

Erosion-Accretion Dynamics and Displacement along the Jamuna River Part of Sirajganj District

Mst. Sadia Siddika Trina, Md. Inzamul Haque*, Md. Asikur Rahman, Md. Ashrafur Islam Dewan, Most. Atia Parvin, Md. Anik Hossain

Dept. of Geography and Environment, Islamic University, Kushtia-7003, Bangladesh

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Abstract

The Jamuna River is one of the largest rivers in Bangladesh, where erosion and accretion occur most frequently. This study analyzed LULC, evaluated the extent of erosion and accretion of the Jamuna River from 1988 to 2024, and assessed its effects, primarily on population displacement in Sirajganj district, where four upazilas are prone to bank erosion: Kazipur, Sirajganj Sadar, Belkuchi, and Chauhali. Landsat TM-5 and Landsat-8 imagery from three different periods (1988, 2006, and 2024) were obtained from the USGS to analyze LULC, CDS (change detection statistics), NDWI (normalized difference water index), and erosion and accretion. The results indicated that from 1988 to 2024, erosion totaled 18,813 hectares, accretion totaled 14,480 hectares, and 3,937 hectares remained unchanged. This represents a more significant erosion than accretion, resulting in the forced displacement of affected people. The CDS result for Sirajganj Sadar shows that the settlement area increased by 74.69% from 1988 to 2024, indicating that population movement from rural areas (such as agricultural or fallow land) to urban areas contributed to this shift. The total population of Sirajganj Sadar was 389,160 in 1991 and 631,877 in 2022, according to the Bangladesh Bureau of Statistics (BBS), reflecting substantial population growth. The population growth of Chauhali Upazila has been relatively steady but has declined over the last decade. In contrast, Kazipur Upazila's growth has increased very slowly during this period, indicating a shift in the population of these areas, which are more prone to bank erosion. This study quantifies the long-term (1988–2024) erosion and accretion dynamics of the Jamuna River in a highly vulnerable area of Bangladesh, directly linking these changes to population migration within specific affected upazilas in Sirajganj District. With its spatially explicit evidence of environmental change driving internal displacement, this integrated method provides important insights for targeted interventions that will help policymakers and stakeholders take practical steps to mitigate bank erosion and its impacts.

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Keywords: *Jamuna River, Sirajganj, erosion and accretion, LULC Change, population displacement.*

1. Introduction

Riverbank erosion is a natural phenomenon in Bangladesh and other lower-confluence deltaic countries (Ali et al., 2021). Bangladesh is home to some of the world's most disaster-prone lands. Severe floods, powerful cyclones, and riverbank erosion caused by them have been a fact of life here. Geologically, Riverbank erosion is one of Bangladesh's most common natural disasters and probably occurs annually as a recurring, highly unpredictable event (Iva et al., 2017). It poses a significant threat by permanently depriving people of their roots and material wealth (Mollah & Ferdaush, 2015). River erosion is a typical geomorphological phenomenon in regions with constructed floodplains. Riverbank erosion is sometimes referred to as a "silent disaster" because it occurs more frequently each year than human-made catastrophes (Hassan, 2015).

The Ganges, Brahmaputra, and Meghna River systems form the largest delta in Bengal. River systems translocate approximately two billion tons of silt annually to the Bengal Delta (Hossain & Sakai, 2008). The largest braided river that meanders through Bangladesh's low-lying, sinking

deltaic floodplain is the Old Brahmaputra, referred to as the "Jamuna" (Ashworth, 1996). Jamuna River, one of Bangladesh's major rivers, has deteriorated over the past decade due to varying rates of erosion and accretion (Hassan et al., 2017). Rivers are dynamic systems because they constantly alter course, so erosion and accretion are normal processes. Even if erosion can occasionally outpace accretion and ruin lives and livelihoods, the impoverished community typically suffers the most (Islam & Rashid, 2011). The multi-channel braided system of the Jamuna River is one of its defining features. It regularly changes, generating sandbars and altering the river's course (Nath et al., 2013). The lower Brahmaputra's Jamuna River experiences significant yearly erosion, resulting in major bankline migration, thousands of homeless families, and substantial land loss. For example, Jamuna's dynamic nature causes great suffering to the people who live along its course and on its islands (Baki & Gan, 2012). Over the past decade, the Jamuna River has caused the erosion of approximately 30 settlements, displacing one-third of the city's population and rendering 400,000 individuals homeless. During the monsoon season, the river Jamuna experiences a substantial increase in water flow, with

* Corresponding author e-mail: mihaque.iu@gmail.com

an average discharge of approximately 40,000 cubic feet per second. During this period, the Jamuna River experienced significant devastation, causing severe damage in Sirajganj District, which lies directly along its banks. Each year, tragedy results in a substantial number of individuals losing their livelihoods and agricultural land (Das, 2014). Following a complete loss due to the river, affected individuals relocate to neighboring districts or other areas (Shetu et al., 2016).

Nowadays, remote sensing and geographical information systems (GIS) techniques are essential tools for identifying LULC changes, disaster-prone areas, damage, and severity, as well as calculating the rate of change (Mohamad et al., 2018; Tobore et al., 2021; Al-Amoush et al., 2017). Despite uneven erosion rates, Bedini (2017) utilizes Landsat imagery and GIS tools to identify significant erosion along the coastline between the Semani and Shkumbini rivers and in Central Albania. A similar study, using Landsat TM and MSS satellite imagery in Chandpur district, Bangladesh, found that bar deposition in the Meghna River exceeded riverbank erosion, with an estimated 3,517 square meters of deposition between 1990 and 2002 (Nath et al., 2013). Using remote sensing, Uddin et al. (2011) measured morphological changes and susceptibility to erosion along the Jamuna riverbank. A study revealed that riverbank erosion has increasingly affected people in the riverine zone of the Jamuna, where Sirajganj Sadar was the most erosion-prone area (Rabbi et al., 2013). A spatial-temporal analysis of the erosion and accretion on the East and West Riverbanks of the Jamuna River was conducted by Hassan et al. (2017). They analyzed the spatial and temporal dynamics of erosion and accretion along the Jamuna River from 1995 to 2015, using Landsat imagery and Geographic Information System (GIS) techniques. Although considerable research has been conducted on riverbank erosion in Sirajganj, a comprehensive study is still lacking. Almost all previous studies on the Jamuna River have focused on either morphological dynamics, based on erosion and accretion along the bank line, or the socioeconomic aspects of the changes. Limited studies focus on the long-term

spatiotemporal dynamics of erosion and deposition, with inadequate integration of advanced techniques like indexing (NDWI classification) for precise monitoring. Furthermore, while geoenvironmental impacts are explored extensively, comprehensive assessments of socio-economic consequences remain underrepresented, particularly regarding the livelihoods of affected communities. However, a significant gap remains in understanding how spatiotemporal land use and land cover (LULC) dynamics contribute to forced displacement due to erosion.

