

# Spatio-temporal analysis of the island and adjacent sandbars areas fluctuation using a geospatial technology: A study of Majuli Island, Assam

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## Abstract

*River islands are dynamic, ephemeral landforms found in major river systems worldwide, particularly abundant in South Asia's Himalayan Rivers. They are formed by natural fluvial processes of erosion and deposition can be influenced by catastrophic-tectonic events and human activities. In the Anthropocene, river island inhabitants face significant challenges due to climate change and natural disasters that uproot communities and destroy livelihoods. This study focuses on Majuli, the largest inhabited riverine island in the world, located on the Brahmaputra River in Assam, India. Majuli is threatened by annual floods and severe erosion, which is exacerbated by human activities such as agriculture, deforestation, construction, and urbanization. The main objective of this research is to detect land cover changes on Majuli Island area from 1964 to 2021 for the 57 years' period and analyse micro-level changes in areas occupied by sandbars before and after the monsoonal rainfall from 1986 to 2021. The primary causes of variability in the area of the Majuli Island and the shrinking of its neighbouring sandbars owing to, naturally occurring rain-driven downstream low line floods during the southwest and/or retreating monsoons and also floods occurred due to the earthquakes driven landslide followed by glacial lake outburst floods (GLOFs) during the Anthropocene period.*

**Keywords:** *River Island; earthquake; bank erosion; Majuli; GLOF; Assam*

## Introduction

River islands are very small, frequently ephemeral landforms that are found in between river banks. They can be found in major river systems worldwide, and they are especially abundant in South Asia's Himalayan Rivers, where they are referred by many names, including *char*, *chapor*, *baet*, and *diara*. "They present "hybrid [geographies]... neither fully land nor entirely water... [representing] the fluid and complex

worlds that lie within the rivers" (Lahiri-Dutt & Samanta, 2013, p. x). Put differently, these are "fluidscapes" (Mukherjee & Ghosh, 2020), or "liminal spaces" (Lahiri-Dutt & Samanta, 2013), "constantly adapting to the changing courses and configurations" (Baruah, 2022). Certain river islands can also be traced back to catastrophic tectonic events, even if they are primarily the result of both fluvial dynamics and human involvement.

The classic hybrid waters and lands that challenge and conflate traditional ideas of borders and territorialities are these river islands (Sur, 2021). The inhabitants of river islands have forever adapted to natural calamities and environmental changes, but they also face the uncertain and unpredictable impacts of the Anthropocene. The world community studying climate change is focusing on small river island because of their small populations, but river islands that support millions of people remain invisible because of the “slow disasters” (Baruah, 2022) that continue to destroy them, uprooting *char* from their customary livelihoods and leaving them homeless or without land. However, those who live in *char* are more than just victims of natural calamities. The expression “dancing with the river” by Lahiri-Dutt & Samanta (2013) may be a beneficial way to describe life on *chars*.

One such riverine island is Majuli, located in Assam, India, on the Brahmaputra River- the most inhabited riverine island in the world and a significant component of India’s Neo-Vaishnavite *Satra* culture of Hinduism as well as one of the oldest cultural heritage sites in Assam. Millions of people living on river islands in South Asia are commonly known as *char* dwellers, (also locally as *choruas* or *chouras*). They are marginalised both socially and economically; include a sizeable portion of migrants and refugees, permanently settled at the danger of illegitimacy (Chakraborty, 2009) or are continually on the move “like the drifting grains of sand” (Lahiri-Dutt & Samanta, 2013).

The north-eastern region of India is situated in zone V seismic zone, and suffer from frequent landslides and floods. This is because the Himalayan Frontal Thrust (HFF)

borders the northern and eastern portions of the Brahmaputra River valley, while the Lohit and Naga thrusts form an arc in the eastern portion (Nandy, 2017)). As a result, Majuli and upper Assam are affected by the destructive floods, intense braiding and critical bank erosion that the river Brahmaputra inflicts every year, and catastrophic flooding nearly every four to five years (Dasgupta & Mukhopadhyay, 2014). The geometry and morphology of the channel alter frequently and dramatically.

The main objective of this research is to assess and detect changes in the land cover of the Majuli island area between 1964 and 2021. The study also intends to examine and highlight the micro-level changes in the areas occupied by the sandbars of the island before and after the monsoon at various points in time between 1986 and 2021. The research also finds out the reasons behind the changes in the area of the island and change of the sandbars too.

### Study area

Brahmaputra is a large, tropical, trans-boundary river with one of the high sediment load with 721 Mt./yr<sup>-1</sup> of suspended sediment (Fischer, et. al., 2017) and has the unique distinction of possessing largest inhabited river islands of Majuli, located north of Jorhat town in Assam, India. It is bounded by Brahmaputra on the south, Subansiri River on the northwest, and the Kherkatia Xuti River, an anabranch of River Brahmaputra along the northeast. The topographical positioning of the island is unstable, extending between 26° 45’ N to 27° 12’ N and 93° 39’ E to 94° 35’ E (Fig. 1) situated 84.50 meters above the mean sea level. The total area of the island was 1,255 km<sup>2</sup> in 1901. Guinness World Records states that Majuli, with 880 km<sup>2</sup> is

