Majuli towards Degradation: A Spatio-Temporal Analysis on Land Area and Vegetation Cover Changes in the World's Largest Inhabitant River Island

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Abstract
Majuli, the world's largest inhabited river island, is undergoing severe riverbank erosion and vegetation depletion, endangering its cultural heritage and the livelihoods of its 0.2 million residents. This study utilizes Landsat series satellite data from 1987, 1999, 2011 and 2023, integrated with Geographic Information System (GIS) software, to quantify changes in land area and vegetation cover over 36 years. Digitizing land area using the Normalised Difference Water Index (NDWI) method analysis indicates that erosion significantly exceeds deposition, with the island's area declining from 726.83 sq. km. (as per digitization) in 1987 to 650.17 sq. km. in 1999, briefly increasing to 717.84 sq. km. in 2011, before decreasing to 654.18 sq. km. in 2023.

Vegetation analysis, utilizing the Normalized Difference Vegetation Index (NDVI) method, Land Use and Land Cover (LU/LC) classifications, reveals a drastic reduction in dense vegetation from 0.40 sq. km. in 1987 to none in 2023 and in sparse vegetation from 59.26 sq. km. to 2.28 sq. km. The study emphasizes that increasing population pressure, fluvial activities and agricultural demands are key factors exacerbating these environmental changes. It recommends integrated restoration and conservation efforts involving Government agencies, NGOs and local communities to mitigate erosion and to restore vegetation on Majuli.

Keywords: Majuli River Island, NDWI, NDVI, GIS, Fluvial activities.

Introduction

The river Brahmaputra, which originates near the Chemayungdung glacier near Mansarovar Lake in Tibet, is a transboundary river that flows through China, India and Bangladesh and is known by various names: Yarlung Tsangpo in Tibet-China, Dihang or Siang in Arunachal Pradesh, Brahmaputra in Assam and Meghna in Bangladesh[7,9,10]. The highly braided river in Assam is characterized by having numerous tributaries, a high carrying capacity of sediments, seasonal flow variation, channel configuration, multiple sandbars and islands[5,14,24]. In the Brahmaputra valley of Assam, the river deposits a huge volume of sediment, thus making it one of the most productive regions of the country[8]. The river also causes severe floods, causing damage to livelihoods and property.

Majuli is set amid the river Subansiri on the north, the Brahmaputra on the south and a spill channel of the Brahmaputra River called Kherkatia Xuti on the northeast. Majuli, also known as the land of '*Satras'* (religious center), home to numerous Assamese Vaishnavite monasteries, serves as a cultural hub, preserving the traditional art, music and dance forms of Assam has made the island distinguishable from other societies[19]. Majuli is also considered a center for Neo-Vaishnavism[21,22]. But now, some of the '*Satras'* nearer to the river bank are getting threatened due to river erosion[13].

Riverbank erosion is a prominent fluvial issue in the modern era, presenting a global challenge of unforeseeable proportions. The unpredictability of this problem extends worldwide, stemming from a combination of natural forces and human influence[25]. This process involves the gradual removal of soil from the riverbed and the adjacent banks, ultimately leading to sediment accumulation. The consequences of river bank erosion are evident in the loss of land in certain areas, which results in the displacement of the locals now and then[23]. The intertwining characteristics of braided rivers and the occurrence of floods play a pivotal role in the initiation of riverbank erosion[26].

This intricate process involves the gradual erosion of soil from one bank and its subsequent deposition on another, facilitating a gradual shift in the alignment of the riverbanks over a period of time. Assam, specifically, contends with riverbank erosion triggered by heavy rainfall, floods and the intricately braided nature of the Brahmaputra River basin. Annually, this erosion contributes to the loss of lives, livestock, residences, household possessions, infrastructure, agricultural land and livelihoods while also posing a threat to natural resources[1].

The extent of soil erosion is contingent upon the interplay between the intensity of rainfall, which triggers erosion and the soil's capacity to resist these erosive forces. The soil's ability to resist erosion is denoted as its erodibility, a value influenced by factors such as soil structure, infiltration capacity and organic matter content[6,18]. Within Majuli, riverbank erosion presents a critical threat to this island's stability. Majuli emerged as a product of cyclic natural transformations in the course of the Brahmaputra river,

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instigated by recurrent significant earthquakes across various epochs, coupled with intense floods and silt deposition[11]. The island is always prone to fluvial erosion caused mostly by the Brahmaputra and the Subansiri rivers, which have wiped out almost forty villages in the recent decade as per Census of India 2001 and 2011.

