Journal of Environmental Science 11 (2024) 49-60

IES
University of Rajshahi

Journal of Environmental Science

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Geospatial Analysis of Land Cover Dynamics and Riverine Changes in Char Ashariadaha, Rajshahi, Bangladesh (1988–2023)

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A R T I C L E   I N F O

Keywords:
Land Cover Change,
Floodplain Dynamics,
NDWI,
Remote Sensing, Sediment Redistribution

A B S T R A C T

This study provides a geospatial analysis of land cover dynamics and river transformation in Char (riverine island) Ashariadaha, Rajshahi, Bangladesh, over a 35-year period (1988–2023). Utilizing multi-temporal Landsat imagery, supervised classification, and the Normalized Difference Water Index (NDWI), the research quantifies transitions across four land cover types: vegetation, bare soil, sand area, and water body of river. Key findings reveal substantial vegetation expansion (+10.65km²) and bare soil reduction (-7.85km²), indicating ecological stabilization and sediment redistribution. The NDWI analysis highlights dynamic river transformations, with 9.54km² of erosion and 6.00km² of accretion, underscoring active sedimentation processes. Change detection analysis further demonstrates significant transitions, such as bare soil to vegetation (7.86 km²), emphasizing natural recovery mechanisms.

The study integrates advanced remote sensing techniques to investigate floodplain dynamics in a sediment-rich environment, providing insights into hydrological alterations, biodiversity implications, and land use transitions. The findings contribute to global floodplain research by offering a replicable methodology for monitoring dynamic landscapes using cost-effective satellite data. Actionable insights include the need for floodplain management strategies, reforestation in accreted areas, and sustainable land use practices. This research highlights the critical role of geospatial analysis in understanding and managing complex riverine systems.

1. Introduction

Rivers are dynamic systems that shape landscapes and influence ecosystems through processes such as erosion, accretion, and sediment transport (Das, 2020; Khan *et al*., 2019). These processes are essential for sustaining biodiversity, maintaining soil fertility, and supporting human livelihoods. However, increasing human activities and climatic variability have led to intensified changes in river morphology and land cover, causing significant environmental and ecological consequences (Islam *et al*., 2016; Hassan *et al*., 2021). Globally, studies on river morphology and land cover dynamics are vital for understanding the interplay between terrestrial and aquatic systems, with implications for flood management, ecosystem health, and sustainable land use planning (Blum and Törnqvist, 2000).

Bangladesh, a deltaic country, is shaped by the interactions of three major river systems: the Ganges, Brahmaputra, and Meghna. These rivers are critical to the country's socio-economic and environmental systems, supporting agriculture, transportation, and fisheries. However, they are also highly dynamic and

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Receive 21 August 2024; Revised Received 11 December 2024; Accepted 04 December 2024;
Available Online 12 December 2024
Published by Institute of Environmental Science, University of Rajshahi

prone to significant morphological changes due to sediment transport, monsoonal flooding, and anthropogenic interventions (Chowdhury *et al*., 2020). Understanding these changes is particularly important in regions like Char Ashariadaha, where river dynamics influence not only the natural environment but also human livelihoods.

Char Ashariadaha, located along the Padma River in the Rajshahi district of Bangladesh, is an ecologically sensitive region prone to periodic flooding, sediment deposition, and erosion. The region has witnessed significant geomorphological changes over the past few decades, driven by both natural processes and human activities (Rahman *et al*., 2020). Despite its ecological and socio-economic importance, few studies have explored the temporal changes in river morphology and land cover dynamics in this area comprehensively. By addressing this gap, this study provides valuable insights into the spatio-temporal patterns of these changes, contributing to the growing body of knowledge on riverine environmental dynamics.

The advancement of remote sensing and geospatial techniques has revolutionized the study of river systems, allowing for detailed spatial and temporal analysis of river morphology and associated land cover changes. Tools such as the Normalized Difference Water Index (NDWI) enable precise identification of waterbody extents, while supervised classification techniques facilitate the mapping of land cover types. Change detection analysis further provides critical insights into the transitions between land cover categories, enabling a better understanding of the processes driving these changes (Haque*et al*., 2022).

This research employs a multi-temporal geospatial analysis using Landsat imagery from 1988 to 2023 to quantify river morphological transformations and land cover transitions. The primary objectives of this study are:

i. To detect and classify land cover changes over a 35-year period, identifying key transitions between vegetation, sand, bare soil, and water body categories.

ii. To analyze the temporal dynamics of river morphology by quantifying areas of erosion, accretion, and stability.

iii. To derive actionable insights into the environmental implications of these changes and inform future research on sustainable riverine management.

Through its focus on integrating geospatial analysis and temporal change detection, this study provides a comprehensive understanding of river morphological and land cover transformations in a floodplain environment, emphasizing the importance of sustainable river management practices.

2. Study Area

Char Ashariadaha is located in the Rajshahi district of Bangladesh along the Padma River, one of the most dynamic and sediment-rich rivers in the world. It lies between 24°22'00" N and 24°26'00" N latitude and 88°18'00" E and 88°26'00" E longitude, encompassing an area of approximately 58 km² based on classification data derived from Landsat imagery (Table 1). The Padma River, as a distributary of the Ganges, carries a high sediment load and exhibits frequent channel migration, making the area prone to significant geomorphological changes, including erosion, accretion, and sediment deposition.