In this context, this study utilizes the Landsat TM Satellite and GIS to evaluate spatial and temporal changes in the Sirajganj district and calculate the erosion and accretion of the River Jamuna. Through digital image processing applied to temporal satellite images, the analysis enables researchers to evaluate the detection of river and erosion changes, while displaying the patterns and shifting river channels over time. Remote sensing provides a rapid, synoptic view of large areas, integrating with GIS techniques, making it an ideal tool for monitoring riverbank erosion and shoreline shifting at regular intervals (Sarkar et al., 2012). The bank line change analysis is crucial for predicting river path changes, assessing potential impacts on life and the environment, especially migration, and visualizing different spatial changes. So, the objectives of this study are to analyze the spatiotemporal variation of bank line shift of the Jamuna River to calculate the erosion-accretion rate from 1988 to 2024 and to explore the pattern of LULC changes in different upazilas of Sirajganj district. Furthermore, this study also tries to develop a population displacement scenario based on the riverbank line shift and LULC change in different parts of the study area.

2. Materials and Methods

2.1 Study Area

Sirajganj District is a district in the North Bengal region of Bangladesh, which is a part of the Rajshahi Division and is located between 24°01' and 24°47' north latitudes and between 89°15' and 89°59' east longitudes (Figure 1).

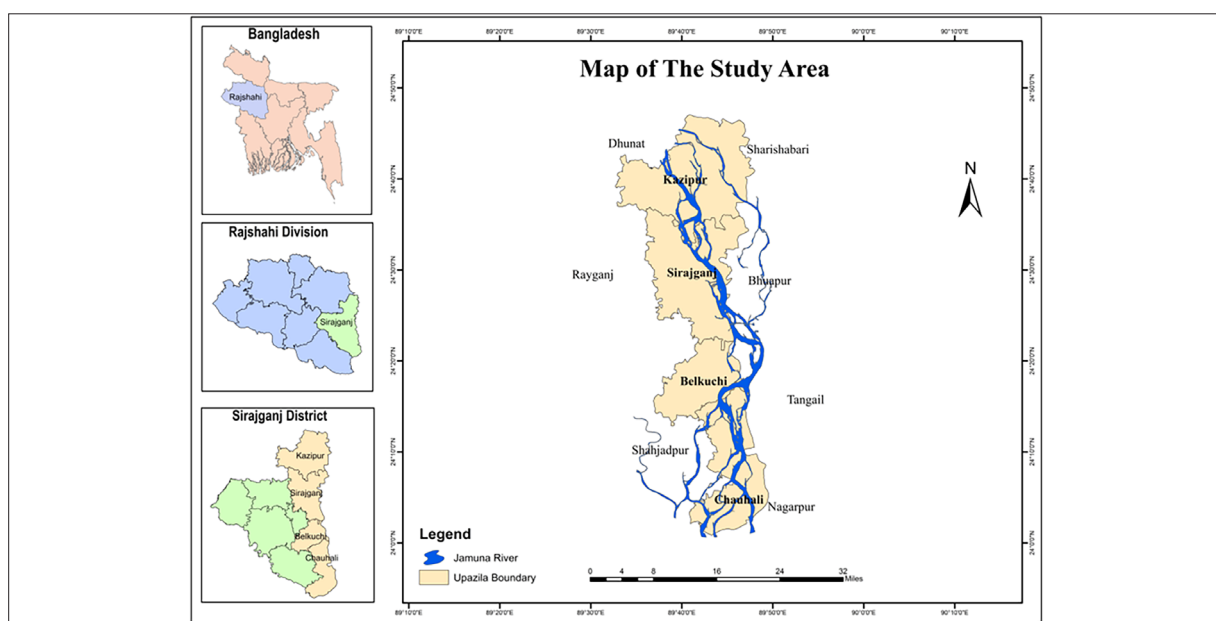


Figure 1. Study Area Map

This district comprises 9 upazilas: Tarash, Ullapara, Sirajganj Sadar, Shahzadpur, Raiganj, Kazipur, Chowhali, Belkuchi, and Kamarkhand. Four upazilas (Sirajganj Sadar, Kazipur, Chowhali, and Belkuchi) are more prone to riverbank erosion and are thus selected for the study. The study area encompasses 1,023.7 square kilometres, as illustrated in Figure 1.

2.2 Sources of Data

The data (Table 1) used in this study came from various secondary sources and included three Landsat images (spatial) and population data (non-spatial).

Table 1. Description of the collected data

Data Type	Year of Data	Data Source
Landsat imagery	1988, 2006, 2024	USGS (https://earthexplorer.usgs.gov/)
Population Data	1991, 2001, 2022	BBS (Bangladesh Bureau of Statistics)

2.3 Satellite image collection and pre-processing

The detail information about the collected satellite imageries are presented in Table 2. Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) images of Sirajganj in 1988, 2006, and 2024 were collected

from the USGS official website (<https://earthexplorer.usgs.gov/>). Pre-processing satellite images before change detection is crucial, as it aims to establish a more direct linkage between the data and biophysical phenomena (Coppin et al., 2004).

Table 2. Detailed Information of the Landsat Images used in this study

Satellite	Sensor Type	Path/Row	Date of acquisition	Spatial Resolution (m)	Cloud Cover (%)	Image Quality
Landsat 5	TM	138/43	1988-01-09	30	1.00	9
Landsat 5	TM	138/43	2006-01-26	30	0.00	7
Landsat 8	OLI/TIRS	138/43	2024-01-28	30	0.32	9

All Landsat data used in this study were acquired under clear atmospheric conditions (to get cloud-free images). The collected images were projected onto the Universal Transverse Mercator (UTM) coordinate system and stored as GeoTIFFs. PCS WGS (World Geodetic System) 1984 UTM Zone 45 N (datum) was the projection used for all the images. Data is processed using ENVI (Environment for Visualizing Images) version 5.3 software. First, metadata and radiometric calibration transform the Landsat scene's DN (Digital Number) into absolute radiance units ($W m^{-2} sr^{-1}$). After that, atmospheric adjustment was performed using

the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) module (Soto Carrión, 2022).