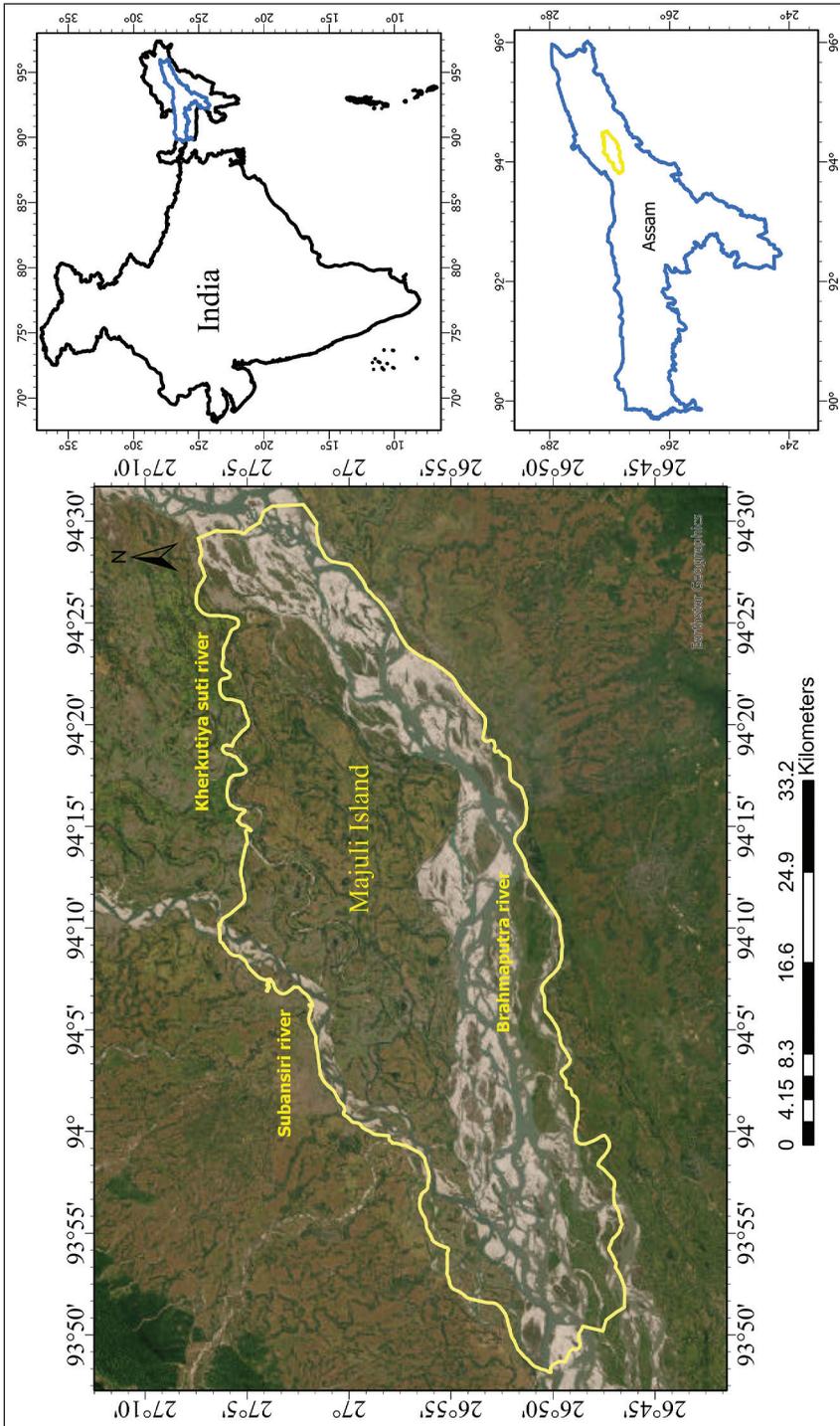


Fig. 1: Location of Majuli island

the world's largest populated riverine island (Web Source: *Guinness World Records*, Largest River Island, n.d.). A more recent study by Sarma and Phukan (2004) calculated the area of the island as 421.65 km<sup>2</sup> in 2001, one third of its size in 1901, much reduced due to bank erosion and shifting sandbars. The island however, sustains biodiversity due to its unique physiographic and topographical features as well as its variable monsoon season. With the exception of the driest months of December and January, the region is consistently moist due to its location, wetlands, and high water table. From 1980 to 2004, the average annual rainfall was 1704.65 mm. The average temperature is 7.3°C in the winter and 26.8°C in the summer.

The island, with high moisture content and rainfall, and flat plains, promotes the growth of evergreen and deciduous trees, grasses, and a variety of marsh vegetation, bamboos, and canes. It is primarily composed of fine sand and silt in varying proportions, with often less than 5% clay (Goswami, 1985). However, the soil contains a lot of inorganic clay in the areas of Salmora, Dakhinpat, and Bessa Mara villages, which lie on the southwest side of Majuli and borders the Brahmaputra River (Singh & Goswami, 2011).

### **Data base and methodology**

The Majuli island's land cover changes were assessed between 1964 and 2021, while the area of the sand bars landcover changes were identified between 1986 and 2021. The study area's cloud free pre-monsoon (April) and post-monsoon (October) seasons satellite imageries of the years 1991, 2001, 2011, and 2021 were considered for decadal changes, while the oldest satellite imagery of 1986 was used for change detection for the maximum period. These five satellite images, each with

a resolution of 30 meters, were obtained from the Indian Remote Sensing Landsat 5 TM, Landsat-8 OLI, and TIRS sensors. The present study employed the island's oldest data, a 1: 50,000 scale toposheets of the year 1964 (83F/13, 83F/14, 83I/4, 83I/7, 83I/8, 83I/12, 83I/15, 83J/1, 83J/5, and 83J/8) for the change detection of the island area. Further, all the images were digitised using one geometric coordinate system and then geo-referenced with respect to the 1: 50,000 scale Survey of India toposheets. Images of 1986 to 2021 years are geometrically rectified. The UTM projection and WGS 84 datum have been taken for georeferencing. The bank line of the Brahmaputra River is demarcated from each set of images, and the channel patterns are digitised using the ArcGIS 10.8.1 version. To detect the land cover change during different time period from 1986 to 2021, we apply the following formula:

$$\text{Change detection (A)} = X - Z$$

Where,

A= Change detection of the Majuli island between the former and the later year.

X = Area in km<sup>2</sup> in the later year.

Z= Area in km<sup>2</sup> in the former year.

