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Historical Morphodynamics and Hydromorphogeobathymetry Investigation of an Area Around Dibru-Saikhowa National Park, Assam

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Abstract

Remote sensing and GIS technologies presently has an essential tool for fluvial morphological studies i.e. historical morpho-dynamics, mean river with, spatio-temporal analysis of erosional / depositional areas, bankline migration analysis as well as geological mapping, geomorphological mapping, gravity changes and groundwater storage changes, and bathymetry analysis. These studies have been performed in an area around Dibru-Saikhowa National Park is a river island in the upper Brahmaputra valley of Assam, India by using multi-temporal, multi-spatial, and multi-spectral Landsat satellite imageries from 1973 to 2021; Geo-technical investigations and sub-soil explorations data of year 2020; Gravity Recovery and Climate Experiment (GRACE) data from 2004 to 2017; and bathymetric survey data of year 2020. River width has been measured at 123 cross-sections of Brahmaputra river and observed that average river width is suddenly change from 13.03 Km in 1996 to 17.53 Km in 1997, when Dibru-Saikhowa National Park become an isolated patch of land forming as river island. The area around Dibru-Saikhowa National Park is highly morpho-dynamics in term of erosion, deposition and bankline migration. The average depositional area from 1973 to 2021 on right bankline and left bankline is 3.23 Km^2, and 2.90 Km^2 respectively, while average erosional area from 1973 to 2021 on right bankline and left bankline is 4.70 Km^2, and 5.79 Km^2 respectively. The erosion rate and bankline migration rate is higher along the left bank then the right bank. Dibru-Saikhowa river island has a total area of 340.79 Km^2 in 1998 but having lost significantly to erosion it has an area of 219.60 Km^2 in 2021. Landsat satellite imageries analysis result (1998-2021) shows that the Dibru-Saikhowa river island is continuously shrinking due to heavy erosion and flooding, and it has lost its area every year, and average rate of land degradation is 5.27 Km^2 / year. GRACE data are providing a quantity of available gravity and terrestrial water storage changes. The available datasets have been divided into two group 2004-2010, 2011-2017 and analyzed, and observed that the gravity and groundwater storage have been shifted approx. 5 Km from NW to SE direction during the period of 2004-2017. The same pattern has been also observed in the bathymetric data analysis. it has cleared that the maximum depth of water has detected in the mainstream of Brahmaputra river, which is continuously moving from north-west to south-east direction due to gravity change over the study period.

Keywords

Morphology, Geo-technical, Geomorphology, Gravity Change, Bathymetry, Brahmaputra River

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1. Introduction

Morpho-dynamics and fluvio-morphological activities are originated mostly in the floodplain areas of the world specially in braided and meander river [1]. The morphology of the river and the morpho-dynamics of the river process led to free-flowing rivers equilibrium conditions [2]. Flow strength, discharge, and channel size are affected the river morphology and the morpho-dynamics of a river network [3]. Two extremely big rivers of India (Ganga river, Brahmaputra river and its major tributaries) have shown severe bankline erosion, major frequent bankline migration, forming a new channel, and various morpho-dynamics, river morphology activities [4-7]. The unpredictable character of seasonal rainfall in the monsoon in India can encourage mixed behavior in river flows that can change river characteristics and result flooding, changes in drainage patterns, and deposition of sediments. Humid and tropical monsoonal region of south-east Asia, especially the north-east India where Brahmaputra river is situated receives a very high rainfall within a short span of time resulting frequent bankline migration, channel distractions, and foremost riverbank erosion and sedimentation.

The Dibru-Saikhowa National Park situated in the upper Assam area which is a part of the lower Himalayan and enclosed by tertiary sequences and recent alluvial sediment. The area is surrounded by Brahmaputra river in the north, Siang-Dibang-Lohit river in the north-east, and Dibru-Dangori river in the south. Several studies on river morphology and behavior of Brahmaputra river in Assam have been attempts by [6, 8-31]. They have noticed the momentous variations in the flow pattern and its direction of Siang-Dibang-Lohit river in the north-eastern side and Dibru-Dangori river in the southern side of Dibru-Saikhowa National Park.

