American Journal of Geophysics, Geochemistry and Geosystems
Vol. 7, No. 1, 2021, pp. 38-52
http://www.aiscience.org/journal/aj3g
ISSN: 2381-7143 (Print); ISSN: 2381-7151 (Online)

Why Indian Largest River Island Majuli Is Shrinking: Biophysical and Fluvial Geomorphological Study Through Historical Multi-Temporal Satellite Imageries

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Abstract

The present study on Majuli island, the largest India river island of the Brahmaputra, aims to studying why it is shrinking. For that biophysical and fluvial geomorphological studies have been done through historical multi-temporal satellite imageries. The Majuli island is located in the middle of two structurally dynamic belts, viz. the Himalayan belt in the north and the Patkai-Naga-Arakan belt in the south. Major part of Majuli Island cover part of vast Brahmaputra flood plain which constitutes a thick pile of Quaternary alluvial deposits and has a gentle to moderate slope. Geologically, the Majuli Island comprises rocks ranging in age from Pleistocene to Holocene. The area is broadly comprising alluvium sediments. Majuli has a total area of 1256.36 Km^2 and 1255.00 Km^2 in 1891 and 1901 respectively but having lost significantly to erosion it has an area of 630.72 Km^2 in 1973, 536.96 Km^2 in 1996, 473.16 Km^2 in 2000, 461.27 Km^2 in 2005, 454.88 Km^2 in 2010, 451.42 Km^2 in 2015, and 435. 87 Km^2 in 2020. According to literature review, Landsat satellite imageries analysis, and various sources, Majuli island is continuously shrinking due to heavy erosion and flooding. The length of Majuli island has additionally diminished enormously from 79.70 Km in 1915 to 75.16 Km in 1975 and afterward 63.33 Km in 2005, and 53.08 Km in 2020 (about 33.40% decrease contrasted with 1915). The particular stretch of Majuli island along Brahmaputra river has lost approximately 3.07 Km^2 area per year and gained only 1.66 Km^2 per year. The erosion and deposition pattern of the Majuli island along Brahmaputra river is showing a decreasing trend, and after the year of 2011, these has more-or-less no erosion and deposition, which corresponds to the good flood management in Majuli island over the last few years, but Majuli island needs corrective measure, appropriate planning, and governmental support to stabilize the riverbank lines and protect riverbank from erosion.

Keywords

Majuli Island, Geomorphology, Geology, Soil, Land Use, Satellite Imagery

Received: January 14, 2021 / Accepted: February 18, 2021 / Published online: March 4, 2021

1. Introduction

Riverbank collapse is a huge issue worldwide and is related with land misfortune and deposition of sediments along the river course [1]. Land loss as a consequence of riverbank collapse not just undermines the presence of infrastructures or agricultural lands close to the riverbank yet additionally presents danger to aquatic living spaces and causes sedimentation downstream because of the generation of fine-grained residue [2]. In India, the greater part of the hydrological challenges is because of the high sediment load of the rivers, which ultimately brings about riverbed aggradations, bank erosion and channel widening [3]. In addition, the erosion of the riverbank in the Brahmaputra-Barak and Ganga basin is due to similar reasons, which are

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caused by high flood discharge in the river, bed slope and composition of bed and bank materials [4]. The land escaped once because of riverbank erosion can't be rebalanced by the riverine landmass that developed by the river itself in due course of time [5].

Brahmaputra is one of largest unbranching mega-river, and it is the 7th largest tropical river in terms of average annual discharge [6], and it is transporting a very high sediment flux (average 850 tons / Km^2) [6] from a source addressing the dynamic zone of the continent-continent crash between the Indian and Eurasian plate [7]. It has a huge-braided channel in Assam. The astonishingly high sediment flux of the Brahmaputra has been assessed for effectively induced erosion of the Himalayas, slope erosion of the lower regions of the Himalayas and movement of alluvial deposits stored in the Assam valley [4, 8-14]. The Brahmaputra river is considered as the lifeline of Assam, as its valley goes through the valley of Assam and the alluvial store by the river is quite valuable regions of the nation [15]. Still, this lifesaving river is frequently associated with an excess of disasters [16]. Every year, during the monsoon months, there is widespread flooding in the valley and river erosion as a result of the increasing flow of the river and its tributaries [17-18]. Majuli island of the wonderful Brahmaputra River in Assam, India, is viewed as the greatest river island on the biosphere [19]. According to article published in the Telegraph [20], the largest river island of the world is Bananal island, Brazil, and it covered an area is 19,162 Km^2, while Majuli island covered an area of 1255 Km^2 [21-22], Due to erosion and land degradation, at-present the Majuli island area is only 435 Km^2 [23]. The proceeded with presence of Majuli is under the danger of extinction n because of serious bank erosion by the Brahmaputra river [14]. The mean yearly flow of the Brahmaputra at Bechamara in Majuli during 1975-1990 was 8,830 m^3/s [24]. Average annual suspended sediment load of Brahmaputra measured at Pandu, 240 Km d/s of Majuli, is 402 MMT during the period 1955-1979 [11]. The Subansiri river is the largest tributary of the Brahmaputra situated at north of the Majuli island had a mean annual flow. Subansiri River is the biggest feeder of the Brahmaputra found north of Majuli Island, with an average annual flow of 1670 m^3/s during the period of 1956-1982. The Subansiri river carries on an average 35.48 MT of suspended sediment annually [24]. Majuli is home to the pristine cultural heritage of Assam, and it is a focal point of Neo-Vaishnavite culture of Hinduism, and a key spot of journey throughout the previous 400 years [25], which makes it an important cultural heritage site of this country.

2. About the Study Area

Majuli is the 2nd biggest river island in the world which is located on the Brahmaputra river in the state of Assam. It stretches-out for a length of around 54 Km in east-west and a width of around 10 Km to 21 Km north-south way, within the latitude of 26.895874 N to 27.110570 N, and longitude of 93.944623 E to 94.437495 E with mean height of 84.5 m amsl. It is framed by the Brahmaputra river in the south and south-west, the Kherkatia-Suti river, a branch of the Brahmaputra river in the north-east, joined by the outfall of the Subansiri river and its tributaries in the north and north-west (Figure 1). These tributaries typically bring floods with fine silt and heavy loads of mud sediment. They have exceptionally steep slopes, shallow braided shifting channels, and sandy beds. Another important element is the formation of islets coming about because of the braided nature of the river around the Majuli Island, locally called the chaporis. On the island there are minor lakes and oxbow lake formations with typical wetland character locally known as beels. These are amazingly wealthy rich in flora and fauna and serve as a breeding place for many exceptional species.

Majuli has a total area of 1250 Km^2 in 1661 but having lost significantly to erosion it has an area of only 880 Km^2 in 20th century. Based on Landsat satellite imageries, the area of Majuli island is continuously shrinking and it was 536.96 Km^2 in 1996, 473.15 Km^2 in 2000, 486.27 Km^2 in 2005, 477.88 Km^2 in 2010, 451.42 Km^2 in 2015, and 435. 87 Km^2 in 2020. According to Census of India 2011, total population of Majuli tehsil with 248 villages is 167,304; majority being tribal, has a very rich heritage and has been the home of Assamese Vashnavite culture with colossal alternative for mystical and eco-tourism [26].

2.1. History of Majuli Island

Primarily, the island was a thin and long piece of land called Majoli (land in the middle of two parallel rivers) that has Brahmaputra flowing in the north and the Burhidihing flowing in the south, till they met at Lakhu [27]. Frequent earthquakes in the time frame of 1661-1696 set up for a disastrous flood in 1750 that proceeded for 15 days, which is referenced in in historical texts and reflected in folklore [28]. Because of this flood, the Brahmaputra river split into two anabranches - one flowing along the original channel and the other flowing along the Burhidihing channel and the Majuli island was formed [29]. The Burhidihing's point of conjunction moved 190 Km east and the southern channel which was the Burhidihing turned into the Burhi Xuti [30]. The northern channel, which was already the Brahmaputra, turned into the Luit Xuti. In due course, the flow in the Luit Xuti diminished, and it came to be known as the Kherkutia Xuti; and the Burhi Xuti extended through disintegration to turn into the primary Brahmaputra River [31].

