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Morphological Study of Brahmaputra River in Assam Based on Historical Landsat Satellite Imagery from 1996 to 2020

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Abstract

This study has made use of remote sensing data to provide a general overview of the course of the Brahmaputra river in Assam over the past two-and-half decades and to uncover many specific features. The study has demonstrated the potential of applying remote sensing data for the rapid interpretation of the features of the braided river covering a large area. The study has revealed the benefits of effective use of geospatial data and riverbank mapping specially for preparation of soil texture map, geological map, geomorphological map, lineament map, and analysing braiding indicators, mean river width, erosion / deposition trends, and bankline migration trends. The methodology, analyses and results from this study can guide similar studies on tributaries of the Brahmaputra river and/or other riverbank management systems in Assam. The erosional area from 1996 to 2020 along Brahmaputra river in the Assam state is 1,624.62 Km^2, while the depositional area is 917.22 Km^2. The Brahmaputra river has lost approximately 67.69 Km^2 of land per year and gained only 38.22 Km^2 per year. The erosional areas from 1996 to 2020 is continuously decreasing, and it has decreased approx. 47%, which corresponds to the good flood management in Brahmaputra river over the last few years, but the study area needs corrective measure, appropriate planning, and governmental support to stabilize the bank lines and protect them from riverbank erosion. The results of this study can be a base for further analysis in future considerations of long-term erosion protection measures along the Brahmaputra river in Assam. The results can be made more precise by considering char lands and with high-resolution satellite imagery e.g. QuickBird, GeoEye, WorldView.

Keywords

River Morphology, Erosion/Deposition, River Migration, Brahmaputra River, and RS/GIS

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1. Introduction

River and channel are kinds of natural watercourses on the surface of the earth and have become the critical part of geological components. The river course has repeatedly moved in space as time goes on and will in general achieve balance positions to oblige itself with different fluvial geomorphic similarly as a climatic condition [1]. This change happens in various regions, including fluvial, glacial, dry, wind, coastal and karst morphology in view of the Earth's dynamic events [2]. River morphology is the consequence of a common collaboration of four general classifications of factors like fluid dynamics, (including velocity, discharge, roughness, and shear stress), channel character or channel configuration (including channel width, depth, and material) [3]. Riverbank erosion has significant ramifications for short as-well-as long-term channel adjustment, development of plan form, braiding, sediment dynamics of river basin, and d/s sedimentation issues [4]. Recognizing the behavior through which river channels have travelled through time is basic to deal with numerous geomorphic and river management issues, considering enormous size, for example, paces of progress is important to quantify and screen channel movement [5]. A sounder comprehension of morphological changes of alluvial

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rivers, bankline movement because of erosion and deposition measure just as method to identify the pattern can be reasonable for the management of alluvial environments.

Large number of studies identified with the morphology of Brahmaputra river system focuses on the primary river channel of Brahmaputra [6-17].

The numerous river morphological model of the Brahmaputra river has been explained by [6, 18-19] in Bangladesh and by [20] in Assam. [7, 18, 21-23] have analyzed the river morphology, river bankline migration, and hydraulic process of the Brahmaputra in Bangladesh. Sedimentation study of the char bars of the Brahmaputra river was analyzed by [6, 19-20, 24-27]. In hydrological point of view, [28] has conducted a morphological study of the Brahmaputra in Assam. The [29] has regularly performed the geomorphological investigation of the Brahmaputra basin. Erosion rate and river bankline migration of the Brahmaputra river have been analyzed by [6, 18, 30-31] in Bangladesh; and [9-10, 32-33] in Assam. [34] has done the hydro-geomorphological mapping of the Brahmaputra in Assam. Danish Hydrological Institute (DHI) has set-up the river morphological model, real-time flood forecasting and early warning model, and embankment breach prediction model in Brahmaputra river for Flood and Riverbank Erosion Management Agency of Assam (FREMAA) under Assam Integrated Flood and Riverbank Erosion Risk Management Investment Program (AIFRERMIP) [35].

The main objectives of this paper are preparing soil texture map, geological map, geomorphological map, lineament map of the Assam state, and analysing braiding indicators, mean river width, erosion / deposition trends, and bankline migration trends along the Brahmaputra river within Assam from 1996 to 2020 using multi-temporal satellite imageries.

2. Study Area

The Brahmaputra river is the youngest (in term of geology) major river of the world, flows across the rising younger Himalayan range, originate from Mansarovar lake at an elevation of 5300 m in Tibet. In the present study, a reach of 681.29 Km on main Brahmaputra river and its course in Assam from u/s of Confluence of Dihang, Dibang and Lohit to Dhubri near India-Bangladesh international border has been considered. River morphology studies are required to identify the order of streams and river reaches (or stretches) throughout the length of the rivers [35]. Therefore, Brahmaputra river has been divided into 6 reaches. The lengths of reaches range from 73 Km to 151 Km. Care has been taken to avoid that intersections reaches are close to vulnerable areas with major river morphological changes. Reaches wise river cross-section at 500 m interval on Brahmaputra river starting from Ranaghat bridge (Pasighat) to South Salmara Mankachar (India-Bangladesh border) has demarcated. Details of the demarcated river reaches, their lengths, and total number of cross-sections are given in Table 1 and shown in Figure 1.

Table 1. Reach Name and its Total Lengths.

S. No.	Reach No. and Name	Length of Reach (Km)	Total Number of Cross-Sections
1	01 - Confluence of Dihang, Dibang and Lohit to Bogibeel Bridge	120.91	240
2	02 - Bogibeel Bridge to Nimati Ghat	73.95	147
3	03 - Nimati Ghat to Tezpur	151.19	307
4	04 - Tezpur to Pandu	131.18	264
5	05 - Pandu to Goalpara	113.26	228
6	06 - Goalpara to Dhubri	90.80	196
	Total	681.29	1382

2.1. River and Drainage System

The origin of the Brahmaputra river is at an altitude of 5300 meters from the Kailash ranges of the Himalayas. It flows through Tibet, then enters India through Arunachal Pradesh and flows through Assam and Bangladesh, then it connects with Bay-of-Bengal. The total basin area of Brahmaputra river is 580 thousand Km^2 up to its confluence within Bangladesh. Out-of-that, 293 thousand Km^2 area fall in Tibet, 240 thousand Km^2 area fall in India-Bhutan, and 47 thousand Km^2 area fall in Bangladesh. The drainage area in India is 194 thousand Km^2 which is about 5.9% of the total geographical area of the country.

The Assam valley from Kabo to Dhubri during its course consists of about 48 important tributaries on the north bank of the river and 44 on its south bank. Important north bank tributaries and south bank tributaries is shown in Figure 2.

2.2. Topography

The shape of Brahmaputra basin is irregular. The max. length of basin from east to west is 1,540 Km, while max. width of the basin from north to south id 682 Km. The basin lies between 25° 02' 30.63" N to 30° 58' 12.15" N latitude and 81° 51' 38.23" E to 97° 40' 00.80" E longitude. The elevation in upper part of Brahmaputra basin in Tibetan plateau are elevation varying from 3,000 to 5,300 m (amsl) with numerous glaciers [36], while whole Brahmaputra basin elevation are ranges from 5300 m to 0 m (Figure 2). The

Brahmaputra river drains diversified environments such as cold-and-dry plateau of Tibet, rain-drenched Himalayan slopes, the alluvial plains of Assam and the ambient deltaic lowlands of Bangladesh [35].