The present paper involves study of historical morpho-dynamics, historic river morphology changes from 1973 to 2021, geo-technical investigation of soil properties of an area around Dibru-Saikhowa National Park, geology, landform, geomorphology, gravity changes, groundwater storage change of an area around Dibru-Saikhowa National Park, and bathymetric analysis of Brahmaputra river, Siang-Dibang-Lohit river, and Dibru-Dangori river.

2. About the Study Area

The study area situated in upper part of Brahmaputra valley in Assam. This area selected for the study has not been studied in detail for morpho-dynamics and hydromorphogeobathymetry. The area is bounded by Brahmaputra river in the north, Siang-Dibang-Lohit river in the north-east, Dibru-Dangori river in the south, and located between 27°29'24.73" N to 27°49'25.16" N latitude and 95°33'48.23" E to 94°57'19.64" E longitudes, and covered the total geographical area of 1065.35 Km^2, out-of-that area, the Dibru-Saikhowa National Park has enclosed an area of 219.63 Km^2 in 2021 (Figure 1) with an average elevation of 123 m amsl. The study area falls in Survey of India (1:50,000) toposheets No. 83M02 (G46F02), 83M06 (G46F06), 83M10 (G46F10); and Tinsukia-Dibrugarh districts.

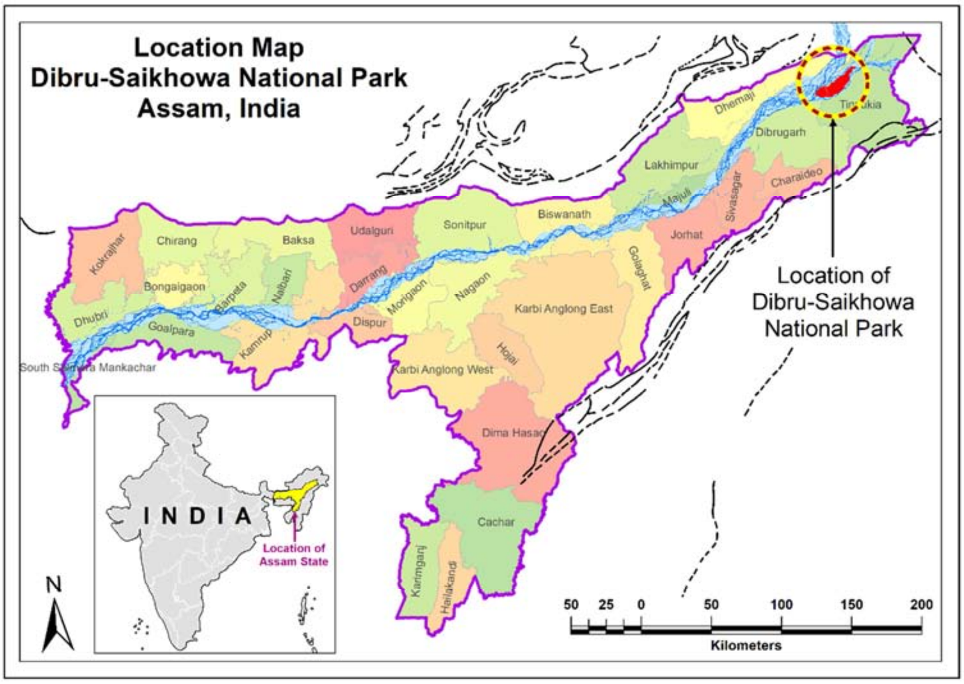


Figure 1. Location Map of Study Area.

Dibru-Saikhowa National Park become an isolated patch of land forming as river island in 1998, which is 2nd largest river island in India after Majuli river island. The island is mainly consisting of moist semi-evergreen forests, moist mixed deciduous forests, and grassland. Dibru-Saikhowa is also a haven for many endangered species like Chinese Pangolin, Assamese Macaque, Hoolock Gibbon, Capped Langur, Slow Loris, Water Buffalo, and also haven for many endangered species and rich in fish diversity.

The average annual rainfall of the study area is 3034 mm, about 90% of the annual rainfall takes place during monsoon period June to September, only 5.5% of annual rainfall happens during winter and about 4.5% of rainfall occurs during the summer months. The least amount of rainfall occurs in December with an average of 14 mm, while the greatest amount of precipitation occurs in July with an average of 493 mm. The Brahmaputra, Siang, Dibang and Lohit river floods are caused by heavy monsoon rains in that areas and summer-time snowmelt in the upper reaches. The average annual temperature in the study area is 23.5°C. January is the coldest months with an average temperature of around 17.0°C, while August is the hottest month of the year with an average annual temperature of around 28.3°C.