Consequently, the island grapples incessantly with the alarming challenges of both flood hazards and river bank erosion, threatening its invaluable cultural heritage and even its existence[15]. The erosion is higher on the southern side due to the presence of the Brahmaputra river in comparison to the other two rivers[2]. The land cover change pertains to continuous alterations in the attributes of the land, encompassing factors like vegetation type and soil characteristics. In contrast, land-use change involves modifying how a specific land area is utilized or managed by human activity. This often entails reshaping the natural landscape due to urban expansion. Remarkably, this transformation supports various local and global repercussions, including the decline of biodiversity and its implications for human well-being, along with habitat loss and the degradation of ecosystem services[20]. Primarily encouraged by urban growth, this phenomenon holds heightened significance for developing and underdeveloped nations. Nonetheless, while natural factors can contribute to land cover change, human intervention remains pivotal for land-use change[12]. In this study, an attempt has been made to observe the trend of bank line and vegetation cover change over an extended of 36 years on Majuli island using Landsat series data. This information will be helpful for long-term planning and management for floods and erosion control. With some proper planning, afforestation, awareness and by undertaking various measures ensuring protection from illegal activities with a little control over settlement and agricultural activities around this area, the said problem can be mitigated.

Study Area

Geographically, the study area Majuli extends between 26° 51′ N to 27° 11′ N latitude and 93° 57′ E to 94° 30′ E longitude (Fig. 1). Majuli is renowned for its unique ecosystem, comprising of wetlands, water bodies and a diverse range of flora and fauna. The island is vulnerable to annual flooding and erosion, which poses a significant threat to its landscape and inhabitants. As per the 2011 census, Majuli had a population of 167,304, with a sex ratio of 955 females for every 1,000 males, reflecting a balanced demographic structure.

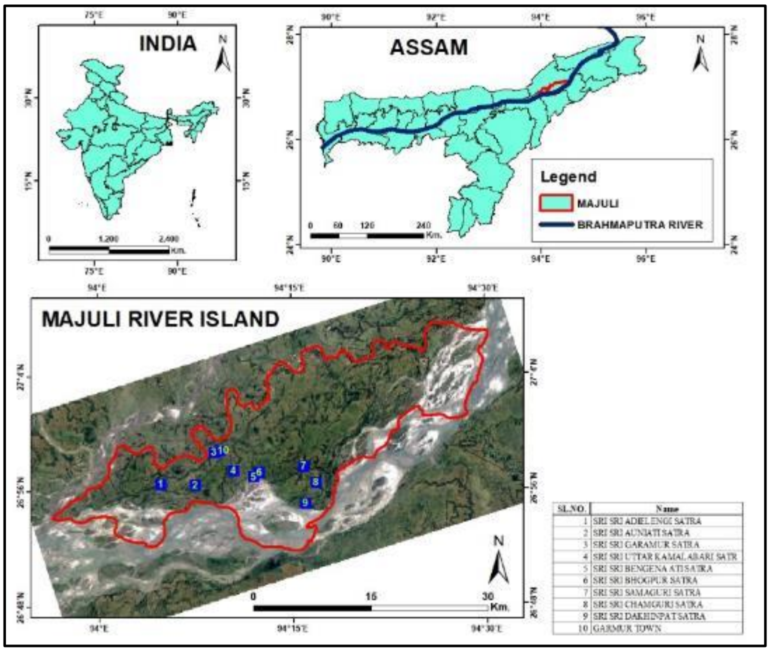

Figure 1: Location map of the study area

Table 1
Details of satellite data used

Year	Platform	Sensor	Date of Acquisition	Path/Row	Resolution	Band used
1987	LANDSAT 5	TM	02-02-1987	137/042	30m	NDVI- B3, B4 NDWI- B2, B4
1999	LANDSAT 5	TM	03-02-1999			
2011	LANDSAT 5	TM	04-02-2011			
2023	LANDSAT 8	TIRS	20-01-2023			NDVI- B4, B5 NDWI- B3, B5

Source: USGS website

Data Used: For the study, satellite images of the Landsat series (Table 1) of different years were downloaded from the USGS website and vector files like India and State boundaries are collected from the DIVA GIS portal. For a better idea of the region, maps are projected to geodetic datum WGS1984 and project coordinates UTM zone 46 N.

Material and Methods

The Science of Remote Sensing (RS) and GIS has made it possible to study the spatio-temporal changes in the landmass of the Majuli River island and the changes in vegetation cover over 36 years. For the study, software like MS Excel, QGIS 3.30.3, Arc GIS 10.8 and Google Earth Pro are used to process, analyse and interpret the data. From the Landsat series data of the years 1987, 1999, 2011 and 2023, raster calculations of NDWI and NDVI are carried out in the GIS software. The methodology used in the study is shown in the methodological flow chart as in fig. 2.