Similarly, to measure the rate of change of the area of the Majuli Island the following formula as given by Shiferaw (2011) was used.

$$\alpha \text{ (Rate of change)} = \frac{A - B}{C}$$

Where,

$\alpha$  = The rate at which the land cover type changes.

A = land cover type in the latter year.

B = land cover type in the former year.

C = The elapsed time from A to B

Table 1: Areal changes of Majuli Island, 1964 to 2021

Data source	Area (Km <sup>2</sup> )	Change detection (Km <sup>2</sup> )	Rate of change km <sup>2</sup> /year
Toposheets, 1964	682.70		
Satellite image, October 1986	498.77	-183.93	-7.99
Satellite image, October 1991	504.85	+6.08	+1.52
Satellite image, October 2001	494.70	-10.15	-1.02
Satellite image, October 2011	553.46	+58.76	+5.88
Satellite image, October 2021	546.18	-7.28	-0.73
Overall change, 1964 - 2021		-136.52	-2.34

Table 2: Year wise changes in area of the sandbars and number of mid channel/lateral sandbars along the Majuli Island, Assam

Years	Area occupied by sandbars (Km <sup>2</sup> ) (Pre-monsoon)	Area occupied by sandbars (Km <sup>2</sup> ) (Post-monsoon)	Change Detection (Km <sup>2</sup> )	Rate of change between Pre and Post monsoon (Km <sup>2</sup> /season)	No. of mid channel bars (Pre-monsoon)	No. of mid channel bars (Post-monsoon)	Increase in the No. of Mid channel bars
1986	457.59	459.40	1.81	0.36	248	267	19
1991	528.90	435.71	-93.19	-18.64	98	311	213
2001	490.08	446.28	-43.80	-8.76	128	201	73
2011	517.77	439.16	-78.61	-15.72	123	210	87
2021	423.29	436.71	13.42	2.68	244	311	67

The above mentioned method has been updated and applied in order to access and detect the micro-level changes of the land cover under the sandbars category in the study area before and after the monsoon.

Change detection (a) = x-z

Where,

a= Change detection of the sandbar area in the island between the pre-monsoon and post-monsoon

x = Area occupied by sandbars in km<sup>2</sup> during the post-monsoon.

z= Area occupied by sandbars in km<sup>2</sup> during the pre-monsoon.

Similarly, to measure the rate of change of the area occupied by sandbars of the Majuli Island, the formula by Shiferaw (2011) has been improvised and used to suit the present study at micro level:

$$\alpha \text{ (Rate of change)} = \frac{a-b}{c}$$

Where,

$\alpha$  = The rate at which the land use /land cover changes of sandbars.

a = Area occupied by sandbars in km<sup>2</sup> during the post-monsoon.

b = Area occupied by sandbars in km<sup>2</sup> during the pre-monsoon.

c = The elapsed time from a to b (in months)

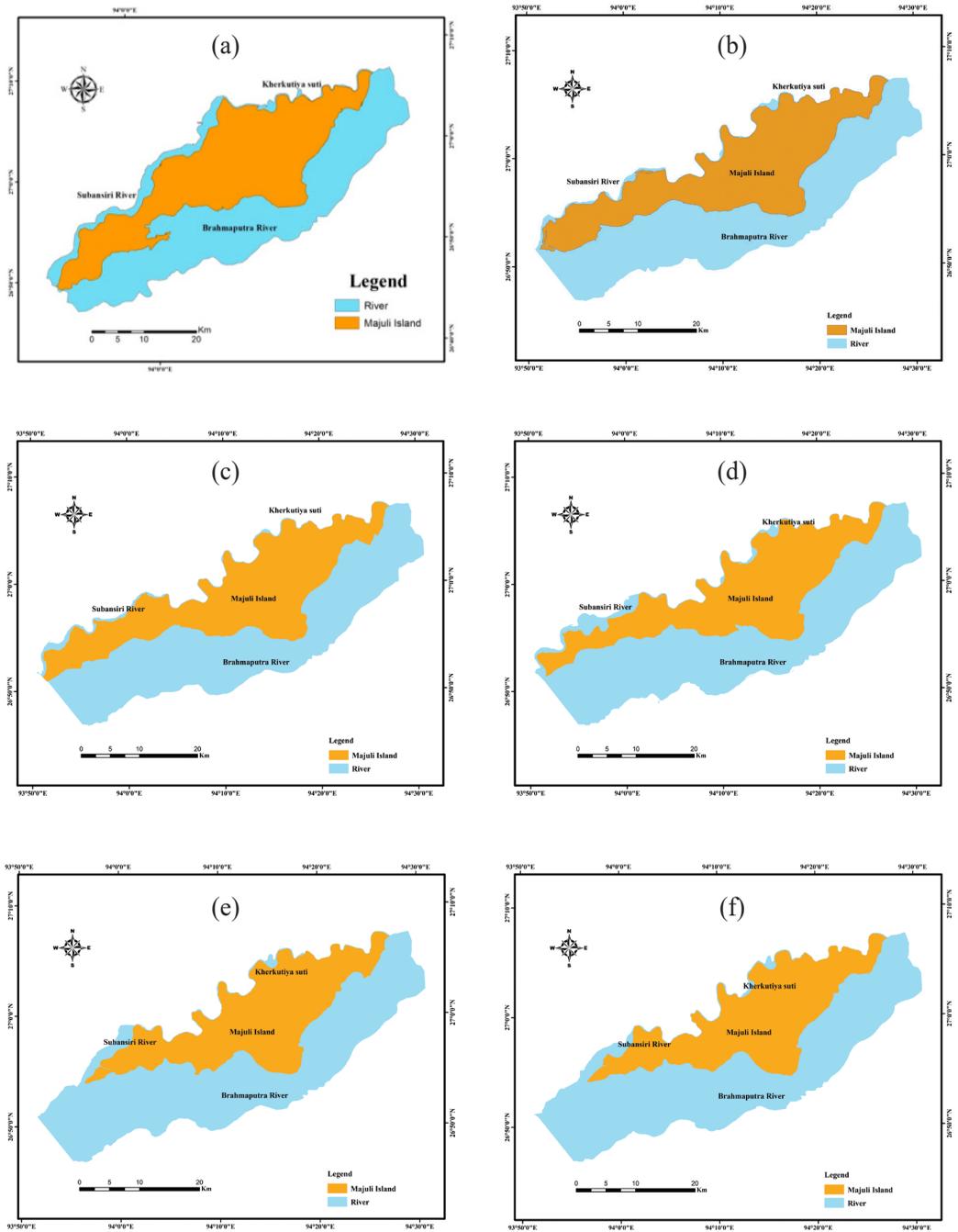


Fig. 2: Variability in the area of the Majuli island between 1964 to 2021: a) 1964, b) 1986, c) 1991, d) 2001, e) 2011, and f) 2021.