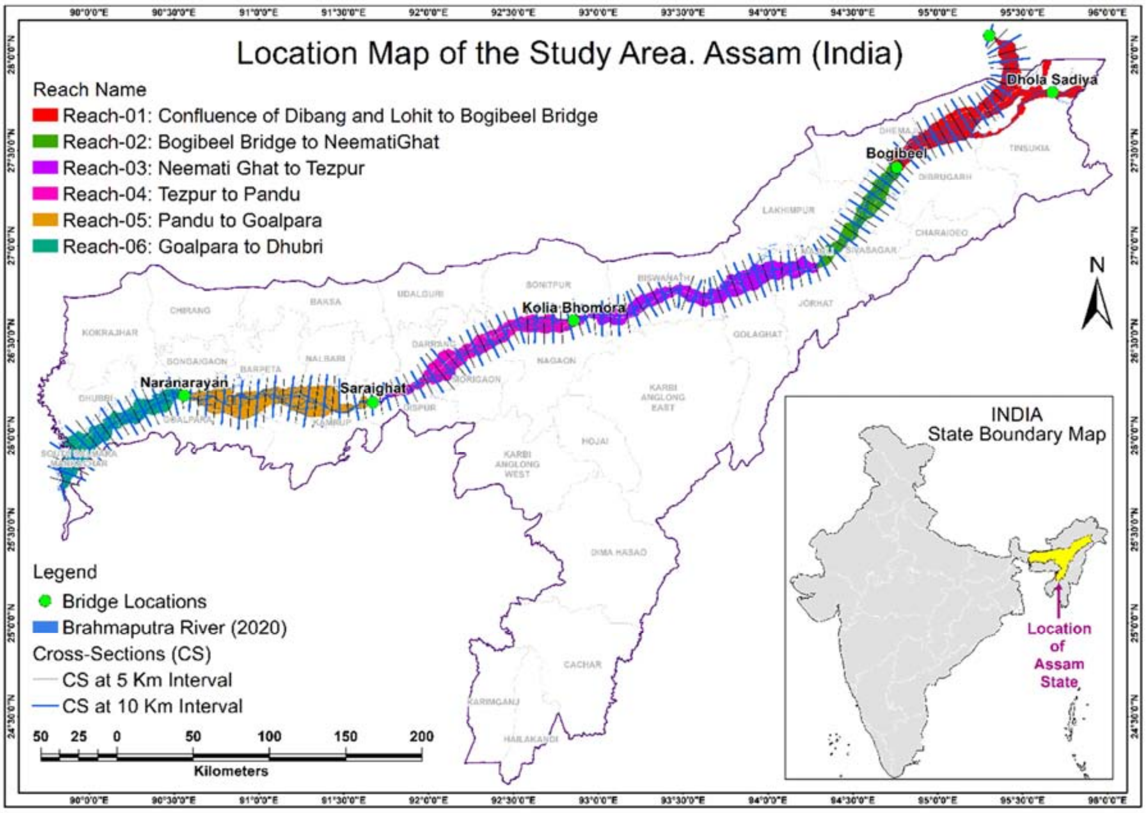

Figure 1. Location Map of the Study Area, Assam.

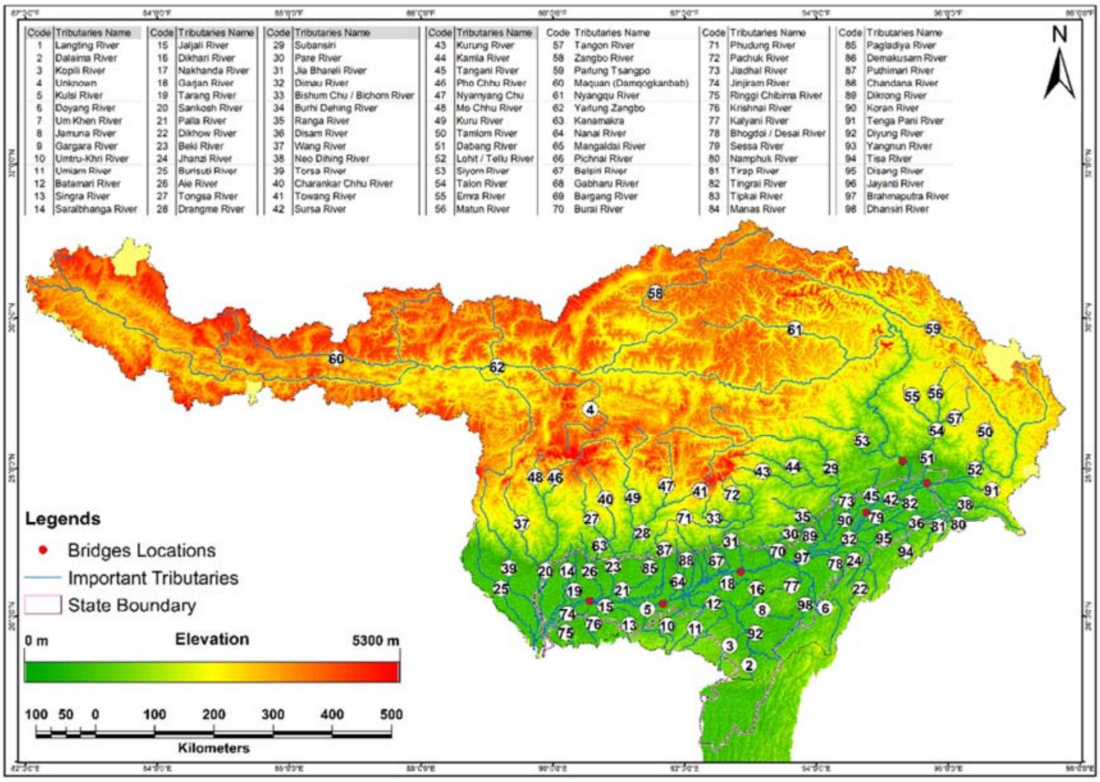

Figure 2. Important Tributaries and Topographic Map of Brahmaputra Basin.

3. Data Use, Source and Methodology

Table 2. Data Used and their Sources.

S. No.	Data layer / maps	Data sources
1.	Landsat series satellite imageries from 1996 to 2020	Landsat satellite imageries from 1996 to 2020 were downloaded from Earth Explorer, USGS. 1) Landsat-5 TM satellite imageries: 1996, 1997, 1998, 1999, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011. 2) Landsat-7 ETM+ satellite Imageries: 2000, 2001, 2002, 2003, 2012, 2013. 3) Landsat-8 OLI satellite imageries: 2014, 2015, 2016, 2017, 2018, 2019, 2020. Total Number of Satellite Scenes = 275. Spatial Resolution: 30 m Source: https://earthexplorer.usgs.gov
2.	Elevation data	Shuttle Radar Topography Mission (SRTM) DEM data of Brahmaputra basin with 30 m spatial resolution has been downloaded from NASA & USGS EROS Data Centre. Area covered: 503,855.63 Km^2 Source: http://glcfapp.glcf.umd.edu:8080/esdi
3.	Soil texture	Soil map has been downloaded from National Soil Survey, and National Atlas and Thematic Mapping Organization (NATMO), 1981. 1) This map has been geo-referenced and digitized and prepared a soil texture map. 2) This maps also updated through Landsat-8 OLI satellite imagery (2020) and has been verify through limited field check. Source: https://www.nbsslup.in
4.	Geology	Geological quadrangle maps have been downloaded from Geological Survey of India (GSI) website. 1) These maps have been geo-referenced and digitized and prepared a geological map. 2) The geological map has been updated through Landsat-8 OLI satellite imagery (2020), and Survey of India (SoI) Toposheets at 1:50,000 scale with limited field check. Source: http://www.portal.gsi.gov.in
5.	Geomorphology	Geomorphological map of the Assam state has been prepared by using Landsat-8 OLI satellite imagery (30 m) and SRTM DEM data (30 m) with limited field check. Geological map (structural i.e. lineaments, faults, folds, joints; and lithological) from Geological Survey of India (GSI), and Survey of India (SoI) topographic maps at 1:50,000 scale have also referred [37].

