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Dynamics of River Channel and Land Degradation in Majuli Island: A Geomorphological Perspective

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ABSTRACT

River channels exhibit a complex interplay of spatial and temporal characteristics influenced by various factors, including geological formations and river dynamics. Majuli, the world's largest river island spanning 352 square kilometers, showcases a unique landscape shaped by periodic flooding and progressive changes. This study investigates the evolution of river channels and land degradation in Majuli Island from 1973 to 2021. Utilizing Landsat data spanning nine consecutive years, spatial analyses were conducted using ArcGIS 10.3 to assess channel migration, channel cross-profile changes, alterations in channel patterns, physical boundary patterns; land use and land cover (LULC) changes, and land degradation trends. The integration of temporal and spatial analyses facilitated the detection of shifts in channel morphology and land degradation patterns across the island. The findings reveal a substantial land degradation of approximately 81.56 square kilometers over the study period, attributed to channel migration and alterations in channel patterns influenced by the geological characteristics of Majuli and the dynamics of the Brahmaputra River. Spatial analysis highlights the necessity for mitigation measures, particularly in the southern and western regions of Majuli, to address the identified vulnerabilities.

INTRODUCTION

The land transformation in humid climatic region is dominated by fluvial processes. The continuous processes of river work in flood plain result different landforms development. The climate change effect the intensity of river work depending upon different geographical situations. The impact of climate change affects the rainfall intensity impacting the stream flow and resultant landscape. The irregular patterns of rainfall and river basin runoffs contribute to fluctuations in river discharge, leading to both aggradational and degradational changes in the river's features. The river morphometry get influence by the intensity of sediment load and channel discharge of a river system, affecting river bank, flood plain as well as the river courses due to transformation in different landform. The largest river island in the world, "Majuli," has a total area of 352 square kilometers (136 square miles), is dominated by the mighty Brahmaputra River. It is an island in Assam's Brahmaputra River, and in 2016 India's first island was recognized as a district. The Brahmaputra River and its tributaries, the Kherkuti Suti and Subansiri rivers, form the borders of the island district, which is situated in the north of the Jorhat district in Assam.(Borah, 2017; Bordoloi& Das, 2023)Flood and erosion lead to channel migration in Assam is a continuous process and is active in Majul too (C. Gogoi& Goswami, 2013). The result is the shrinking of Majuli geographical area due to degradation processes active in the river channel. Erosion of the island is a continuous process since historical times and possess a significant concern (Dutta M.K. et al., 2010). The channel dynamics of the Brahmaputra River have undergone alterations over time as a result of periodic and gradual changes. Development of anabranches is a characteristic feature of this river, the locations of which, however, are unpredictable (Goswami U et al., 1999).

The Majuli has a subtropical monsoon climate (Kumar &Parida, 2021;B. Gogoi, 2022; Deka, 2023;), which means that summers there are hot and muggy(Basumatary et al., 2018; Kashif et al., 2023a; Pandey et al., 2023). The temperature may potentially reach a peak of 34˚C during these times. It typically receives 215 centimeters of rain annually during the monsoon season(Bora, 2004; J. N. Sarma, 2005a; Marandi et al., 2021).The primary goal of this work is to investigate the channel behavior of Majuli Island in Assam, with a focus on erosion and deposition. This research will be important in developing effective remedial strategies to avoid erosion and deposition.

The study focuses on the basic channel behavior and fluvial deposition processes, including aggradations, degradation as well as fluvial erosion and associated landforms. These activities significantly influence both changes in channel width and variations in channel cross-sections. In order to better understand the influence of these processes, the research investigates channel behavior, migration, widening, and pattern and suggesting mitigation measures. The Early works in Majuli are mainly associated with disaster (Dey, 2012; Ramachandran, 2022; Kashif et al., 2023b) socio-cultural(Chanda, 2019; R. Das & Bhattacharjee, 2020; Saikia, 2021;Nath & Barua, 2022)(Nayak et al.,2008 flood analysis (Chetri, 2020; Chetry, 2023; Shah & Shah, 2023)and Erosion (Sankhua et al., 2005; A. Sarma, 2014; Kotoky et al., 2015a; Kalita, 2016; Sahay et al., 2020;)etc, and the mitigation plan for southern margin along the river Brahmaputra. This paper triggered to make a detail analysis of the entire Majuli and planned to find the vulnerable areas for proper land use, structural as well as non-structural measures for the sustainability of the Island.

2. Study Area:

Majuli is primarily an alluvial river island created by the Brahmaputra River. Its geography is comparatively flat and low-lying, and its elevation is around the river level(D. Das, 2014).The island has a total size of 875 sq km, a length of 80 km, and a width of 10-15 km from north to south. Majuli is situated 85–90 meters above mean sea level. (R. Das & Bhattacharjee, 2020). It is formed in that stretch of the river where the largest number of tributaries drains out and forms their deltas on the Northern and the Southern banks. Majuli lies between latitude 26°45' N to 27°10' N and longitude 93° 40' E to 94° 43' East (Bora, 2004; Jain et al., 2007; Kotoky& Dutta, 2015).The island today is separated from the mainland of Assam by 2.5 KM. It is approached from Nimati Ghat in Jorhat district by ferry, which is on the south of the island, and Kamalabari in Majuli is where one lands. The other mainland towns in proximity to the island on the North bank of mainland are North Lakhimpur and Dhakuwakhana. (Murthy &Sadokpam, 2013).

The island is bounded by the river Subansiri on the North west, the Kherkatia Suti (an anabranch channel of the river Brahmaputra) in the northeast and the main Brahmaputra River on the South and the South west. (Hazarika et al., 2010; D. Sarma, 2013; Jyoti & Kumar, 2022). These tributaries usually bring flashy floods with heavy load of fine silt and clayey sediments. They have also very steep slopes, shallow braided shifting channels and had course of sandy beds.

There is an ongoing, persistent endeavor by the Indian government to have Majuli recognized as a UNESCO World Heritage Site, aiming at fostering the comprehensive advancement of this culturally affluent island. Swamps and wetlands are fairly common in Majuli. The older rivers are responsible for creating the larger marshes. In 1917, there were 112 swamps and marshes documented, covering a combined area of 20.13 km 2. From 1966 to 1972, that number dropped to 50, covering a combined area of 17.88 km 2. (J. N. Sarma&Phukan, 2004).