Further, aside from the supervised classification, several stages and techniques were established to map, analyse, interpret, and quantify the available data sets.

The Central Water Commission (CWC) provided the mean monthly water discharge and sediment load data from 1990 to 2000 for Bessa Mara CWC gauging station, located in the southeast part of Majuli. However, the data from 1994 to 1996 was unavailable; hence not included in the analysis.

## Results and discussions

### Alteration in the area of Majuli: 1964 to 2021

The total area of the Majuli island was 1255 km<sup>2</sup> in 1901 (Sarma and Phukan, 2004; Allen, *et al.* 2010), but has been mostly lost due to the frequent rain driven monsoonal floods. From 1964 up to 2021, Majuli shows a decreasing trend in its spatial extent.

The selected year-wise variation in the area of the island reveals a loss of 183.93 km<sup>2</sup> (7.99 km<sup>2</sup>/year) over a span of 23 years from 1964 to 1986. However, there was minor increase in its area- some 6.08 km<sup>2</sup> (1.52 km<sup>2</sup>/year)- briefly from 1986 to 1991 after which there was sustained decrease for decade up to 2001 amounting to 10.15 km<sup>2</sup> (1.02 km<sup>2</sup>/year). Our estimates for the years 1964 to 2001 are nearly identical to that of Sarma & Phukan (2004), who had estimated the average annual erosion rate of 1.77 km<sup>2</sup>/year from 1917 to 1972, 1.84 km<sup>2</sup>/year from 1972 to 1996, and 6.42 km<sup>2</sup>/year from 1996 to 2001, establishing the fact of gradual increase in the rate of erosion during the last phase along the Island. Similarly, the period 2001 to 2011 also shows a remarkable increase of

58.76 km<sup>2</sup> at 5.88 km<sup>2</sup>/year in the area of the island (Table 1 and Fig. 2a to 2f).

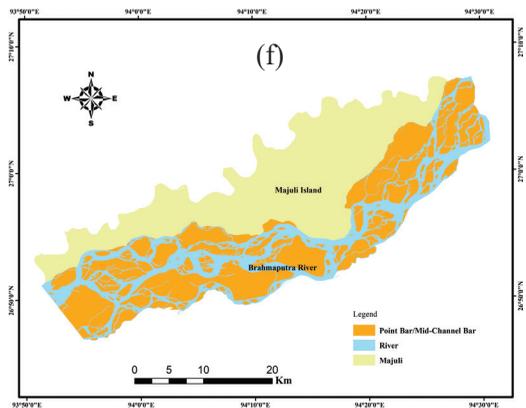
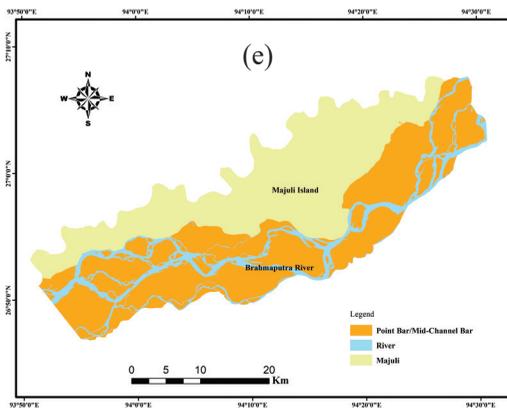
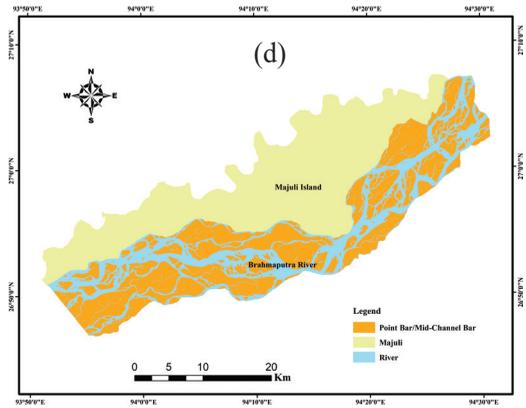
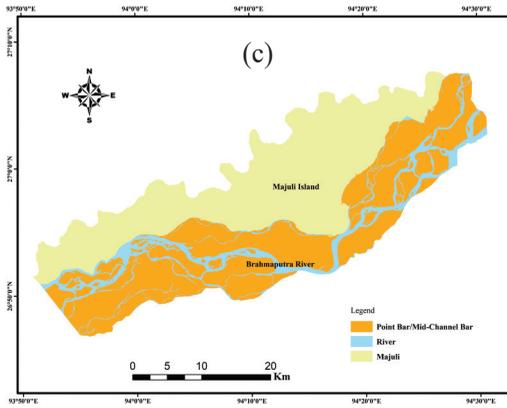
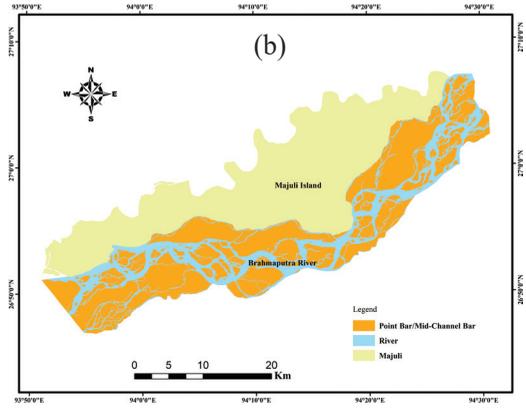
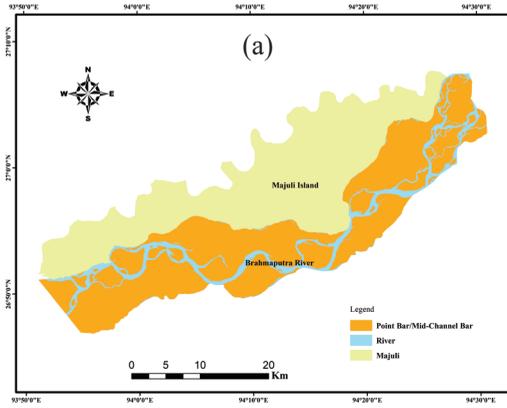
From 1964 to 2021 the area of the island decreased considerably from 682.7 km<sup>2</sup> in 1964 to 564.28 km<sup>2</sup> in 2021 within 57 years, when the total area of the island reduced by 136.52 km<sup>2</sup> and average annual rate of erosion was 2.34 km<sup>2</sup>/year due to the bank erosion and channel migration (Table 1).

