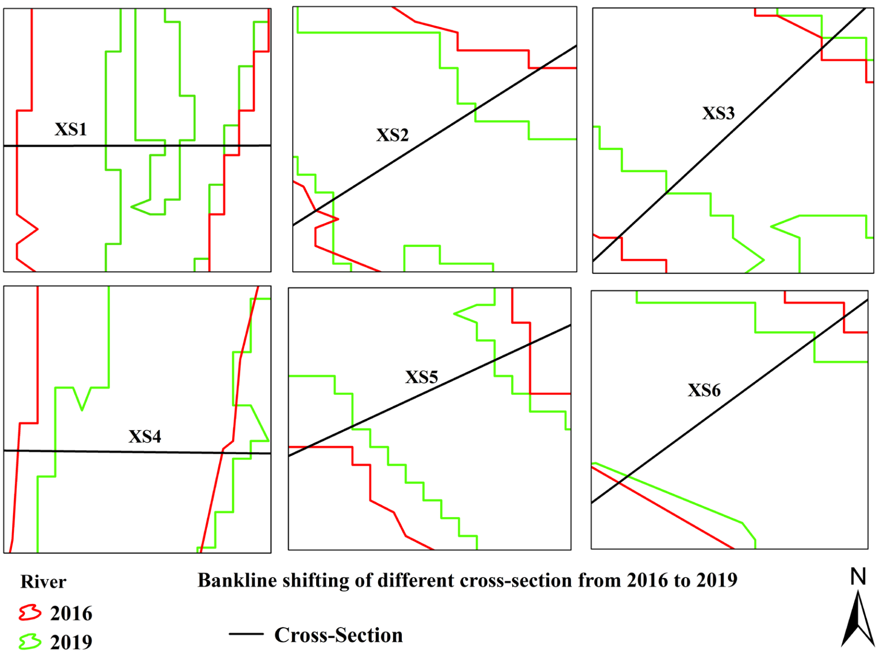


Figure 13. Bankline shifting of different cross-section from 2016 to 2019.

shifting from left to right, as demonstrated by cross Sections 3 and 4. A thorough analysis of river cross sections between 2006 and 2010 (Table 3) showed significant changes to the river's left bank. Sections 5 and 6 showed a rightward movement that contributed to more accretion, while Sections 1 through 4 showed a leftward shift that created accretion. During this time, the river's right

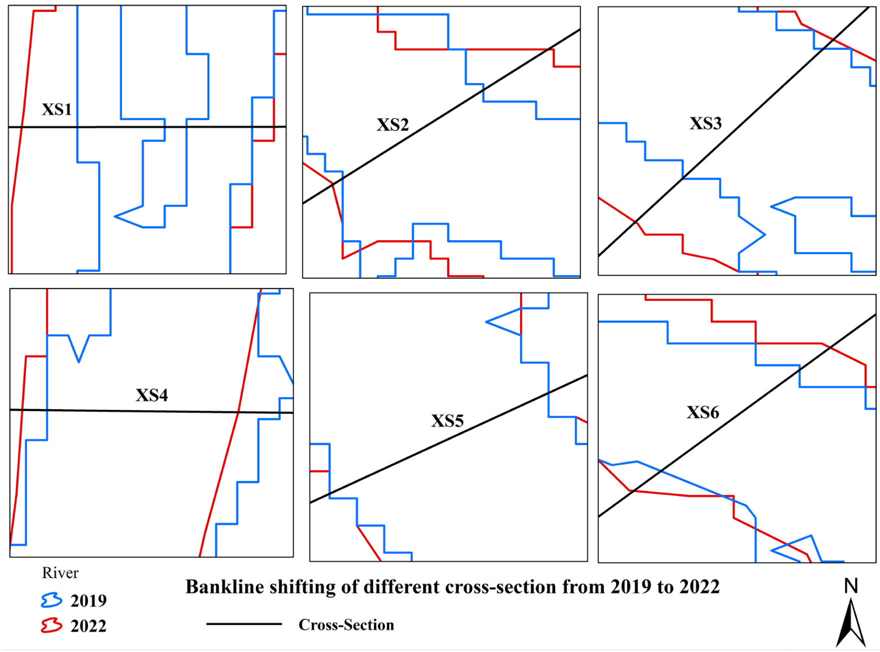


Figure 14. Bankline shifting of different cross-section from 2019 to 2022.

Figure 15. Bankline shifting of different cross-section from 2003 to 2022.

bank had modifications as well. To be more precise, accretion was shown by a shift that occurred from right to left in cross Sections 1 and 2, and from right to right in cross Sections 4, 5, and 6. Interestingly, the bankline of cross Section 3 did not appear to change. There were some interesting modifications on the left bank of the river between 2010 and 2013 (Table 4). Erosion was seen in cross Sections 1, 3, and 6, which may have been caused by natural processes such

Table 2. Bankline shifting of the Gorai River from 2003 to 2006.