2.4 Methods

Figure 2 shows the detailed methodological framework of the study. Firstly, spatiotemporal changes in the study area were analyzed by LULC classification from 1988 to 2024. NDWI was also conducted to calculate the river's erosion and accretion. Finally, a migration scenario was developed based on the analysis of Change Detection Statistics (CDS) and Population data.

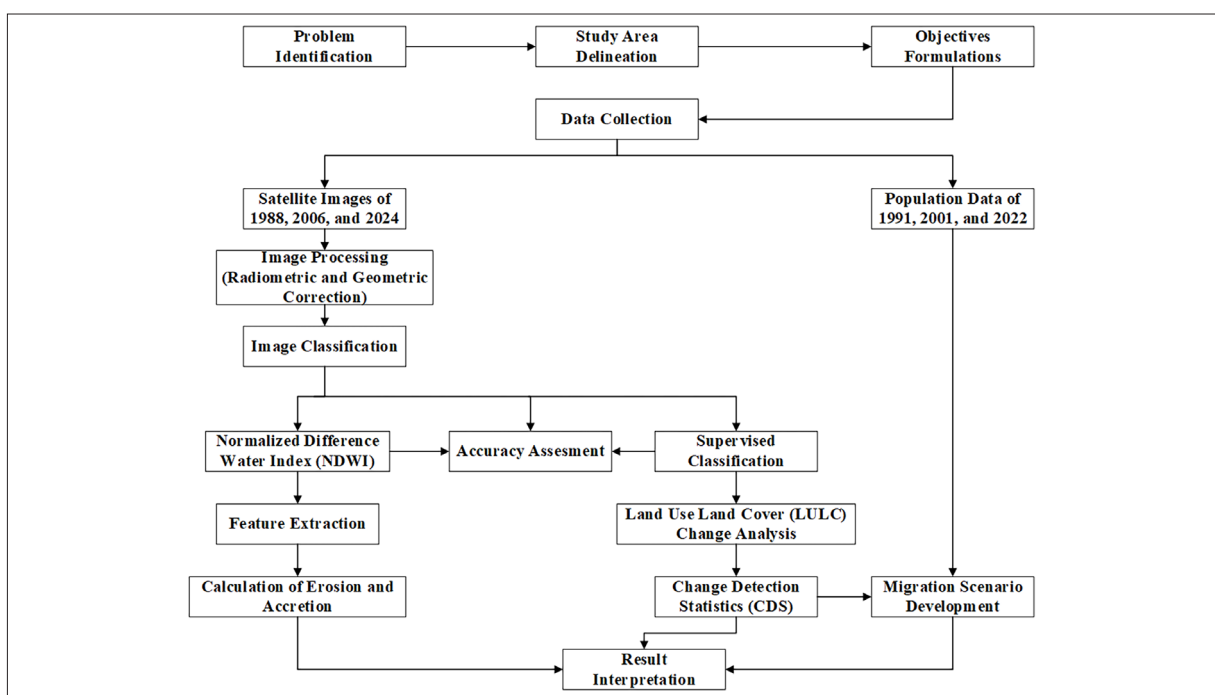


Figure 2. Methodological Framework

2.5 Satellite Image Classification

A classification scheme that identifies the LULC classes was considered when producing the LULC map using satellite imagery. The appropriate number of LULC classes varies, depending on the specifications of a particular project for a specific application (Shekar & Mathew, 2023). Six broad

classifications (Agricultural land, vegetation, Water body, Char Land, Fallow Land, and Settlement) were employed to categorize the LULC of the study area. The following table (Table 3) contains a thorough overview of the classes. Each class was created based on texture, tone, and color.

Table 3. Details of the LULC classification scheme

S. No.	Class	Description
1	Agricultural Land	Places like parks and regularly tilled, cultivated croplands have high densities of grass, plants, and crops.
2	Vegetation	Reserve forest, plantation, etc.
3	Waterbody	Areas submerged in water include lakes, streams, ponds, reservoirs, and rivers.
4	Charland	Landmasses formed through the accumulation of massive sand, silt, and clay sediments over time and were carried by rivers.
5	Fallow land	Other people could eventually alter or use these areas, regardless of whether they have minimal vegetation. This group includes areas with sandy soils near rivers and streams, land with bare rock, and land without crops.
6	Settlement	Developed regions for roads, buildings, human habitation, and vegetation, aside from spaces created by humans, roadside trees, and trees planted around homes.

The training samples for each classification category were compiled. For each study year, nearly 260 training datasets were identified from the pre-processed images for LULC classes. Using ENVI (version 5.3) software, training samples were manually chosen from the pre-processed satellite images.

This study employed the supervised classification algorithm, the Maximum Likelihood Classifier (MLC). For the classification of medium-resolution satellite imagery, the MLC has been frequently used (Abusmier & Al-Kofahi, 2025; Anil et al., 2011; Ratnaparkhi et al., 2016; Zubair Iqbal & Javed Iqbal, 2018).

$$D = \ln(ac) - [0.5 \ln(|Covc|)] - [0.5 (X - Mc) T (Covc - 1) (X - Mc)] \quad (1)$$

Where the weighted distance or likelihood D of an unknown measurement vector X belongs to one of the known classes, and Mc is based on the Bayesian equation (Kantakumar et al., 2016).

2.6 Classification Accuracy Assessment

The accuracy assessment evaluates the classification of LULC images compared to reference data or maps (Foody, 2002). Google Earth is a valuable source of positional data for mapping land use and land cover in small geographical areas. A study conducted by Abineh and Zubairul (2015) found that its accuracy in assessing land use and land cover using Google Earth was over 75%. For accuracy assessment, 120 points were created in classified images by a stratified random method, and these points were compared with the reference map from Google Earth Pro. The classification accuracy was evaluated using a confusion matrix that included user accuracy, producer accuracy, overall accuracy, and the Kappa coefficient (Foody, 2020). The user, producer, overall accuracy, and Kappa statistics were calculated using specific formulas.

$$\text{User Accuracy} = \frac{\text{Number of Correctly Classified Pixels in each Category}}{\text{Total Number of Reference Pixels in that Category (The Row Total)}} \times 100 \quad (2)$$

$$\text{Producer Accuracy} = \frac{\text{Number of Correctly Classified Pixels in each Category}}{\text{Total Number of Reference Pixels in that Category (The Column Total)}} \times 100 \quad (3)$$

$$\text{Overall Accuracy} = \frac{\text{Total Number of Correctly Classified Pixels (Diagonal)}}{\text{Total Number of Reference Pixels}} \times 100 \quad (4)$$

$$\text{Kappa Coefficient (T)} = \frac{(TS \times TCS) - \sum(\text{Column Total} \times \text{Row Total})}{(TS \times TS) - \sum(\text{Column Total} - \text{Row Total})} \quad (5)$$