### Fluctuation in the Sandbars area adjacent to Majuli Island, Brahmaputra River: 1986 to 2021

Since the beginning, the island has experienced frequent monsoon driven floods and bank erosion. Studies conducted at various times provide a concerning picture of the expanding Brahmaputra River to the extent of 3870 km<sup>2</sup> during 1912-1928 (First survey), 4850 km<sup>2</sup> during 1963-1975 (Second survey), and 6080 km<sup>2</sup> during 2006 (Third survey by North Eastern Space Application Centre/NESAC). This indicates increase in channel width of the river Brahmaputra over time. During the southwest and/or northeast monsoon, the river washes out the banks, widening the channel and depositing sediment in the form of mid-channel bars/sand bars.

During 1986 to 2021, the area of the sandbars has not shown significant variation overall; more during pre-monsoon period than post monsoon, varying between 423 and 529 km<sup>2</sup> in the former and 435 and 460 km<sup>2</sup> in the latter (Table 2). These changes of the sandbars are correlated with the results of the change detection area of Majuli over the period of 1986 to 2021 (Table 1).

Assessing the change detection of the area occupied by sand bars, it is revealed that the area occupied by the sandbars during



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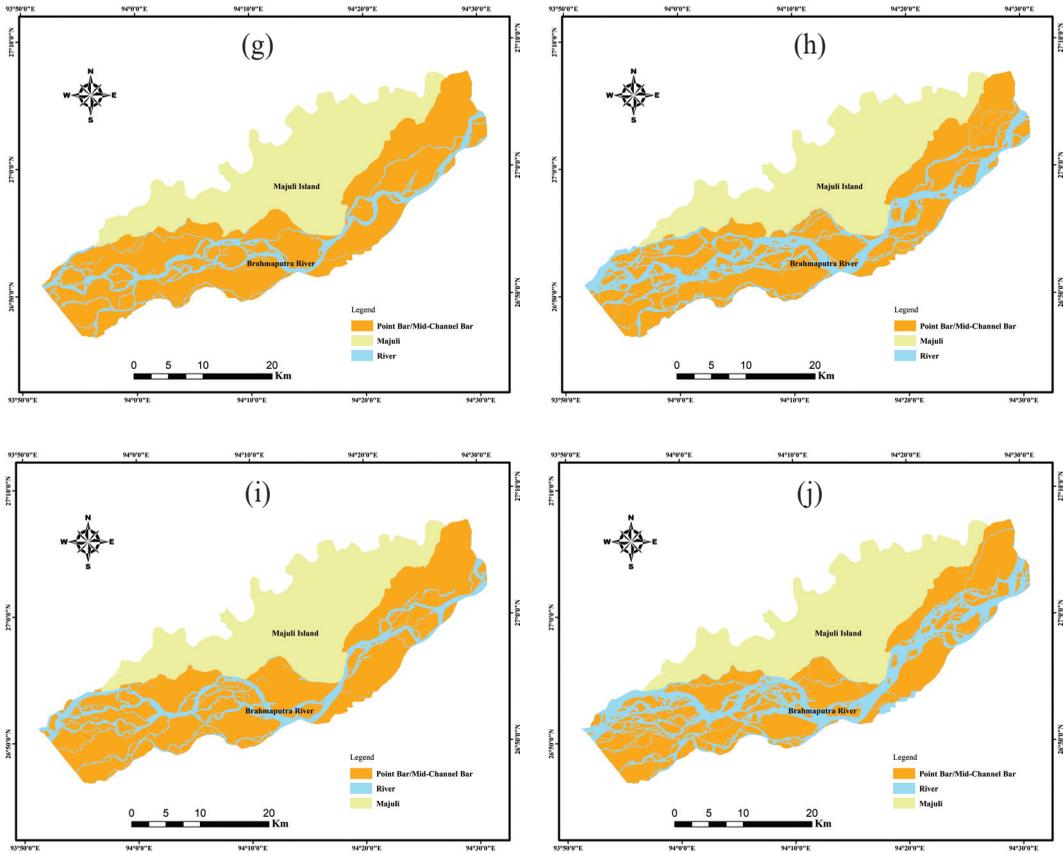


Fig. 3: Majuli Island's Pre and Post-Monsoon Sand bar Pre and Post-Monsoon variability in the Sandbars of the Majuli island: a) Pre-Monsoon - 1986, b) Post-Monsoon - 1986, c) Pre-Monsoon - 1991, d) Post-Monsoon - 1991, e) Pre-Monsoon - 2001, f) Post-Monsoon - 2001, g) Pre-Monsoon - 2011, h) 2011 Post-Monsoon - 2011, i) Pre-Monsoon - 2021, and j) Post-Monsoon - 2021.