The methodology employed in this study utilizes the raster calculation method, NDWI and NDVI to analyze the land and vegetation cover of Majuli River island. The NDWI method, which uses near-infrared (NIR) and green spectral bands to highlight water features, was applied to trace the island's land area, with raster calculation where pixel values range from -1 to 1, higher range indicating the presence of water bodies. The formula used for NDWI is:

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}.$$

After running the NDWI algorithm for different years, the island's land area was digitized and overlay analysis (intersection and difference methods) was performed to demarcate unchanged, erosional and depositional areas. Cross-validations of the bank lines were done using historical images from Google Earth software and field visits were conducted to ensure its accuracy and reliability. Simultaneously, NDVI, which measures the difference between NIR and red light to quantify vegetation cover, was used to analyze the island's changing vegetation patterns. The formula used for NDVI is:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

NDVI values were classified, with those below 0 indicating non-vegetation and those above 0 representing various types of vegetation. Five threshold values were applied for classification, ranging from water bodies to dense and healthy vegetation[3,4] (Table 2).

The LU/LC maps were reclassified again for statistical calculation of the total change of features in the respective years. As the Landsat data that has been used, has a 30m spectral resolution, a pixel covers an area of 900 sq.m. Each LU/LC class's total pixel value is multiplied by 900 sq.m. and is converted into sq. km. to determine their total area coverage. Each year's accuracy assessment is done using the pre-existing statistical technique, the Kappa coefficient. About 50 random sample points were created for each class to verify the classification and an accuracy threshold of over 84 percent was consistently maintained.

Results and Discussion

Majuli River island stands as an integral component of the Brahmaputra alluvium and lies between the Himalayan and Indo-Burmese orogenic belts. The interplay of these two active orogenies has given rise to a complex tectonic landscape characterized by numerous thrusts and cross-faults. The Brahmaputra fault (east-west) and the Dibrugarh and Simen lineaments (northeast-southwest) are responsible for the ongoing transformation of the river-island which is also influenced by tectonic elements[16].

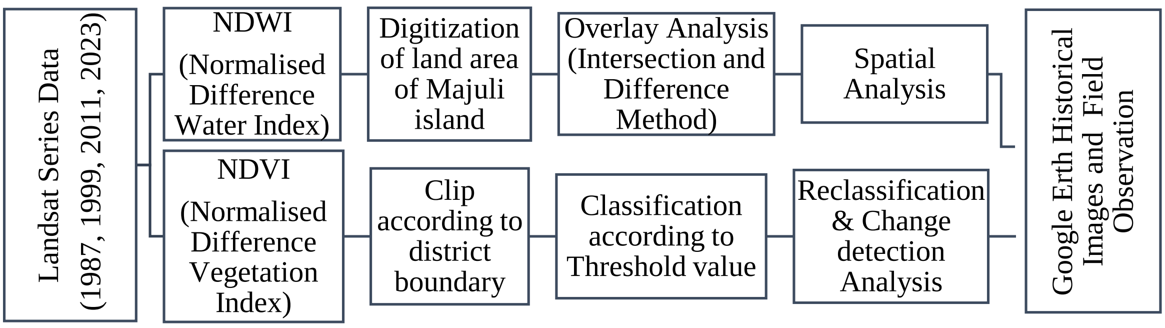

Figure 2: Methodological flow chart

Table 2
NDVI Classification

Range of NDVI Value	Features
BELOW 0	Waterbody
0-0.2	Bare Soil, Rock, Sand and Cloud
0.2-0.3	Shrub/Grassland
0.3-0.5	Sparse Vegetation
ABOVE 0.5	Dense and Healthy Vegetation

Bank line change of Majuli River Island: A spatio-temporal change analysis of Majuli's bank line was conducted in 1987, 1999, 2011 and 2023 (Fig. 3) and a cross-check was performed using historical images from Google Earth software. A total of 21 GPS points were recorded around the island's boundary to check accuracy. The bank line adjacent to the river Brahmaputra (southern part) is more vulnerable in comparison to the other two rivers.

For quantitative comparison and analysis of four years, an erosion, deposition and unchanged area map has been prepared (Fig. 4). From the analysis of the data (Table 3), it is found that in the year 1987, the land area of the Majuli river island was measured at 726.83 sq. km. (as per digitization). However, over the next twelve years, by 1999, the combined forces of the rivers had caused significant erosion in comparison to deposition, leading to a reduction in the island's extent to 650.17 sq. km., thus eroding an area of 117.32 sq. km. and deposition of about 40.66 sq. km. It is worth noting that this reduction in the land area could be attributed to major floods and geological disturbances triggered by events like the 1988 earthquake[17].

On an average annual basis, the island experienced erosion of about 9.78 sq. km. and deposition of 3.39 sq. km. Notably, an area of 609.51 sq. km. remained unchanged during this period. During the period from 1999 to 2011, the deposition rate was much higher than the erosion rate.