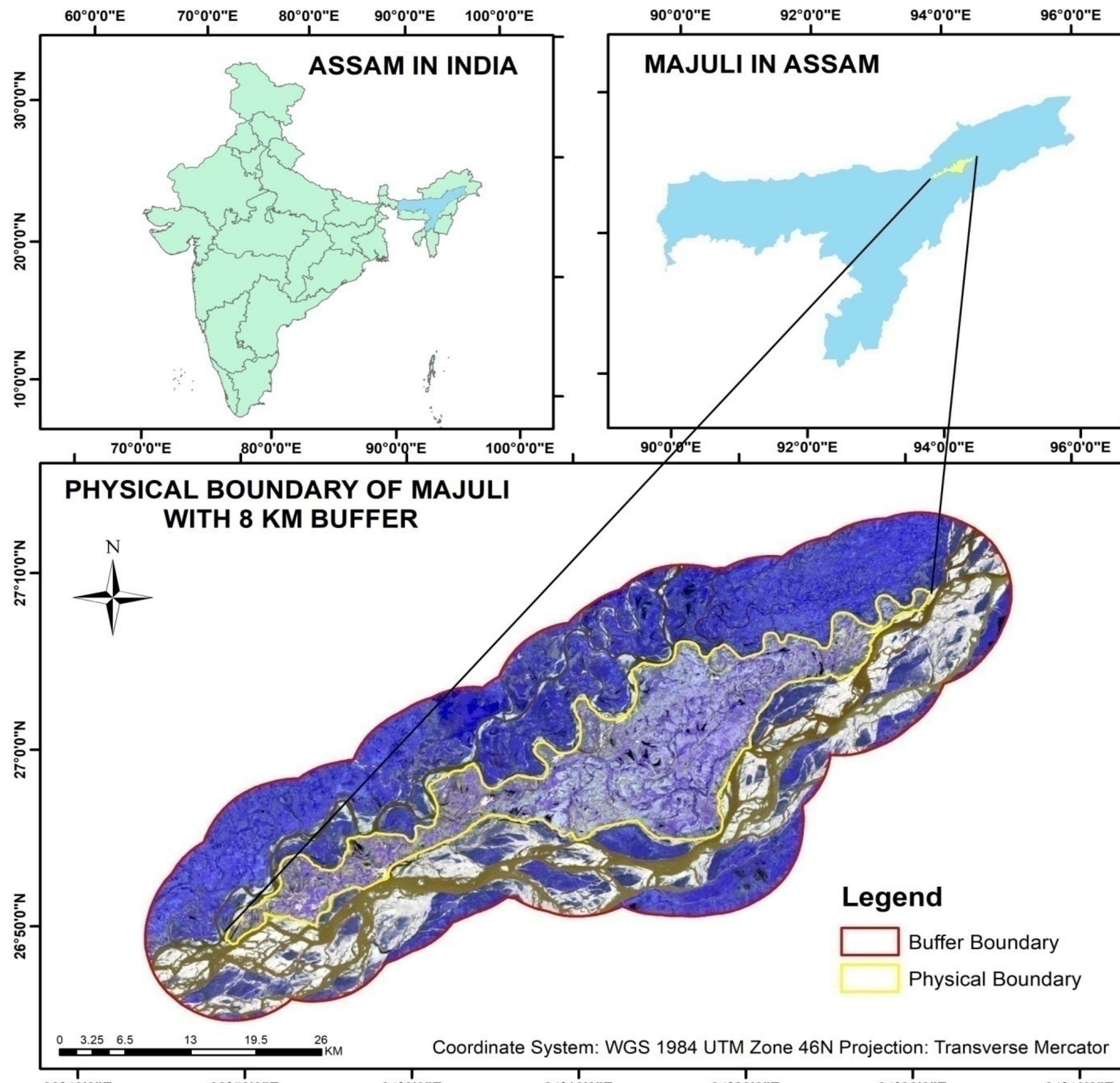


Figure No. 1: Location Map of the Study Area

3. Materials and Methods

Data types and Source:

The current research relies on the collection of Remote Sensing (RS) and Geographic Information System (GIS) data to generate valuable insights. The data necessary for this study were sourced from various reputable and reliable references. Which are detailed in Table No. 1. For the analysis of channel change and channel cross profiles, Landsat data spanning nine consecutive years was utilized. These datasets were instrumental in achieving the specific objectives of the study.

Table 1: Details of the Satellite data used.

SL No.	Year	Sensor	Band	Spatial Resolution
1	1973	Landsat -1 MSS	B4, B5, B6, B7	60 m
2	1986	Landsat -5 TM	B1, B2, B3, B4, B5	30 m
3	1993	Landsat -5 TM	B1, B2, B3, B4, B5	30 m
4	2003	Landsat -5 TM	B1, B2, B3, B4, B5	30 m
5	2013	Landsat -8 OLI	B2, B3, B4, B5, B6	30 m
6	2015	Landsat -8 OLI	B2, B3, B4, B5, B6	30 m
7	2017	Landsat -8 OLI	B2, B3, B4, B5, B6	30 m
8	2019	Landsat -8 OLI	B2, B3, B4, B5, B6	30 m
9	2021	Landsat -8 OLI	B2, B3, B4, B5, B6	30 m

Methods:

In this research, Geographic Information System (GIS) was employed to conduct a temporal study of channel behavior and land degradation in Majuli. The study involved digitizing the channel and physical boundaries of the study area using ArcGIS 10.3 software with Landsat data (Table 1). The initial step involved digitizing the physical boundaries, followed by using the union tool to merge the physical boundary shape files from two consecutive years to compare the change of land area. The resulting union shape file was then clipped to analyze and quantify the degradation and aggradations within the study area. In this work, land degradation and channel behavior in Majuli were studied over time using a geographic information system (GIS). Using ArcGIS 10.3 software and Landsat data, the investigation involved digitizing the channel and geographical borders of the study region (Table 1

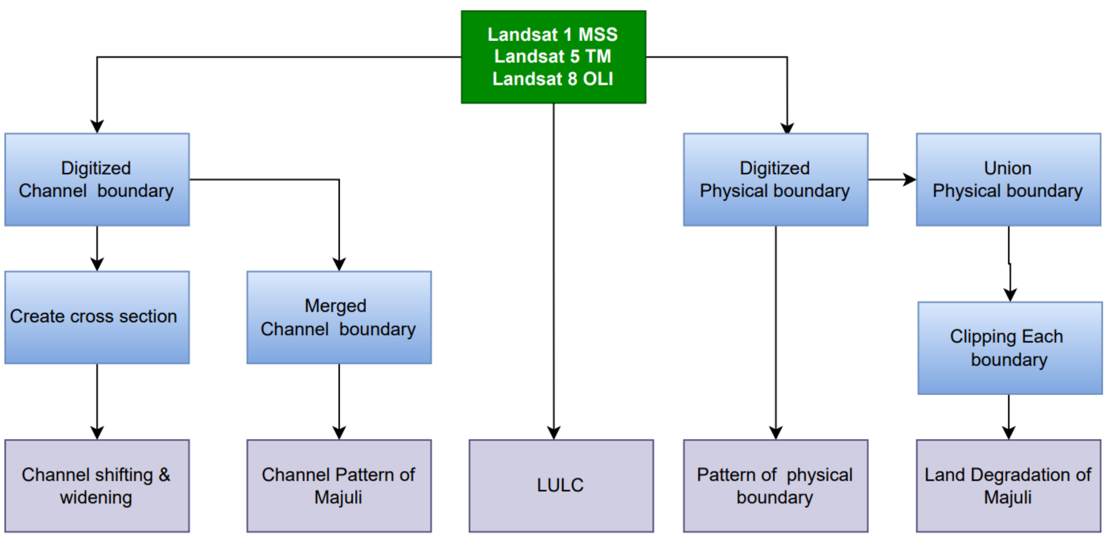


Figure No.2: Flowchart of the methods used to identify and map the Temporal Study of the channel behaviour and land degradation.

4. Results and Discussion:

4.1. The Channel Behaviour of Majuli

Geomorphological studies are very important to know the channel behaviour or dynamics of a river channel (Lane & Richards, 1997a; Newson, 2002). There are different techniques, such *as historical sources*(RICHARDS et al., 2002a ;J. Hooke, 2003b; J. M. Hooke, 2007a;), *repeated cross-profiling* (Lawler, 1993a ; Casagli et al., 1999; Arnaud-Fassetta, 2003a; J. M. Hooke, 2007b; Downs & Gregory, 2014; Hasanuzzaman et al., 2022a;),*botanical evidences* (Hickin, 1984; A. Simon & Hupp, 1992; Lawler, 1993a; Grabowski et al., 2014; Hasanuzzaman et al., 2022b;), *sedimentological evidences*(Lawler, 1993b; Lane & Richards, 1997b; RICHARDS et al., 2002b ;Arnaud-Fassetta, 2003b; Brooks et al., 2003; J. Hooke, 2003a; Rodrigues et al., 2006), *terrestrial photogrammetry*(Welch & Jordan, 1983; Lawler, 1993c; Lane et al., 1994; Lane, 2000; Brasington et al., 2003; Magdaleno& Fernández-Yuste, 2011; Flener et al., 2013), *and planimetric resurvey*(Davies-Colley & Quinn, 1998; ALLEN et al., 1999; Miřijovský et al., 2015; Oyedotun, 2016 Duró et al., 2018a),have been used to measure the lateral shifting of river bank, erosion-deposition and channel change (Lawler, 1993c; Thakur et al., 2012; Duró et al., 2018b). The Geomorphological changes are very common natural processes which found in riverine systems (Hasanuzzaman et al., 2022c).