There is a few Satras of Vaishnava strict belief. Of these

blessed seats, Auniati, Daksinpath, Garamur and Kamlabari are the four prominent. What is of exceptional significance is its satra foundation, comprising of separate structures, built for different purposes [32]. The Vaishnava Satras were established by Sankardeva, the father of Assamese culture. The historic and auspicious "Manikanchan Sanjog" was the first Satra in Majuli. Thusly 65 Satras developed which engendered the ethnic and socio-social standards.

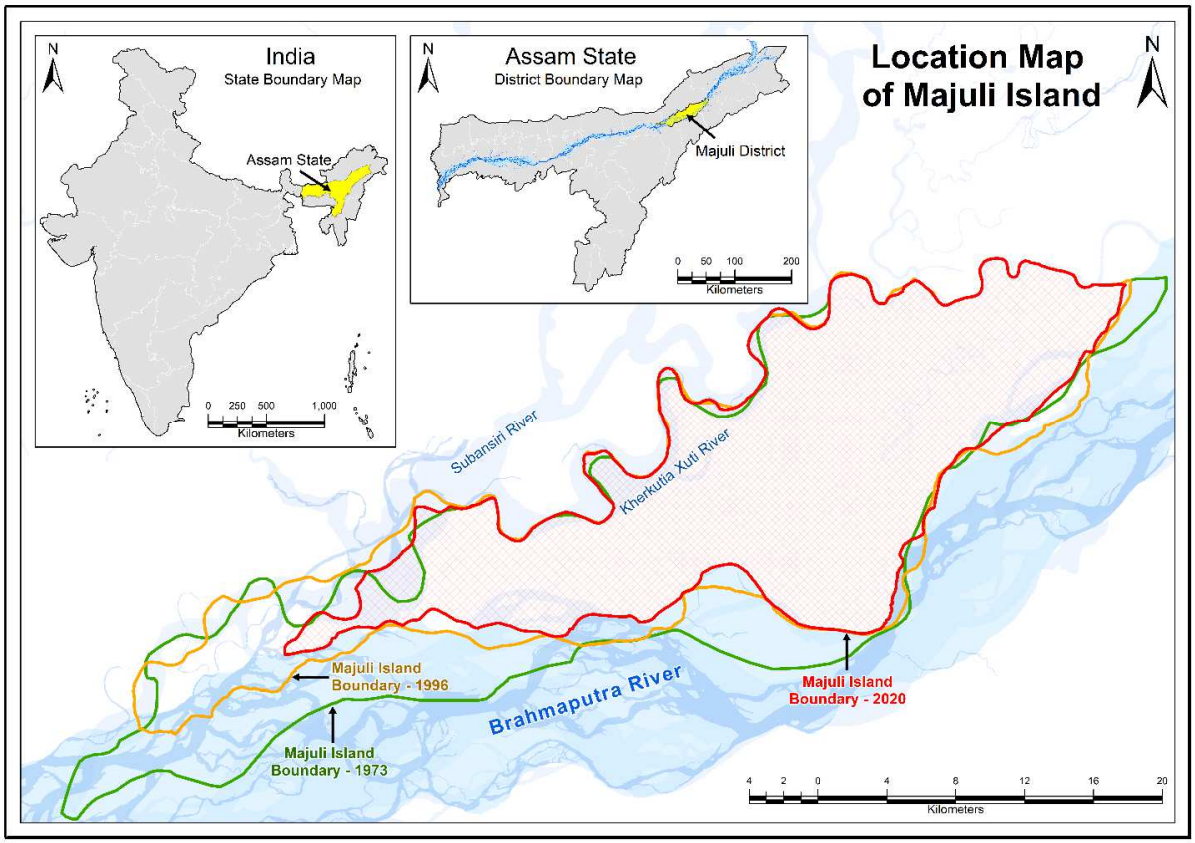

Figure 1. Location Map of Majuli Island, Assam.

At present there are just 22 Satras in Majuli and rest have been moved to other more secure places because of flood and erosion. These Satras are the treasury of "Borgeet", Matiakhara, Jumora dance, Chali dance, Noyua dance, Nande Vrigee, Sutradhar, Ozapali, Apsara dance, Satria Krishna dance, Dasavater dance, and so on which were contributed by Shri Sankardeva [33]. Local people talk in Assamese and Mising language mainly. A few communicate in the Deori language also.

2.2. Demography of Majuli Island

Majuli is a river island in the Brahmaputra river, Assam and in 2016 it befitted into the first river island to be made a district in India. There have 248 villages in Majuli. Out of 248 villages, the Ratanpur Miri Gaon is most populated village with the population of 5085, while Mowamari Chapori NC is least populated village with no population [21]. Majuli tehsil has total population of 167,304 according to the Census 2011. Out of which 85,566 are males while 81,738 are females. In 2011 there were all over 32,236 families dwelling units (total number of households) in Majuli. The average sex ratio of Majuli is 955 per 1000 male. According to Statistical Office, Garamur, Majuli, 2011, the total literates persons are 114,107 in which total male literates are 63,969 and female literates are 50,138. Literacy rate in Majuli is 78.56%. Demographic changes in Majuli island are given in Table 1.

Table 1. Demographic Changes in Majuli Island.

S. No.	Year	Population	Growth Rate (%)	S. No.	Year	Population	Growth Rate (%)
1.	1901	31,219	-	6.	1971	095,618	02.22
2.	1911	40,420	29.47	7.	1991	135,378	41.58
3.	1941	75,040	85.65	8.	2001	153,362	13.28
4.	1951	81,001	07.94	9	2011	167,304	09.09
5.	1961	93,541	15.48	10.	2021*	179,675	07.39

Source: The Statistical Office, Garamur, Majuli. Census of India, 2011, * Population Projection through Geometrical Increase Method

Majuli island has 84,873 population engaged in either main or marginal works out of them 49,369 male and 35,504 female population are working population. Full time workers in Majuli island are 53,484 and 31,389 are marginal (part time) workers.

3. Data Source and Methodology

Remote sensing satellite information having capacity to give thorough, succinct perspective on fairly large area at regular interval with quick turnaround time makes it proper and ideal for contemplating and observing river erosion and its bankline migration. For analysis of shrinking area of Majuli island, the Landsat satellite imageries from 1973 to 2020 (30 satellite scenes in total) were downloaded from Earth Explorer, USGS at http://earthexplorer.usgs.gov. The details of satellite remote sensing data with year, satellite name, sensor type, and spatial resolution is given in the Table 2.

Table 2. Satellite Remote Sensing Data Collection.

S. No.	Years	Satellite	Sensor	Spatial Resolution (m)
1.	1973	Landsat-1	MSS	59*79
2.	1976, 1977	Landsat-2	MSS	59*79
3.	1986, 1990, 1996, 1997, 1998, 1999, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011	Landsat-5	TM	30
4.	2000, 2001, 2002, 2003, 2012, 2013	Landsat-7	ETM+	30
5.	2014, 2015, 2016, 2017, 2018, 2019, 2020	Landsat-8	OLI	30

Apart from above stated data, the below listed data (Table 3) have been used for this study.

Table 3. Data used, sources and methodology.