1986 and 2021 increased by 1.81 km<sup>2</sup> and 13.42 km<sup>2</sup> respectively during the post-monsoon as compared to the pre-monsoon season. Similarly, table 2 shows that the area occupied by the sandbars in the years 1986 and 2021 increased at the rate of 0.36 and 2.68 km<sup>2</sup>/month respectively in the pre-monsoon and post-monsoon seasons.

The years 1991, 2001, and 2011 saw the sandbars register a decrease in area, as shown in figures 2(c) to 2(h). In 1991, the change in the area under the sandbars drastically reduced to 93.19 km<sup>2</sup>/season during the post-monsoon as compared to the pre-monsoon season. Similarly, the sandbar area between the pre-monsoon and post-monsoon periods in 1991 decreased at the rate of 18.64 km<sup>2</sup>/

season (Table 2). Although area under the sandbars decreased exponentially during the post-monsoon period [Fig. 2(c) and 6(d)] the number of islands increased phenomenally by 213 in the post-monsoon as compared to the pre-monsoon period, due largely to the series of flood episodes that deposited abundant sand during the monsoon season.

In 2001, the area under the sandbars decreased by 43.8 km<sup>2</sup>/season during the post-monsoon period as compared to the pre-monsoon period, decreasing at a rate of 8.76 km<sup>2</sup>/month [Table 2 and Fig. 3(e) and 3(f)]. The area covered by sandbars in 2011 decreased by 78.61 km<sup>2</sup>/season between the pre-monsoon and post-monsoon periods (Table 2) at a rate of about 15.72 km<sup>2</sup>/month [Fig. 3(g) and 3(h)]. However, due to extreme rainfall events, a series of flood episodes during the monsoon deposited abundant sand on the banks of the island, leading an increase of 73 and 87 islands during the post-monsoon in comparison to the pre-monsoon period during 2001 and 2011 respectively (Table 2).

## Discussion

### ***Justification of Majuli Island decreasing area***

In addition to the frequent rain-driven orographic monsoonal floods, another significant contributing factor is that the Brahmaputra valley in Assam is located between two tectonically active belts: The Patkai–Naga–Arakan belt in the south and the Himalayan belt in the north. Along these margins, after the great earthquakes of 8.7 magnitudes of 1897 and 15<sup>th</sup> August 1950, the morphology of the island underwent dramatic changes due to the constant alterations of

the river banks (Oldham, 1899; Poddar, 1952; Goswami, 1998; Goswami, et. al., 1999; Kotoky, *et al* 2003). The enormous earthquake caused the Brahmaputra River bed to spread by 3 to 4 meters (Goswami, 1985). Thereafter the rate of the island bank erosion and channel migration has increased year after year. After 1950, the flood water danger level at Dibrugarh upsurges to 344 feet (104.2 m) from 340 feet, and even lowest water limit surges up to 332 feet (101.2 m) from 320 feet (97.5 m) (Fig. 4) (Goswami, 1998). This indicates that the island's area began to shrink after the 1897 and 1950 earthquakes.

### ***Rationale of variability in the Island area (1964 to 2021) and adjacent sandbars (1986 to 2021)***

Nevertheless, the rate of the annual change is not consistent. The October 1991 satellite image has shown increased area of the island by 6.08 km<sup>2</sup>; highest change detection in pre and post monsoon sandbars to the extent of 93.19 km<sup>2</sup> in area and the lowest post-monsoon sand bar area of 435.71 km<sup>2</sup> (Table 1 & 2). These changes were due to the highest mean water discharge of 28,652.38 m<sup>3</sup>/s and 758.9 tons of sediment load (Fig. 5) in July (CWC, n.d.). The highest water discharge of 59,207 m<sup>3</sup>/s was recorded on 11<sup>th</sup> July 1991. This unquestionably is the reason for the increase in the area of Majuli Island during October 1991.

The majority of earthquakes of moderate and large magnitude cause landslides, which can range from small soil cover failures to massive, devastating rock avalanches. Heavy rains can cause landslide deposits on slopes to remobilize and transform into debris

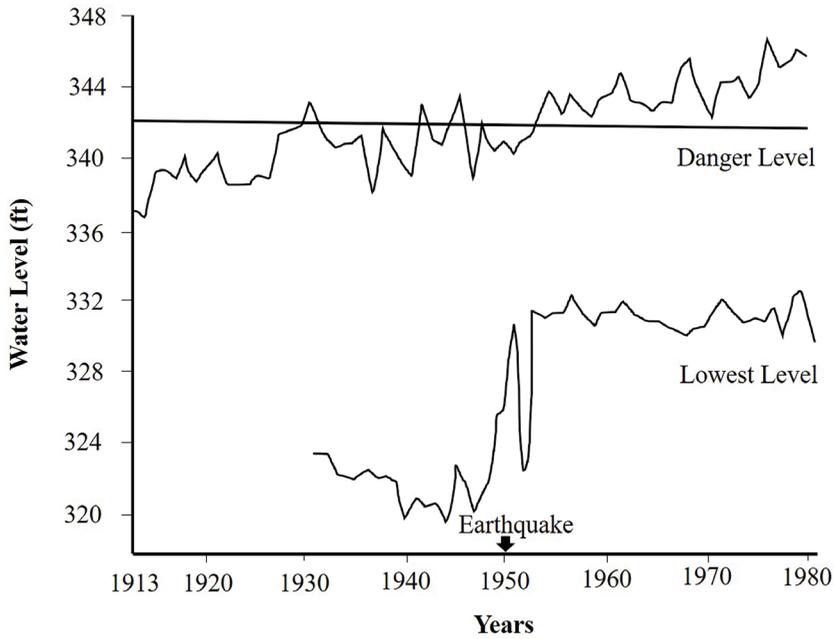


Fig. 4: Highest and lowest flood levels at Dibrugarh before and after 1950  
(Source: Goswami, 1998).