Rivers are the dynamic feature of the environment which is constantly changing on the earth (D. Simon & Fuad, 1992; NAIMAN et al., 2002). The fluvio-geomorphic characteristics of the rivers vary in time and over space in response to the environmental controls as well as human activities (Barman, 2020).

River channel behaviour and its aspects, such as pattern activities, mainly depend on seismicity, anthropogenic activities, e.g., deforestation, unplanned flood interventions, and flooding(Micheli et al., 2004; Saur & Rathore, 2022a; Simonović, 2012).

Channel dynamics are natural occurrences in the rivers due to the influence of human activities and climatic factors as well. Channel dynamics are significant Geomorphological processes that involve the channel migration, erosion, deposition and meandering of an alluvial river channel within its floodplain region (Hasanuzzaman et al., 2022a).

4.2. Channel migration or Shifting and Channel widening from 1973-21:

Channel widening and channel shifting are geomorphic processes that are inextricably related in riverine systems. Channel widening, which is characterized by an increase in channel width through time, frequently precedes or coexists with channel shifting, which is characterized by lateral movement of the river's course. Widening may be constructed by Sediment dynamics, hydraulic forces, flow changes, natural morphological evolution, or may be self-initiated through lateral erosion after solely removing the bank protections. Sediment accumulation can spread the channel, changing its width, while hydraulic forces and changes in flow dynamics influence both widening and lateral movement. Furthermore, erosion of riverbanks, which frequently contributes to channel expansion, plays an important part in the lateral migration of the channel.

River channel migration is a natural hazard which is disastrous in many parts of the world, e.g., Majuli, Assam. Majuli faces in large-scale damage to the infrastructure, loss of lives significantly affects livelihood (Chetry, 2020; Pradhan et al., 2021; Baruah, 2022). It also brings rapid and random changes in land use and land cover (LULC) (Kathwas et al., 2022). River channel migration is a process wherein the main river starts flowing in a new river course due to aggradations, neo-tectonics, and anthropogenic activities. It is a fluvial-Geomorphological event of a flat valley floor and erodible banks across the globe (Saur & Rathore, 2022b). Channel shifting or migration is a common natural phenomenon, which mostly associated with weak geology, extreme flood and land cover alterations (Rakhal et al., 2021). It also has large impact on the ecology, economy, society and agriculture.

The channels of Majuli are characterized by heavy flow during rainy season, enormous volume of sediment load, continuous change in channel morphology, bank line migration and lateral changes in channels which further causes severe bank erosion leading to a considerable loss of good fertile land every year (J. N. Sarma, 2005b; Mount et al., 2013; Kotoky et al., 2015b; Roy et al., 2020; Bhuyan et al., 2023;).

Table 2:Channel widening and channel Shifting of Kherkatia Suti from 1973 to 2021.

Cross section	Channel wide in 1973 (km)	Channel wide in 2021 (km)	Channel widening from 1973-2021 (km)	Channel narrowing from 1973-2021 (km)	Shift from 1773 to 2021 in south bank of Kherkatia suti (km)
A	0.264	0.158	-	0.106	- 0.067
B	0.267	0.087	-	0.18	- 0.040
C	0.225	0.053	-	0.172	- 0.009

(+) symbol defines Aggradations of river channel & (-) symbol defines Degradation of river channel

From the above table, we can see that the Kherkatia Suti is mostly shifted towards the south direction. The channel pattern of the Kherkatia Suti in Assam changes continuously. It is noteworthy to observe that in the period spanning from 1973 to 2021, a discernible trend of channel narrowing has been identified in all cross-sections of Kherkatia Suti. This narrowing is quantified as 0.106 km in cross-section A, 0.180 km in cross-section B, and 0.172 km in cross-section C. The consistent reduction in channel width across specified cross-sections highlights the gradual disappearance of the Kherkatia Suti river morphology during the studied period.

Table 3: Channel widening and channel shifting of Subansiri River from 1973 to 2021.

Cross section	Channel wide in 1973 (km)	Channel wide in 2021 (km)	Channel widening from 1973 to 2021(km)	Channel narrowing from 1973-2021 (km)	Shift from 1773 to 2021 in south bank of Subansiri (km)
I	0.222	0.180	-	0.042	+0.257
II	1.422	0.144	-	1.278	-0.832
III	2.280	0.255	-	2.025	-0.078
IV	0.762	0.212	-	0.55	+0.747
V	0.952	0.161	-	0.791	-0.054
VI	0.462	0.092	-	0.37	-0.034
VII	0.916	0.174	-	0.742	-0.020
VIII	1.247	0.130		1.117	+1.712
IX	1.307	1.794	0.487	-	+2.865
X	2.265	2.367	0.102	-	+0.299

(+) symbol defines Aggradations of river channel & (-) symbol defines Degradation of river channel.

The Subansiri river is one of the most dynamic and unstable rivers in Assam. The channel pattern of the Subansiri River in Assam is significantly changing continuously. From the above table, during 1973 -2021, the Subansiri River is mostly shifted or migrated towards the south. From the 1973 to 2021 the bank line of the river changes significantly.

In the Subansiri River, an evident trend of narrowing is observed in nearly all cross-sections from 1973 to 2021, with respective reductions in channel width. Specifically, this reduction measures 0.042 km in cross-section I, 1.278 km in cross-section II, 2.025 km in cross-section III, 0.55 km in cross-section IV, 0.791 km in cross-section V, 0.37 km in cross-section VI, 0.742 km in cross-section VII, and 1.117 km in cross-section VIII. Notably, only two cross-sections, IX and X, exhibited a contrasting trend, experiencing widening with increments of 0.487 km in cross-section IX and 0.102 km in cross-section X.

Table 4: Channel widening and channel shifting of Brahmaputra River from 1973 to 2021.

Cross section	Channel wide in 1973 (km)	Channel wide in 2021 (km)	Channel widening From 1973-2021 (km)	Channel narrowing From 1973-2021 (km)	Shift from 1973 to 2021 in north bank of Brahmaputra (km)
1	8.503	6.690	-	1.813	-0.633
2	8.485	8.306	-	0.179	-1.023
3	9.974	5.951	-	4.023	+4.486
4	7.669	6.588	-	1.081	+1.106
5	4.901	3.378	-	1.523	+0.202
6	7.909	10.048	2.139	-	-2.158
7	8.639	6.021	-	2.618	-0.146
8	8.017	6.657	-	1.36	+2.526
9	7.769	8.002	-	0.233	-1.159
10	7.597	8.002	0.405	-	-3.475

(+) symbol defines Aggradations of river channel & (-) symbol defines Degradation of river channel.

It is observed from the map analysis of the Brahmaputra River along the southern margin of Majuli is unstable in bank line during the observation period 1973 to 2021.The river is observed in 10 cross sections of the channel are named 1 to 10. In the period channel migration is calculated, from the table, it is observed that some portion of the river has shifted towards the north direction; then again, some other part is shifted towards the south direction. So, in this period, the variation of nature of the channel line shifting towards the north direction is more.