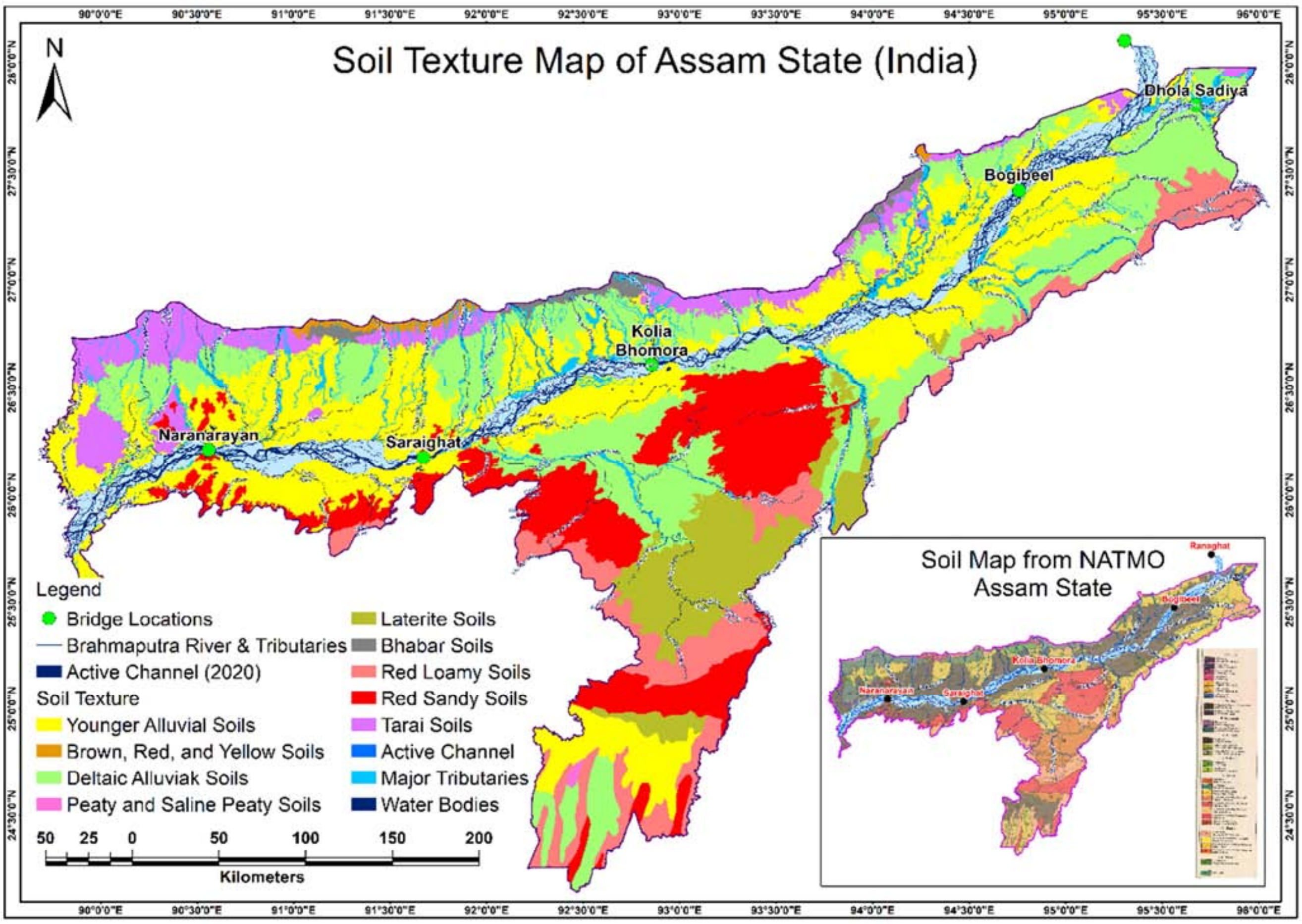

Figure 3. Soil Texture Map of Assam State.

4. Result and Discussion

4.1. Soil Texture Mapping

Soil is the most valuable nature resource and one of the major prime requisites of life [35]. Geology (parent material), topography and climate play an important role in their formations. The following activities have been performed for generation of soil texture map of the Assam state.

Scanning and Geo-referencing of Collected Paper Maps: The collected paper maps from 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 maps obtained after geo-processing stage have 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 and mosaic soil map has 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 SRTM 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 Assam state is shown in Figure 3.