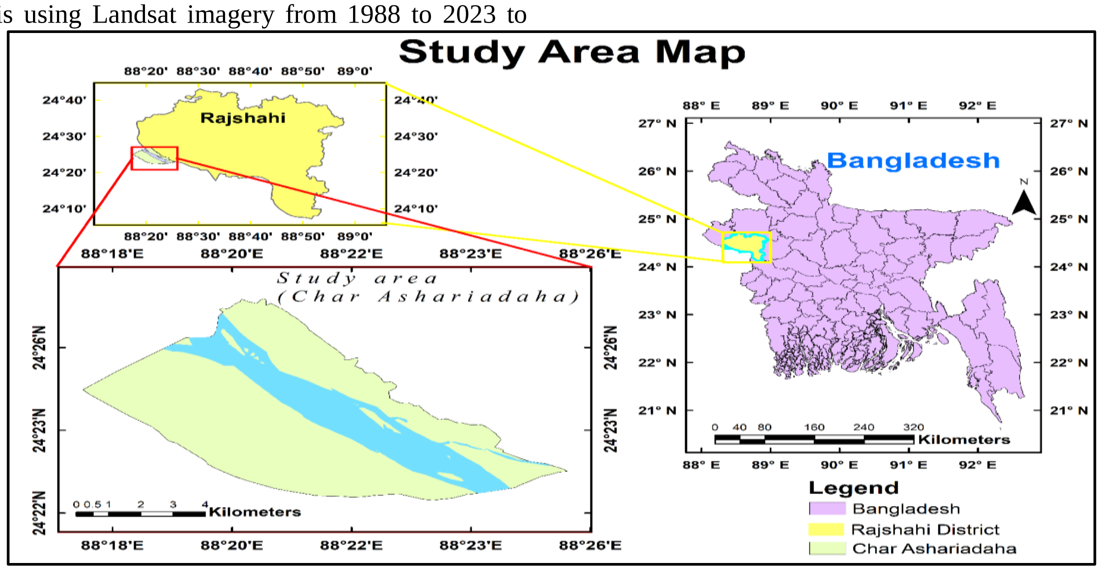


Figure 1. Study Area Map of Char Ashasriadaha, Rahshahi.

This area is part of the Padma River's floodplain, characterized by its dynamic environment and seasonal variability. During the monsoon season, periodic flooding contributes to sediment deposition, which, in turn, shapes landforms such as sandbars and riparian zones. In contrast, during the dry season, reduced flow often exacerbates erosion and alters channel morphology. These processes significantly influence the land cover, making Char Ashariadaha an ideal location for studying river morphological changes and associated land transformations over time (Chowdhury *et al*., 2020; Das, 2020).

Ecologically, Char Ashariadaha is a significant region due to its role in supporting riparian biodiversity and providing fertile land for agriculture. However, its dynamic nature presents challenges, such as the loss of agricultural land due to riverbank erosion and the formation of unstable sandbars. Over the past 35 years, substantial changes have been observed in land cover, with vegetation expanding in areas previously covered by bare soil and sand, while waterbody extents have diminished significantly.

Table 1. Geographical and Environmental Characteristics of Char Ashariadaha

Parameter	Details
Location	Rajshahi District, Bangladesh
Latitude	24°22'00" N to 24°26'00" N
Longitude	88°18'00" E to 88°26'00" E
Total Area	~58 km²
Dominant Features	Floodplain, sediment-rich areas
Climate	Tropical monsoon
Key Rivers	Padma River

To provide a spatial context, Figure 1 illustrates the geographical location of Char Ashariadaha, showing its position along the Padma River and key features such as river channels and adjacent landforms. A summary of the area's geographical and environmental characteristics is presented in Table 1.

3. Data and Methods

This section describes the data acquisition, preprocessing steps, and analytical methods used to study the temporal dynamics of land cover and river transformations in Char Ashariadaha over a 35-year period (1988–2023). The methodological framework integrates remote sensing and geospatial analyses to derive actionable insights.

3.1 Data Acquisition

Multi-temporal Landsat imagery was utilized as the primary dataset for this study due to its long-term availability, consistent resolution, and suitability for environmental analysis. Landsat data provides spatial resolution of 30 meters and includes spectral bands covering the visible to infrared regions, making it ideal for detecting land cover and hydrological changes.

Satellites Used:

Landsat 5: Operational from 1984 to 2013, equipped with the Thematic Mapper (TM), which captures data in seven spectral bands, including visible, near-infrared (NIR), and thermal infrared spectra (Chander*et al*., 2009).

Landsat 8: Operational since 2013, featuring the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), which offer enhanced spectral resolution and radiometric sensitivity compared to earlier sensors (Roy *et al*., 2014).

Temporal Range:

Imagery spanning 1988 to 2023 was selected to analyze long-term changes. Eight specific years (1988, 1993, 1998, 2003, 2008, 2013, 2018, and 2023) were chosen to provide snapshots of change at regular intervals. The summary of satellite imagery used, including acquisition details, is presented in **Table 2**, which highlights the source and characteristics of each dataset used in this study.

Seasonality:

All imagery was acquired during the **dry season (November–February)** to minimize cloud cover and seasonal variability, ensuring consistent temporal comparison and capturing stable landscape features (Masek*et al*., 2006).