3. Data Used and Sources

Survey of India (SoI) topographical map at 1:50,000 scale, toposheet No. (open series maps (OSM) No.) of 83M02 (G46F02), 83M06 (G46F06), 83M10 (G46F10) have been downloaded from Survey of India website: http://soinakshe.uk.gov.in/Home.aspx, and geo-processed for the same.

Landsat series satellite data from 1973 to 2021 were downloaded from Earth Explorer, USGS (https://earthexplorer.usgs.gov). Landsat-1 MSS satellite data of years 1973-1974; Landsat-2 MSS satellite data of year 1977; Landsat-5 TM satellite data of years 1986 to 1999, 2004-2007, 2009, 2011; Landsat-7 ETM+ satellite data of years 2000-2003, 2010, 2012-2013; and Landsat-8 OLI satellite data of years 2014-2021 (years 48, 39 datasets in total) have been downloaded and geo-processed for analysis (Figure 2). The spatial resolution of these satellites is ranging from 57 m (Landsat-1, Landsat-2) to 30 m (Landsat-5, Landsat-7, Landsat-8).

Figure 2. Multi-Temporal Landsat Satellite Remote Sensing Data from 1973 to 2021.

Shuttle Radar Topography Mission (SRTM) DEM data of an area around Dibru-Saikhowa National Park with 30 m spatial resolution has been downloaded from NASA & USGS EROS Data Centre (http://glcfapp.glcf.umd.edu:8080/esdi).

Geological district resource map of Tinsukia and Dibrugarh districts have been downloaded from Geological Survey of India (GSI) website: http://www.portal.gsi.gov.in. These maps have been geo-referenced and digitized and prepared a geological map. The geological map has been updated through Landsat-8 OLI satellite imagery (2021), and Survey of India (SoI) Toposheets at 1:50,000 scale with limited field check.

Gravity Recovery and Climate Experiment (GRACE) data for gravity change and groundwater storage change of years 2004 to 2017 (years 13 in total) have been downloaded from https://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons. This dataset contains gridded monthly global water storage/height anomalies relative to a time-mean, derived from GRACE and GRACE-FO and processed at JPL using the Mascon approach.

4. Result and Discussion

4.1. Morphological Analysis

River morphology is a scientific field dealing with changes in the shape of rivers, mainly due to sedimentation and erosion processes. The morphology of rivers is also a complex issue, which can be subdivided into several areas including overland flow and channel flow, drainage systems and channel networks, discharge and basin area, stream erosion-deposition and transportation [32]. The focus of this study is monitoring the changes of the channels in an area around Dibru-Saikhowa National Park, Assam.

4.1.1. Mean River Width

The river width has been measured at 123 cross-sections of Brahmaputra river of an area around Dibru-Saikhowa national park, Assam by using multi-temporal Landsat satellite remote sensing data from 1973 to 2021. Year wise average river width has been plotted and shown in Figure 3. It is observed that the average river width is suddenly change from 13.03 Km in 1996 to 17.53 Km in 1997, when Dibru-Saikhowa National Park become an isolated patch of land forming as river island.