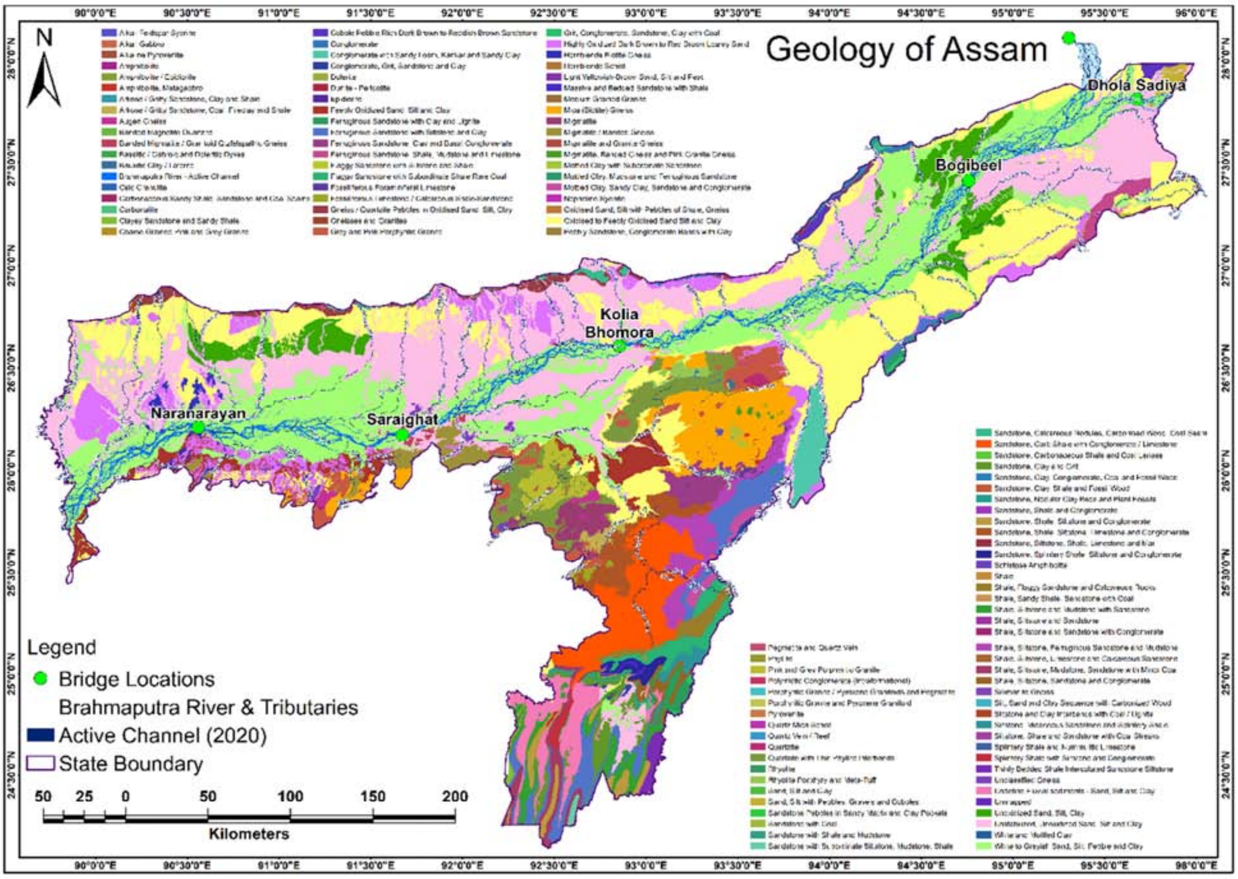

Figure 4. Geological Map of Assam State.

4.2. Geological Mapping

The geology of the study area plays an important role in the long-term morphological process [35]. Published geological quadrangle maps from have been downloaded from Geological Survey of India (GSI) website, and the same have been used for the preparation of a geological map of Assam state. The geological map has been updated through Landsat-8 OLI satellite imagery (2020), Survey of India (SoI) Toposheets at 1:50,000 scale, and SRTM DEM data (30 m) by using ArcGIS-10.7 software along with limited field check (Figure 4).

Various geologists have contributed to diverse geological aspects of the study area. Notable among these are [38-54]. They have recorded the principal rock formations: Newer or low-level alluvium, older alluvium, Kimin formation, Subansiri formation, Dihing formation, Dupitila formation, Namsang formation, Girujan clay formation, Tipam sandstone formation, Bokabil formation, Bhuban formation, Renji formation, Jenam formation, Laisong formation, Kopili formation, Shella formation, Langpar formation, Sylhet Trap, Kaharbari formation, and Talchir Formation. Details of formation has been shown in Figure 4.

4.3. Geomorphological Mapping

Landforms are the most distinguishing features on the surface of the Earth. Since they affect the life of human beings in various ways, they have been used for habitation, farming, construction of roads and dams, building materials and mineral extraction and the life of human beings by accelerated erosion, mass movement, landslides, their study undertakes great importance for the mankind [55].

The geomorphological map of the Assam state has been prepared by using Landsat-8 OLI satellite imagery (30 m) and SRTM DEM data (30 m) with limited field check. Geological map (structural i.e. lineaments, faults, folds, joints, and lithological) and Survey of India (SoI) topographic maps at 1:50,000 scale have also been referred. The various geomorphic units and their component were identified and mapped. The geomorphological map of Assam state is shown in Figure 5.

4.4. Lineaments Mapping

Lineaments play significant role in the study of river morphology. Well water yields often show a positive correlation with linear characteristics or with intersection of two features [56-57]. Hence, mapping of landforms and lineaments using remote sensing data and GIS is now very common [58]. Lineaments can Specified as linear features of geological significance spanning several Kms in length. These linear features typically represent faults, fractures or shear zones and are identified on satellite images based on tonal contrast, stream / river alignment, and differences in vegetation and knock-points in topography [58-59]. Lineament studies from satellite remote sensing imageries are provide important information on sub-surface fractures that can control the circulation and storage of groundwater [60]. A lineament map of the study area has been prepared using Landsat-8 OLI satellite imagery and SRTM DEM data and shown in Figure 6. Total 845 lineaments have been identified and marked in the Assam state. A detail summary of the lineaments is given in Table 3.

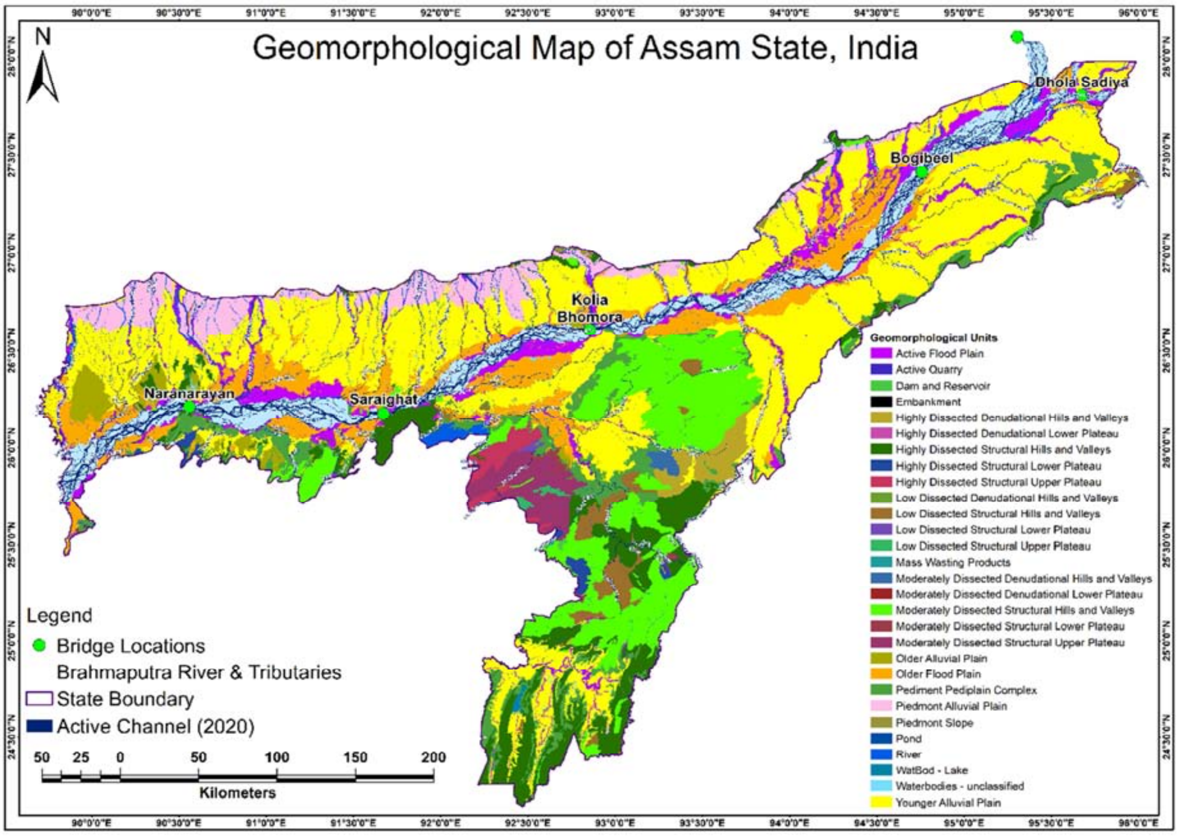

Figure 5. Geomorphological Map of Assam State.