Table 2. Summary of Satellite Imagery Used

Satellite	Scene Identifier	Acquisition Date	Processing Level	Archive Date	Tier
Landsat 5 TM	LT05_L2SP_138043_19881124_20200917_02_T1	1988-11-24	L2SP	2020-09-17	T1
Landsat 5 TM	LT05_L2SP_138043_19931208_20200913_02_T1	1993-12-08	L2SP	2020-09-13	T1
Landsat 5 TM	LT05_L2SP_138043_19981222_20200908_02_T1	1998-12-22	L2SP	2020-09-08	T1
Landsat 5 TM	LT05_L2SP_138043_20031118_20200904_02_T1	2003-11-18	L2SP	2020-09-04	T1
Landsat 5 TM	LT05_L2SP_138043_20081201_20200828_02_T1	2008-12-01	L2SP	2020-08-28	T1
Landsat 8 OLI	LC08_L2SP_138043_20131113_20200912_02_T1	2013-11-13	L2SP	2020-09-12	T1
Landsat 8 OLI	LC08_L2SP_138043_20181111_20200830_02_T1	2018-11-11	L2SP	2020-08-30	T1
Landsat 8 OLI	LC08_L2SP_138043_20231125_20231129_02_T1	2023-11-25	L2SP	2023-11-29	T1

3.2 Rationale for Using Dry Season Data

Dry season imagery was specifically chosen to address the challenges posed by rainy season conditions:

Minimizing Cloud Cover:

Rainy season imagery often suffers from high cloud cover, obscuring critical features and reducing classification accuracy.

Eliminating Seasonal Noise:

Dry season data capture permanent features, avoiding temporary changes caused by flooding orvegetation regrowth.

Focus on Long-Term Trends:

Seasonal fluctuations could distort analyses intended to detect long-term transformations.

This approach ensures that the study focuses on reliable and consistent datasets, enabling robust temporal analyses.

3.3 Image Preprocessing

Preprocessing steps were applied to standardize the imagery and ensure data quality for analysis:

Atmospheric Correction:

Applied using the Level-2 Surface Reflectance Product (L2SP), which standardizes reflectance values across scenes by correcting for atmospheric interference (Masek*et al*., 2006).

Geometric Calibration:

Images were reprojected to the Universal Transverse Mercator (UTM) Zone 45N coordinate system for spatial consistency across datasets.

3.4 Land Cover Classification

Land cover classification was performed to analyze spatial and temporal transitions in four primary categories:

Categories: a). **Vegetation**, b). **Bare Soil** c). **Sand Area** d). **Water body of River**

Methodology:

Maximum Likelihood Classifier (MLC) was employed for its accuracy in distinguishing spectrally similar classes. Training areas were manually selected using ground-truth data and high-resolution imagery.

Validation:

Accuracy assessment was performed using confusion matrices. Each classified map was validated with approximately 200 reference points distributed across all categories. The resulting overall accuracy ranged from **79.5% to 88.5%**, with Kappa coefficients between **0.72 and 0.85**. The detailed accuracy metrics, including user's accuracy (UA) and producer's accuracy (PA) for each land cover class, are summarized in **Table 3**, which highlights the reliability of the classification results over the selected years.

Table 3. Summary of Accuracy Assessment Results

Year	Overall Accuracy (%)	Kappa Coefficient	Vegetation (UA/PA) (%)	Waterbody (UA/PA) (%)	Bare Soil (UA/PA) (%)	Sand Area (UA/PA) (%)
1988	81.0	0.75	87 / 86	85 / 82	84 / 83	86 / 85
1993	82.5	0.77	85 / 87	88 / 86	83 / 84	85 / 85
1998	79.5	0.72	82 / 83	83 / 82	78 / 79	82 / 80
2003	84.0	0.78	86 / 85	88 / 85	86 / 87	85 / 84
2008	86.8	0.81	86 / 87	89 / 86	84 / 83	86 / 86
2013	88.0	0.84	87 / 88	88 / 86	86 / 87	86 / 85
2018	87.5	0.83	86 / 87	88 / 86	84 / 83	86 / 85
2023	88.5	0.85	88 / 89	90 / 88	85 / 86	89 / 90

3.5 NDWI Analysis for River Morphology

The Normalized Difference Water Index (NDWI) was used to detect waterbody boundaries and analyze river transformations:

NDWI = (Green - NIR) / (Green + NIR)

Processing Steps:

Bands Used:

Landsat 5: Green (Band 2), NIR (Band 4).
Landsat 8: Green (Band 3), NIR (Band 5).

Threshold:

NDWI values greater than **0.1** were classified as waterbodies.

Transformation Mapping:

Waterbody extents from 1988 and 2023 were compared to delineate stable, eroded, and accreted regions.
The NDWI-based river transformation map, derived from the analysis of 1988 and 2023 imagery, highlights stable, eroded, and accreted regions (see Figure 4 in Results)

3.6 Change Detection Analysis

Temporal change detection was conducted to quantify transitions between land cover classes and identify patterns of erosion and accretion:

Cross-Tabulation Matrix:

Quantified transitions (e.g., vegetation to bare soil, waterbody to sand) to capture land cover dynamics.

Erosion and Accretion Analysis:

NDWI-derived polygons were overlaid with land cover maps to identify riverbank erosion and sediment deposition areas.

Temporal Trends:

Transformation maps and bar charts were created to visualize changes over decades.

3.7 Area Calculations

The area of each land cover class was calculated using polygon shapefiles derived from classified maps. These calculations provided quantitative evidence of changes over time, complementing the visual results.

3.8 Methodology for Actionable Insights

The results from land cover classification, NDWI analysis, and change detection were synthesized to derive actionable recommendations:

Conservation Areas:

Identified erosion-prone zones for priority stabilization efforts.

Land Use Planning:

Highlighted accreted areas for potential agricultural or reforestation activities.

Flood Risk Assessment:

Emphasized regions with waterbody shrinkage as critical zones for integrated floodplainmanagement.

4. Results and Discussion

This section presents the study findings, focusing on the temporal dynamics of land cover and river morphology in Char Ashariadaha from 1988 to 2023. The results are interpreted in the context of their environmental implications and their alignment with the study objectives.

4.1.1 Spatial Changes in Land Cover (1988–2023)

Classified land cover maps **(Figure 2)** illustrate the significant transformations in Char Ashariadaha's landscape over the 35-year study period.
The analysis focused on four primary land cover categories: vegetation, bare soil, sand area, and water body of river.