S. No.	GIS Data Layer	Data Sources and Methodology
1.	SoI Toposheet at 1:50,000 Scale	Survey of India Toposheets, 2005. Toposheet No.: 83E/16 (G46D16), 83F/13 (G46J13), 83I/04 (G46E04), 83I/08 (G46E08), 83J/01 (G46K01), and 83J/05 (G46K05) Source: http://www.soinakshe.uk.gov.in
2.	Elevation Data	ALOS PALSAR (DEM) Data: Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) Digital Elevation Model (DEM) Data with 12.5 m spatial resolution. Source: Alaska Satellite Facility, Fairbanks. U.S. state of Alaska. 2004-2015 Source: https://vertex.daac.asf.alaska.edu
3.	Drainage Network and Drainage Density	Drainage network and drainage density has been generated in GIS environment using ALOS PALSAR (DEM) data, and ArcHydro tool in ESRI ArcGIS 10.7 software.
4.	Slope Map	Topography, slope, relief maps have been created using Spatial Analyst Extension in ArcGIS 10.7, and ALOS PALSAR (DEM) data with 12.5 m spatial resolution.
5.	Land Use / Land Cover Data	LULC map with level-I classification scheme has been prepared by using Landsat-8 OLI satellite imagery with 30 m spatial resolution of year 2020. These data layers are also updated with best available Google Earth satellite imagery. These data layers are also verified through limited field check.
6.	Soil Map	Soil map has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), National Soil Survey, State Agricultural Department and updated through Landsat-8 satellite remote sensing data, and field data.
7.	Geological Map	Geological quadrangle map has been downloaded from Geological Survey of India (GSI) website, and updated through Landsat-8 satellite imagery, and Survey of India (SoI) Toposheets at 1: 50,000 scales with limited field check. Source: http://www.portal.gsi.gov.in
8.	Geomorphological Map and Lineament Mapping	Geomorphological map at 1:50,000 scale along with geological structures i.e. lineaments have been prepared using Landsat-8 OLI data, ALOS PALSAR (DEM) data, and other ancillary data i.e. topographical map, geological map.
9.	Demographic Data	The Statistical Office, Garamur, Majuli. Census of India, 2011. Source: https://censusindia.gov.in/2011census

4. Fluvial Geomorphological Study

Geomorphology is investigated using a combination of remote and field techniques, in which the attributes of individual landforms are placed in their spatial context with respect to other nearby landforms, and with respect to broad-scale landscape features [34]. The assessment of fluvial geomorphology and geomorphic measures includes both the estimating of channel morphology and the observing and examination of the flow regime and sediment supply that drive geomorphic measures in the watershed [35]. These estimations take into consideration the geomorphic characterization of the watershed to be determined, and rehashed estimations over a period take into consideration the movement rates to be measured and for the effects of land use change and urbanization to be assessed. Fluvial geomorphology considers identify and quantify these processes which are subject to environment, land use, topography, vegetation, geology, and other natural and anthropogenic impacts.

4.1. Geology

Geological mapping comprises of a combination of exercises

executed in field, to gather the maximum information about the geological constitution of a particular territory. All information gathered, onsite detailed work and information obtained from accessible literature contribute to understanding the geology of the study area. The authors have gone through the following steps in the preparation of a geological map of the study area: (i) preliminary literature survey, (ii) satellite remote sensing based geological study, (iii) on site geological mapping, (iv) compilation of the geological map with identification of geological and tectonic features, and (v) definition of a detailed investigation plan with the aim to detail geological structures, geomorphological forms, geo-technical, geo-mechanical conditions boundaries, and hydro-geological characteristics along the alignment.

Systematic papers, geological maps concerning different geological aspects of lithological characteristics, structural geology, tectonic style, litho-stratigraphy, morphological elements, geomorphology, nontectonic activity, and river dynamics of the area have been critically reviewed. Survey of India topographic maps, 3D images from Google-Earth, ALOS PALSAR DEM data, and satellite remote sensing data based geological study has been performed in two distinct phases. 1st phase undertook a preliminary desktop analysis during which the observed geological structures were identified and reported on map, and 2nd phase carried out on-field checking of identified elements. The geologic mapping was carried out at a scale of 1:50,000 using sampling method. The results of remote sensing interpretation and geological field survey were integrated into the GIS to produce a geological map (Figure 2).

The general geology of the Majuli Island has been mapped by the Geological Survey of India (GSI) in the usual way. Various geologists have contributed to diverse geological aspects of the study area. Notable among these are: [36-40], etc. They recorded the principal rock formations as described in Table 4.

Table 4. Stratigraphic Sequence of Majuli Island.

Notation	Lithology	Formation	Group	Age
Q_2b_2	Unoxidized grey loose sand, silt, clay with cobbles, pebbles, and gravels	Channel Deposit (= Barpeta-II)	Newer Alluvium	Recent
Q_2b_1	Unoxidized grey silty clay and sand all micaceous with associated gravels and pebbles	Dhansiri (= Barpeta-I)		Holocene - Recent
$Q_{12}S$	Oxidized brownish grey to greyish brown sand, silt and with occasional pebbles and cobbles	Hatikuli (= Sorbhog)	Older Alluvium	Pleistocene to Holocene

Source: Geological Survey of India (GSI), 2017

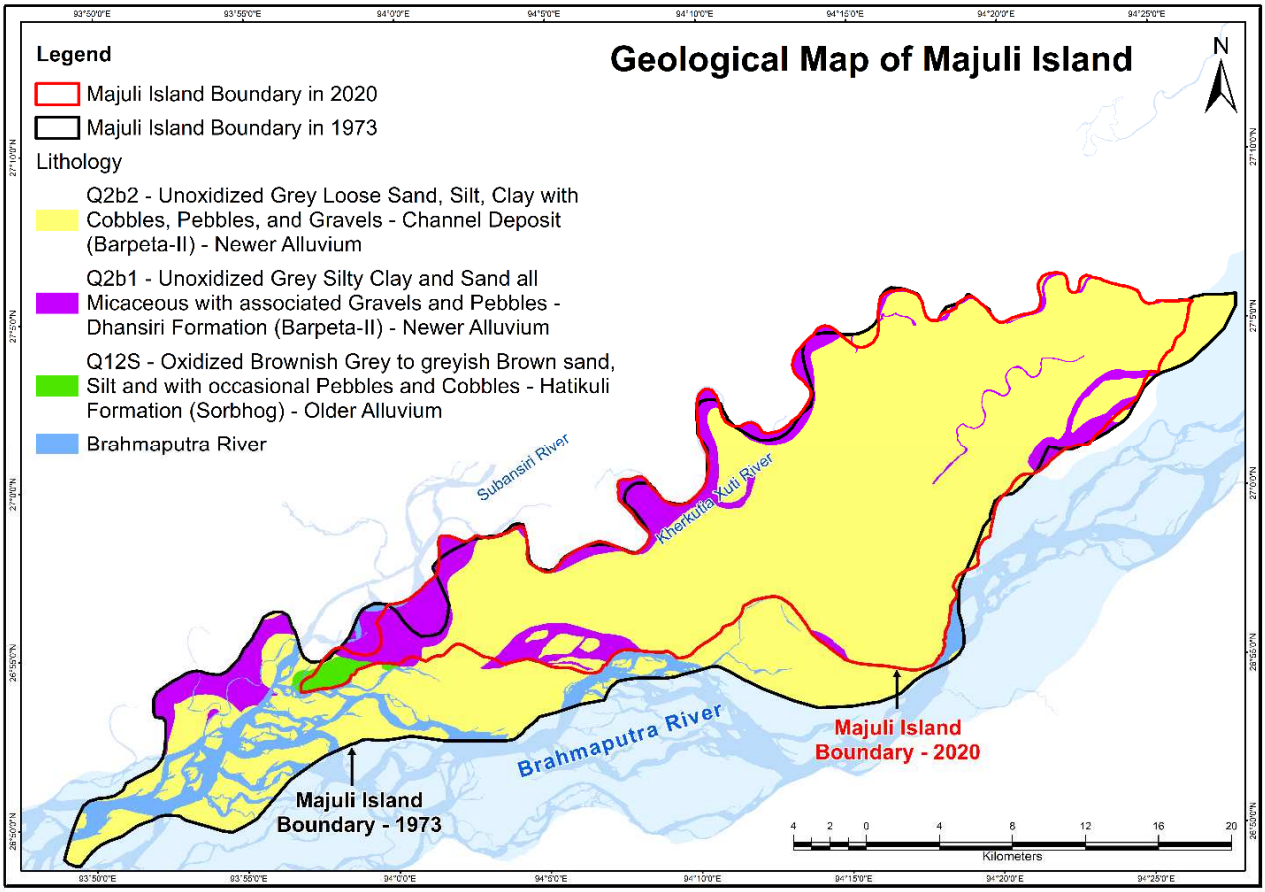

Figure 2. Geological Map of Majuli Island, Assam.