Where TS = Total Sample and TCS = Total Corrected Sample

2.7 Normalized Difference Water Index (NDWI)

This study utilized the NDWI to extract the river from the images, enabling the calculation of erosion and accretion. McFeeters (1996) developed the NDWI to enhance the water-related features of landscapes. The NDWI is calculated as:

$$NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \quad (6)$$

The water cover is mixed with impurities and varies spatially. Using the NDWI threshold for classification is an effective technique to distinguish water from other land cover types. In remote sensing processing, the classification method is widely used for extracting different land cover types (Qiao et al., 2012). McFeeters (1996) reported that NDWI values above zero are presumed to characterize water surfaces. In contrast, values lower than or equal to zero are considered non-water (e.g., agricultural land, vegetation, settlement, etc.) (Szabo et al., 2016). This study utilized the NDWI index to detect changes in land cover. The NDWI threshold range was reclassified into discrete classes by dividing it into five ranges and defining thresholds for NDWI classification (Table 4).

Table 4. The threshold value range used for NDWI classification

Feature	1988	2006	2024
Vegetation	-0.80 to -0.60	-0.73 to -0.44	-0.96 to -0.71
Agricultural Land	-0.53 to -0.44	-0.44 to -0.34	-0.73 to -0.37
Fallow Land	-0.39 to -0.33	-0.33 to -0.14	-0.35 to -0.16
Char Land	-0.22 to -0.02	-0.21 to -0.01	-0.15 to -0.008
Water	0.01 to 0.32	0.02 to 0.43	0.02 to 1.00

2.8 Feature Extraction and Calculation of Erosion and Accretion

After NDWI reclassification, the reclassified images were converted into polygon shapefiles for quantification using ArcMap 10.8.2. The transformed layers of the classified images from 1988, 2006, and 2024 were visually interpreted to determine the river boundaries. The unchanged area was calculated by intersecting the data from the previous year with that of the following year.

For erosion, the unchanged area was subtracted from the river area in 1988, 2006, and 2024, respectively. To quantify the amount of degraded land cover from 1988 to 2006, 2006 to 2024, and 1988 to 2024, attribute tables of these unchanged areas were summarized by computing the geometric union of polygon shape files for each pair of sequential years. Accretion was calculated according to the same procedure suggested by Mou et al. (2023) and Hassan et al. (2017).

2.9 Change Detection

Change detection is valuable in many LULC change detection applications, including cultivation, urban expansion, and landscape change (Salem et al., 2020). The most commonly used change detection methods include thematic change detection, image overlay, principal components analysis (PCA), image ratioing, NDVI differencing, and change vector analysis (Han et al., 2009). The ENVI 5.3 CDS tool was utilized in this study to evaluate the change detection in the study area. The CDS method utilizes two distinct images of the same scene taken at different times to identify changes over time. This study used three classified images of different years (1988, 2006, and 2024) to calculate changes in the study area. The change magnitude (C_i) in each class was determined using the following equation (Vivekananda et al., 2021):

$$C_i = L_i - B_i \quad (7)$$

The percentage of change in each LULC class was calculated by dividing the change in a class by its coverage area in the base year and then multiplying by 100.

$$P_i = \frac{L_i - B_i}{B_i} \times 100 \quad (8)$$

Where i = Number of classes in an image, C_i = Magnitude of change in class " i ", P_i = Percentage of change in class " i ", L_i = Base image, B_i = Latest image

3. Results and Discussion

3.1 LULC change analysis

LULC patterns of Sirajganj District for the years 1988, 2006, and 2024 are shown in Figure 3, and Table 5 represents the area of the classified land cover. The changing trend of the classified land cover is summarized in Table 6. Agricultural Land in the study area shows an uneven trend. Agricultural land increased by approximately 89,842 hectares within the first 18 years (1988-2006) and decreased by approximately 81,700 hectares within the next 18 years (2006-2024). Over the 36-year period (1988-2024), agricultural land increased by approximately 8,141 hectares.

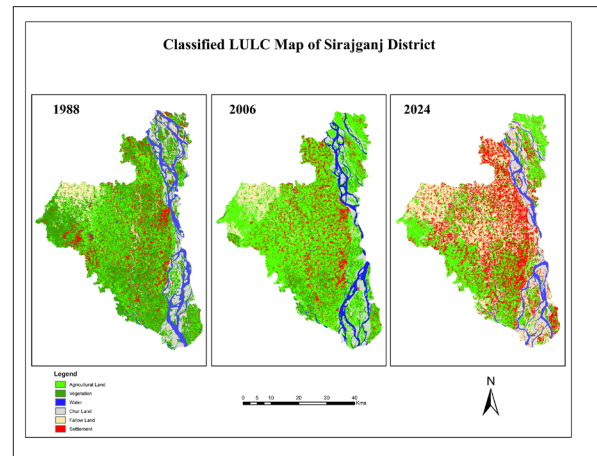


Figure 3. Classified LULC Map of Sirajganj District

Table 5. Calculated area of classified land use and land cover in Sirajganj District

LULC Type	Area (Hectare)		
	1988	2006	2024
Agricultural Land	68536.37	158379.17	76678.32
Vegetation	101167.30	16144.60	5268.15
Water	18888.07	16221.81	13996.82
Char Land	21721.56	14380.70	12776.83
Fallow Land	15684.06	17571.77	74028.52
Settlement	23965.75	27270.15	67216.82

Government policies, technological advancements, and rising demand for agricultural products led to an increase in agricultural land from 1988 to 2006 (Ali, 2007). However, from 2006 to 2024, a decline occurred, and the possible causes behind it were urbanization, industrialization, land conversion, and climate change (Haque et al., 2022). Despite these changes, the overall trend from 1988 to 2024 shows a positive development in agriculture. Over the past 36 years, the areas of vegetable, water, and char land decreased by approximately 9,5989, 4,891, and 8,944 ha, respectively. Fallow land and Settlement have increased by approximately 58344 and 43251 ha, respectively, over this period. Similarly, Haque et al. (2023) found a prominent decrease in char land beside the area of settlements, which increased over time in Sirajganj.