Vegetation Expansion

Vegetation coverage exhibited a steady increase from 21.54km² in 1988 to 32.19km² in 2023, representing a growth of approximately 49%. This trend reflects natural regrowth processes and potential conservation efforts in the region, which have likely contributed to enhanced ecological stability. The expansion is particularly notable in areas where previously bare soil or sand areas have transitioned to vegetation over time. Diagram 1 visually illustrates this consistent growth trend, underscoring vegetation's dominant role in the landscape by the end of the study period.

Bare Soil Reduction

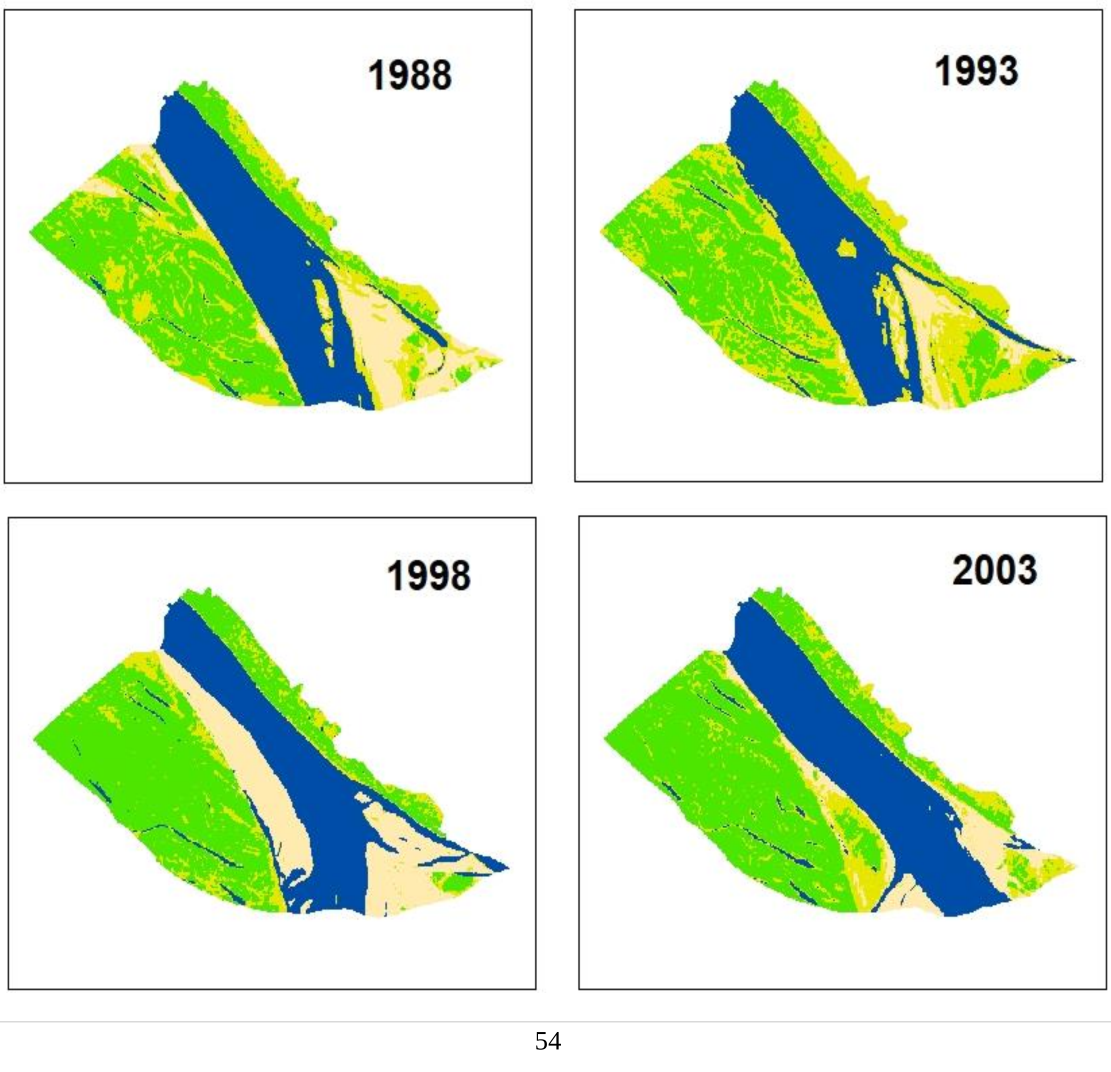
Bare soil, including built-up regions, declined dramatically from 12.27km² in 1988 to just 4.42km² in 2023—a reduction of nearly 64%. This decline suggests effective stabilization processes, possibly through sediment deposition and vegetation regrowth. The gradual decrease aligns with broader trends of land cover stabilization, as depicted in Diagram 1, and highlights the region's shift toward less exposed soil over time.

Sand Area Variability

Sand areas exhibited significant fluctuations, peaking at 11.53km² in 1998 before declining to 7.45km² in 2023. This variability reflects the dynamic sediment transport processes influenced by hydrological and seasonal flow variations. For instance, the peak observed in 1998 may correspond to intensified sediment deposition events during periods of higher river discharge, while the subsequent reduction aligns with stabilization trends.

Water body of River Reduction

The waterbody area experienced a steady decline, shrinking from 18.57 km² in 1988 to 14.93 km² in 2023. This reduction, amounting to a loss of approximately 20%, highlights significant hydrological changes in the region, likely driven by sediment deposition and upstream flow modifications. The declining trend in waterbody areas is evident in **Diagram 1**, which visually summarizes the temporal changes across all land cover categories from 1988 to 2023.