In the context of the Brahmaputra River, an analysis spanning eight distinct cross-sections reveals a prevalent pattern of channel narrowing. Within this study, the majority of cross-sections, encompassing a total of eight, exhibit a reduction in channel width over the observed period. Specifically, widening is discerned in only two select cross-sections within the river channel. This pattern underscores the noteworthy trend of channel contraction, highlighting the evolving morphological dynamics of the Brahmaputra River.

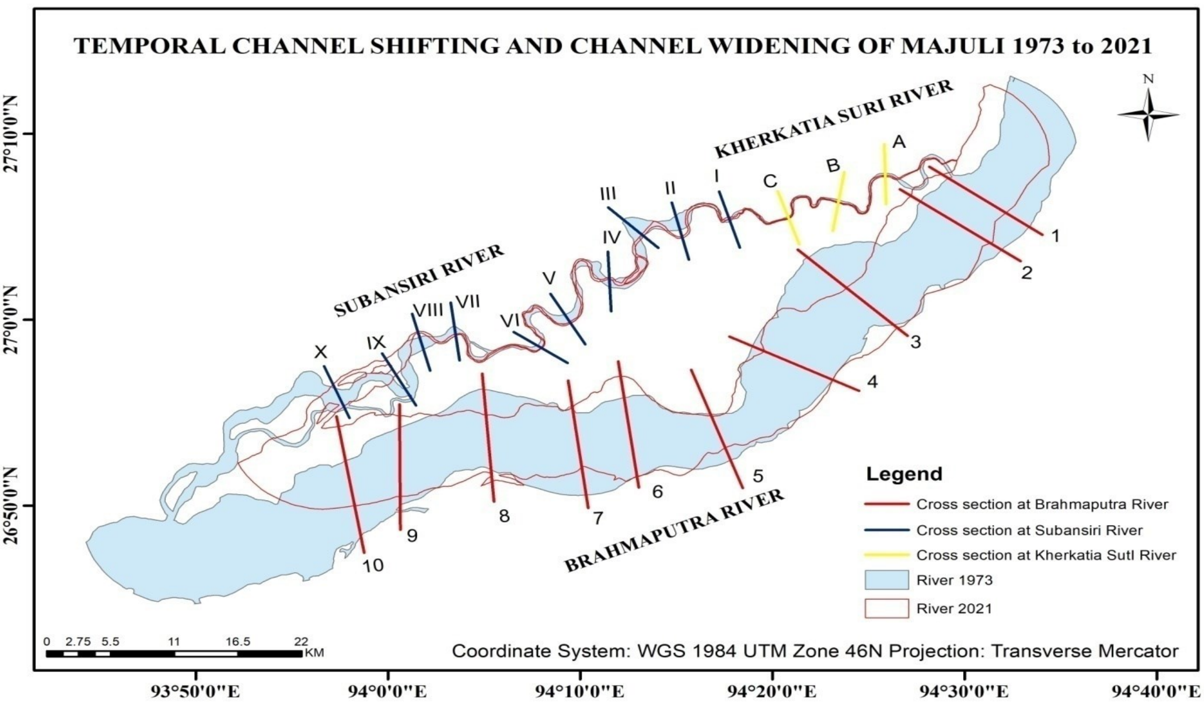


Fig No. 3: Temporal channel shifting and channel widening of Majuli from 1973-2021.

4.3. Change in channel pattern of Majuli:

The present study is an attempt to evaluate the temporal and spatial changes in channel pattern of the Majuli and also to examine the possible transition from one pattern to another over the period 1973–2021.

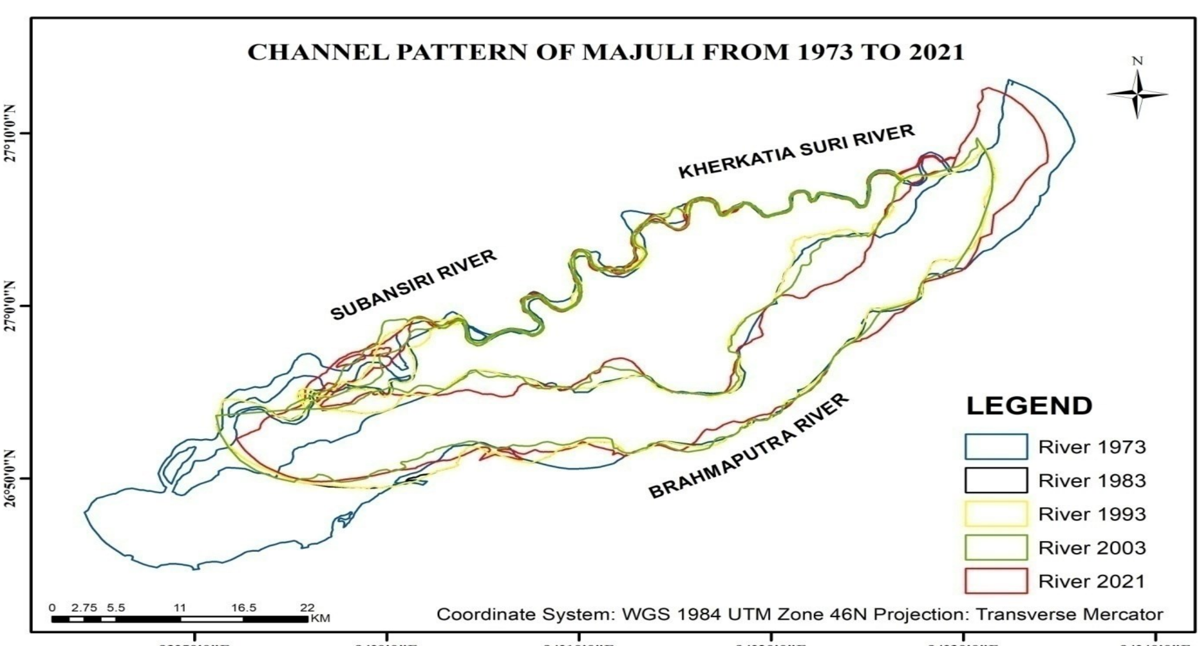


Figure No. 4: Channel pattern of Majuli from 1973-2021.

The Brahmaputra River and its tributaries are one of the largest sands-bar braided rivers in the world having a seasonal high discharge, high sediment load and characterized by frequent channel pattern changes and shift. The channel morphology and configuration of the Brahmaputra undergo dramatic changes in response to variation in flow regime and pattern of sediment transport in the river. The problems of channel change due to bank erosion, channel movement and sediment deposition.

The Subansiri River has been continuously changed because of its morphology. The river is mostly shifted towards the South. The Kherkatia Suti is an anabranching channel or a seasonal river. It is seasonal resulting into disappearing of river.

4.4. Pattern of Physical Boundary of Majuli from 1973 to 2021:

The Majuli's physical boundary, which covers the period from 1973 to 2021, shows a significant change in the region's geographical area. Calculations highlight the overall trend by showing changes in land area over this time. Particularly, there was a greatest land loss of 89.62 square kilometers between 1973 and 1983 due to degradation by river work. However, from 1983 to 1993, a negligible growth of 8.42 sq km was noted due to shifting of river and bank erosion. From 1993 to 2003, there was a little loss of 0.47 sq km, and from 2003 to 2013, there was a loss of 2.36 sq km perhaps due to some bank erosion measures were implemented in vulnerable areas. However, there was an increase of 2.48 sq km from 2013 to 2021 mainly by aggradations due to river shifting. There was a net loss of 81.55 sq km from 1973 to 2021. This pattern signifies a concerning trend of degradation and environmental impact on the region.