Table 6. LULC Change detection of the study area

LULC Type	Area Change (Ha)		
	1988-2006	2006-2024	1988-2024
Agricultural Land	89842.8	-81700.85	8141.95
Vegetation	-85022.7	-10876.45	-95899.15
Water	-2666.26	-2224.99	-4891.25
Char Land	-7340.86	-1603.87	-8944.73
Fallow Land	1887.71	56456.75	58344.46
Settlement	3304.4	39946.67	43251.07

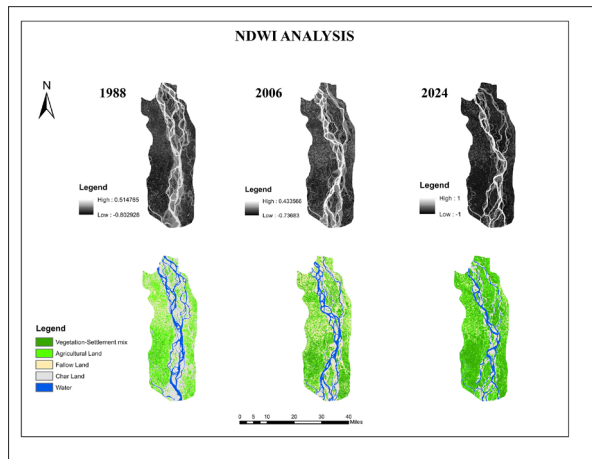


Figure 4. NDWI Analysis of Selected Area

3.2 NDWI Analysis

River areas were extracted using NDWI images. In this study, NDWI was used for three consecutive years (1988, 2006, and 2024) to extract the river from the study area for calculating erosion and accretion.

3.3 Accuracy Assessment Result

The accuracy assessment results for the classified images of the respective years (1988, 2006, and 2024) are presented in Table 7.

Table 7. Accuracy Assessment result of the LULC map

Kappa Coefficient	Overall Accuracy	Settlement	Fallow Land	Char Land	Water	Vegetation	Agricultural Land	Class Names	
0.76	77.50%	89.47%	68.97%	100.0%	95.24%	100%	58.62%	Producers Accuracy	1988
		85.00%	100%	100%	100%	100%	85.00%	Users Accuracy	
		0.82	1.00	1.00	1.00	0.08	0.80	Conditional Kappa	
0.67	73.33%	78.26%	52.17%	100%	78.95%	73.33%	72.41%	Producers Accuracy	2006
		100%	75.00%	73.33%	100%	73.33%	51.22%	Users Accuracy	
		1.00	0.69	0.71	1.00	0.69	0.3567	Conditional Kappa	
0.82	85.83%	91.67%	79.17%	94.12%	100%	83.33%	75.76%	Producers Accuracy	2024
		91.67%	79.17%	100%	100%	33.33%	100%	Users Accuracy	
		0.89	0.74	1.00	1.00	0.29	1.00	Conditional Kappa	

The overall accuracy ranges from approximately 73% to 85%, with the kappa coefficient ranging from 0.6733 to 0.8272 from 1988 to 2024. Kappa values <40 percent are considered poor, 40-55 percent fair, 55-70 percent good, 70-85 percent very good, and >85 percent excellent (Ismail & Jusoff, 2008). Thus, according to these agreement scales, the classification indicates good to excellent agreement. The overall accuracy of the classified images is considered acceptable for this study.

3.4 Erosion and Accretion Scenario

Table 8 displays the erosion and accretion of the Jamuna River in Sirajganj for three time frames: 1988–2006, 2006–2024, and 1988–2024. Between 1988 and 2006, 17,199 hectares of erosion and 18,804 hectares of accretion occurred, with 5,551 hectares remaining unchanged. During the second assessment period between 2006 and 2024, 18,547 hectares experienced erosion, 12,609 hectares accreted, and 5,808 hectares remained unchanged. Between 1988 and 2024, the amount of erosion was 18,813 hectares, accretion was 14,480 hectares, and 3,937 hectares remained unchanged.

Table 8. Erosion, Accretion, and Unchanged Area of the study area

Year	Previous Years	Final Years	Unchanged Area (ha)	Erosion (ha)	Accretion (ha)
1988-2006	22750	24355	5551	17199	18804
2006-2024	24355	18417	5808	18547	12609
1988-2024	22750	18417	3937	18813	14480

Figure 5 illustrates the erosion and accretion of the study area over the past 36 years (1988-2024). The erosion and accretion rates have been acquired considering a three-time span- (1988-2006), (2006-2024), and the amount of erosion was 17199 ha, and the amount of accretion was 18804 ha, which means the erosion rate was less than the accretion rate. Similarly, Momen et al. (2020) found that the erosion of the Jamuna River was less than the accretion during the period of 1988-2003, indicating a contraction of the river during that time. The unchanged area represents the river that has not undergone significant erosion or deposition (Wohl, 2005). On the other hand, over the last 18 years (2006-2024), erosion was 18,547 ha, and the accretion was 12,609 ha, indicating that erosion was more significant than accretion. The amount of unchanged area was 5808 ha. Pahlowan & Hossain (2015) found similar results where the amount of erosion was more significant than the accretion from 2004 to 2014. That means that although the accretion was sometimes more significant than the erosion overall (36 years), the amount of erosion is high compared to accretion. Moreover, the 3937-ha area has not experienced significant erosion during this period.

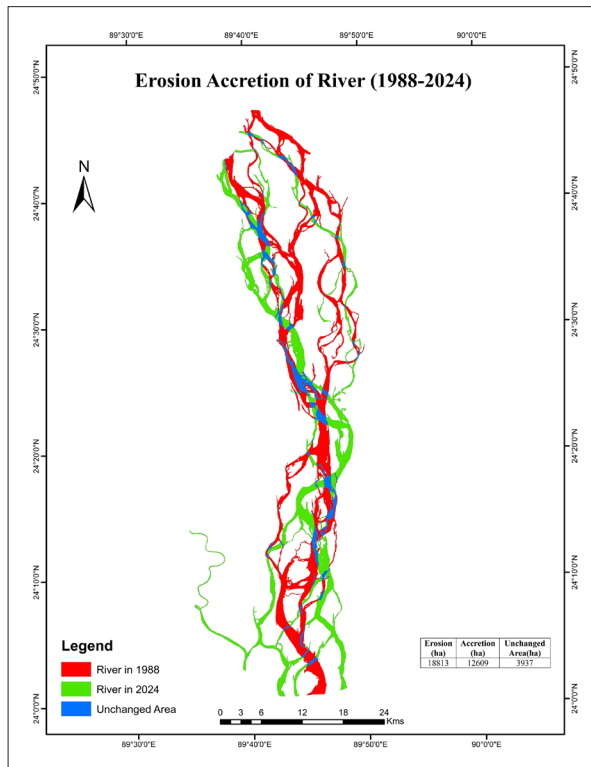


Figure 5. Erosion and Accretion of River (1988-2024)