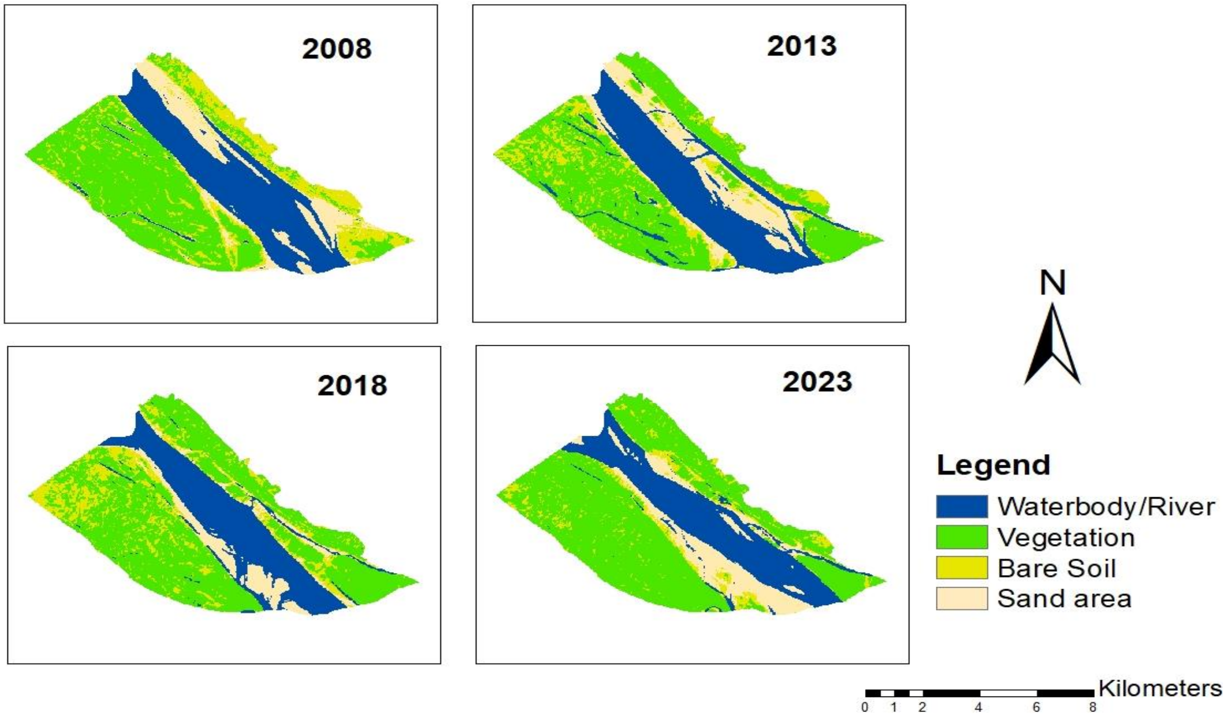


Figure 2. Classified Land Cover Maps (1988, 1998, 2008, and 2023).

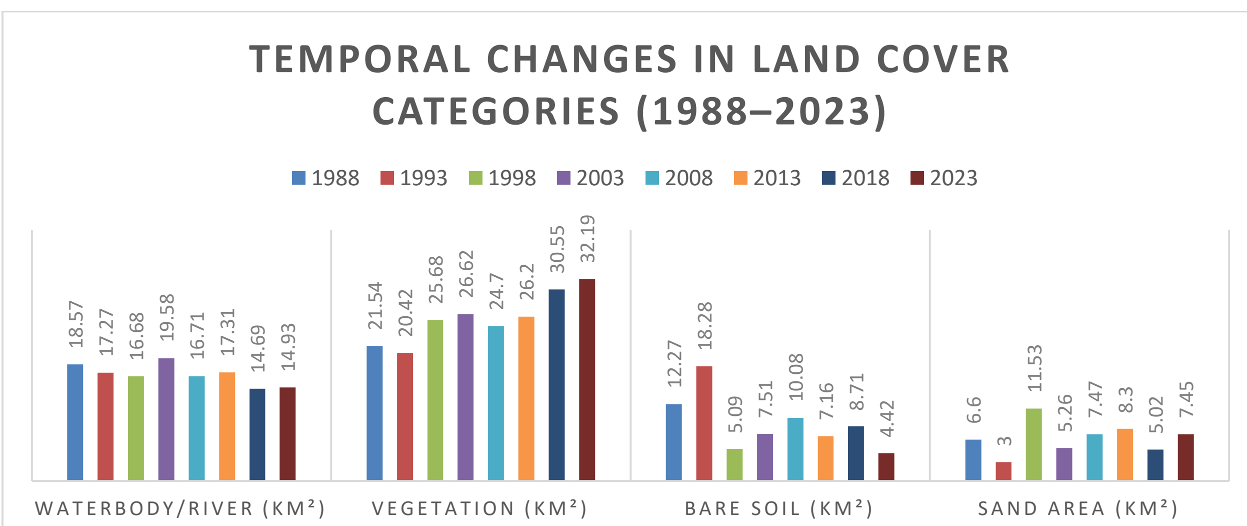


Diagram 1. Bar Diagram of Temporal Changes in Land Cover Categories (1988-2023)

4.1.2 Change Detection Analysis

A detailed change detection analysis (**Figure 3**) revealed significant transitions between land cover categories in Char Ashariadaha from 1988 to 2023, providing insights into the region's dynamic land cover processes.

Bare Soil to Vegetation

The most significant transition observed was from bare soil to vegetation, covering an area of 7.86km². This substantial shift highlights the region's ecological recovery, likely driven by reduced anthropogenic disturbances and natural regrowth processes. Vegetation expansion in these areas contributes to enhanced soil stabilization and ecological resilience, reflecting broader trends observed across floodplain environments.