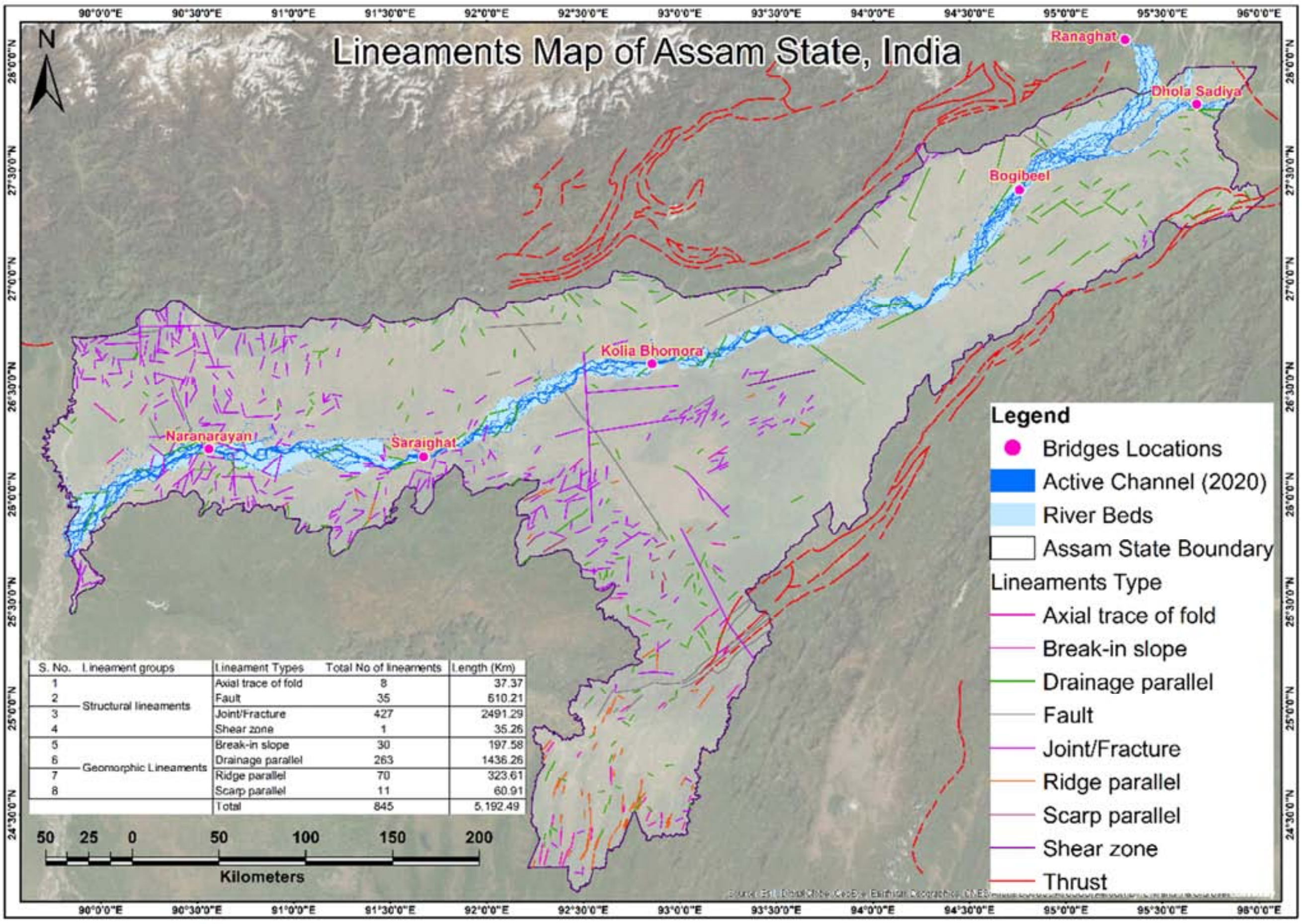

Figure 6. Lineaments Map of Assam State.

Table 3. Detail Summary of the Lineaments.

S. No.	Lineament Groups	Lineament Types	Total No of Lineaments	Length (Km)
1	Structural lineaments	Axial trace of fold	8	37.37
2		Fault	35	610.21
3		Joint/Fracture	427	2491.29
4		Shear zone	1	35.26
5	Geomorphic Lineaments	Break-in slope	30	197.58
6		Drainage parallel	263	1436.26
7		Ridge parallel	70	323.61
8		Scarp parallel	11	60.91
		Total	845	5,192.49

4.5. Mean River Width

The river width has been measured at 1382 cross-sections of Brahmaputra river by using multi-temporal satellite remote sensing data from 1996 to 2020. 1382 cross-sections vs river width (m) have been plotted from 1996 to 2020 (Figure 7), and it is observed that river width is large in the flood year. Reached wise mean river width is given in Table 4.

Table 4. Reaches wise Mean River Width.

S. No.	Reach No	Reach Name	Cross-Sections (from-to)	Total Number of Cross-Sections	Mean River Width (1996 to 2020) (Km)
1	Reach-01	Confluence of Dihang, Dibang and Lohit to Bogibeel Bridge	000+000 to 119+000	240	10.412
2	Reach-02	Bogibeel Bridge to Nimati Ghat	119+500 to 193+500	147	8.529
3	Reach-03	Nimati Ghat to Tezpur	194+000 to 347+000	307	8.647
4	Reach-04	Tezpur to Pandu	347+500 to 479+000	264	8.286
5	Reach-05	Pandu to Goalpara	479+500 to 593+500	228	10.073
6	Reach-06	Goalpara to Dhubri	594+000 to 690+500	196	10.329
[#]*Total Number of Cross-Sections, *Average River Width of Brahmaputra River*				1382[#]	9.379*