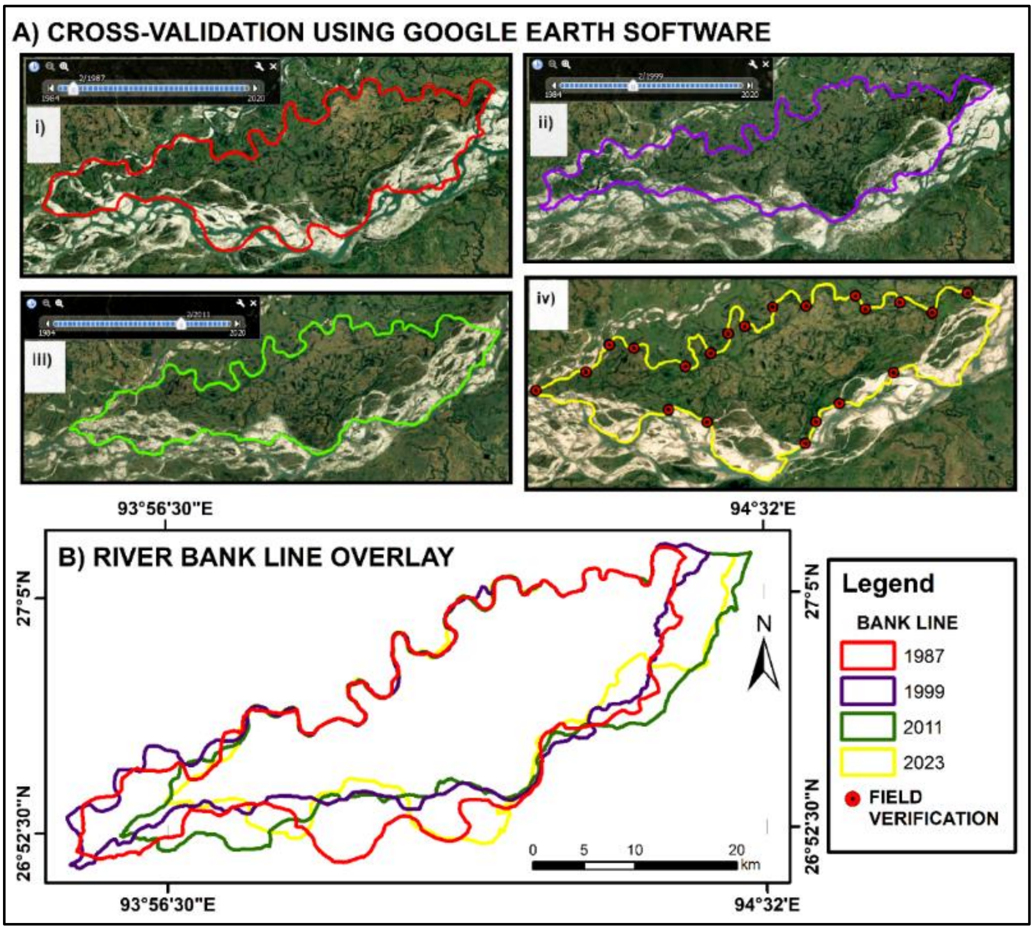

Figure 3: A) Bankline overlay in historical images of Google Earth software i) 1987, ii) 1999, iii) 2011, iv) 2023 B) Bankline overlay (1987 to 2023)

Table 3
Change in Land Area from 1987 to 2023

Year	Total Area (sq. km.)	EROSION (sq. km.)	Deposition (sq. km.)	Unchanged (sq. km.)	Average Annually Eroded Area (sq. km.)	Average Annually Deposited Area (sq. km.)
1987	726.83	—	—	—	—	—
1999	650.17	117.32	40.66	609.51	9.78	3.39
2011	717.84	73.27	140.95	576.90	6.11	11.75
2023	654.18	117.52	53.86	600.32	9.79	4.49
Total	654.18	162.65	90.00	564.17	4.52	2.50

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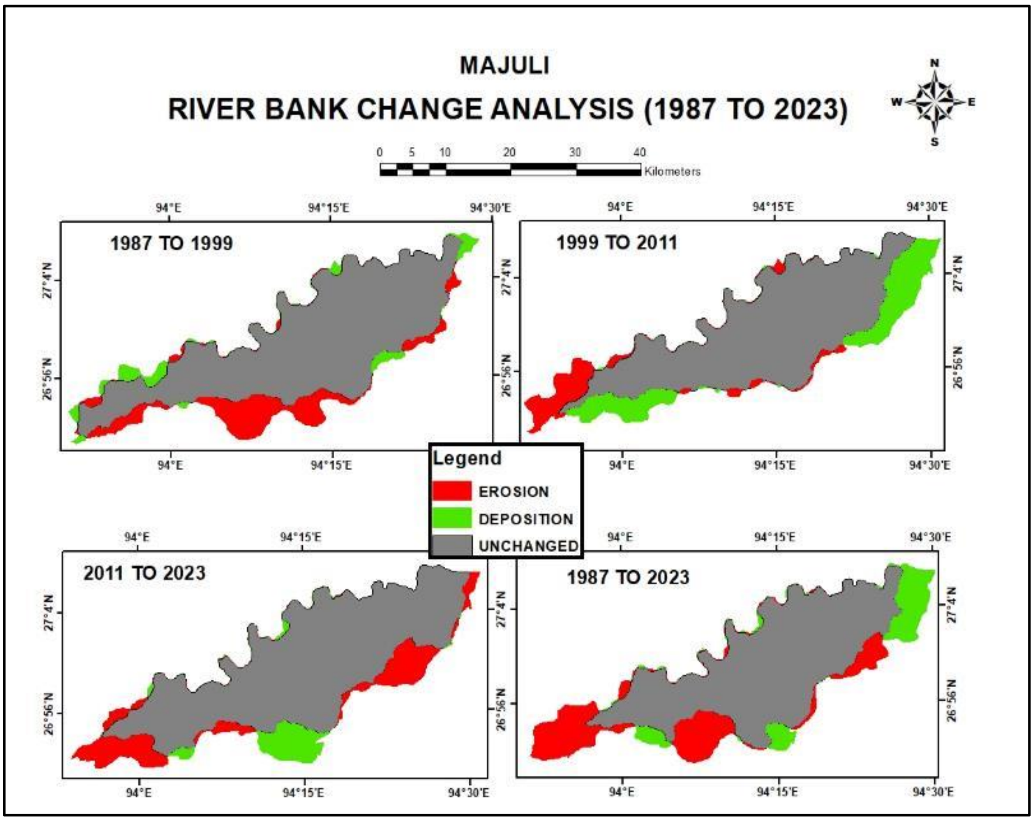