Waterbody to Vegetation

Another notable change was the transition from waterbody to vegetation, accounting for 3.26km². This shift suggests sediment deposition and stabilization processes in the floodplain. Such changes are indicative of declining waterbody extents and increasing sedimentation, which supports vegetation establishment over time.

Vegetation to Waterbody

In contrast, transitions from vegetation to waterbody were minimal, covering only 0.53 km². This limited change underscores the relative stability of vegetated areas, even in a dynamic hydrological setting. The ability of established vegetation to withstand seasonal flow variations further highlights the resilience of riparian ecosystems.

Sand Area Transitions

Sand areas exhibited dynamic changes, transitioning to bare soil, vegetation, and waterbody categories. These shifts reflect the continuous sediment transport and deposition processes influenced by seasonal hydrology and riverine dynamics.

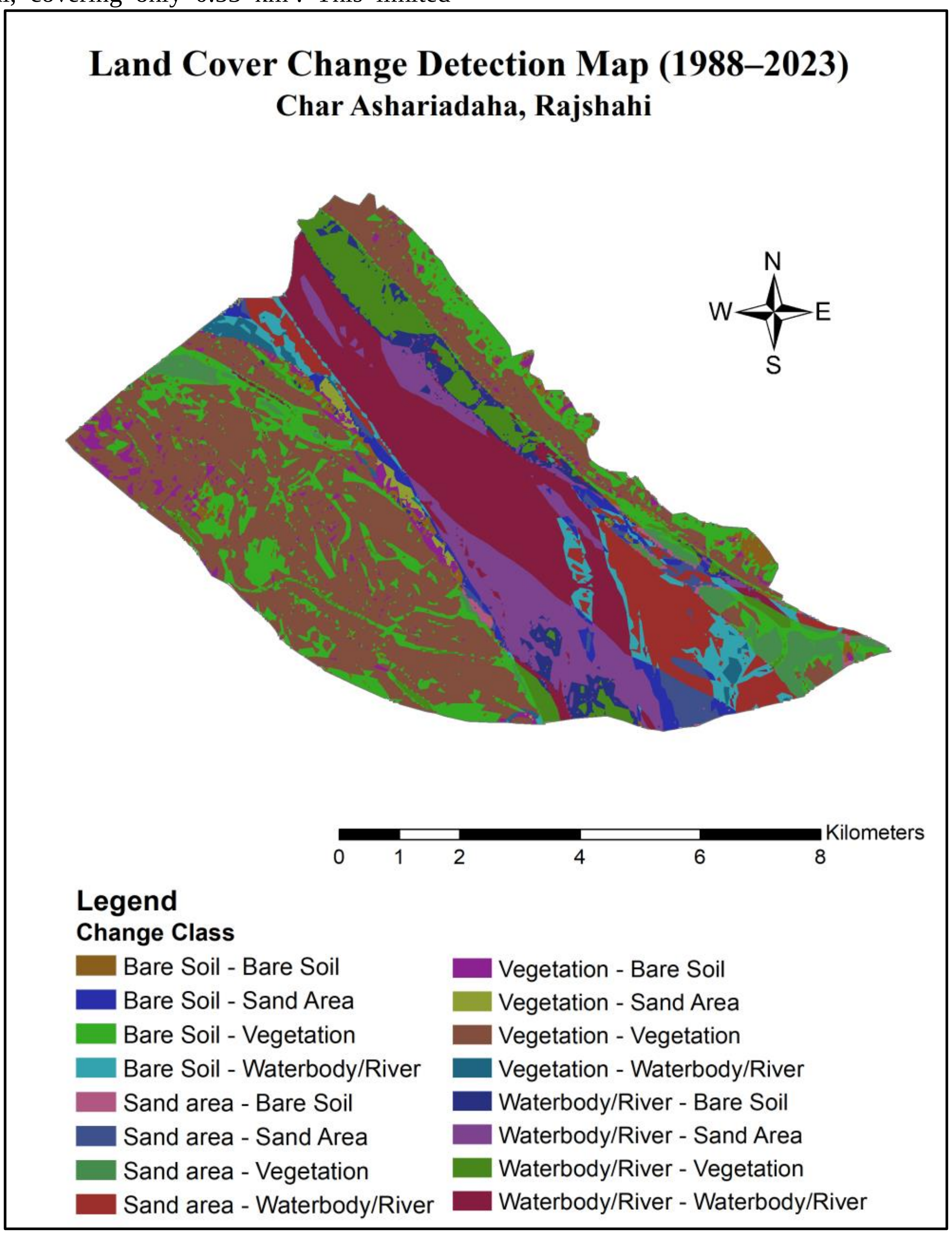


Figure 3. Specific transitions between land cover categories from 1988 to 2023

Figure 3 provides a spatial visualization of these transitions, highlighting the intricate interplay between sediment transport, vegetation regrowth, and waterbody reduction over the study period. Similarly, **Diagram 2** summarizes the quantitative aspects of these transitions, offering a clear representation of the scale and magnitude of changes across land cover categories.