Erosion, accretion, and unchanged areas in the study area were observed by analyzing Landsat images from 1988, 2006, and 2024. Figure 6 represents the highest eroded area, 18547 ha, from 2006 to 2024, and the highest accreted area, 18804 ha, from 1988 to 2006. The highest erosion may be attributed to increased river discharge, bank instability, human activities, etc., while the highest accretion may be due to significant sediment deposition or changes in river morphology, possibly influenced by upstream activities or natural river dynamics. A study found that dams and/or

embankments in the river’s vulnerable area altered the flow of water, reducing erosion and triggering deposition in the channel. On the contrary, sand mining caused river erosion (Lusiagustin & Kusratmoko, 2017).

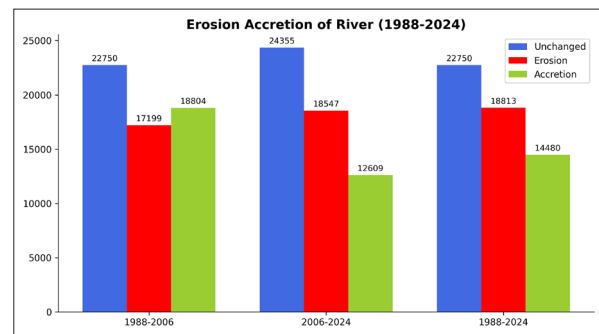


Figure 6. Erosion & Accretion of River from 1988-2024

3.5 Change Detection Statistics (CDS)

Tables 9 to 13 present change-detection statistics for Sirajganj District and its four upazilas (more prone to riverbank erosion) from 1988 to 2024. Between 1988 and 2006, there were significant changes in the fallow land, agricultural land, and vegetation in the Sirajganj District. 59.35% of vegetation and 59.07% of fallow land were converted into agricultural land, while 8.01% was converted into vegetation. Additionally, at this time, 48.11% of the water and 47.09% of the char land were converted to agricultural land. From 2006 to 2024, a major conversion was observed from vegetation to agricultural land, which was 57.71%. Another conversion of agricultural land (26.43%) was from fallow land. Considering water, the area converted into char and fallow land was about 20.93% and 28.28%, respectively. Moreover, conversion from char land to water and fallow land occurred, with respective amounts of 23.6% and 20.93%. Besides, 31.61% of agricultural land was converted into fallow land during this period.

Table 9. CDS of Percentage Change of LULC Between 1988 and 2024 (Sirajganj District)

		Area (Initial State_1988) in percentage								
		Agricultural Land	Vegetation	Water	Char Land	Fallow Land	Settlement	Row Total	Class Total	
Area (Final State_2024) in percentage	Class Names									
	Agricultural Land	37.09	60.09	22.72	24.09	26.74	20.41	100	100	
	Vegetation	2.18	4.33	4.1	3.66	1.46	0.97	100	10	
	Water	2.56	2.39	18.41	14.35	6.33	3.77	100	100	
	Char Land	1.93	1.81	14.84	17.49	6.37	3.06	100	100	
	Fallow Land	28.58	16.69	27.00	28.5	43.22	20.57	100	100	
	Settlement	27.65	14.69	12.93	11.90	15.88	51.22	100	100	
	Class Total	100	100	100	100	100	100	0	0	
	Class changes	62.91	95.67	81.59	82.51	56.79	48.78	0	0	
Image Difference	-29.42	-34.36	-27.65	-25.85	44.22	48.27	0	0		

Significant changes in land cover were observed between 1988 and 2024 (Table 9). Considering agricultural land, the area was converted into fallow land and settlement, with conversion rates of 28.58% and 27.56%, respectively. Significant changes were observed from vegetation

to agricultural land, fallow land, and settlement; their proportions are 60.09%, 16.69%, and 14.59%, respectively. From the water, about 22.72%, 14.84%, 27%, and 12.93% of areas were converted into agricultural land, char land, fallow land, and settlement, respectively. Besides, char land

was converted into agricultural land, water, fallow land, and settlement, and the conversions are 24.09%, 14.35%, 28.5%, and 11.90%, respectively. Moreover, 26.47% of fallow land was converted into agricultural land, and 15.88% was converted into settlement. During this period, 20.41% and 20.57% of the settlements were converted into agricultural and fallow land, respectively.

In Kazipur Upazila between 1988 and 2006, significant conversions from vegetation to agricultural land occurred. 67.97% of vegetation was converted into agricultural land in this period. 55.72% of water was converted into agricultural land. Similarly, char land was converted into agricultural land and water; the conversion amounts are 58.75% and 18.69%, respectively. In the meantime, 58.80% of fallow land was converted into agricultural land, and 42.32% of settlement was also converted into agricultural land. From 2006 to 2024, a significant conversion from vegetation to agricultural

land was observed, representing a 43.36% change. During this period, 31.46% and 16.11% of agricultural land were converted to fallow land and settlement, respectively. 20.29% of water was converted into char land, and 29.42% into fallow land. Furthermore, 28.11%, 18.39%, and 23.43% of char land were converted to agricultural land, water, and fallow land, respectively. The change of fallow land into agricultural land was 26.69%. From 1988 to 2024 (Table 10), the primary conversions of agricultural land were vegetation (28.75%), water (37.78%), char land (38.18%), fallow land (38.59%), and settlement (24.19%). The conversion of char land was from vegetation (9.29%), water (10.55%), and fallow (11.59%). Fallow land was significantly converted from agricultural (35.24%), vegetation (29.48%), water (23.02%), and settlement (17.35%). The most extensive settlement conversion was from agricultural land (29.40%). Significant changes also were from vegetation (21.66%) and fallow (14.82%).