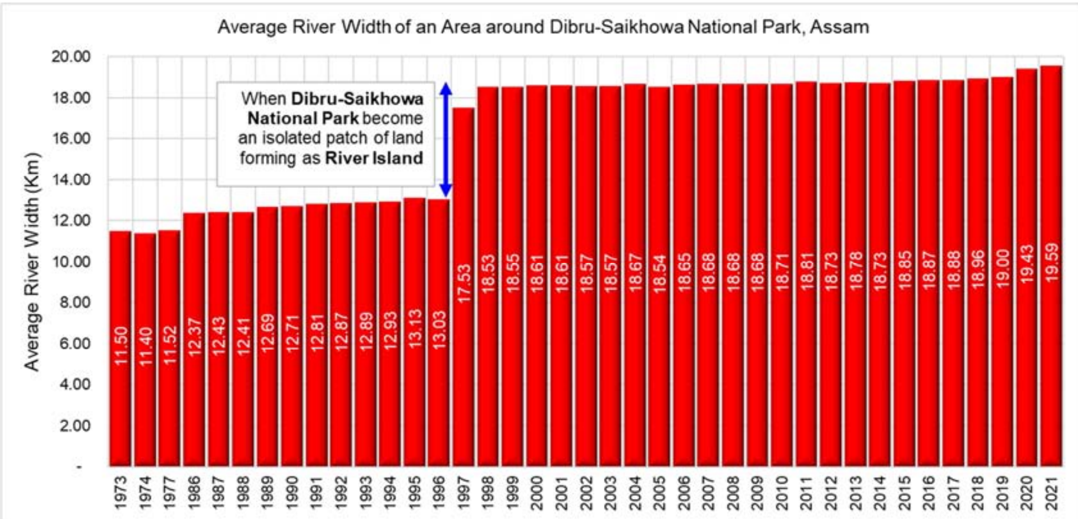


Figure 3. Year wise Average River Width (1973 to 2021) of an Area around Dibru-Saikhowa National Park, Assam.

4.1.2. Erosion and Deposition Trends

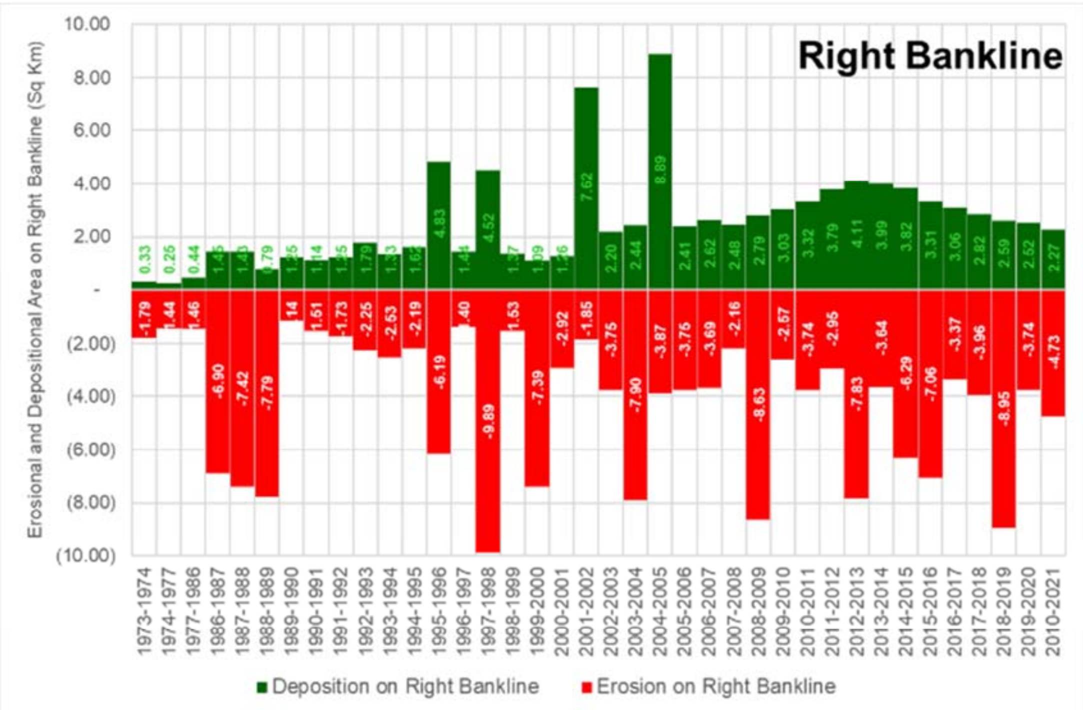
Multi-temporal satellite remote sensing data of Landsat-1 MSS (57*79 m), Landsat-2 MSS (57*79 m), Landsat-5 TM (30 m), Landsat-7 ETM+ (30 m), and Landsat-8 OLI (30 m) have been used to digitize bank lines from 1973 to 2021 (48 years, 39 datasets in total). The area of erosion and deposition between each cross-sections line (123 in total) 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 1973 to 2021 were calculated. Year wise (1973-2021) total erosion and deposition statistics on left bankline and right bankline of an area around Dibru-Saikhowa National Park along Brahmaputra river and its tributary in Assam is given in Table 1 and shown in Figure 4. Negative values are used for erosion and positive values are used for deposition.