Figure 4: Erosional and Depositional activities (1987 to 2023)

The primary factor driving deposition was the gradual shifting of the Brahmaputra River's bank line towards the south. The land area of the Majuli River island has increased by 67.67 sq. km., leading to an overall expansion of the land area from 650.17 sq. km. in 1999 to 717.84 sq. km. in 2011. Erosion during this period accounted for a reduction of 73.27 sq. km. and a total of 576.90 sq. km. of landmass area remained unchanged.

The annual average erosion rate during this period was 6.11 sq. km. while the deposition rate was 11.75 sq. km. Particularly, deposition saw an increase during this time frame, leading to an extension of the landmass. In the period from 2011 to 2023, the island experienced a considerably higher rate of erosion compared to depositional processes. The landmass area of the Majuli river island measured 717.84 sq. km. in 2011, but decreased to 654.18 sq. km. by 2023, thereby losing an area of 63.66 sq. km. The erosion resulted in an average loss of 117.52 sq. km. and a deposition of 53.86 sq. km. over a span of 12 years. On average, annually, there was a deposition rate of 4.49 sq. km., while erosion accounted for 9.79 sq. km. A substantial area of 600.32 sq. km. remained unchanged during this period.

Between the years 1987 and 2023, the land area of the Majuli River island experienced a significant change, decreasing from 726.83 sq. km. to 654.18 sq. km. Over these 36 years, a total of 162.65 sq. km. of landmass was eroded, while 90.00 sq. km. of landmass was deposited. During the entire period, the study determined that the total average annual erosion rate was 4.52 sq. km. per year and the average annual deposition rate was 2.50 sq. km. per year. These figures provide a clearer perspective on the pace of erosion and deposition processes occurring on the Majuli river island over the given timeframe.

Land Use and Land Cover Changes: The LU/LC change dynamics of the Majuli River island have been analyzed for the years 1987, 1999, 2011 and 2023. The results obtained through the NDVI study (Fig. 5) and field observation reveal a rapid reduction in vegetation cover on the island, primarily due to various human-induced and fluvial factors. The LU/LC mapping of the concerned area shows changes about areas at the NDVI range threshold of values below 0 representing water bodies; 0 to 0.2 indicating bare soil, rock, sand and cloud; 0.2 to 0.3 shrub or grassland; 0.3 to 0.5 sparse vegetation and a value above 0.5 representing dense and healthy vegetation (Table 2). However, significant changes have been seen in all the features after the computation.

In the span of 36 years (1987-2023), the vegetation cover has eventually decreased from sparse, dense and healthy vegetation to shrub or grassland and non-vegetation areas (bare soil, rock, sand and cloud). The three features, namely dense vegetation, sparse vegetation and shrubs or grassland, are interrelated with each other, as the growth of shrubs or grassland will lead to sparse vegetation and gradually towards dense vegetation.

The NDVI values (Table 4) of the year 1987 ranged from -0.412 to 0.61; in 1999, from 0.455 to 0.64; in 2011, from -

0.404 to 0.57; and in 2023, from -0.108 to 0.36. A high NDVI value indicates healthy vegetation and values decrease gradually according to vegetation coverage. From the NDVI range of the said years, a sharp decline in vegetation coverage can be seen. The sparse and dense vegetation over the selected region has decreased from 59.66 sq. km. in 1987 to 80.27 sq. km. in 1999, 51.49 sq. km. in 2011 and 2.28 sq. km. in 2023. A total of 57.38 sq. km. of sparse, healthy and dense vegetation (Table 5) vanished during the period of study. It simply indicates a huge change in vegetation cover, which is one of the main reasons behind the increase in erosional activities.