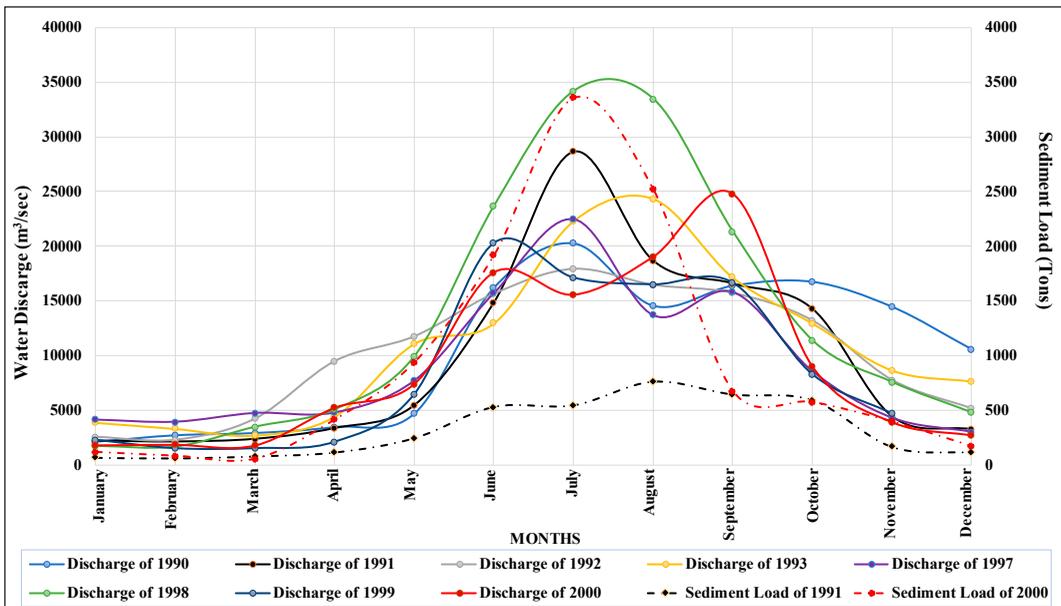


Fig. 5: Mean monthly water discharge and sediment load, 1990 to 2000  
(Except 1994 to 1996 due to absence of the CWC data)

flows. More slow effects include rivers flushing surplus material downstream, which can cause channel avulsions that alter the frequency of flooding as well as floodplain accretion (Fan et. al. 2019). The increase in area of the island in October 2011 as revealed from satellite image to the tune of 5.88 km<sup>2</sup>/year and 439.16 km<sup>2</sup> post-monsoon sand bar area (Fig. 2e and Table 1 & 2) can be linked to the earthquakes swarm during 27<sup>th</sup> July to 08<sup>th</sup> December 2010 experiencing fifteen earthquakes of 3.5 to 4.8 magnitudes (Dasgupta & Mukhopadhyay, 2014). At the same time, the river Gainadi (carries heavy sediment load with high velocity) and river Jiadhhal (also called as ‘Sorrow of Dhemaji district’ due to severe annual floods) witnessed high-magnitude flash flood due to incessant rains in the last week of July till 15<sup>th</sup> of August 2011 in Assam and Arunachal Pradesh. This flash flood not only devastated vast swaths of agricultural land and affected 1.5 lakh people, but also breached riverbanks and submerged National Highway-515 cutting off the district from the rest of the state (Flood & Erosion Problems, Government of Assam). This might potentially be the source of a series of landslides caused by the fifteen earthquakes and the subsequent floods, which could extend Majuli Island and resulted in significant sediment load.

### ***Reason for decline of the Majuli Island area in 2000***

The size of the Majuli island has shrunk significantly by 10.15 km<sup>2</sup> as seen in October 2001 satellite image (Fig. 2f and Table 1). The number of sandbars (i.e. 201) before and after the 2001 monsoon has been comparatively less within the selected years (Table 1 and 2). On

11<sup>th</sup> June 2000, catastrophic flood discharge of around >10<sup>5</sup> m<sup>3</sup>/s outburst in the upper Assam appear to be the most important reason for the decline in the size of the island. The gigantic landslide (>30\*10<sup>8</sup> m<sup>3</sup>) blocked the Yigong River on 9<sup>th</sup> April 2000, swept down through the Zemu creek that formed a fan of 2.5 km<sup>2</sup> area that dammed River Yigong (a tributary of Yarlung Zangbo- the name of Brahmaputra in China). This landslide has dammed the river followed by flooding after breaching the temporary dam. Additionally, this GLOF event occurs during the monsoon season. This was the second seismotectonic driven glacial lake outburst floods since 1900 situated at the junction of two active strike-slip faults- the Jiali and Yigong-Lulang. The complex interplay between earthquake, landslide, GLOF and downstream flood had a cascading effect (Evans & Delaney, 2010; Mukherjee & Ghosh, 2020 and Hu, et. al. 2021) leading to significant erosion of 10.15 km<sup>2</sup> of Majuli (Table 1), clearly visible in October 2001 satellite image. Some landslides impound lakes and rivers, which may collapse days or decades later, and floods occur in mountain valleys hundreds of kilometers downstream (Fan, et. al. 2019). It was also noted that there was minimum decrease of 43.80 km<sup>2</sup> in the extent of sandbars (Table 2) between the pre-monsoon and post-monsoon period as seen in the image of 2001 compared to the sandbars of 1991 and 2011. Compared to all other selected years, the June 2000 monthly mean water discharge was the lowest at 17604.18 m<sup>3</sup>/s (Fig. 5). However, the Yigong River’s GLOF caused a mega-flood on June 11, 2000, which resulted in water discharges at the Bessa Mara CWC gauging station to the tune