The dynamicity of Dibru-Saikhowa National Park is due to both erosion and sediment deposition activities by neighboring rivers i.e. Brahmaputra river, Siang-Dibang-Lohit river, and Dibru-Dangori river. Overall erosion of an area around Dibru-Saikhowa National Park along Brahmaputra river in Assam from 1973 to 2021 exceeds overall deposition. The depositional areas on right bankline and left bankline is 77.51 Km^2, and 69.63 Km^2 respectively, while erosional areas on right bankline and left bankline is 112.83 Km^2, and 139.02 Km^2 respectively. The average depositional area from 1973 to 2021 (48 years, 39 datasets in total) on right bankline and left bankline is 3.23 Km^2, and 2.90 Km^2 respectively, while average erosional area from 1973 to 2021 on right bankline and left bankline is 4.70 Km^2, and 5.79 Km^2 respectively. From these statistics it is clear that left bankline is more active then the right bankline. The area around Dibru-Saikhowa National Park along Brahmaputra river has lost approximately 10.49 Km^2 of land per year and gained only 6.13 Km^2 per year. Referring to Figure 4, the erosion and deposition pattern of Brahmaputra river is showing a decreasing trend, which corresponds to the good flood management in that area over the last few years.

Table 1. Year wise (1973-2021) Total Erosion and Deposition Statistics on Left Bankline and Right Bankline of an Area around Dibru-Saikhowa National Park along Brahmaputra River in Assam

S. No.	Years	Right Bankline (Area in Sq. Km)		Left Bankline (Area in Sq. Km)	
		Deposition	Erosion	Deposition	Erosion
1	1973-1974	0.33	-1.79	1.79	-3.34
2	1974-1977	0.25	-1.44	1.32	-3.53
3	1977-1986	0.44	-1.46	1.43	-6.75
4	1986-1987	1.45	-6.90	1.03	-6.95
5	1987-1988	1.43	-7.42	1.23	-6.92
6	1988-1989	0.79	-7.79	1.35	-4.98
7	1989-1990	1.25	-1.14	2.04	-4.87
8	1990-1991	1.14	-1.51	2.19	-5.03
9	1991-1992	1.25	-1.73	2.41	-5.34
10	1992-1993	1.79	-2.25	2.55	-5.89
11	1993-1994	1.33	-2.53	1.93	-4.99
12	1994-1995	1.62	-2.19	2.86	-5.82
13	1995-1996	4.83	-6.19	3.79	-6.79
14	1996-1997	1.44	-1.40	2.52	-3.99
15	1997-1998	4.52	-9.89	1.42	-26.46
16	1998-1999	1.37	-1.53	1.03	-1.85
17	1999-2000	1.09	-7.39	0.49	-7.19
18	2000-2001	1.26	-2.92	0.47	-5.42
19	2001-2002	7.62	-1.85	1.39	-2.88
20	2002-2003	2.20	-3.75	2.73	-17.03
21	2003-2004	2.44	-7.90	5.04	-5.41
22	2004-2005	8.89	-3.87	9.11	-6.07
23	2005-2006	2.41	-3.75	3.14	-4.66
24	2006-2007	2.62	-3.69	2.74	-1.03
25	2007-2008	2.48	-2.16	1.55	-2.43
26	2008-2009	2.79	-8.63	1.32	-2.44
27	2009-2010	3.03	-2.57	0.99	-2.91
28	2010-2011	3.32	-3.74	0.63	-3.79
29	2011-2012	3.79	-2.95	3.11	-1.21
30	2012-2013	4.11	-7.83	4.11	-8.95
31	2013-2014	3.99	-3.64	5.37	-1.61
32	2014-2015	3.82	-6.29	4.79	-8.55
33	2015-2016	3.31	-7.06	4.24	-8.03
34	2016-2017	3.06	-3.37	4.04	-4.30
35	2017-2018	2.82	-3.96	3.41	-2.79
36	2018-2019	2.59	-8.95	3.09	-2.32
37	2019-2020	2.52	-3.74	2.90	-7.69
38	2010-2021	2.27	-4.73	1.54	-4.83
	Total	77.51	-112.83	69.63	-139.02
Average rate of erosion and deposition (Km^2 / Year)		3.23	-4.70	2.90	-5.79