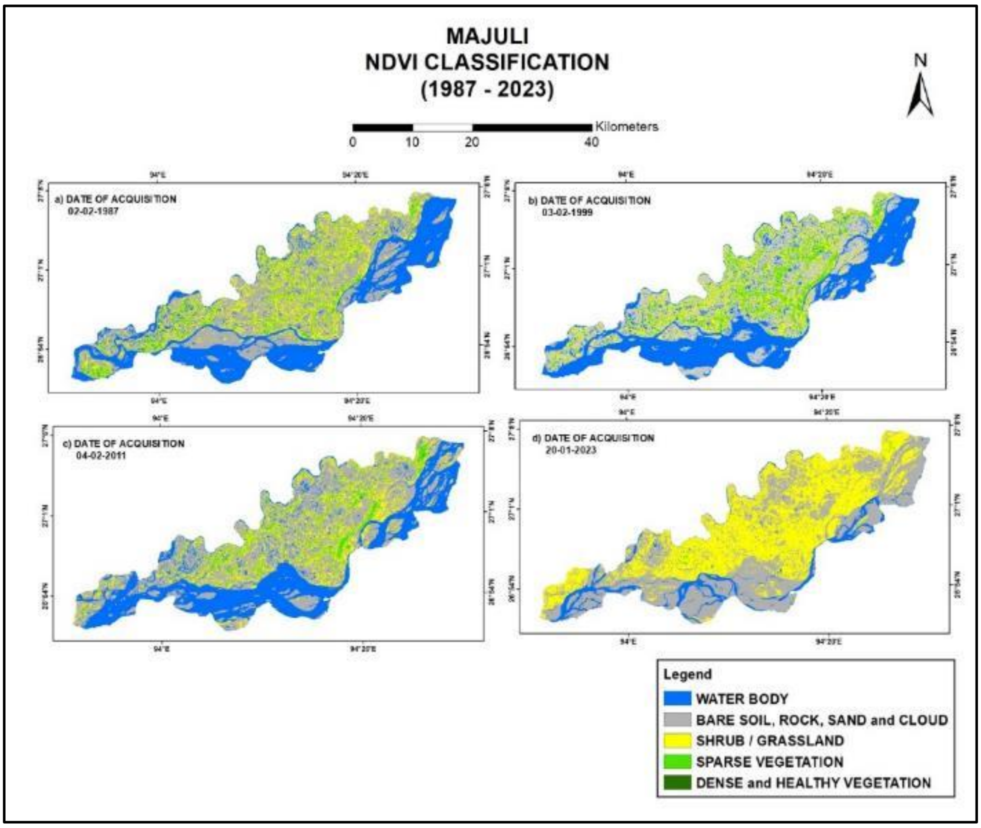


Figure 5: Land Use and Land Cover Classification

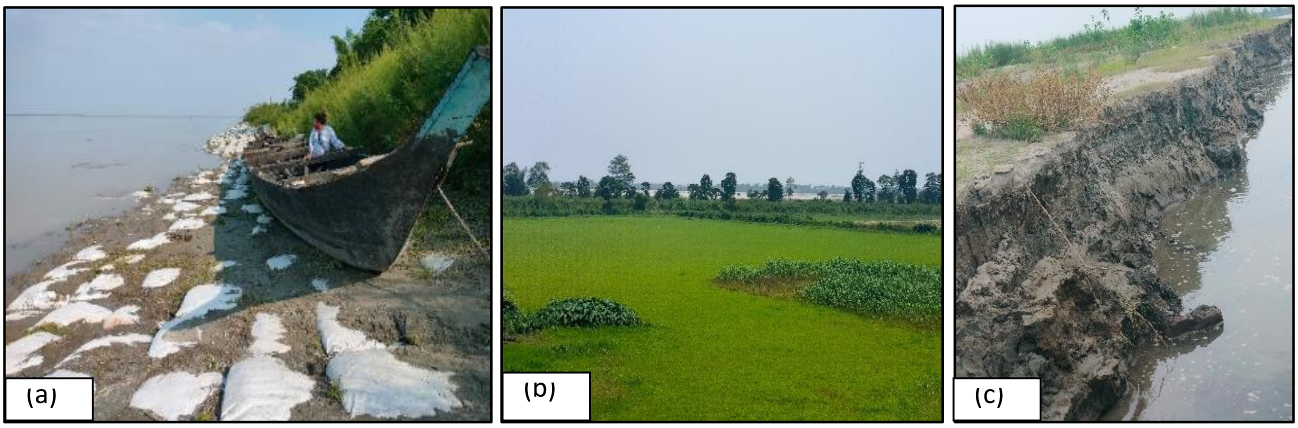
Table 4
LU/LC Change Analysis (1987-2023)