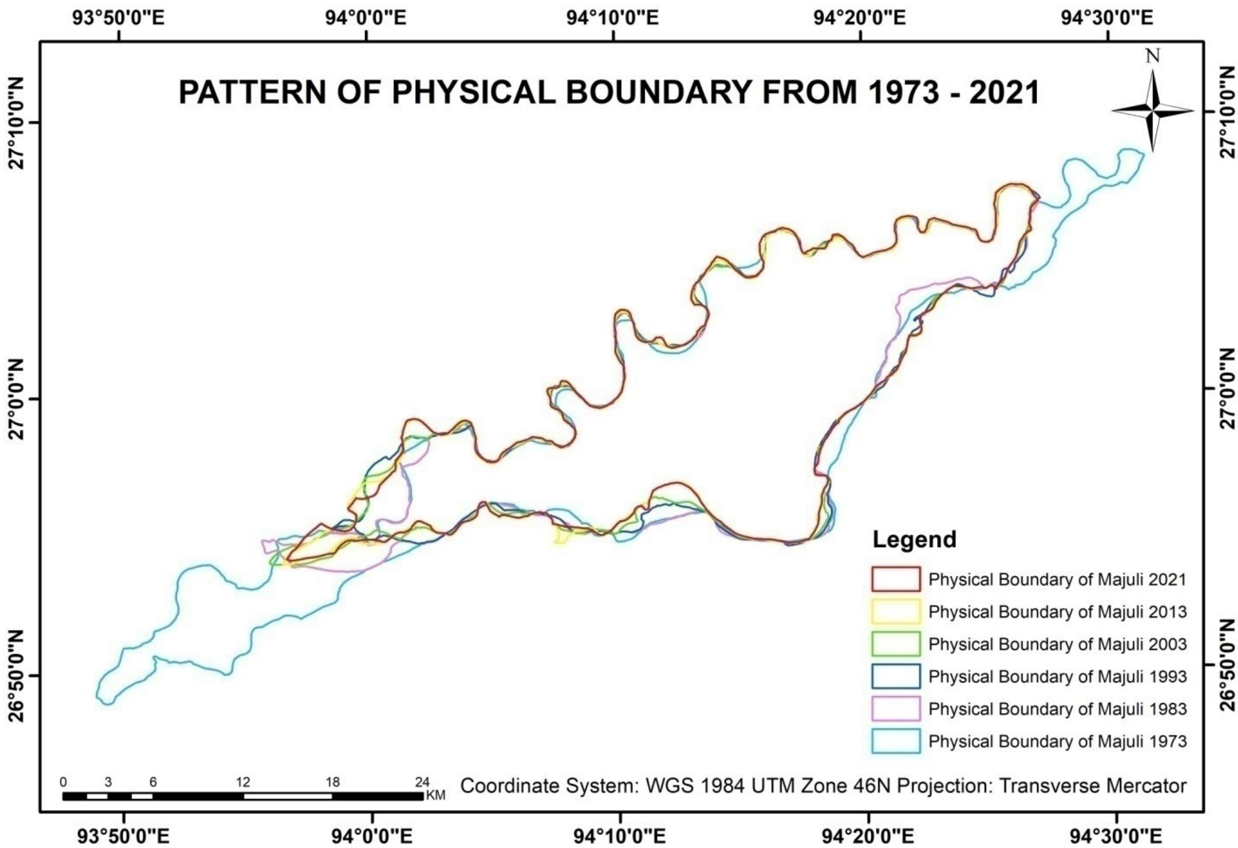


Figure No. 5: Pattern of physical boundary from 1973-2021.

Table 5: Area of the pattern of physical boundary from 1973-2021.

Year	Area (sq km)
Land area in 1973	499.82
Land area in 1983	410.20
Land area in 1993	418.62
Land area in 2003	418.15
Land area in 2013	415.79
Land area in 2021	418.27

Over nearly five decades, the land area of a specific region underwent notable fluctuations, reflecting shifts in its geographical makeup. Initially measuring 499.82 square kilometers in 1973, the region experienced a significant decrease by 1983, shrinking to 410.20 square kilometers. Despite this decline, a gradual recovery ensued, evident in the 1993 measurement of 418.62 square kilometers. This upward trend continued with minor variations into the new millennium, maintaining a relatively stable range around 418 square kilometers, as observed in 2003, 2013, and 2021. However, further analysis reveals that this overall loss was predominantly concentrated in the region's eastern and western sectors. Factors such as geographical location, climate, human activities, and potentially inadequate conservation efforts likely contributed to this vulnerability. Particularly, the western area, influenced by the dynamic Subansiri River, is recognized as particularly susceptible to degradation, affecting the local environment and ecology of Majuli.

4.5. Land degradation of Majuli from 1973 to 2021:

Land degradation is a major problem in Majuli. Land degradation is a great threat for our future and it requires great effort and resources to ameliorate. It is the result of natural activities as well as human-induced actions which exploit land, causing its utility, biodiversity, soil fertility, and overall health to decline.

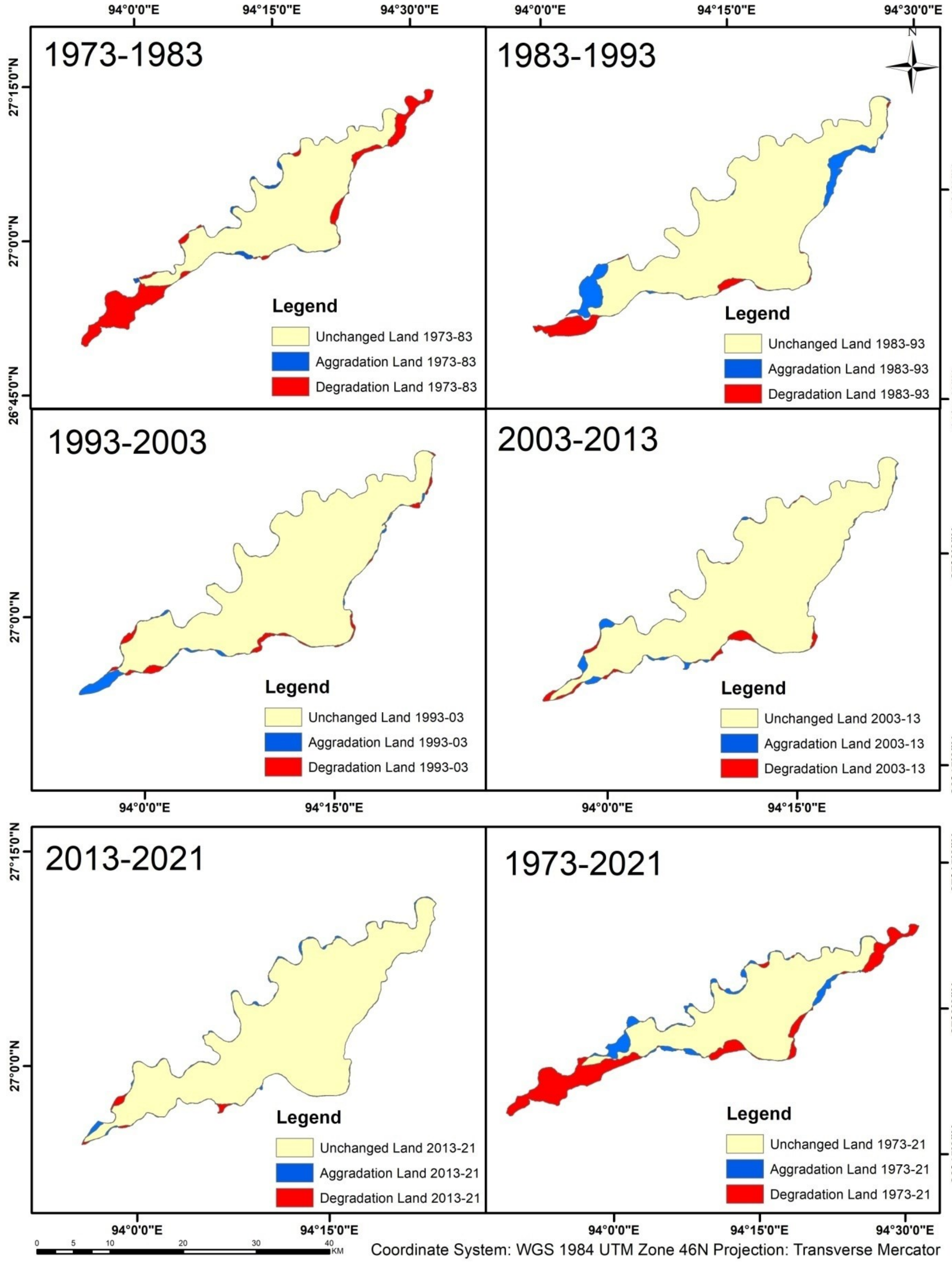


Figure No. 6: Land degradation of Majuli from 1973-2021.