Cross-section	left bank shifting (m)	Direction	Right bank shifting (m)	Direction
XS1	47	Right	12.22	Left
XS2	4.79	Right	51.47	Left
XS3	158.45	Right	4.58	Right
XS4	10.74	Left	79.87	Right
XS5	4.64	Left	29.29	Left
XS6	5.24	Left	30.94	Left

Table 3. Bankline shifting of the Gorai River from 2006 to 2010.

Cross-section	left bank shifting (m)	Direction	Right bank shifting(m)	Direction
XS1	60.61	Right	9.62	Left
XS2	2.02	Right	58.63	Left
XS3	32.62	Right	0	No Shifting (Erosion & Accretion are not found here)
XS4	117.29	Right	73.11	Right
XS5	8.8	Left	25.27	Right
XS6	21.64	Left	3.37	Right

Table 4. Bankline shifting of the Gorai River from 2010 to 2013.

Cross-section	left bank shifting (m)	Direction	Right bank shifting(m)	Direction
XS1	1.29	Left	90.83	Left
XS2	8.11	Right	226.66	Right
XS3	245.72	Left	132.18	Left
XS4	99.29	Right	5.08	Left
XS5	13.5	Right	78.01	Left
XS6	1.87	Left	3.38	Left

meandering or changes in water flow velocity. Cross Sections 2, 4, and 5, on the other hand, showed a contrasted shift that caused accretion and moved from left to right. Point bars, which are formed when sediments build up on the inner bend of meander loops, may result from this change. During this time, there were distinct changes on the river's right bank. The changes in cross Sections 1, 3, 4, 5, and 6 were from right to left and indicated accretion. In contrast, the right bankline in cross Section 2 moved from the right to the left, producing.

The left bank of the river migrated to the left in 2013-2016 (**Table 5**), according to the cross-sectional analysis, indicating erosion in every cross section. On the other hand, no movement was seen in cross Section 2, indicating that erosion or accretion has not occurred here. On the opposing conjunction, in 2013 the right bank of the river moved to the right in every cross section that remained, suggesting that erosion had taken place. Moreover, it is clear from the data that the river's left bank migrated to the right in each section in 2016-2019 (**Table 6**), which resulted in erosion. On the other hand, erosion also occurred as the river's right bank moved in the direction of the right in cross Sections 1, 3, and 4. Nevertheless, accretion occurred in cross Sections 5 and 6, where the right bank moved to the left. With the exception of cross Section 5, which stayed the same, it appears that the river's left bank moved toward the left between 2019 and 2022 (**Table 7**) leading to erosion in all but that cross section. However, in 2019, the river's left bank moved toward the right in cross Sections 1, 2, 3, and 6, resulting in erosion. On the other hand, no discernible movement was seen in cross Section 5, suggesting that neither erosion nor accretion had occurred. The analysis of the river cross sections from 2003 to 2022 (**Table 8**) reveals interesting changes in the left bankline. Specifically, cross Sections 1, 4, and 5 showed that the left bank of the river shifted from left to right, resulting in the creation of accretion. This may have led to the formation of point bars and changes in the channel's shape, which could have significant impacts on the river's ecology and hydrodynamics. On the other side (for the right bankline) cross Sections 1, 2, 4, and 6 showed that the right bank shifted from right to right, which resulted in erosion. This could be due to natural factors such as increased water velocity or changes in sediment supply, or human activities such as channelization or land use changes. Meanwhile, cross Sections 3 and 5 showed that the right bank shifted from right to left, resulting in accretion. This shift could be due to natural processes such as deposition or changes in flow patterns, or human activities such as bank stabilization or vegetation management.

Table 5. Bankline shifting of the Gorai River from 2013 to 2016.

Cross-section	left bank shifting (m)	Direction	Right bank shifting (m)	Direction
XS1	210.01	left	111.13	right
XS2	34.23	left	0	No shifting (Erosion and accretion are not found here)
XS3	7.17	left	67.2	right
XS4	191.17	left	16.95	right
XS5	54.92	left	99.06	right
XS6	35.11	left	26.38	right

Table 6. Bankline shifting of the Gorai River from 2016 to 2019.

Cross-section	left bank shifting (m)	Direction	Right bank shifting (m)	Direction
XS1	179.99	right	30.07	right
XS2	34.13	right	131.14	left
XS3	89.04	right	20.94	right
XS4	62.94	right	48.13	right
XS5	83.28	right	66.14	left
XS6	11.23	right	37.23	left

Table 7. Bankline shifting of the Gorai River from 2019 to 2022.

Cross-section	left bank shifting (m)	Direction	Right bank shifting (m)	Direction
XS1	76.4	left	30.02	right
XS2	20.33	left	131.09	right
XS3	103.51	left	21.39	right
XS4	35.2	left	58.54	left
XS5	No shifting (Erosion and accretion are not found here)		No shifting (Erosion and accretion are not found here)	
XS6	46.18	left	51.78	right

Table 8. Bankline shifting of the Gorai River from 2003 to 2022.