Years	**1987**				**1999**			
Features	**NDVI Range**	**Pixel Count**	**Area (in sq.km.)**	**Percentage (%)**	**NDVI Range**	**Pixel Count**	**Area (in sq.km.)**	**Percentage (%)**
Water Body	- 0.412-0	293503	264.15	32.34	- 0.455-0	347303	312.5727	38.27
Bare Soil, Rock, Sand and Cloud	0-0.2	387640	348.88	42.72	0-0.2	326370	293.733	35.96
Shrub / Grassland	0.2-0.3	160045	144.04	17.64	0.2-0.3	144610	130.149	15.94
Sparse Vegetation	0.3-0.5	65846	59.26	7.26	0.3-0.5	89027	80.1243	9.81
Dense and Healthy Vegetation	0.5-0.61	443	0.40	0.05	0.5-0.64	167	0.1503	0.02

Years	**2011**				**2023**			
Features	**NDVI Range**	**Pixel Count**	**Area (in sq.km.)**	**Percentage (%)**	**NDVI Range**	**Pixel Count**	**Area (in sq.km.)**	**Percentage (%)**
Water Body	- 0.404-0	292446	263.20	32.23	- 0.108-0	69747	62.7723	7.69
Bare Soil, Rock, Sand and Cloud	0-0.2	412602	371.34	45.47	0-0.2	433750	390.375	47.80
Shrub / Grassland	0.2-0.3	145214	130.69	16.00	0.2-0.3	401444	361.2996	44.24
Sparse Vegetation	0.3-0.5	57125	51.41	6.29	0.3-0.36	2536	2.2824	0.28
Dense and Healthy Vegetation	0.5-0.57	90	0.08	0.01				

Table 5
Change Analysis from 1987 to 2021

YEARS	1987	2023	Changes (in sq.km.)
Features	**Area (in sq.km.)**	**Area (in sq.km.)**	
Water Body	264.15	62.77	-201.38
Bare Soil, Rock, Sand and Cloud	348.88	390.38	41.50
Shrub / Grassland	144.04	361.30	217.26
Sparse Vegetation	59.26	2.28	-56.98
Dense and Healthy Vegetation	0.40	0.00	-0.40
(−) indicates a decrease in area cover			



Photos

Photo Plate (a): Geobag installation for erosion prevention, demonstrating the use of geotextile bags to stabilize the riverbank and reduce soil loss.

Photo Plate (b): Newly deposited soil, now transformed into grassland, indicating the effectiveness of sediment deposition in natural land reclamation.

Photo Plate (c): Riverbank erosion, highlighting the ongoing process of soil loss due to fluvial action, leading to land degradation and instability.

From the field verification, it is found that the process of vegetation degradation is driven by factors such as population growth, increased number of settlements, expansion of agricultural fields, infrastructure development and fluvial activities such as flood, soil erosion and siltation have also contributed to the reduction of dense vegetation cover. This degradation has led to the gradual disappearance of dense vegetation from the Majuli River island. At present, the only notable increase is observed in the area covered by shrubs and grasslands by 217.26 sq. km. This shift in vegetation types has contributed to the ongoing erosion issues faced by the island.

Conclusion

The Majuli River island has been facing a persistent and significant erosion issue and a decline in vegetation cover for a long time, which poses a grave threat to its existence and cultural heritage. The erosion of the world's largest inhabited river island should be acknowledged as a national concern given the gravity of the situation, which necessitates immediate attention to restore ecological equilibrium. The southern bank of the Majuli island experiences a higher annual erosion rate from the Brahmaputra River compared to the other two rivers. Specific areas like Majar Chapori, Mayadebi, Baghgaon, Nimati Ghat and Bengena Ati villages have encountered significant levels of erosion.

In the span of 36 years (1987–2023), due to erosional activities of the rivers, Majuli lost a notable reduction in the island's land net area of 72.65 sq. km., with an average annual erosion rate of 4.52 sq. km. and deposition of 2.50 sq. km. The annual erosion rate of the rivers is much higher than the depositional rate on the island. During the field visit, it was observed that the deposited areas were not suitable for habitation and cultivation because of loose, infertile sand and the area had transformed into '*chaporis*' (grasslands), which were being used for grazing their cows and other domestic animals, as well as for some seasonal crop cultivation.

The reduction in the number of villages mentioned in Census data of India (2001 and 2011) counted from 284 to 244 attributed to this erosion and the resulting geographical changes that the island has been experiencing. The erosion of Majuli's landmass is a critical issue leading to the displacement of communities and the loss of habitable areas. The ongoing change in vegetation on the Majuli River island poses a threat to its biodiversity. The transition from primary to secondary vegetation can have far-reaching implications for both global biodiversity and the issue of global warming. In the context of developing countries, a reduction in vegetation cover at the community level can have consequences on a global scale.