The morphology and behavior of the Brahmaputra river around Dibru-Saikhowa National Park undergo drastic changes in response to various flow regimes. Erosion in the Brahmaputra river around Dibru-Saikhowa National Park is a common occurrence, but it becomes a matter of serious concern as soon as it takes the form of a disaster. 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. The erosion rate and eroded area is higher along the left bank then the right bank. The erosion is quite expanded in the extreme flood year (1986, 1987, 1988, 1996, 1998, 2000, 2004, 2009, 2013, 2015, 2016, 2019) of both bankline of that area.



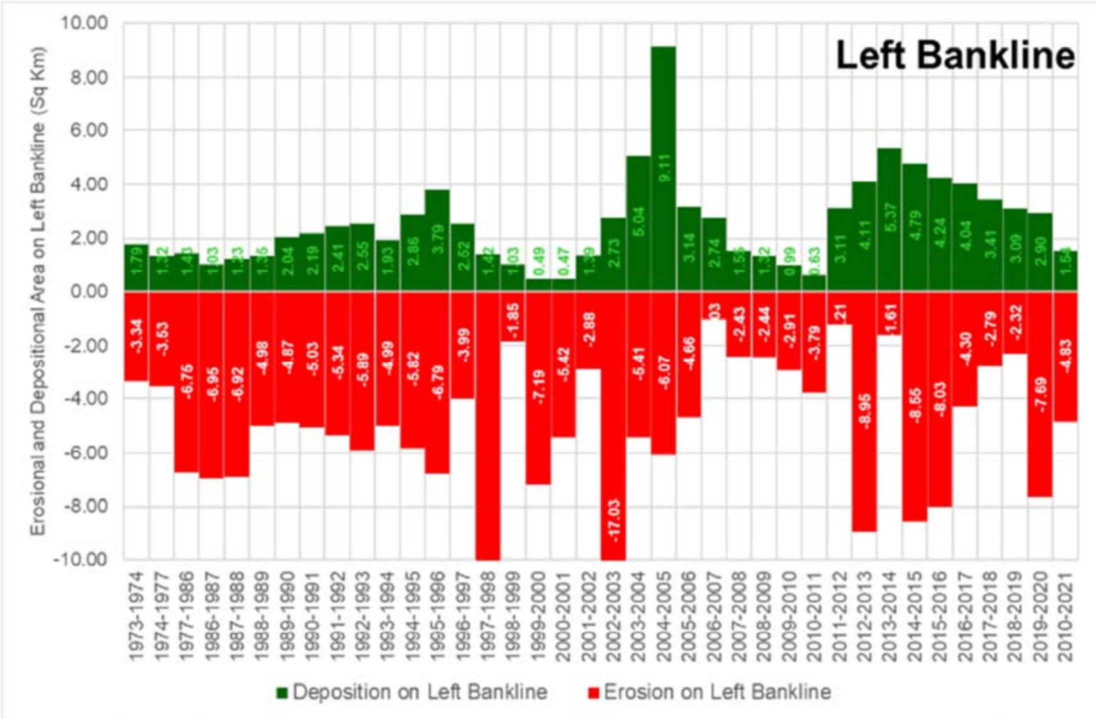


Figure 4. Year wise (1973-2021) Total Erosion and Deposition Area on Left Bankline and Right Bankline of an Area around Dibru-Saikhowa National Park along Brahmaputra River in Assam.

4.1.3. Bankline Migration

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) [30]. GIS techniques (spatial-temporal analysis of satellite imageries), using advanced satellite remote sensing data from 1973-2021 have been used to identify changes in the river course and further computation has analyzed river bankline migration. The multi-temporal remote sensing data were individually processed and analyzed 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 vectorizations in GIS.