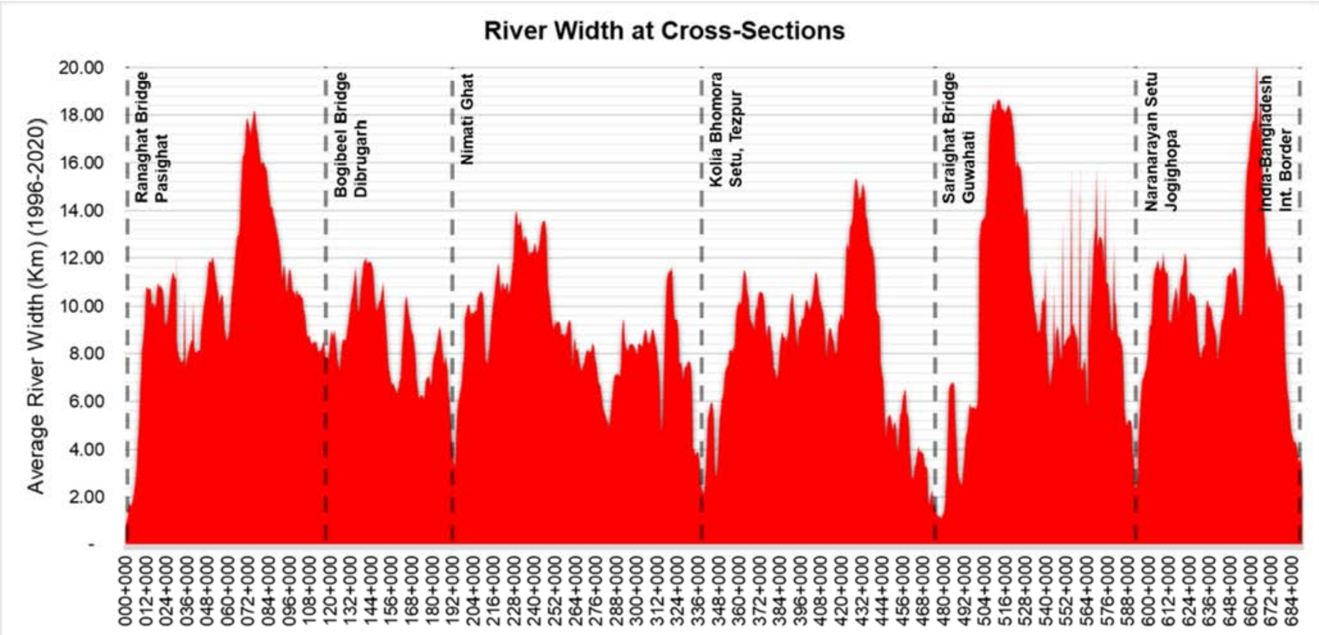

Figure 7. Cross Section vs River Width (1996 to 2020).

4.6. Plan Form Index and Braiding Indicators

Degree of braiding of highly braided river can be measured by plan form index (PFI), which has been developed by [61]. This can be measured by ((T/B) x 100) / N, where: T = flow top width, B = overall width of the channel, and N = number of braided channels. Plan form index (PFI) indicates to the fluvial landform disposition with regard to an allotted water level and its smaller value is represent of a higher degree of braiding. [61] has also proposed a broad range of classification of the braiding phenomenon based on the PFI values. According to him if PFI value is less than 4, then river is highly braided; if PFI values are ranging between 4 and 19, then river is moderately Braided, and if PFI value is more then 19, then river is low braided.

The newer braiding indicator PFI has been adopted for the study to analyze the braiding behavior of Brahmaputra river. The PFI has been measured at 1382 cross-sections of Brahmaputra river by using multi-temporal satellite remote sensing data from 1996 to 2020. Reached wise plan form index (PFI) of the Brahmaputra river is given in Table 5.

Table 5. Reached wise Mean Plan Form Index (PFI) of the Brahmaputra River.

S.No.	Reach No. and Name	Total Number of Cross-Sections	Mean PFI	Braiding Indicators
1.	Confluence of Dihang, Dibang and Lohit to Bogibeel Bridge	240	15.53	Low Braided
2.	Bogibeel Bridge to Nimati Ghat	147	11.38	Moderately Braided
3.	Nimati Ghat to Tezpur	307	09.14	Moderately Braided
4.	Tezpur to Pandu	264	12.92	Low Braided
5.	Pandu to Goalpara	228	05.40	Moderately Braided
6.	Goalpara to Dhubri	196	02.63	Highly Braided

4.7. Riverbank Erosion and Deposition Areas

Multi-temporal satellite remote sensing data of Landsat-5 TM (30 m), Landsat-7 ETM (30 m), and Landsat-8 OLI (30 m) have been used to digitize bank lines from 1996 to 2020 (25 years). The area of erosion and deposition between each cross-sections line (at 500 m interval) on left bankline and right bankline along the Brahmaputra river in Assam were calculated and mapped using ArcGIS 10.7 software. Erosion and deposition area on left bankline and right bankline between each cross-sections line from all the unions from 1996 to 2020 were calculated. Year wise (1996-2020) total erosion and deposition statistics on left bankline and right bankline of Brahmaputra river in Assam is given in Table 6 and shown in Figure 8. Negative values are used for erosion and positive values are used for deposition.

Table 6. Year wise (1996-2020) Total Erosion and Deposition Statistics on Left Bankline and Right Bankline of Brahmaputra River in Assam.

S. No.	Years	Right Bankline (Area in Sq. Km)		Left Bankline (Area in Sq. Km)	
		Deposition	Erosion	Deposition	Erosion
1	1996-1997	32.31	-31.83	10.20	-37.83
2	1997-1998	14.18	-26.64	11.49	-44.04
3	1998-1999	33.00	-71.93	9.17	-85.76
4	1999-2000	7.77	-49.79	17.13	-38.26
5	2000-2001	67.09	-26.41	17.70	-51.61
6	2001-2002	13.74	-35.78	55.15	-22.99
7	2002-2003	13.78	-31.92	16.41	-41.00
8	2003-2004	11.97	-37.48	11.98	-48.10
9	2004-2005	50.33	-37.32	25.87	-39.66
10	2005-2006	17.11	-28.22	33.96	-24.89
11	2006-2007	36.34	-22.30	54.55	-18.89
12	2007-2008	9.52	-42.38	10.12	-35.94
13	2008-2009	12.29	-41.82	13.57	-32.09
14	2009-2010	26.71	-30.98	9.15	-48.10
15	2010-2011	24.67	-57.91	35.58	-46.99
16	2011-2012	18.20	-21.16	17.99	-15.01
17	2012-2013	11.53	-29.02	18.02	-43.11
18	2013-2014	13.03	-14.43	17.57	-23.39
19	2014-2015	5.44	-19.30	15.11	-35.08
20	2015-2016	7.30	-14.90	20.90	-33.23
21	2016-2017	7.52	-31.58	19.38	-23.07
22	2017-2018	7.56	-17.90	12.14	-21.91
23	2018-2019	9.50	-13.34	2.32	-25.27
24	2019-2020	6.27	-17.60	4.59	-36.39
	Total	457.16	-751.97	460.06	-872.66
	Average	19.05	-31.33	19.17	-36.36

Overall erosion of the Brahmaputra river in Assam from 1996 to 2020 exceeds overall deposition. The depositional areas on right bankline and left bankline is 457.16 Km^2, and 460.06 Km^2 respectively, while erosional areas on right bankline and left bankline is 751.97 Km^2, and 872.66 Km^2 respectively. The average depositional area from 1996 to 2020 (25 years) on right bankline and left bankline is 19.05 Km^2, and 19.17 Km^2 respectively, while average erosional area from 1996 to 2020 (25 years) on right bankline and left bankline is 31.33 Km^2, and 36.36 Km^2 respectively. From these statistics it is clear that left bankline is more active then the right bankline. The Assam valley of the Brahmaputra river has lost approximately 67.69 Km^2 of land per year and gained only 38.22 Km^2 per year. Referring to Figure 8, the erosion and deposition pattern of Brahmaputra river is showing a decreasing trend, which corresponds to the good flood management in Assam state over the last few years.