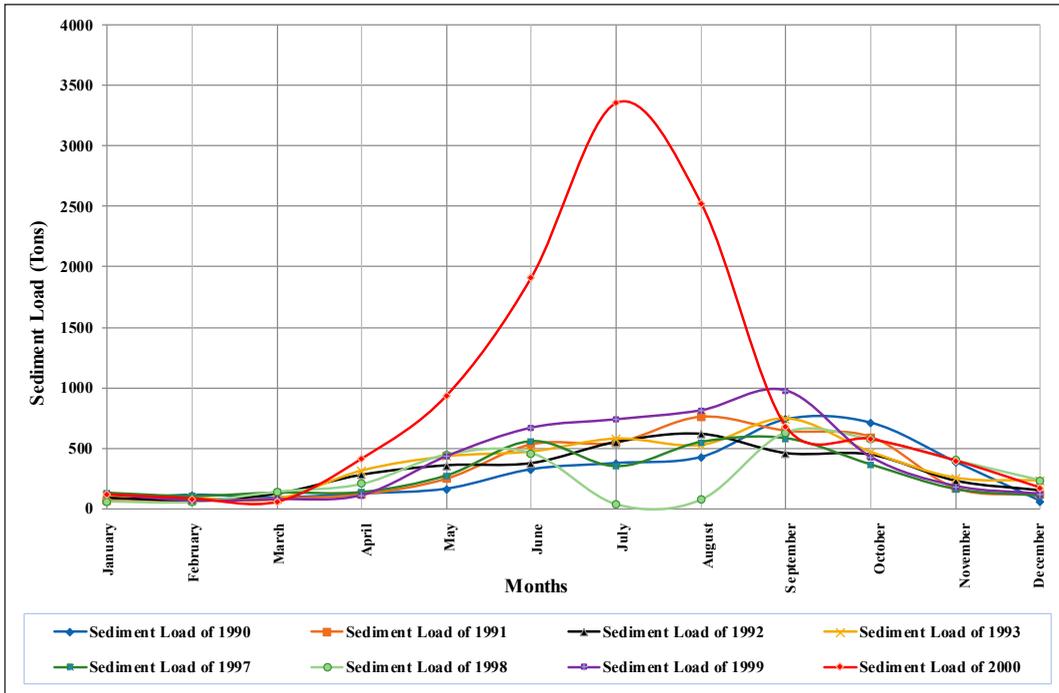


Fig. 6: Mean monthly sediment load, 1990 to 2000 (Except 1994 to 1996 due to absence of the CWC data)

of 38836.53 m<sup>3</sup>/s on June 12 and 36927.35 m<sup>3</sup>/s on June 13, 2000, respectively (CWC, n.d.). This means that the time it takes to reach the peak flood in a GLOF hydrograph, the arrival time of the flood wave at Bessa Mara gauging site was delayed by an average of one day. Consequently, the monthly sediment load was also significantly higher (3358.42 tons) compared to the other selected years (Fig. 6). This was one of the most significant water discharges and sediment loads, which led to the extreme erosion of Majuli Island in 2001.

### Conclusion

The study is not without some limitations that includes lacking 30-meter-resolution satellite

images before the year 1986 and inability to get information of water discharge and sediment load from the Basa Mara CWC gauging station of Majuli district between 1994 to 1996, and even prior to 1990 and after the 2000. However, these limitations have not seriously impacted the results of this study.

The distinctive feature of Majuli Island is its susceptibility to severe natural and man-made consequences. The primary causes of the Island's and its surrounding sandbars' shrinking area include natural rain-driven southwest and/or retreating monsoonal downstream low line floods, landslides triggered by earthquakes, and floods from landslide dam lake breaches (GLOFs).

Following the massive 8.7-magnitude earthquakes in Assam in 1897 and 1950, Majuli Island began to shrink. Over the 57-year period from 1964 to 2021, bank erosion and channel migration caused a drastic reduction in the island's area, from 682.7 km<sup>2</sup> to 546.18 km<sup>2</sup>, resulting in a net loss of 136.52 km<sup>2</sup>. Changes in sandbar area between 1986 and 2021 are also closely associated with the overall decline in island size.

It was clearly established that the annual water discharge along Majuli was inconsistent. Due to the high mean monthly water discharge bringing on its wake tons of sediment load resulted in the increase of the island's area though small by any measure in 1991.

The cascading interplay of an earthquake, subsequent landslide, glacial lake outburst flood (GLOF), and downstream flooding caused extensive erosion of Majuli in 2001. The primary trigger was an earthquake-induced landslide in 2000 that blocked the Yigong River, forming a 2.5 km<sup>2</sup> debris fan and damming the river. The resulting dam breach unleashed a GLOF, generating a mega-flood that eroded over 10 km<sup>2</sup> of the island.

Most large- and moderate-magnitude earthquakes trigger landslides, including catastrophic rock avalanches. Subsequent heavy rainfall can remobilize these landslide deposits on slopes, converting them into debris flows downstream while also generating channel avulsions that alter flood frequency and floodplain accretion. This sequence unfolded from July to December 2010, when

a cluster of moderate-intensity earthquakes triggered multiple landslides across Assam. The intense rainfall that ensued produced flash floods in the Gainadi and Jiadhhal rivers. These earthquake-induced landslides boosted sediment delivery, leading to heightened siltation that likely expanded the island's area by 58.76 km<sup>2</sup> in 2011.

Since 1950, the island's area has significantly declined, with occasional increases driven by complex interactions among intense monsoon rainfall, earthquakes, landslides, glacial lake outburst floods (GLOFs), and resulting floods. These processes highlight the critical influence of hydrological and meteorological forces in continuously shaping and reshaping the island, rendering it one of the world's most dynamic but increasingly vulnerable riverine islands.

### Competing interest

The corresponding author declares that they have no conflict of interest.

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