Table 10. CDS of Percentage Change of LULC Between 1988 and 2024 (Kazipur Upazila)

		Area (Initial State_1988) in percentage								
Area (Final State_2024) in percentage	Class Names	Agricultural Land	Vegetation	Water	Char Land	Fallow Land	Settlement	Row Total	Class Total	
	Agricultural Land	21.38	28.75	37.78	38.18	38.59	24.19	100	100	
	Vegetation	1.48	3.18	7.94	6.26	4.10	1.60	100	100	
	Water	6.61	7.65	15.57	8.42	8.76	5.42	100	100	
	Char Land	5.89	9.29	10.55	13.29	11.59	5.07	100	100	
	Fallow Land	35.24	29.48	23.02	27.68	22.14	17.35	100	100	
	Settlement	29.40	21.66	5.14	6.16	14.82	46.38	100	100	
	Class Total	100	100	100	100	100	100	0	0	
	Class changes	78.62	96.82	84.43	86.70	77.86	53.63	0	0	
	Image Difference	76.42	-88.35	-45.53	-48.12	472.58	134.46	0	0	

In Sirajganj Sadar, from 1988 to 2006, agricultural land experienced significant conversions from vegetation (73.48%), water (41.30%), char land (37.84%), fallow land (66.19%), and settlement (24.80%). A notable portion of water was converted from char land (28.13%), while 23.61% was converted into char land. Between 2006 and 2024, 37.93% of the vegetation was converted to agricultural land. 30.18% of char land was converted into water, while 18.47% was converted into char land.

Fallow land was significantly converted from agricultural (37.96%), vegetation (22.19%), water (25.88%), char land (25.57%), and settlement (54.04%). In the meantime, the settlement was primarily converted from agricultural land (34.19%), vegetation (23.15%), and fallow land (18.20%). From 1988 to 2024 (Table 11), vegetation (15.72%), char land (13.67%), and fallow land (16.27%) were the significant sources of conversion into agricultural land. 18.54% of char land and 10.41% of fallow land were converted into water.

Table 11. CDS of Areal Change of LULC Between 1988 and 2024 (Sadar Upazila)

		Area (Initial State_1988) in percentage								
Area (Final State_2024) in percentage	Class Names	Agricultural Land	Vegetation	Water	Char Land	Fallow Land	Settlement	Row Total	Class Total	
	Agricultural Land	16.46	15.72	12.12	13.67	16.27	4.47	100	100	
	Vegetation	0.43	0.70	3.29	4.43	2.66	0.43	100	100	
	Water	5.46	6.65	24.88	18.54	10.41	2.83	100	100	
	Char Land	2.59	5.25	18.73	21.73	6.35	1.52	100	100	
	Fallow Land	33.21	39.48	25.37	27.09	21.64	11.59	100	100	
	Settlement	41.86	32.20	15.60	14.54	42.67	79.16	100	100	
	Class Total	100	100	100	100	100	100	0	0	
	Class changes	83.54	99.30	75.12	78.27	78.36	20.84	0	0	
	Image Difference	-42.80	-96.21	-19.96	-32.38	1031.21	156.46	0	0	

Only a substantial amount of water (18.73%) was converted into char land. A substantial amount of vegetation (39.48%) was converted into fallow land, with significant conversion from agricultural land (33.21%), water (25.37%), char land (27.09%), and settlement (11.59%). Moreover, there is a considerable amount of conversion of settlement from agricultural land (41.86%), vegetation (32.20%), water (15.60%), char land (14.54%), and fallow land (42.67%).

Between 1988 and 2006, a significant change was observed in the fallow land of Belkuchi, where 68.32% of the fallow land was converted to agricultural land. Furthermore, vegetation (65.85%), water (41.91%), and char land (56.40%) were also converted into agricultural land. Between 2006 and 2024, in Belkuchi, 47.71% of vegetation and 25.07%

of fallow land were changed into agricultural land. 16.40% and 24.90% of water turned into char and fallow land, respectively. On the other hand, 16.31% of char land turned into water. Also, 36.28% of char land was converted to fallow land. Agricultural land (35.46%), vegetation (22.51%), and fallow land (32.39%) were changed to settlement. From 1988 to 2024 (Table 12), a significant change occurred in agricultural land, with 47.90% converted to settlement. Also, 37.30% of vegetation, 15.47% of water, 23.56% of char land, and 26.27% of fallow land were converted into settlements. Vegetation (41.77%) and fallow land (25.74%) turned into agricultural land. 13.07% of char land and 17.81% of fallow land became water. Moreover, Water (25.06%) and char land (26.06%) were converted into fallow land.

Table 12. CDS of Percentage Change Between 1988 and 2024 (Belkuchi Upazila)

		Area (Initial State_1988) in percentage							
Area (Final State_2024) in percentage	Class Names	Agricultural Land	Vegetation	Water	Char Land	Fallow Land	Settlement	Row Total	Class Total
	Agricultural Land	39.07	41.77	22.68	23.60	25.74	7.29	100	100
	Vegetation	1.92	2.29	0.49	0.46	0.47	0.38	100	100
	Water	1.17	4.49	17.64	13.07	17.81	0.11	100	100
	Char Land	0.67	3.35	18.67	13.25	10.57	0.05	100	100
	Fallow Land	9.28	10.81	25.06	26.06	19.14	3.05	100	100
	Settlement	47.90	37.30	15.47	23.56	26.27	89.12	100	100
	Class Total	100	100	100	100	100	100	0	0
	Class changes	60.93	97.71	82.36	86.75	80.86	10.88	0	0
	Image Difference	36.47	-96.10	-40.51	-61.59	747.10	216.44	0	0

Between 1988 and 2006, in Chauhali, vegetation (46.30%), water (43.54%), char land (41.83%), fallow land (40.85%), and settlement (38.76%) were converted into agricultural land. Additionally, agricultural land (16.20%), vegetation (19.97%), char land (22.30%), and fallow land (24.89%) were converted into water. 15.20% of agricultural land, 19.14% of vegetation, and 21.50% of water were converted into char land. From 2006 to 2024, in Chauhali, 30.09% of the vegetation was converted into agricultural land. However, agricultural land (15.89%), char land (27.05%), and fallow

land (15.00%) were converted into water. Besides 17.21% of agricultural land, 24.09% of water, and 16.69% of fallow land converted to char land. Surprisingly, agricultural land (28.29%), vegetation (19.83%), water (30.59%), and char land (34.13%) were turned into fallow land. On the other hand, 20.90% of agricultural land, 23.65% of vegetation, and 9.92% of water were converted to settlement. Between 1988 and 2024 (Table 13), in Chauhali, 31.12% of char land was converted to fallow land, which was a significant change.