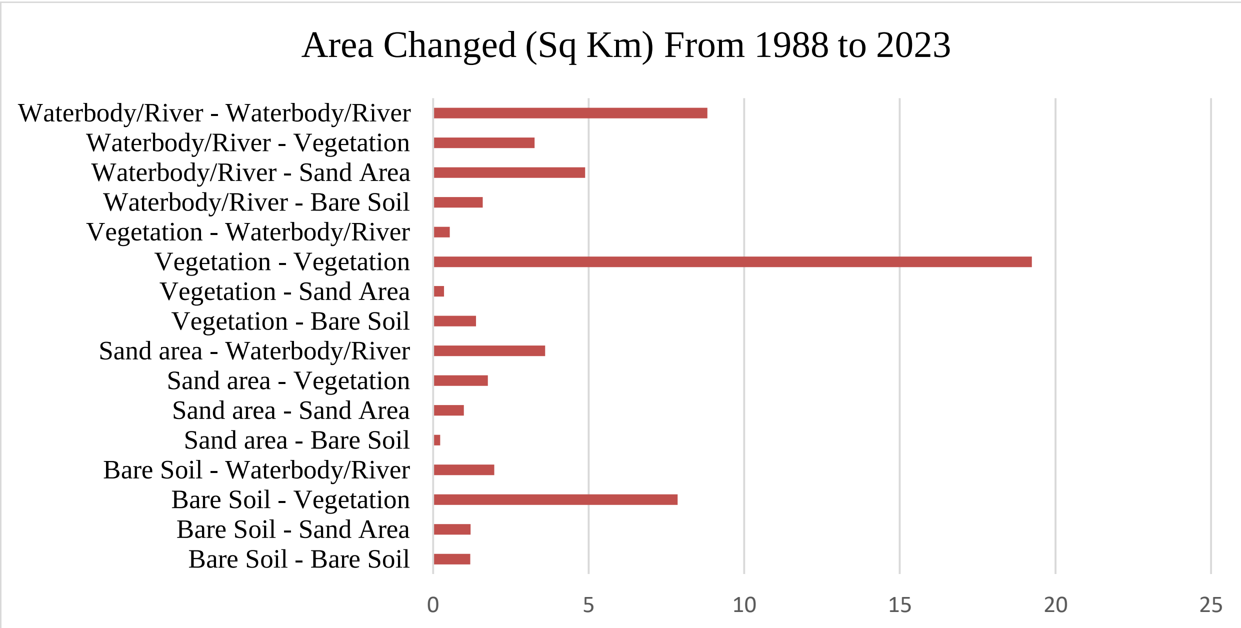


Diagram 2. Bar Chart of Area Changes in Land Cover Transitions (1988–2023)

4.2 River Morphology Dynamics

4.2.1 NDWI-Based River Transformation (1988–2023)

The NDWI-based river transformation map (**Figure 4**) provides a comprehensive visualization of the dynamic changes in river characteristics in Char Ashariadaha over the 35-year study period. This analysis is pivotal in understanding the spatial and temporal riverine transformations driven by sediment transport, hydrological variability, and natural geomorphic processes. The map categorizes the riverine landscape into three distinct regions-**stable**, **eroded**, and **accreted** areas-each offering insights into the processes shaping the floodplain.

Stable Areas

Stable areas, covering approximately **8.26 km²**, represent regions of the river that remained unchanged throughout the study period. These areas are indicative of hydrological stability, where flow dynamics and sediment transport processes have maintained equilibrium. Stability in such zones suggests minimal human or natural disturbances, making them critical for sustaining aquatic ecosystems and riparian biodiversity. These regions also serve as baselines for evaluating the extent and impact of changes elsewhere in the riverine system.

Eroded Areas

Erosion accounted for the loss of around **9.54 km²** of the river area, highlighting the substantial impact of sediment deficits and fluctuating hydrological conditions. Erosion is likely driven by reduced sediment inflow, upstream modifications, and variability in river discharge, which exacerbate bank instability and channel migration. The erosion of riverbanks not only leads to the loss of fertile land but also impacts local livelihoods by diminishing arable land and disrupting aquatic habitats. This finding underscores the need for sediment management strategies to mitigate future erosion and maintain river functionality.

Accreted Areas

Accreted areas, comprising approximately **5.68km²**, reflect regions where new land emerged due to sediment deposition. These areas highlight the active sedimentation processes that are characteristic of the region's dynamic floodplain environment. Accretion often occurs in areas of reduced flow velocity, where sediment is deposited and stabilizes over time, fostering the growth of vegetation. While these areas offer opportunities for agricultural expansion or ecological restoration, their long-term stability depends on managing upstream sediment flows and ensuring sustainable land use practices.