Major part of Majuli Island cover part of vast Brahmaputra flood plain which constitutes a thick pile of Quaternary alluvial deposits and has a gentle to moderate slope. Geologically the Majuli Island comprises rocks ranging in age from Pleistocene to Holocene. The area is broadly comprising alluvium sediments. The newer alluvium group ranging in age from Holocene to recent. Older alluvium has been classified in Hatikuli formation (= Sorbhog formation, $Q_{12}S$) consisting of oxidized brownish grey to grayish brown sand, silt and clay with occasional pebbles and cobbles. The older alluvium group is overlain by the sediments of newer alluvium group of sediments represented by unoxidized alternate sand, silt, silty clay, and clay of Kaziranga (= Hauli formation) of Middle to late Holocene. Kaziranga formation is overlain by Dhansiri formation (= Barpeta-I formation, Q_2b_1) represented by unoxidized micaceous grey silt clay, clay and sand with associated gravels and pebbles and Channel deposit (= Barpeta-II formation, Q_2b_2) consisting of unoxidized grey loose sand, silt, clay with cobbles, pebbles and gravels of Holocene age.

The Tertiary sediment rock shows a general northeast-southwest trend with the beds dipping moderately towards south-east. Geo-technically the area is represented by soft to moderately hard sandstone, shale having low to moderately high permeability and are low to medium (50-500 Kg/cm^2) bearing capacity and fair foundation characteristics. The unconsolidated sand with or without clay of alluvium deposit having cumulative high permeability is whereas bearing capacity and foundation characteristics are low and poor respectively. The prevalence of clay formation in the depth of 30 to 50 m poses problem in storage of ground water in the zone, anyway local variation on the existence of exceptionally restricted thickness of sand beds blended in with clay performing as courses of ground water is additionally noticed.

4.2. Geomorphology

Geomorphology is the scientific investigation of landforms concerning processes of genetic evolution, development and their origins, form, structure, and mass [41]. It is the examination of connection between landform development and processes that shape and configure these landforms, for example, tectonic movements, volcanism, erosion, and deposition cycles [42-43]. The landforms are the most obvious features on the earth's surface [44]. The Brahmaputra Valley of Assam is located in the middle of two tectonically active belts, viz. the Himalayan belt in the north and the Patkai-Naga-Arakan belt in the south [45]. In spite of the new upsurge in erosion rates, the spindle shaped Majuli island is a genuinely stable landmass within the Brahmaputra river channel belt. The Majuli never submerges completely in any event, during most extreme flooding. Majuli is additionally a relic island since it is older than the Brahmaputra river [14].

Remote sensing data is an important resource in the preparation of geomorphological maps [46]. A detailed geomorphological map of the Majuli island has been prepared by visual image interpretation of Landsat-8 OLI satellite data, geological map from Geological Survey of India (GSI), Survey of India (SoI) topographical maps of 1:50,000 scale, and field observations (Figure 3). Geological map (structural and lithological), slope map, and landform map have also been consulted. The various geomorphic units and their component were identified and mapped. The investigation of landforms and drainage uncovers that their development is directly identified with the lithology and structure of the underlying rocks [47]. Several scarps are good examples of inversion of geology, topography and have different drainage pattern [48]. These highlights are the attributes of development in the cycle of erosion.

Referring to Figure 3, a similar investigation of the multi-spectral, multi-spatial, and multi-temporal changes from 1996-2020 in channel configuration demonstrates a three-phase evolution of this new island: (i) bifurcation of the Siang stream and its north-toward the west move, (ii) confluence shift and positive extending of the Brahmaputra channel belt, and (iii) separation of the Lohit river by channel catching [14]. From 1995 ahead, the Lohit river began to redirect its flow from the western flank of the Dibru-Saikhowa Reserve Forest along the Dangori river and in the end the Dibru stream channel was caught by the Lohit river. The Dibru-Saikhowa Reserve Forest turned into a river island by 1998 and the Siang-Dibang-Lohit confluence point (from which forward the flow regime is known as the Brahmaputra river) moved further downstream [49].

As of now, the entire flow n of the Lohit river, halfway flow of the Dibang river and various more modest streams from the southern bank are going through the old Dangori-Dibru course [50]. Also, conversely with the descending movement of the Siang-Dibang-Lohit, the intersection of the Dibru and the between 1915-1975 and during 1975-2005, the move was around 27 Km the upstream direction. Therefore, within a period of 105 years (1915-2020), the net upward move of the intersection was in excess of 40 Km [23]. At present, because of the channel catch by the Lohit river, two neutral confluence points arose - one between the Dangori and the Lohit and another between the Dibru and the Lohit. Both of these south bank rivers, other than the upward move of the confluence, have also gone through substantial reduction in length - the Dibru river reduced by around 64 Km and the Dangori river by 24 Km [49].

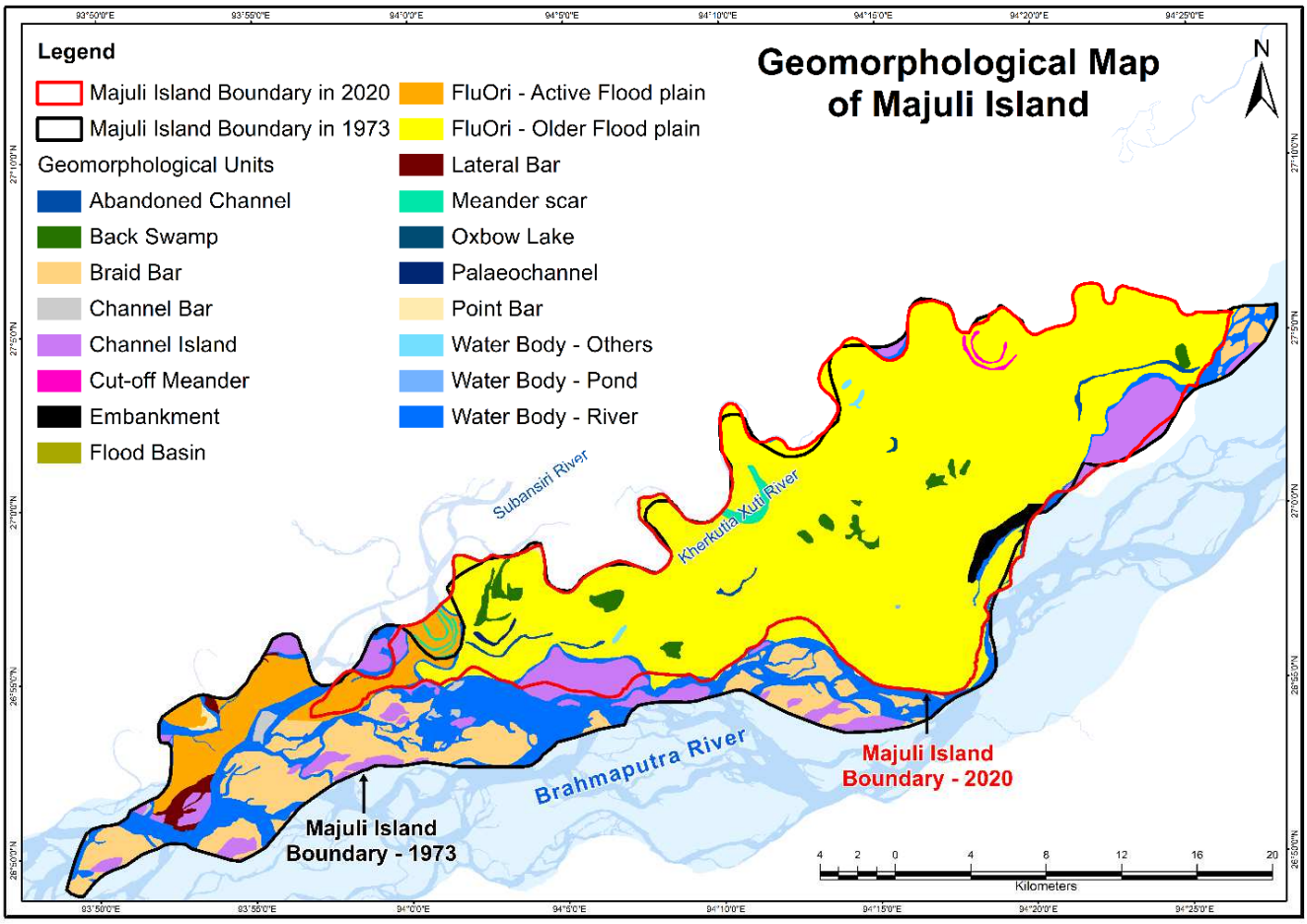

Figure 3. Geomorphological Map of Majuli Island, Assam.