The Island is bounded by three rivers: the Kherkutia Suti (a spill channel of the Brahmaputra River) on the north-east, the Subansiri River and her tributaries on the north-west and the Brahmaputra River on the south and south-west. It is under serious threat due to large-scale bank erosion by the Brahmaputra River. There is urgent need to preserve this socio-culturally rich island of over 0.2 million people.

Table 6: Land degradation, aggradations, unchanged land and Changed of the area of Majuli.

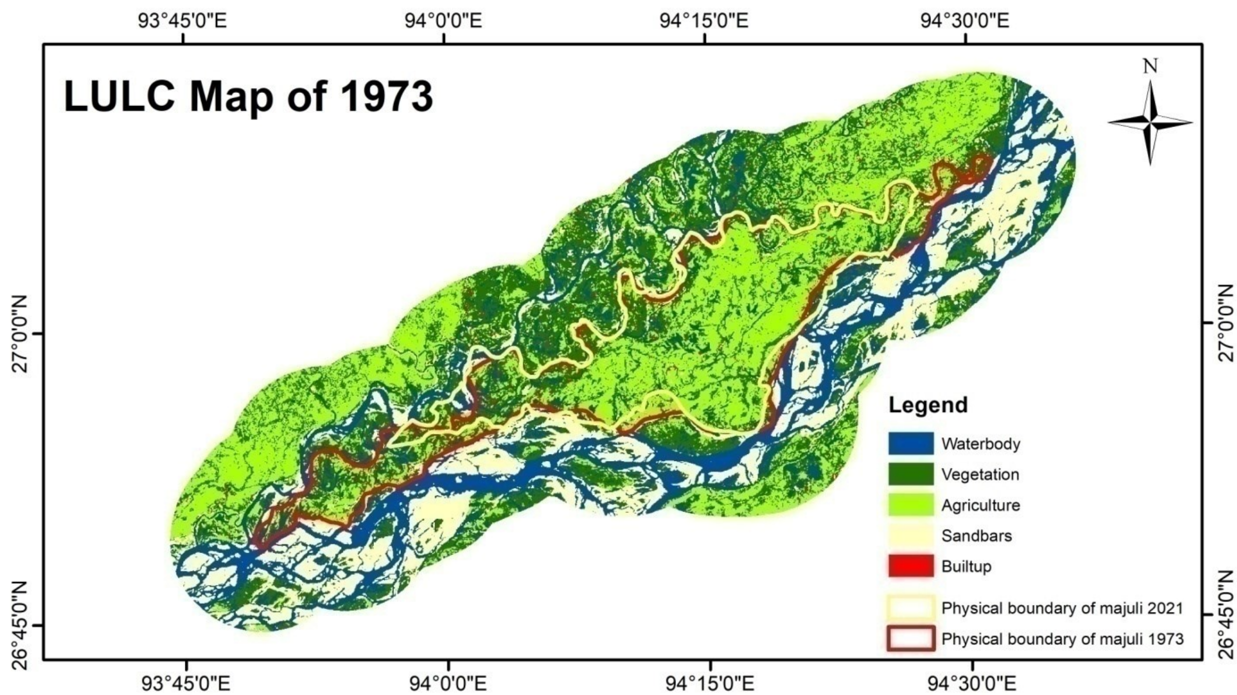
Year	Land Area	Area	Change of the area
1973-1983	Unchanged Land Aggraded Land Degraded Land	399.86 10.33 99.96	Degraded by 89.63 sqkm.

1983-1993	Unchanged Land Aggraded Land Degraded Land	389.86 29 20.33	Aggraded by 8.67 sqkm.
1993-2003	Unchanged Land Aggraded Land Degraded Land	406.a 11.53 12.01	Degraded by 0.48 sqkm.
2003-2013	Unchanged Land Aggraded Land Degraded Land	407.01 8.78 11.13	Degraded by 2.35 sqkm.
2013-2021	Unchanged Land Aggraded Land Degraded Land	410.95 7.32 4.84	Aggraded by 2.48 sqkm.
1973-2021	Unchanged Land Aggraded Land Degraded Land	382.44 35.82 117.38	Degraded by 81.56 sqkm.

Between 1973 and 2021, the land area underwent notable changes, comprising stability, aggradation, and degradation. While much of the land remained unchanged, certain areas saw significant alterations. Initially, from 1973 to 1983, there was substantial degradation, totaling 89.63 sqkm. This was followed by a period of slight aggradation from 1983 to 1993, gaining 8.67 sqkm. However, from 1993 to 2003, a minor degradation of 0.48 sqkm occurred. The subsequent decade, from 2003 to 2013, saw a more pronounced degradation of 2.35 sqkm, but from 2013 to 2021, there was slight recovery with an aggradation of 2.48 sqkm. Overall, despite intermittent recovery phases, the net degradation over the entire period amounted to 81.56 sqkm, indicating a prevailing long-term trend of environmental decline.
The analysis of the provided data uncovers distinct phases of degradation and aggradations. From 1973 to 1983, the island experienced a notable degradation of 89.63 sqkm, followed by a subsequent aggradation of 8.67 sqkm from 1983 to 1993. In the decade spanning 1993 to 2003, a minor degradation of 0.48 sqkm was observed, followed by another degradation of 2.35 sqkm from 2003 to 2013. However, a positive shift occurred from 2013 to 2021, with an aggradations of 2.48 sqkm. The cumulative effect over the entire period from 1973 to 2021 indicates a concerning degradation of 81.56 sqkm. This study underscores the necessity for targeted conservation efforts and sustainable land management strategies to mitigate further degradation and preserve the ecological integrity of Majuli.
The river island of Majuli has been grappling with significant soil erosion since ancient times, posing grave threats to its very existence and rich cultural heritage. Each year, severe soil erosion in Majuli exacerbates the island's vulnerability, shrinking its landmass and placing immense pressure on its ecosystem. As a result of extensive erosion, numerous villages have been completely engulfed, leading to a continuous reduction in land area. This erosion also fuels both internal and external migration, exacerbating the plight of the landless poor. Our research reveals that the Brahmaputra River, characterized by its high discharge and heavy sediment load, remains highly unstable, predominantly shifting northward. Consequently, the relentless erosional activities of the river contribute to the ongoing diminishment of Majuli's land area, with Kherkatia Suti gradually vanishing from its original channel.

4.6. Land use land cover showing loss of agricultural land area and settlements:

The analysis of land use and land cover changes in Majuli from 1973 to 2021 paints a worrisome picture of environmental degradation. Crucial components of the region have suffered significant losses. Water bodies have been notably affected, with a considerable degradation of 20.1222 sq km, likely stemming from alterations in river channels and other environmental factors. Additionally, the loss of 47.7584 sq km of vegetation is alarming, as it not only impacts the ecosystem but also raises concerns about biodiversity and environmental balance. Equally distressing is the degradation of 42.1049 sq km of agricultural land, a vital sector for the region's economy and sustenance.