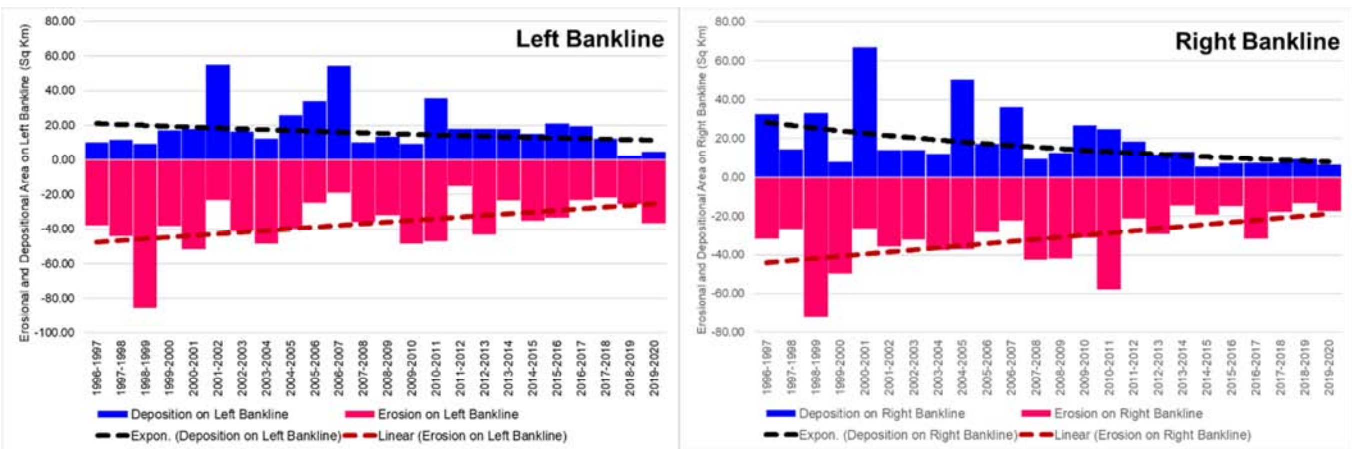

Figure 8. Year wise (1996-2020, 25 years) Total Erosion and Deposition Area on Left Bankline and Right Bankline of Brahmaputra River in Assam.

Each cross-section (at 5 Km interval) wise overall (1996-2020, 25 years) average erosion and deposition area on left bankline and right bankline of Brahmaputra river in Assam is shown in Figure 9.

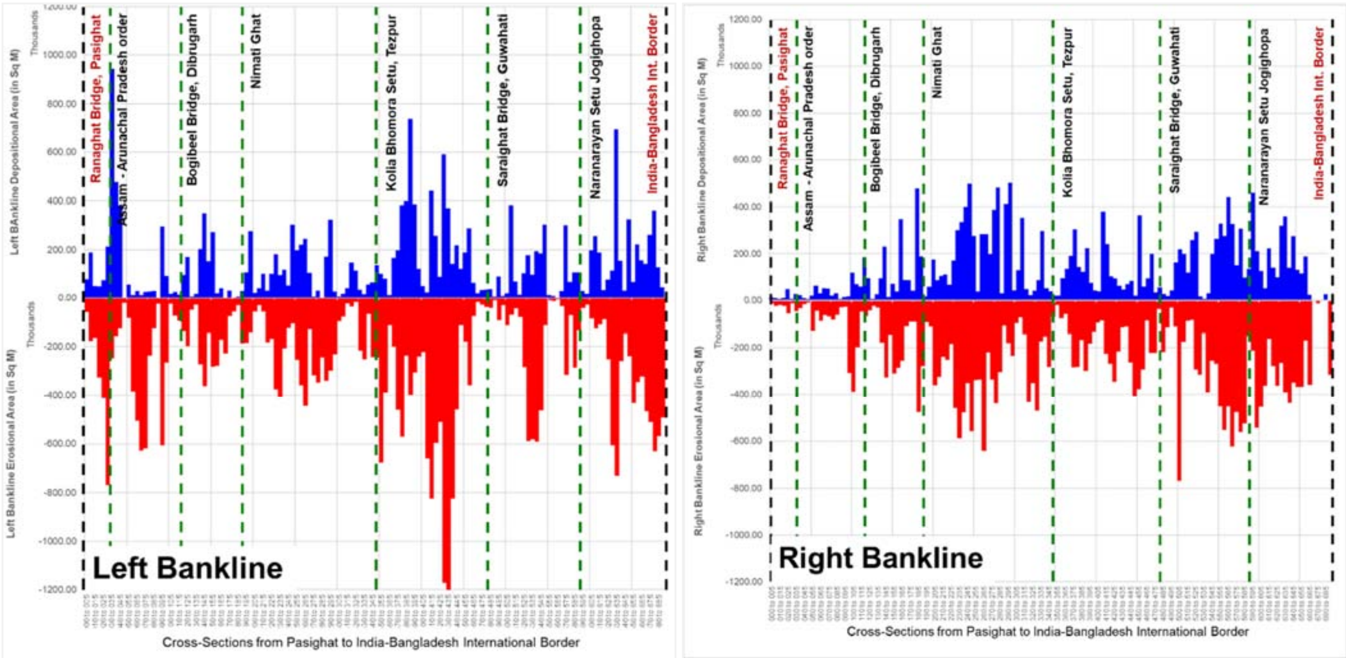

Figure 9. Overall (1996-2020, 25 years) Average Erosion and Deposition Statistics on Left Bankline and Right Bankline of Brahmaputra River in Assam.

The morphology and behavior of the Brahmaputra river undergo drastic changes in response to various flow regimes. Erosion in the Brahmaputra river is a common occurrence, but it becomes a matter of serious concern as soon as it takes the form of a disaster [62]. The study area is also prone to catastrophic flooding, but the situation in the area is grim due to severe erosion along the bankline with flooding. During the monsoon season, rivers coming from the mountains bring huge amounts of water and sediment and fill the entire channel area. Due to the creation of chars, it affects the stability of channels and banklines. As we can see in the Figure 9 the erosion is quite intensive in both banklines and it is not uniform along the banks. The erosion rate and eroded area is higher along the left bank then the right bank.

4.8. River Bankline Migration Analysis

The Brahmaputra river is constantly changing the course of its course due to the geomorphic (water, velocity), climate agents (flood) and human activities (sand excavation, removal of vegetation cover and excavation of fertile soil) [35]. GIS techniques (spatial-temporal analysis of satellite imageries), using advanced satellite remote sensing data from 1996-2020 have been used to identify changes in the river course and further computation has analysed river bankline migration. The multi-temporal remote sensing data were individually processed and analysed in a GIS environment. By overlaying these databases, the river bankline (both - right 'north bankline' and left 'south bankline') migration of the Brahmaputra river has been identified. The shifted parts of the river have been mapped by vectorisations in GIS.

The river bankline migration has been measured at 1382 pre-fixed cross-section lines (at 500 m interval). The bankline migration has been measured in both - right bankline and left bankline with reference to length (in metres) and direction. A positive value (+) indicates that the river bankline has migrated to right direction from previous study year, while a negative value (-) indicates that the river bankline has migrated to left direction from previous study year. Cross-section wise river bankline migration data from 1996 to 2020 (over the years, 25 years) is shown in Figure 10.

Figure 10 show the cross-section wise river bankline migration data from 1996 to 2020 of right bankline and left bankline of the Brahmaputra river in Assam. It is evident from this graph that a minimum of five major geological control points (shown by the red dotted line) are present in the Brahmaputra river and its flood plains [63]. In comparison to other reaches along the Brahmaputra river, these locations are more-or-less stable. These geological control points are given in Table 7.