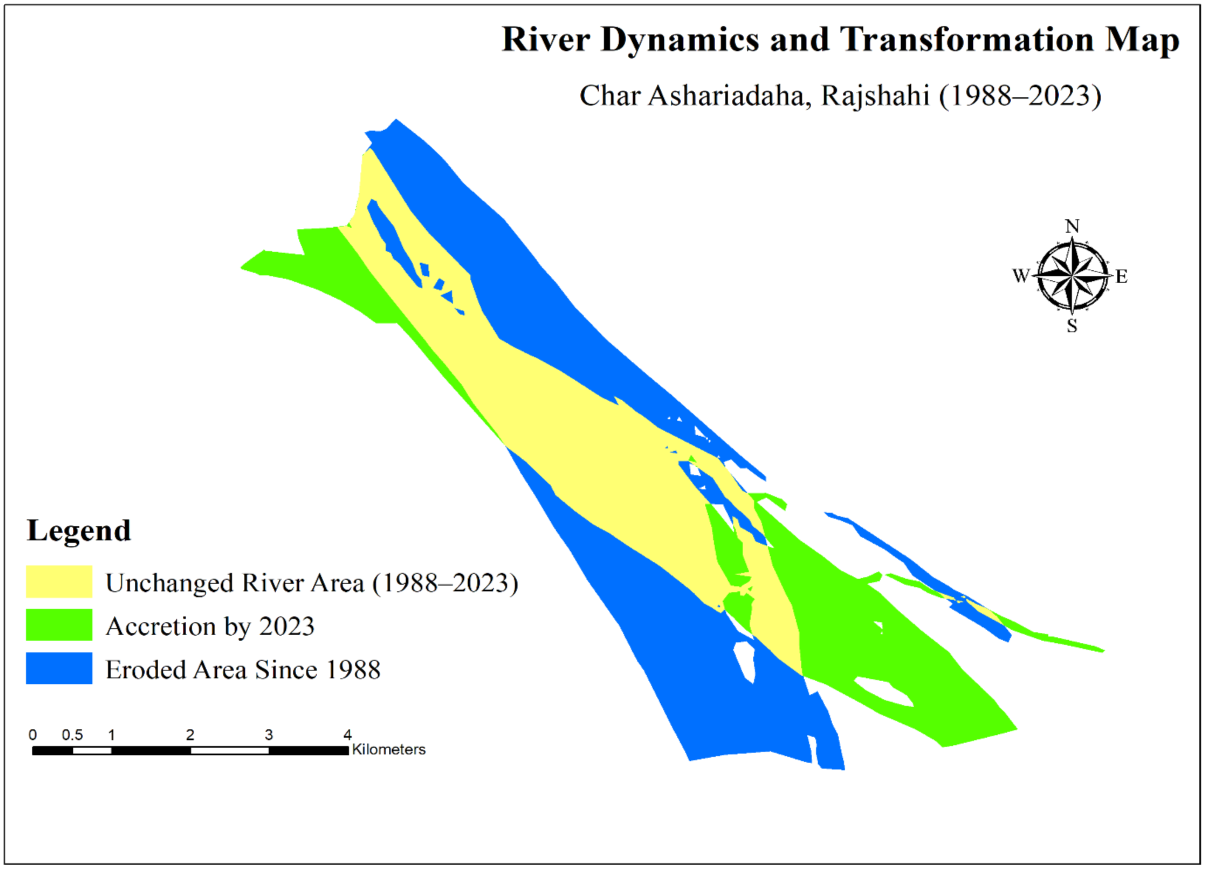


Figure 4. NDWI-Based River Transformation Map (1988-2023)

4.2.2 Integrated Analysis of Land Cover and River Morphology

The findings reveal a clear interplay between land cover dynamics and river morphology:

Vegetation Growth in Accreted Areas:

Accreted regions were predominantly vegetated, indicating natural stabilization and ecological recovery.

Bare Soil Decline and Hydrological Shifts:

Concurrent declines in bare soil and waterbody areas highlight the influence of sediment deposition and hydrological alterations.

Sediment Redistribution:

Sediment deposition in accreted areas enhances soil fertility but also reshapes floodplain topography, impacting land use patterns.

These integrated findings emphasize the interconnectedness of terrestrial and aquatic processes in shaping the landscape of Char Ashariadaha.

4.3 Implications for Environmental Management

The observed changes have broader implications for floodplain management and sustainable development:

Floodplain Management

Declining waterbody areas may exacerbate flood risks during extreme weather events, necessitating improved floodplain management strategies.

Sustainable Land Use

Accreted regions present opportunities for agriculture and reforestation but require careful management to prevent degradation.

Biodiversity Conservation

Stabilizing vegetation in accreted areas can enhance habitat connectivity, supporting biodiversity in the floodplain.

4. Conclusion

This study provided a comprehensive geospatial analysis of land cover dynamics and river morphology changes in Char Ashariadaha, Rajshahi, Bangladesh, over a 35-year period (1988–2023). Significant insights into the interplay between terrestrial and aquatic systems were obtained using multi-temporal Landsat imagery, supervised classification, and NDWI-based transformation analysis. The findings highlight key transitions and their implications for environmental sustainability and management.

Key Findings:

- Vegetation cover exhibited a steady increase, expanding from 21.54km² in 1988 to 32.19km² in 2023, reflecting natural regrowth and ecological stabilization.
- Bare soil and sand areas showed marked reductions and fluctuations, emphasizing ongoing sediment redistribution and stabilization efforts.
- The waterbody/river area experienced a decline from 18.57km² in 1988 to 14.93km² in 2023, indicating significant hydrological changes.
- Change detection analysis revealed notable transitions, particularly from bare soil to vegetation (7.86km²), and highlighted areas of erosion and accretion within the river system.

Integrated Insights:

- The study demonstrated a strong linkage between land cover dynamics and river changes, with sediment redistribution driving ecological transformations.
- NDWI analysis effectively delineated stable, eroded, and accreted areas, underscoring the dynamic processes of sedimentation and hydrodynamics in floodplain environments.

Environmental and Management Implications:

- The declining waterbody area and erosion of riparian habitats necessitate immediate attention to floodplain management and riverbank stabilization strategies.
- Accreted regions offer opportunities for sustainable land use, including reforestation and agriculture, but require careful management to maintain ecological balance.
- Vegetation expansion in accreted areas emphasizes the importance of natural stabilization processes, which can enhance biodiversity and habitat connectivity.

2. **Future Directions**:

- Future research could incorporate higher-resolution satellite imagery to analyze finer-scale transformations and validate these findings with field-based observations.
- Integrating socio-economic dimensions, such as the impact of land cover changes on local communities, would provide a more holistic understanding of these dynamics.
- Expanding the temporal analysis to include seasonal variations would offer deeper insights into the short-term fluctuations and their implications for long-term trends.

By integrating geospatial analysis and temporal change detection, this study contributes valuable insights into the complex interactions between river morphology and land cover in a sediment-rich floodplain environment. These findings highlight the critical need for sustainable management practices to mitigate the adverse effects of environmental changes while leveraging opportunities for ecological and socio-economic benefits.

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