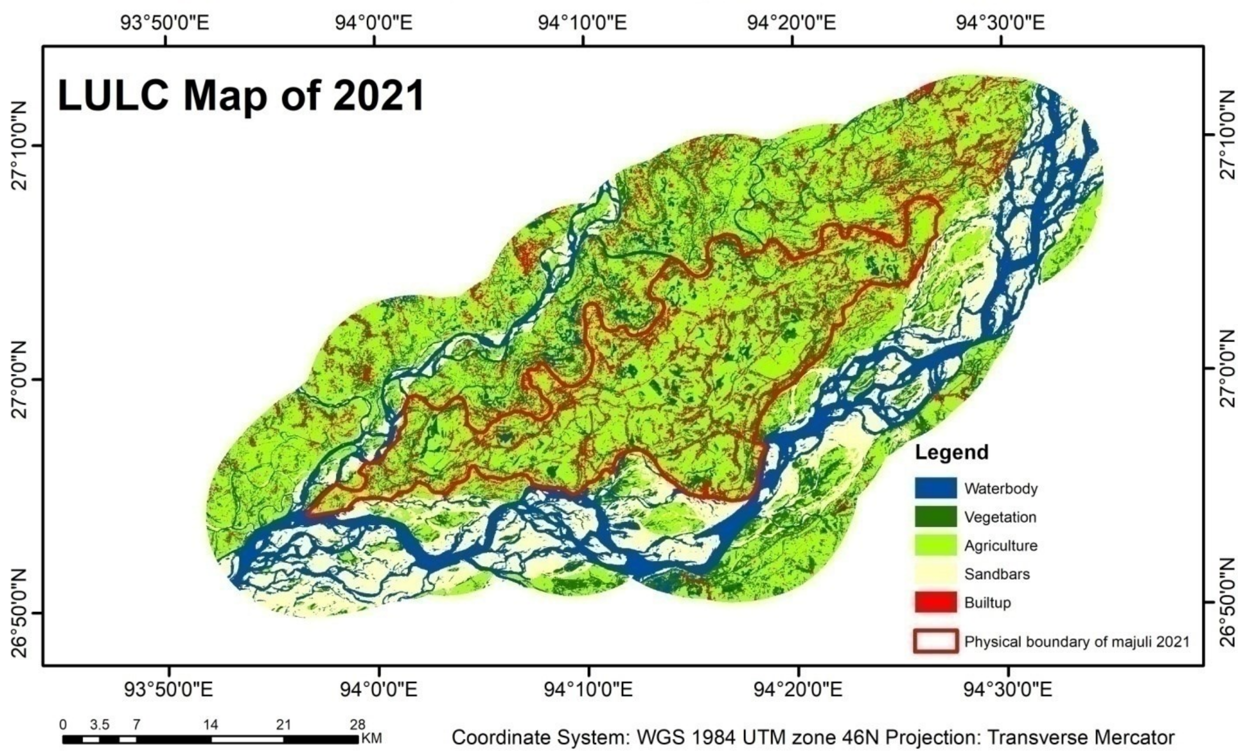


Table 7: LULC showing Degradation of Majuli from 1973–2021.

LULC Classes	Area Sqkm
Water	20.1222
Vegetation	47.7584
Agriculture	42.1049
Sandbars	7.39578
Builtup	2.54241

Furthermore, the degradation of sandbars by 7.3957 sq km and built-up areas by 2.54241 sq km underlines the comprehensive impact of human activities and development on the region's landscape. These trends signify an urgent need for comprehensive conservation strategies, sustainable land management practices, and prudent urban planning to mitigate further degradation. It is imperative to prioritize the preservation of natural habitats, promote sustainable agricultural practices, and carefully manage urban expansion to ensure the long-term ecological resilience and overall well-being of Majuli.

5. Mitigation Measures:

Majuli has been suffering from degradation since prehistoric times, but the rate of degradation has increased dramatically in recent decades. The rate of erosion was 81.56 sqkm from 1973 to 2021, which is a concerning trend. As a result, appropriate planning is required to reduce the land degradation calamity in Majuli. In this research; I present proposed strategies and measures to ameliorate land degradation. This could include relocating a structure, planting marine trees, building embankments, and erecting temporary barriers. Raising embankments and planting marine trees in the southwestern section of the island will undoubtedly aid in preventing land degradation to a large extent.

5.1 Marine tree plants:

Mangroves are typically known to grow in saline and brackish water, although some species can thrive in freshwater as well. Rhizophora and Avicennia are two species that are widely found in rivers and estuaries (SCHOLANDER, 1962; DUKE et al., 1998). Mangroves can grow in fresh water because they have evolved to filter salt from the water they absorb. They contain unique roots known as pneumatophores, or breathing roots, that allow them to receive oxygen straight from the air rather than the water. This adaptation allows mangroves to thrive in low-oxygen soils, which are frequent in freshwater ecosystems (Srikanth et al., 2016). Mangroves have different adaptations that allow them to survive in freshwater areas in addition to their salt-filtering processes. Some mangroves, for example, have waxy leaves that help retain water, whereas others have succulent leaves that store water (Singh &Odaki, 2004). Mangroves can also trap silt, which lowers the salinity of the water near their roots. Mangrove roots have the unusual ability to exude surplus salt, which aids in maintaining a favorable salinity level for growth (Sarker et al., 2021).