Table 13. CDS of Percentage Change Between 1988 and 2024 (Chauhali Upazila)

		Area (Initial State_1988) in percentage							
Area (Final State_2024) in percentage	Class Names	Agricultural Land	Vegetation	Water	Char Land	Fallow Land	Settlement	Row Total	Class Total
	Agricultural Land	15.37	13.72	13.57	13.90	5.95	7.25	100	100
	Vegetation	4.31	4.48	1.46	1.48	1.56	3.33	100	100
	Water	17.07	17.27	18.99	20.06	30.22	8.72	100	100
	Char Land	11.78	18.33	20.34	21.02	22.73	8.68	100	100
	Fallow Land	24.14	28.43	30.81	31.12	30.33	24.27	100	100
	Settlement	27.34	17.77	14.83	12.41	9.20	47.75	100	100
	Class Total	100	100	100	100	100	100	0	0
	Class changes	84.63	95.52	81.01	78.98	69.67	52.25	0	0
	Image Difference	7.38	-91.33	-3.19	-34.26	510.75	836.85	0	0

Agricultural land (24.14%), vegetation (28.43%), water (30.81%), and settlement (24.27%) were converted into fallow land. However, agricultural land (17.07%), vegetation (17.27%), char land (20.06%), and fallow land (30.22%) turned into water. On the other hand, 11.78% of agricultural land, 18.33% of vegetation, 20.34% of water, 22.73% of fallow land, and 8.68% of settlement became char land. Furthermore, agricultural land (27.34%), vegetation (17.77%), water (14.83%), char land (12.71%), and fallow land (9.20%) were converted into settlements in this period.

3.6. Population Displacement Scenario

Due to riverbank erosion in various parts of the Sirajganj district, thousands have been displaced, resulting in increased poverty, food insecurity, and a lack of access to sanitation, healthcare, and drinking water facilities (Abrar & Azad, 2004; Rabbi et al., 2013). The erosion pushes people to migrate to other places like cities or the nearest towns and bound to live in the urban slum areas. There may not only be temporary migration but also permanent migration. CDS of Kazipur Upazila represents the settlement area increased by 22.10% from 1988 to 2024 (Table 12). In the Kazipur upazila of Sirajganj district, 21,961 people, constituting 9.35% of the total population, migrated permanently within neighboring areas due to the need for income and social connections (Mollah & Ferdaush, 2015). The CDS of Sirajganj Sadar indicates that the settlement increased significantly from 4.47% in 1988 to 79.16% in 2024, indicating an increase in the area by 74.69% (Table 10). This suggests a substantial growth in urban areas and settlements within the upazila. The increase in settlement areas is a strong indicator of urbanization, and population movement from rural areas (like agricultural or fallow land) to urban areas could contribute to this shift. A study was conducted on riverbank erosion and induced population migration of Sirajganj Sadar Upazila by Ali et al. (2021) where they found that sufferers migrated in the nearest union about 29.42% as they mostly preferred to migrate within a short distance, followed by Sirajganj Town 27.66%, Dhaka 20.35%, neighboring district 10.86% and others 11.71%, respectively. The displacement scenario can be hypothesized by examining the population growth of these upazilas, as shown in Figure 7. The population of all four areas increased significantly from 1991 to 2022.

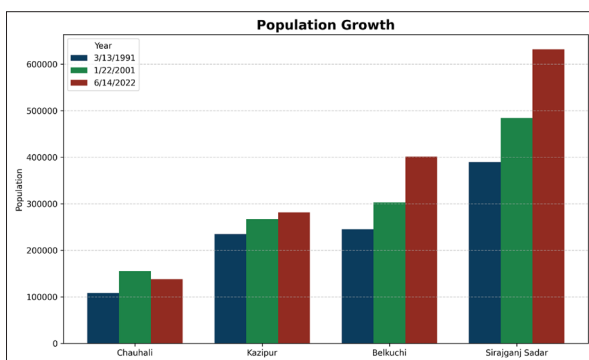


Figure 7. Population Growth of the Study Area

This is especially evident in Sirajganj Sadar, which has experienced the most substantial growth. Belkuchi upazila experienced a modest increase between 1991 and 2001, but the growth rate slowed between 2001 and 2022. Considering

Chauhali and Kazipur, these areas have shown consistent population growth over this period. The population growth of Chauhali Upazila has been relatively steady, decreasing over the last decade, while Kazipur Upazila's growth has increased very slowly during the same period. On the other hand, Sirajganj Sadar has undergone the most dramatic population increase. The population has more than doubled since 1991, and the growth rate has been exceptionally high in the last decade. The total population of Sirajganj Sadar was 389160 in 1991 and 631877 in 2022. This indicates that people from other areas migrated to Sadar Upazila, leading to an increase in population and suggesting internal migration. In Sirajganj, after being affected by riverbank erosion, people immediately tend to migrate for safe shelter and later permanently for survival, where internal migration was observed, including men, women, and children, and the trends of settlement displacement are increasing day by day (Haque et al., 2023).

4. Conclusion

This study analyzed LULC and NDWI, calculated erosion and accretion, and its effects on population from 1988 to 2024 using satellite imagery and population data. The result represented that the amount of erosion increased, and accretion decreased over 36 years, which led to a change in the spatiotemporal characteristics of the study area and revealed the effects of erosion on population displacement. The LULC results showed that over 36 years, vegetation and char land decreased, while fallow land and settlement increased. The CDS result of Sirajganj Sadar representing the settlement area has increased tremendously by 74.69% during this period. The most significant effects of erosion were observed in Chauhali and Kazipur Upazila, as residents of these regions migrated temporarily or permanently to Sadar Upazila, causing Chauhali's population to decline in recent decades.

The findings underline the urgent need for sustainable land management strategies that balance development and environmental conservation. The implications are far-reaching, providing valuable data for policymakers, urban planners, and environmentalists to reduce negative impacts, design resilient land-use policies, and prioritize erosion control, water resource management, and ecological preservation strategies to ensure long-term regional sustainability. This study suggests that drivers of change and specific socioeconomic and policy data are needed to properly understand the underlying reasons for land transformation. The study did not account for climate change impacts, such as fluctuations in precipitation and temperature, and other hydro-morphological factors, which might have a considerable effect on erosion and accretion dynamics. Future research should use high-resolution satellite imagery and incorporate field surveys to enhance accuracy in LULC classification and erosion-accretion analysis. Alongside, collecting field data on migration patterns is crucial for understanding the actual migration scenario. Investing in land reclamation projects to recover and stabilize eroded areas, enhancing their utility for agriculture and settlement, will further aid in proactive erosion management.

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