5. Biophysical Study

5.1. Landuse

Visual image processing was used to process with this large amount of data. Several conventional classification schemes encompass one a two of considerations to categorize the image (for example spectral differentiation, texture) and the emphasis is the natural property of the image [51]. These methodologies are productive with low to moderate spatial resolution satellite images yet fail where the pixel size is essentially smaller than the object of observe [52]. The traditional approach of visual image interpretation is more effective in classifying high to moderate resolution satellite images [53]. Another methodology is to utilize object image classification, anyway without right tools this examination focuses on utilization of conventional visual image interpretation [54]. Traditional visual image interpretation focusses on using multiple properties to extract information based on shape, size, connectivity, association etc. [55].

A level-I land use / land cover showing built-up area - urban settlement, rural settlement; transportation - roads, railways; agricultural area - agriculture crop land, agriculture fallow land; vegetation; watercourses - river, riverbed, water bodies have been captured in polygon layers by using moderate resolution Landsat-8 OLI satellite imagery through on-screen digitization. These land use / land cover data layers have been verified through best available GoogleEarth satellite imagery. Land use / land cover map of the Majuli island is shown in Figure 4. The land use / land cover of the Majuli island comprises mostly of agricultural land (63.15%), riverbed (14.86%), settlement (6.86%), and vegetation (6.14%). It is evident from the Figure 4 that built-up land or settlement (rural and urban) accounts for 42.88 Km^2 forming 6.86% of the total area while water features accounts for 8.74%. Other land use / land cover categories are transportation with 0.26%, ponds / lake with 1.19%, and active channel (7.54%), which is the biggest share while agriculture land including crop land and fallow land of 63.15% area in year 2020.

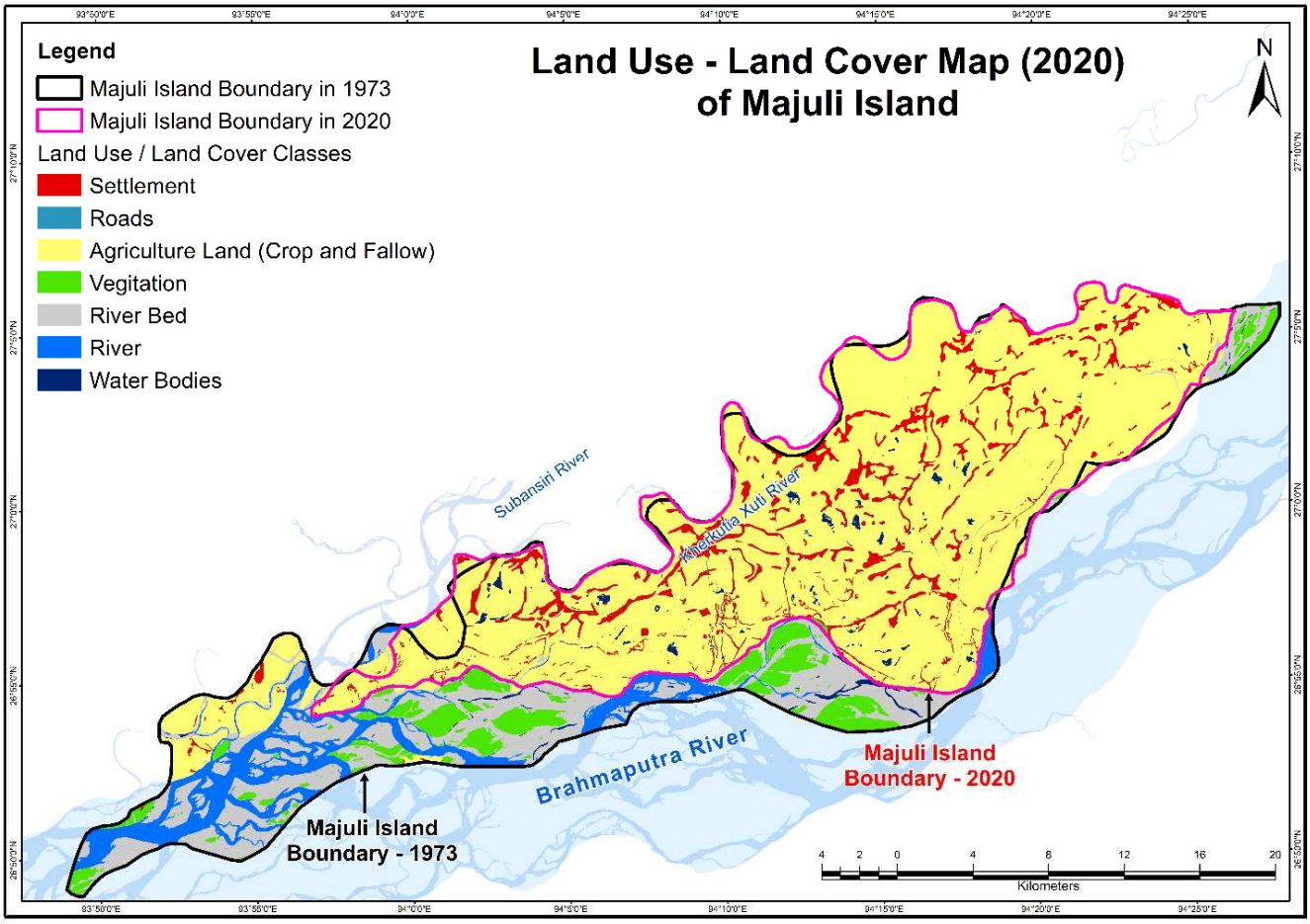

Figure 4. Land Use and Land Cover Map (2020) of Majuli Island, Assam.

5.2. Soil

Soil is the most important nature asset and fills in as one of the superb necessities of life. Soils and in its turn the land through their general richness uphold all horticultural movement and the plant development and subsequently the main component of the characteristic biological system [56]. As respects the soils of Assam, geology (parent material), topography and environment appear to assume imperative part in their developments [57]. Accordingly, under fluctuating geological conditions, topographical characteristics and agro-climatic circumstances various kinds of soils are found to happen in the hills, slopes, piedmonts, plateaus, and plains [58]. For the detailed analysis of soil material and texture of the Majuli island, the authors have been undertaken the following activities.

Scanning and geo-referencing of collected paper maps: The collected paper maps from National Atlas of India, National Soil Survey; National Atlas and Thematic Mapping Organization (NATMO), 1981 have been scanned with proper calibration of scanner and quality checked for archiving and further use. The scanned maps have been then geo-referenced with the help of rectified Landsat-8 OLI satellite image to correlate the geo-position of project area with its position in paper map with required projection system and have been made into a sub-set for preparation of a mosaic of maps to get an idea of the entire project area.

Edge-matching, mosaicking, and tiling of scanned soil maps: The geo-referenced soil map obtained after pre-processing stage has been used to prepare a mosaic to form a complete study area, i.e. joining of more all images. Edge matching has been done bringing two adjoining soil maps of same area into same map file and matching has been done with their edges to form a seamless map file.