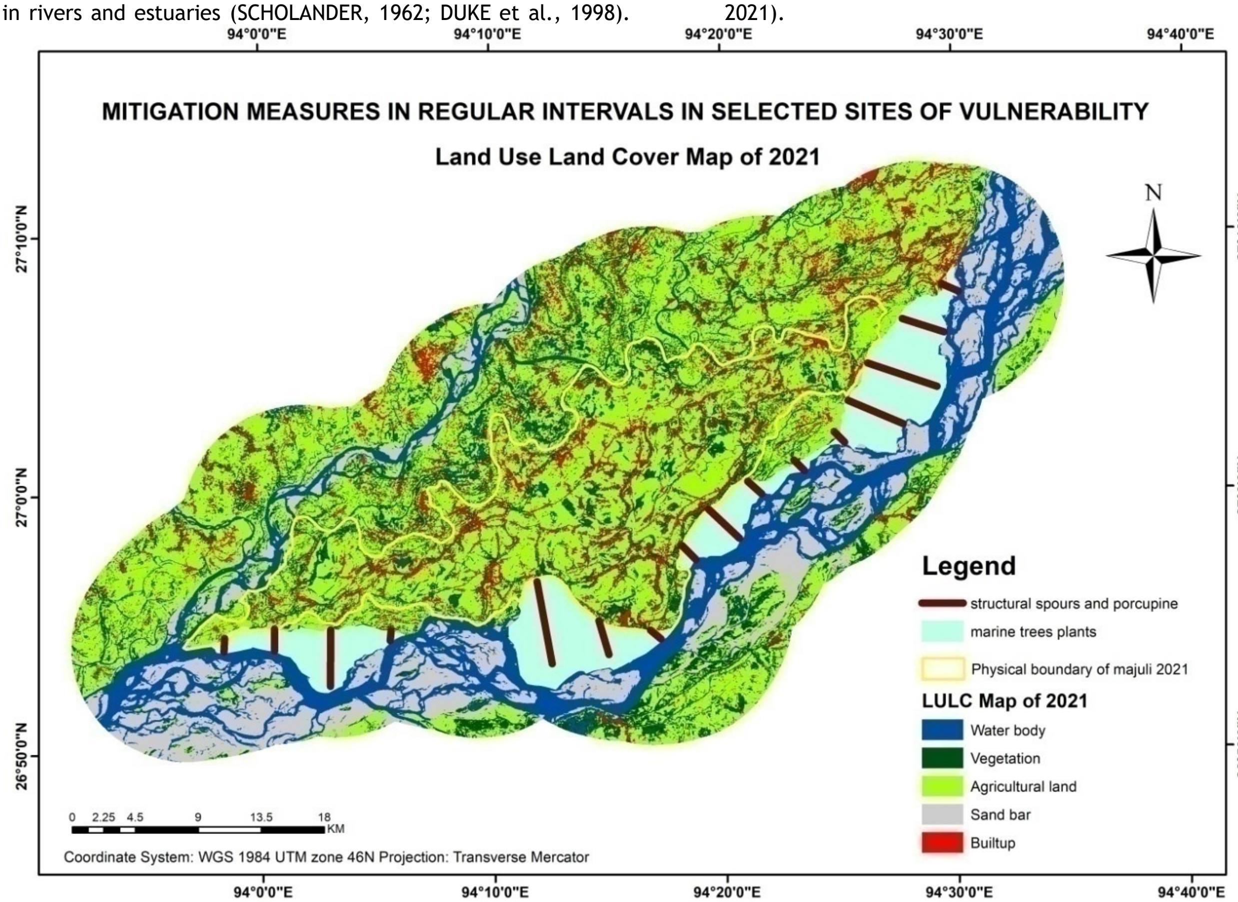


Fig: Structural measures in regular intervals in selected sites of vulnerability

On July 25, 2022, the forest department initiated a significant mangrove plantation effort spanning over 3,500 hectares within the Sundarbans. This strategic endeavor aims to fortify the delta region against the detrimental effects of soil erosion, storms, and cyclones (SENGUPTA, 2022). Additionally, a collaborative effort involving the Ministry of Environment, the Kampot Provincial Administration, Fisheries Administration, and the British Chevening Alumni Association of Cambodia (BCAAC) took place on April 30, 2022. During this initiative, 1,000 mangrove trees were planted in the PrekTnoat Fishing Community and commune located in Bokor town, Kampot province (BunthoeurnOrm, 2022). Looking ahead, the forest department and water resource department is considering future mangrove plantations on the Brahmaputra bank's sandbars as a measure to mitigate soil erosion.

The Brahmaputra River's sandbars provide a unique opportunity to investigate the potential of marine trees and plants for alleviating land degradation in Majuli. These sandbars are transitory islands generated by river deposition, and they are usually home to a variety of salt-tolerant plants that have adapted to the harsh saltwater environment. These plants can aid in soil stabilization and erosion prevention, as well as provide other ecosystem services.

The Sundari tree (Heritiera fomes) is one example of a maritime plant that could be used to mitigate land degradation in Majuli. This tree is well-known for its ability to grow in brackish water and can provide a variety of ecosystem services such as erosion control, carbon sequestration, and biodiversity support (Bhatt &Kathiresan, 2012; Muqsudur Rahman, 2016). Sundari trees are also valuable resources for local communities, producing lumber, honey, and other non-timber forest products.

Overall, using maritime trees and plants in the Brahmaputra River sandbars could be a viable technique for minimizing land degradation in Majuli. However, more research is required to determine the most suited species and to establish successful growing and maintenance procedures. Furthermore, efforts to encourage the conservation of these unique ecosystems should be prioritized in order to preserve their long-term viability.

5.2 Structural spurs and porcupine:

Structural spurs geo textile and porcupine installation are two common methods used for bank stabilization and erosion control along rivers. Structural spurs are man-made structures that extend from the river bank into the water to redirect the flow of water away from the bank and reduce erosion (Lang et al.,2019).

They can be made from materials such as concrete, stone, or timber.
Porcupine installation involves using a series of stakes or posts made from natural materials such as bamboo or willow branches, and then weaving them together with other natural materials like coir ropes or jute mesh to create a barrier. These barriers help to dissipate the energy of the water and prevent erosion.
In the case of Majuli, structural spurs and porcupine installation can be used along the Brahmaputra River to stabilize the riverbank and prevent further land degradation. By redirecting the flow of water away from the bank and creating a barrier, erosion can be significantly reduced. This method can also promote the growth of vegetation along the riverbank, which can further stabilize the soil and prevent erosion.

5.3 Non-Structural Measures

In Majuli, the persistent issue of riverbank erosion has resulted in the complete or partial destruction of over half of the registered villages (107 out of 210). According to data gathered by Majuli's Revenue Circle office during fieldwork, a total of 10,233 families had been resettled as of July 29, 2014. (Sahay & Roy, 2017). It is estimated that a substantial portion of Majuli's population, at least one-third, which amounts to approximately 167,304 individuals according to the 2011 Census, has been directly impacted by erosion. This relentless force of nature has left many residents without land and homes, exacerbating the social and economic challenges faced by the affected communities (Census of India, 2011).
The erosion of riverbanks significantly harms both these means of sustenance and consequently greatly undermines the population's capacity to cope with this issue. Additionally, it is worth noting that within the context of disaster management in India, riverbank erosion is not acknowledged as a natural or environmental hazard. Consequently, those affected by erosion do not receive any form of relief or assistance under existing disaster management regulations.
There is a recognition that riverbank erosion along the Brahmaputra River primarily constitutes lateral erosion, which tends to unfold gradually over time. Given the absence of a comprehensive national or state-level policy to address this specific challenge, the Majuli District Administration has taken on the responsibility of attempting to relocate the displaced families to areas within and around Majuli in an effort to mitigate the impact of erosion. (Sahay et al., 2020). This is undoubtedly insufficient, though, in an island where 250 or more families have been displaced annually for the previous 65 years (Sahaya, 2017).
In order to establish sustainable solutions for those displaced due to riverbank erosion, it is imperative for Indian disaster management regulations to officially classify it as a natural hazard. Our examination reveals that riverbank erosion results from the rapid and unforeseen channel migration associated with heightened sinuosity in a braided river.

CONCLUSION

The research conducted on the channel behavior and land transformation dynamics of Majuli Island in Assam sheds light on the intricate relationship between fluvial processes, climate change, and human activities. Majuli, the largest river island in the world, faces significant challenges due to erosion, channel migration, and land degradation, posing threats to its ecological integrity, socio-cultural heritage, and livelihoods of its inhabitants.
The findings presented in this research highlight the complex interplay of factors influencing the channel behavior of the Brahmaputra River and its tributaries, including sediment dynamics, hydraulic forces, and anthropogenic interventions. Through meticulous analysis of channel widening, shifting patterns, and land use changes from 1973 to 2021, it becomes evident that Majuli has experienced substantial land loss and degradation over the years.
The analysis of channel widening and shifting patterns reveals a consistent trend of erosion and degradation, particularly along the southern margins of Majuli. The Brahmaputra River, characterized by its high discharge and sediment load, exhibits significant lateral migration, leading to the loss of fertile land and displacement of communities.
Furthermore, the research emphasizes the urgent need for effective mitigation measures to address the escalating challenges faced by Majuli. Proposed strategies include the implementation of both structural and non-structural measures, such as marine tree plantation, structural spurs, and porcupine installation, aimed at stabilizing riverbanks, reducing erosion, and preserving the island's ecological balance.
The study underscores the importance of proactive planning and collaborative efforts involving government agencies, local communities, and stakeholders to safeguard Majuli's environment and ensure the sustainability of its socio-economic fabric. By prioritizing conservation, sustainable land management, and disaster resilience, Majuli can strive towards a more resilient future, preserving its unique cultural heritage and ecological diversity for generations to come.

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Data availability Statement

The authors confirm that the data supporting the findings of this study are available within the article and Supplementary material. Raw data supporting this study's findings are available from the corresponding author upon reasonable request.