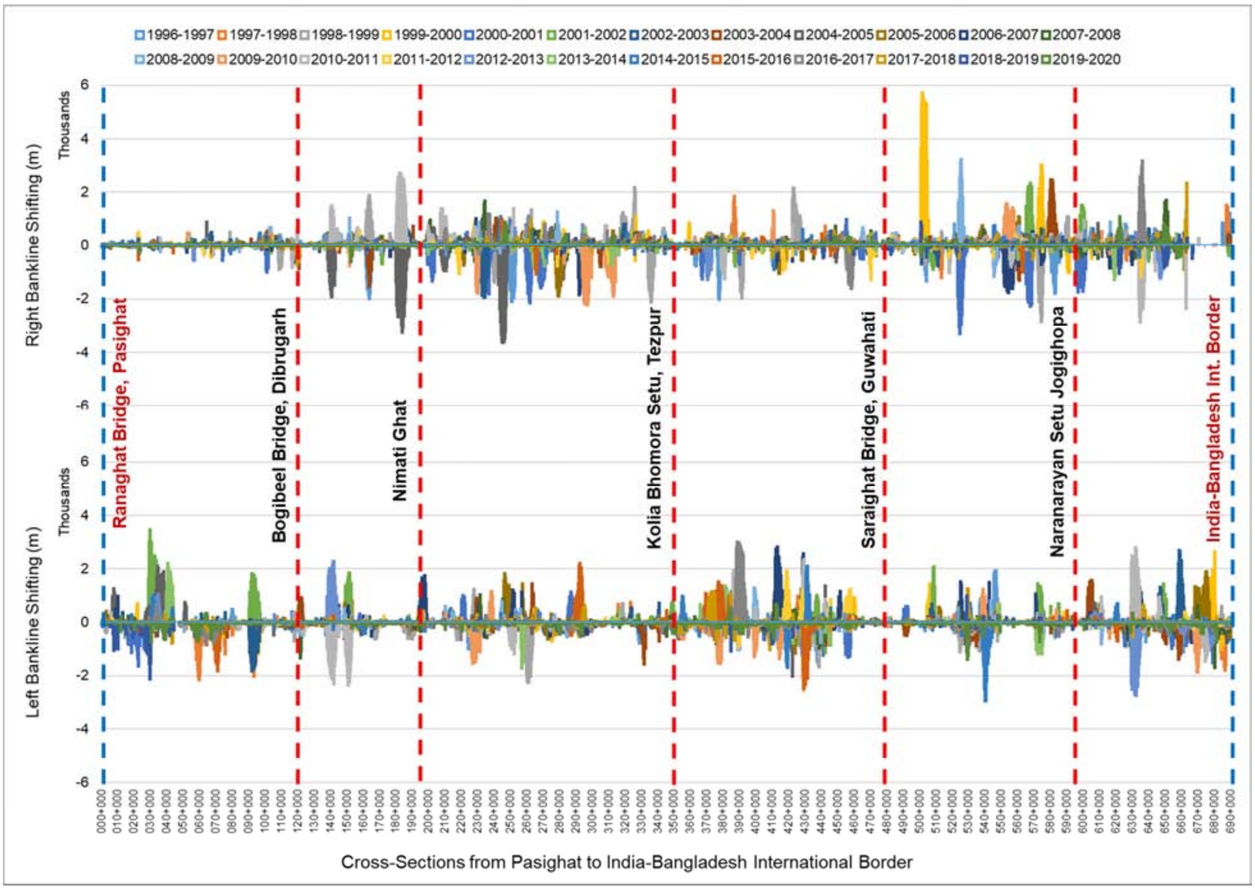

Figure 10. Cross-Section wise River Bankline Migration from 1996 to 2020.

Table 7. Bankline Migration Data at Geological Control Points along Brahmaputra River in Assam.

S. No.	Geological control points	Cross-section Number	25 Years Average River Width (Km)	25 Years Average Bankline Migration (1996 - 2020 (m)#	
				Right Bankline	Left Bankline
1	Bogibeel Bridge, Dibrugarh	119+000	4.94	- 57.32 *	+ 25.40 *
2	Nimati Ghat, Jorhat	193+500	3.42	+ 2.55	- 3.73
3	Kolia Bhomora Setu, Tezpur	347+000	2.92	- 1.17	- 0.62
4	Saraighat Bridge, Guwahati	479+500	1.24	+ 1.32	+ 0.31
5	Naranarayan Setu, Goalpara	593+500	2.65	+ 0.89	- 2.33

* Construction of Bogibeel bridge was started on dated 21st April 2002, and bridge has been opened for transportation from 25th December 2018. During the construction stage, this reach was morpho-dynamically more active, due to this shifting rate is too high. After completion of bridge, this reach is more-or-less stable.

5. Conclusion

The amount of erosion due to Brahmaputra river in the Assam state during 1996-2020 is more than the amount of deposition. The erosional area from 1996 to 2020 along Brahmaputra river in the Assam state is 1,624.62 Km^2, while the depositional area is 917.22 Km^2. The Brahmaputra river has lost approximately 67.69 Km^2 of land per year and gained only 38.22 Km^2 per year. The maximum erosion from 1996 to 2020 was observed in Majuli district, then Morigaon district, then Tinsukia district, then Dibrugarh district, then Barpeta district, while the minimum erosion was observed in Jorhat district, then Nalbari district, then Sivasagar, and then other districts. The maximum deposition from 1996 to 2020 was observed in Tinsukia district, then Biswanath district, then Majuli district, then Sonitpur district, then Dhemaji district, while minimum deposition was observed in Sivasagar district, then Bongaigaon district, then Jorhat district, and then other districts. The erosional areas from 1996 to 2020 is continuously decreasing, and it has decreased approx. 47%, which corresponds to the good flood management in Brahmaputra river over the last few years.

The total vulnerable and erosional bankline length from 2010 to 2020 along Brahmaputra river is 918.39 Km. The maximum vulnerable and erosional bankline lengths have in Majuli district (141.66 Km), then Barpeta district (82.61 Km), then Tinsukia district (66.95 Km), then Dibrugarh district (64.55 Km), then Goalpara district (58.38 Km), then Sonitpur district

(53.08 Km), while the minimum vulnerable and erosional bankline lengths have in Nalbari district (3.19 Km), then Sivasagar district (7.69 Km), then Dispur district (19.12 Km), then other districts. The left (south) riverbank has 499.78 Km (54.42%) vulnerable and erosional bankline lengths, while the right (north) riverbank has 418.61Km (45.58%) vulnerable and erosional bankline lengths. The very-highly sensitive bankline length is 198.30 Km (21.59%), highly sensitive bankline length is 172.28 Km (18.76%), moderate sensitive bankline length is 199.95 Km (21.77%), and low sensitive bankline length is 347.85 Km (37.88%).

According to this study, the study area needs corrective measure, appropriate planning, and governmental support to stabilize the river banklines and protect riverbank from erosion. The erosion in the study area is quite intense and its impact on the people of the area is quite severe. The bank erosion in the study area is severe and the migration of the Brahmaputra river is causing the banks to erode and widen the channel by undercutting and bank caving. During the monsoon season, the bankline is highly unstable in various areas along the Brahmaputra river and the bank's failures are very high.

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