Preparation of soil map with attribute of soil type, soil textures, soil depth: The geo-referenced soil maps have been used to assist in visual classification of satellite imagery for obtaining soil categories. The Geological Survey of India (GSI) maps, Survey of India (SoI) toposheets (1:50,000), Landsat-8 OLI satellite imageries, and ALOS PALSAR (DEM) data have been used for updating the soil categories. The final vector data layers have been stored in a geodatabase. The soil categories have been classified according to Indian Council of Agricultural Research (ICAR) soil group. Soil texture classes of the Majuli island is shown in Figure 5.

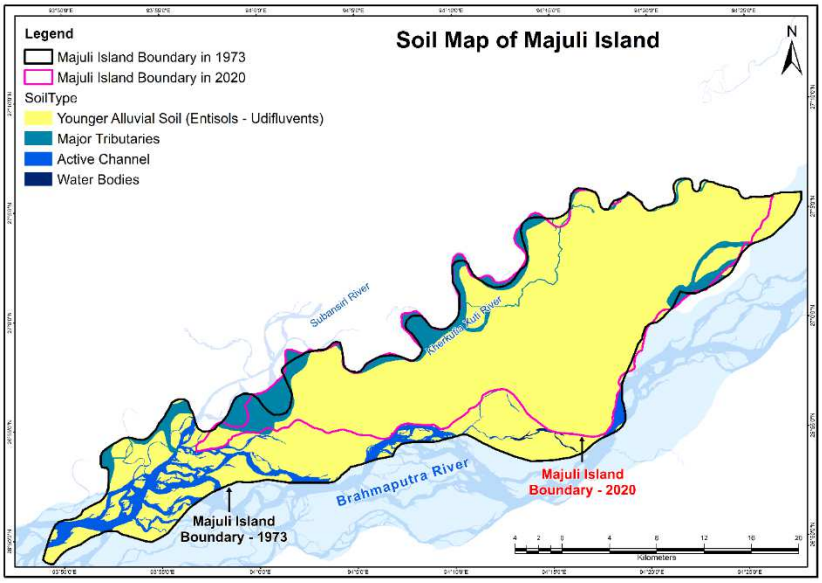

Figure 5. Soil Map of Majuli Island, Assam.

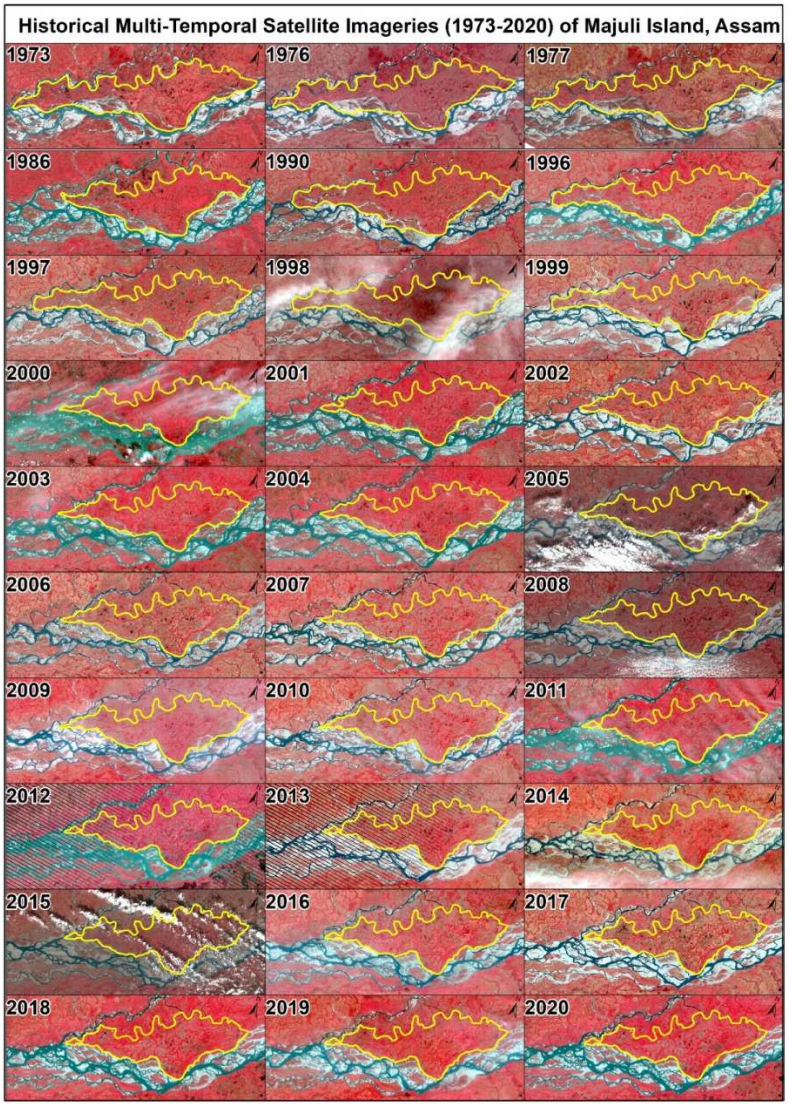

Figure 6. Historical Multi-Temporal Satellite Imageries (1973-2020) of Majuli Island, Assam.

5.3. Majuli Island Area Analysis

Riverbank erosion and bar deposition is common in the study area. Multi-temporal satellite remote sensing data i.e. Landsat-1 MSS, Landsat-2 MSS, Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI have been used to digitize Majuli island from 1973 to 2020 (47 years, 30 in total), and shown in Figure 6. The total area of Majuli island from 1973 to 2020 were calculated using ESRI ArcGIS 10.7 software and given in Table 5. Areas from earlier literature were also add in that table.

Table 5. Majuli Island Area from 1891 to 2020.

S. No.	Year	Area of Majuli Island (Km^2)	S. No.	Year	Area of Majuli Island (Km^2)
1	1891[a]	1256.36	18	2005	461.27
2	1901[b]	1255.00	19	2006	459.32
3	1917[c]	751.31	20	2007	458.71
4	1973	630.72	21	2008	456.85
5	1976	591.76	22	2009	455.21
6	1977	584.96	23	2010	454.88
7	1986	573.79	24	2011	453.19
8	1990	557.53	25	2012	452.60
9	1996	536.96	26	2013	452.10
10	1997	532.93	27	2014	451.75
11	1998	529.45	28	2015	451.42
12	1999	521.80	29	2016	450.19
13	2000	473.16	30	2017	448.36
14	2001	470.09	31	2018	442.17
15	2003	469.52	32	2019	440.12
16	2003	466.42	33	2020	435.87
17	2004	463.93	Rate of land degradation (Km2 / year) = 4.21		

Source: a = [59], b = [22], c = Survey of India Toposheets, S.No. 4 to 33 = Multi-temporal Landsat satellite imagery analysis

Majuli has a total area of 1256.36 Km^2 and 1255.00 Km^2 in 1891 and 1901 respectively, but having lost significantly to erosion it has an area of 630.72 Km^2 in 1973, 536.96 Km^2 in 1996, 473.16 Km^2 in 2000, 461.27 Km^2 in 2005, 454.88 Km^2 in 2010, 451.42 Km^2 in 2015, and 435. 87 Km^2 in 2020. According to literature review, Landsat satellite imageries analysis, and various sources, Majuli island is continuously shrinking due to heavy erosion and flooding.

Referring to Table 5, the Majuli island has lost its area around 819.13 Km^2 in last 120 years (1901-2020). In comparision to 1901, it has lost 65.27% area, and only 34.73% is remaining, and it is continuously shrinking. In the last 47 years (1973-2020) it has lost 194.85 Km^2 area and in last 25 years (1996-2020) it has lost 101.09 Km^2 area. The graphical represent of shrinkage of Majuli island from 1891 to 2020 is shown in Figure 7.