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References

1. Ali A., Brahmaputra River Bank Erosion as a Major Geo-Environmental Problem in Lower Assam, India, *Journal of the Geological Society of India*, **100(4)**, 591-600 **(2024)**

2. Baruah A.J. and Baruah R.K., A study on the area of Majuli Island based on survey of India map/satellite imageries, Brahmaputra Board **(2009)**

3. Bhandari A.K., Kumar A. and Singh G.K., Feature extraction using Normalized Difference Vegetation Index (NDVI): A case study of Jabalpur city, *Procedia Technology*, **6**, 612-621 **(2012)**

4. Bid S., Change detection of vegetation cover by NDVI technique on catchment area of the Panchet Hill Dam, India, *International Journal of Research in Geography (IJRG)*, **2(3)**, 11-20 **(2016)**

5. Brahmaputra Board, Master Plan of Brahmaputra Basin, Part-I, Government of India **(1986)**

6. Briaud J.L., Govindasamy A.V. and Shafii I., Erosion charts for selected geomaterials, *Journal of Geotechnical and Geoenvironmental Engineering*, **143(10)**, 04017072 **(2017)**

7. Das J.N., 10,000 displaced by Assam and Arunachal floods, Food Relief, Retrieved August 27, from https://www.foodrelief.org/10000-displaced-by-assam-and-arunachal-floods/ **(2024)**

8. Edward G., A History of Assam, LBS Publications, Guwahati **(1962)**

9. Goswami D.C. and Das P.J., Hydrological impact of earthquakes on the Brahmaputra river regime, Assam: A study in exploring some evidences, Proc. 18th National Convention of Civil Engineers, Institution of Engineers (India), Assam State Center-Guwahati, Reprinted in My Green Earth, **3(2),** 40-48 **(2002)**

10. Goswami D.C., Brahmaputra River, Assam, India: Physiography, basin denudation and channel aggradation, *Water Resources Research*, **21(7)**, 959-978 **(1985)**

11. Joshi L., Majuli Cultural Landscape Management Authority (MCLMA), Assam, Informatics (India's most popular e-Governance magazine), Retrieved March 23, from https://informatics.nic.in/news/470 **(2024)**

12. Joshi N. et al, A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring, *Remote Sensing*, **8(1)**, 70 **(2016)**

13. Kalita D.J., Impact of flood and riverbank erosion in Majuli, Assam (India) and its restoration measures, *Dimorian Review*, **3(5)**, 21-30 **(2016)**

14. Kashyap M.P., Mahapatra B.M., Mahanta B.N. and Sharma S., Variable bathymetry of River Brahmaputra derived from ADCP data and its effect on the river erosion around the Majuli Island, Assam, India, *Indian Journal of Geosciences*, **76(3)**, 309-318 **(2022)**

15. Kotoky P., Bezbaruah D., Baruah J. and Sarma J.N., Erosion activity on Majuli: the largest river island of the world, *Current Science*, **84(7)**, 929-932 **(2003)**

16. Mahanta B.N., Kashyap M.P. and Mahapatra B.M., Bank Erosion in the largest inhabited river island Majuli: Neotectonic factors for protection strategies, International Conference on Engineering Geology and Geotechniques for Safe and Sustainable Infrastructures EGCON 2022, Kolkata, 157-1559 **(2022)**

17. Majuli District Administration, District Disaster Preparedness and Response Plan (2022-23), Retrieved from https://majuli.assam.gov.in/sites/default/files/public_utility/DDMA%20Plan_compressed.pdf **(2022)**

18. Nath B.K., Effects of Flood and Erosion on Socio-Cultural and Economic Conditions of the People of Majuli Sub-Division, Jorhat District, Assam, Centre of Geography Studies, Doctoral dissertation, Dibrugarh University **(2015)**

19. Nath D., The Majuli Island: society, economy and culture, Anshah Publishing House, New Delhi **(2009)**

20. Patel S.K., Verma P. and Singh G.S., Agricultural growth and land use land cover change in peri-urban India, *Environmental Monitoring and Assessment*, **191**, 1-17 **(2019)**

21. Pegu A., Role of NGOs in economic development: A case study of Majuli, Doctoral dissertation, Assam University **(2013)**

22. Sahay A. and Roy N., Shrinking Space and expanding population: Socioeconomic impacts of Majuli's changing geography, *Focus on Geography*, **60**, 1-26 **(2017)**

23. Sarma J.N. and Phukan M.K., Origin and some geomorphological changes of Majuli Island of the Brahmaputra River in Assam, India, *Geomorphology*, **60(1-2)**, 1-19 **(2004)**

24. Singh B. and Goswami R.K., Influence of landform and geomorphic process on topographic evolution of a river island, *International Journal of Engineering Science and Technology*, **3(7)**, 5562-5571 **(2011)**

25. Thakur P.K., Laha C. and Aggarwal S.P., River bank erosion hazard study of river Ganga, upstream of Farakka barrage using remote sensing and GIS, *Natural Hazards*, **61**, 967-987 **(2011)**

26. Tingsanchali T. and Karim M.F., Flood hazard and risk analysis in the southwest region of Bangladesh, *Hydrological Processes*, **19(10)**, 2055–2069 **(2005)**.

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