Cross-section	left bank shifting (m)	Direction	Right bank shifting (m)	Direction
XS1	0.053	right	17.76	right
XS2	5.41	left	116.31	right
XS3	78.73	left	18.02	left
XS4	42.32	right	7.48	right
XS5	28.44	right	48.99	left
XS6	98.74	left	9.69	right

3.3. Left Bank Changes

In various cross sections, the left bank showed alternating patterns of moving from right to left (accretion) and left to right (erosion) in the initial analysis (2003-2006). The left bank continuously moved from left to right in the second analysis (2006-2010), which resulted in accretion in every part. The left bank had a mixed pattern of changes from left to right (erosion) and right to left (accretion) in different cross sections in the third analysis (2010-2013). All parts experienced erosion as a result of the left bank's migration to the right in the fourth analysis, which ran from 2013 to 2016. The left bank once more moved to the left and produced erosion in all but one of the sections in the fifth analysis (2016-2019). The left bank continuously moved to the left in the sixth analysis (2019-2022), resulting in erosion in all but one part.

3.4. Right Bank Changes

Erosion and accretion were observed on the right bank in the initial analysis (2003-2006), with movements in both directions in different cross sections. In the second examination, which took place between 2006 and 2010, most parts saw accretion as a result of the right bank's constant migration to the left. The right bank consistently shifted to the left, leading to accretion, in the third analysis, which covered the years 2010-2013. During the fourth analysis period (2013—2016), there was a shift in the right bank's direction, resulting in erosion in certain areas and accumulation in others. Most parts experienced erosion as a result of the right bank's constant displacement to the right in the fifth analysis, which ran from 2016 to 2019. Most parts experienced erosion as a result of the right bank's constant migration to the right in the sixth analysis (2019-2022).

4. Discussion

The study of seven Landsat images taken between 2003 and 2022 shows that the Gorai River exhibits dynamic patterns of accretion and erosion along its banks. The patterns that have been seen provide light on the complex interactions between environmental elements that affect the morphology of the river. The time analysis reveals discrete accretion and erosion stages. In contrast to the subsequent period from 2016 to 2019, which was characterized by a considerable increase in erosion, losing 4.60 km^2, the period from 2013 to 2016 stands out with a substantial increase in accretion, gaining 7.12 km^2. These variations highlight the intricate and unpredictable nature of riverbank processes, which reflects the Gorai River's dynamic character. Between 2003 and 2006, the left bank had alternating periods of accretion and erosion. From 2006 to 2010, there was a constant leftward shift and accretion. A mixed pattern on the left bank was found by further investigations, suggesting susceptibility to environmental influences. From 2003 to 2006, there was a combination of erosion and accretion on the right bank; from 2006 to 2010, there was a constant leftward movement and accretion. On the other hand, a directional change on the right bank between 2013 and 2016 produced localized erosion and accretion, demonstrating dynamic reactions to external stressors. The development of sustainable river management techniques requires an in-depth analysis of accretion and erosion trends. The creation of focused solutions to lessen the effects of riverbank changes on nearby communities, agricultural fields, and infrastructure is made possible by an understanding of the temporal and geographical dynamics. The research also emphasizes the necessity of adaptive management strategies that take into consideration the intrinsic diversity in river systems. This study provides a thorough examination of riverbank morpho dynamics, which makes a substantial contribution to science. The patterns that have been discovered suggest that the Gorai River is constantly changing due to a variety of causes, such as manmade interventions, geological characteristics, water levels, and natural processes. Future investigations into the hydrodynamics and geomorphology of rivers will benefit from these results.

5. Conclusion

The investigation of the bank erosion and accretion of the Gorai River in Bangladesh's Kushtia district from 2003 to 2022 offers important new information about the dynamic nature of riverbank changes and their effects on the environment. To visually understand and map these changes, the study used geographic information system (GIS) layers created from satellite remote sensing data, specifically Landsat satellite imagery. A thorough visual interpretation procedure was used to map the patterns of erosion and accretion using Landsat satellite data, and then to record the changes in the river bank line that resulted from these patterns. This thorough approach made it possible to thoroughly analyze the changes that occurred along the riverside between 2003 to 2022, a period of 19 years. The thorough GIS study carried out throughout this time period demonstrated significant variations and changes in the layout of the river bank. The greatest significant erosion was recorded between 2016-2019, which also happened to be the years with the least amount of accretion. On the other hand, the years 2013-2016 demonstrated the least amount of erosion and the largest amount of accretion. The left and right bank lines experienced dynamic changes, showing alternating patterns of accretion and erosion in different cross sections and periods, according to an investigation of river cross sections from 2003 to 2022. The hydrodynamics and ecology of the river may be significantly impacted by these changes. The study demonstrated the value of using geospatial data and riverbank mapping, providing a strong basis for additional research on the Gorai River.

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Author Contributions

All co-authors have been involved in all stages of this study while preparing the final version. They all agree with the results and conclusions.

Conflicts of Interest

The authors declare that they have no competing interests.

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