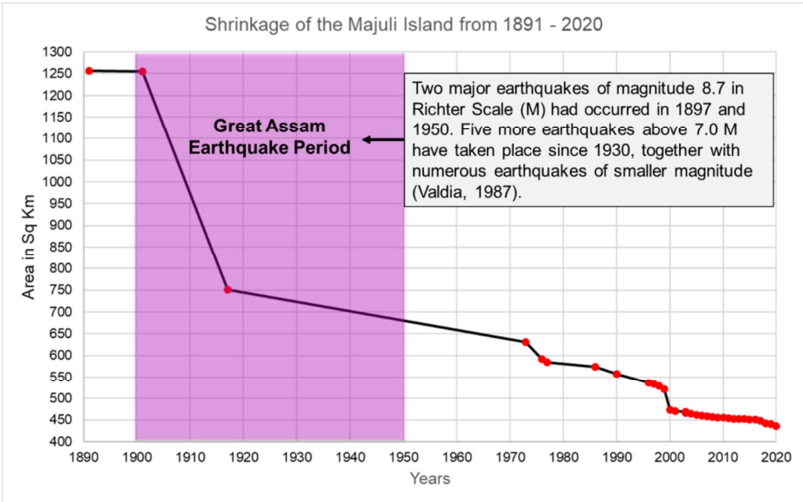

Figure 7. Shrinkage of the Majuli Island from 1891 - 2020.

Majuli island significant shrinking has start, when two major earthquakes of magnitude 8.7 in Richter scale had happened in 1897 and 1950 [60]. Five additional seismic tremors above 7.0 M have occurred since 1930, along with numerous earthquakes of more modest magnitude [45]. Majuli island is continuously shrinking from 1891 to 2020, and it has lost its

area every year, and average rate is 4.21 Km^2 / year. Rate of land degradation of Majuli island from 1996 to 2020 is shown in Figure 8.

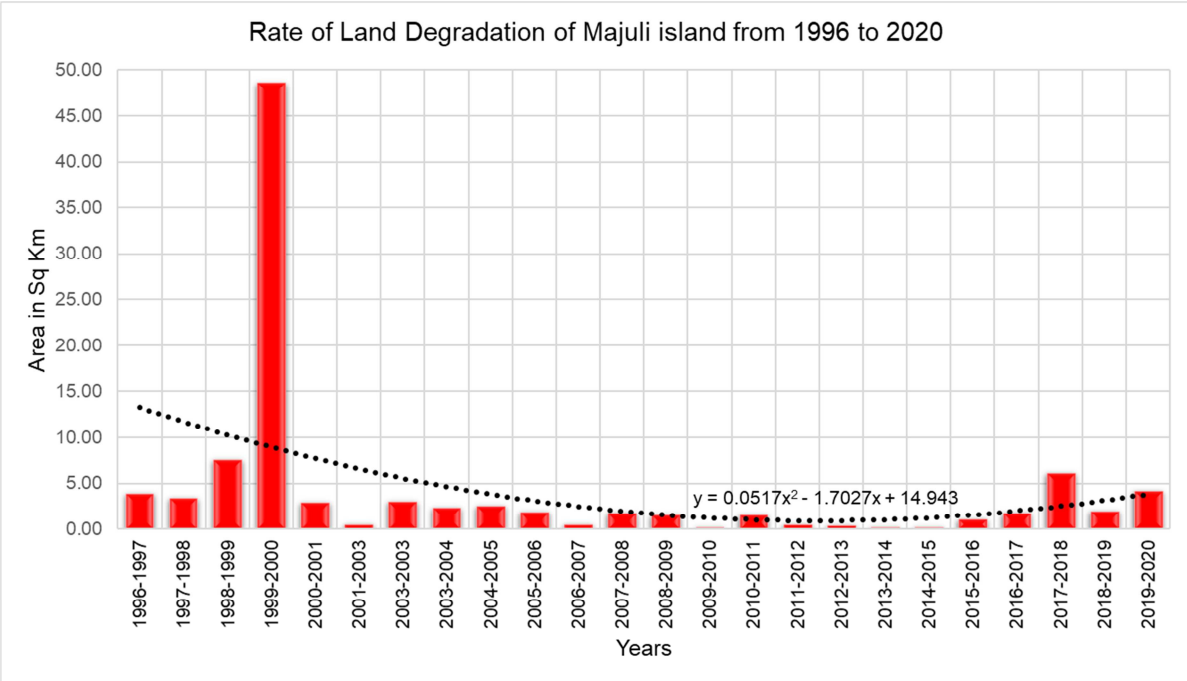

Figure 8. Rate of land degradation of Majuli island from 1996 to 2020.

Referring to Figure 6, the length of Majuli island has reduced greatly from 79.70 Km in 1915 to 75.16 Km in 1975 and then 63.33 Km in 2005, and 53.08 Km in 2020 (about 33.40% reduction compared to 1915). Majuli island is continuously shrinking to upstream, it is shrinking around 6.96 Km to upstream from 1973 to 1996, and 9.63 Km from 1996 to 2020. In the last 47 years, the Majuli island has been shrink around 16.59 Km to upstream from 1973 to 2020 (Figure 9).

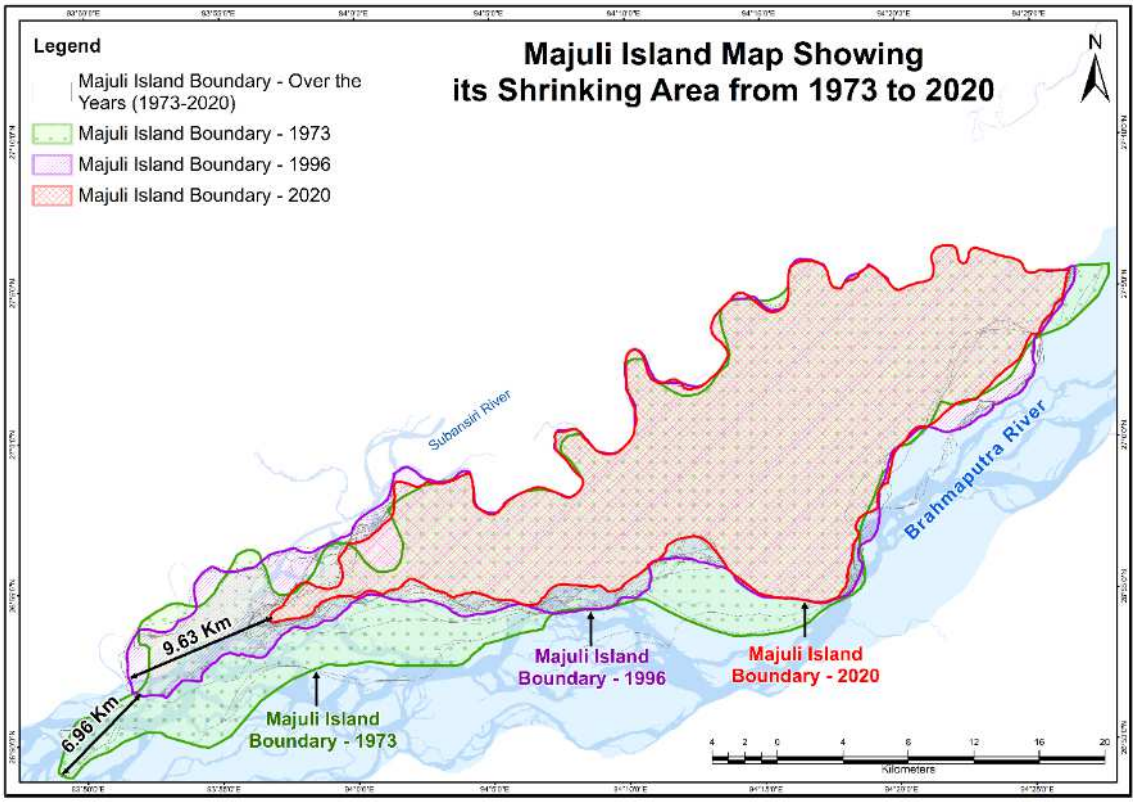

Figure 9. Majuli Island Map showing its Shrinking Area from 1973 to 2020.

Table 6. Year wise (1996-2020) Total Erosion and Deposition Statistics of Majuli Island along Brahmaputra River.

S. No.	Years	Area Statistics in Km^2		S. No.	Years	Area Statistics in Km^2	
		Deposition	Erosion			Deposition	Erosion
1	1996-1997	1.47	-2.11	14	2009-2010	2.71	-1.16
2	1997-1998	0.17	-2.56	15	2010-2011	0.17	-21.33
3	1998-1999	0.44	-6.45	16	2011-2012	2.64	-0.93
4	1999-2000	0.57	-4.93	17	2012-2013	0.37	-0.94
5	2000-2001	4.94	-4.78	18	2013-2014	0.43	-0.18
6	2001-2002	1.61	-3.09	19	2014-2015	0.21	-0.42
7	2002-2003	0.19	-5.58	20	2015-2016	0.03	-0.81
8	2003-2004	0.69	-1.88	21	2016-2017	0.20	-1.53
9	2004-2005	18.46	-2.80	22	2017-2018	0.09	-0.40
10	2005-2006	1.14	-3.05	23	2018-2019	0.06	-0.42
11	2006-2007	0.94	-2.81	24	2019-2020	0.53	-0.42
12	2007-2008	0.71	-3.33	Total Area		39.90	-73.66
13	2008-2009	1.12	-1.75	Average		1.66	-3.07

5.4. Erosion and Deposition Analysis

The extreme braided nature of the Brahmaputra combined with silt and sand layers of the banks is the primary cause of erosion. Erosion in this area was very little before the 1950 earthquake of magnitude 8.6 Richter scale however became dynamic from that point and attained serious dimension after the 1954 flood [45]. In 1987, Majuli endured the most serious flood having lost more than 50,000 cows and harvest [61]. The reasons behind the flooding and erosion are a combination of several natural and anthropogenic elements [62]. The unique geographic setting of the region, high potent monsoon precipitation system, effectively erodible geological formations of the island and in the upper catchments, high seismic activity, siltation, quick channel aggradation, huge deforestation, explosive population growth particularly in the flood- prone belt, and unplanned types of temporary measures of flood control are a portion of the predominant components causing or escalating floods in Majuli [63].

For erosion and deposition analysis of north bankline / right bankline of Brahmaputra river along Majuli island the multi-temporal satellite remote sensing data i.e. Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI have been used. These analyses have been carried-out from 1996 to 2020 by using ArcGIS 10.7 software. Year wise (1996-2020) total erosion and deposition statistics of Majuli island along Brahmaputra river is given in Table 6 and shown in Figure 10. Negative values are used for erosion and positive values are used for deposition.

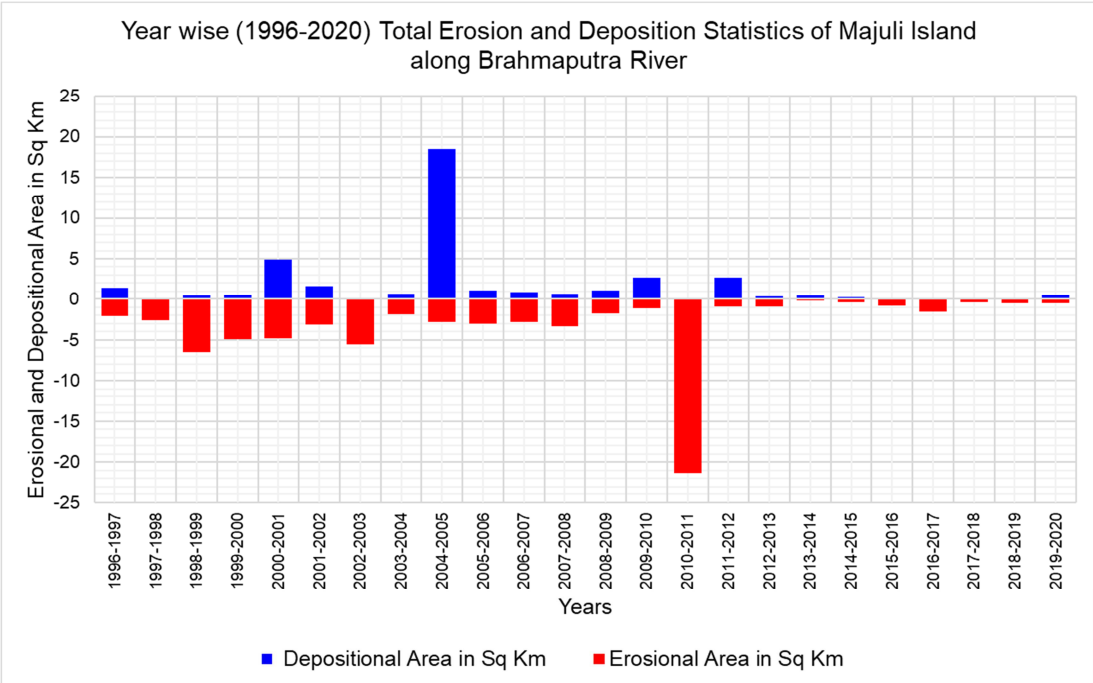

Figure 10. Year wise (1996-2020) Total Erosion and Deposition Statistics of Majuli Island along Brahmaputra River.

Overall erosion of the Majuli island along Brahmaputra river in from 1996 to 2020 exceeds overall deposition. The average depositional area from 1996 to 2020 (25 years) is 1.66 Km^2, while the while average erosional area from 1996

to 2020 (25 years) is 3.07 Km^2. From these statistics it is clear that downstream (south-west) area of Majuli island is more active, where Subansiri river and Brahmaputra river conference point situated in comparison to upstream (north-east). The particular stretch of Majuli island along Brahmaputra river has lost approximately 3.07 Km^2 area per year and gained only 1.66 Km^2 per year. Referring to Figure 10, the erosion and deposition pattern of the Majuli island along Brahmaputra river is showing a decreasing trend, and after the year of 2011, these has more-or-less no erosion and deposition, which corresponds to the good flood management in Majuli island over the last few years.

It may be concluded that riverbank erosion is a natural phenomenon, which is a very severe problem along the Brahmaputra river specially in Majuli Island. The following is considered the most important contributing factors of riverbank erosion in Majuli island.

1) High intensity rainfall and resultant flood events
2) Highly erodible bank material
3) Rate of rise and fall of river water level
4) Number and position of major channels active during flood stage
5) Angle at which the thalweg approaches the bankline
6) Amount of scour and deposition that occurs during flood
7) Variability of cohesive soil in bank material composition
8) Formation and movement of large bed forms
9) Soil characteristics
10) Drainage system
11) Slope
12) Land use / land cover change

6. Conclusion

The erosion in the Majuli island is very escalated and its impacts on the people of the region is very extreme. It is essential that devastating floods are constantly accompanied by serious disintegration. Since days of yore, the flow of excess water from the slopes in the monsoon season in the Brahmaputra river causes havoc in the areas. Bank erosion is a process through which there happens changes in channel dimensions by lateral widening. Bank erosion is serious in the study area and due to moving Brahmaputra river will in general erode the banks and broaden the channel by undermining and bank caving. The bankline in the Majuli island is extremely unstable and bank failures uncontrolled in several territories along the Brahmaputra river during the monsoon season. The Majuli island needs corrective measure, appropriate planning, and governmental support to stabilize the riverbank lines and protect riverbank from erosion. The causes of failure of riverbanks can be seen by the following ways:

1) Underwater erosion along the toe of bank during the falling stage of the river
2) Direct erosion of the riverbank
3) Sloughing of saturated bank caused by rapid drawdown
4) Liquefaction of saturated silty and sandy bank material
5) Erosion due to seepage from banks at low river discharge

Acknowledgements

Author is grateful to Managing Director, DHI (India) Water & Environment Pvt Ltd, New Delhi. India for providing the necessary facilities to carry out this work.

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