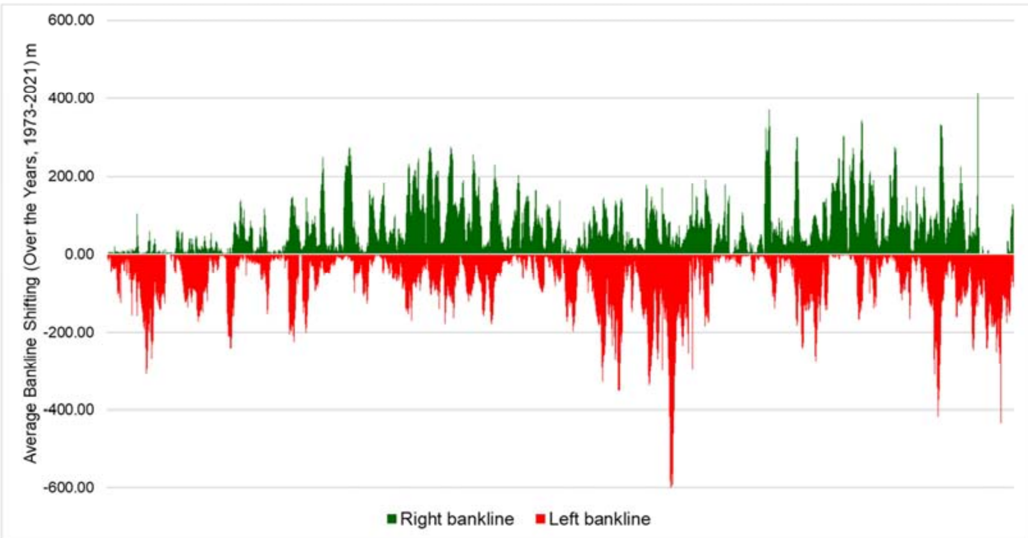


Figure 5. Cross-Section wise Average (1973 to 2021) River Bankline Migration of Brahmaputra River around Dibru-Saikhowa National Park.

The river bankline migration has been measured at 123 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 1973 to 2021 (over the years, 48 years) is shown in Figure 5. Figure 5 show the cross-section wise river bankline migration data from 1973 to 2021 of right bankline and left bankline of the Brahmaputra river around Dibru-Saikhowa National Park in Assam. According to bankline migration analysis the left bankline is more active in comparision to right bankline over the period of 1972-2021.

4.1.4. Dibru-Saikhowa River Island Area Analysis

Multi-temporal satellite remote sensing data of Landsat-1 MSS, Landsat-2 MSS, Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI have been used to digitize Dibru-Saikhowa river island from 1998 to 2021. The total area of Dibru-Saikhowa river island were calculated using ESRI ArcGIS 10.7 software and given in Table 2.

Dibru-Saikhowa river island has a total area of 340.79 Km^2 in 1998 but having lost significantly to erosion it has an area of 306.27 Km^2 in 2000, 267.25 Km^2 in 2005, 255.32 Km^2 in 2010, 246.98 Km^2 in 2015, and 219.60 Km^2 in 2021. According to Landsat satellite imageries analysis from 1998 to 2021, the Dibru-Saikhowa river island is continuously shrinking due to heavy erosion and flooding. Referring to Table 2, the Dibru-Saikhowa river island has lost its area around 121.18 Km^2 in last 23 years (1998-2021). In comparision to 1998, it has lost 35.56% of area, and only 64.44% of area is remaining, and it is continuously shrinking, and it has lost its area every year, and average rate of land degradation is 5.27 Km^2 / year. The graphical represent of shrinkage of Dibru-Saikhowa river island from 1998 to 2021 is shown in Figure 6. Dibru-Saikhowa river island is continuously shrinking, in the last 23 years, it is shrunk around 7.53 Km to upstream from 1998 to 2021 (Figure 7).

Table 2. Dibru-Saikhowa River Island Area from 1998 to 2021.

S. No.	Year	Area of Island (Km^2)	S. No.	Year	Area of Island (Km^2)
1	1998	340.79	13	2010	255.32
2	1999	321.80	14	2011	254.39
3	2000	306.27	15	2012	252.25
4	2001	296.62	16	2013	247.97
5	2002	288.47	17	2014	247.20
6	2003	275.91	18	2015	246.98
7	2004	269.95	19	2016	239.81
8	2005	267.25	20	2017	235.24
9	2006	266.14	21	2018	233.35
10	2007	264.75	22	2019	231.07
11	2008	263.44	23	2020	229.76
12	2009	257.08	24	2021	219.60

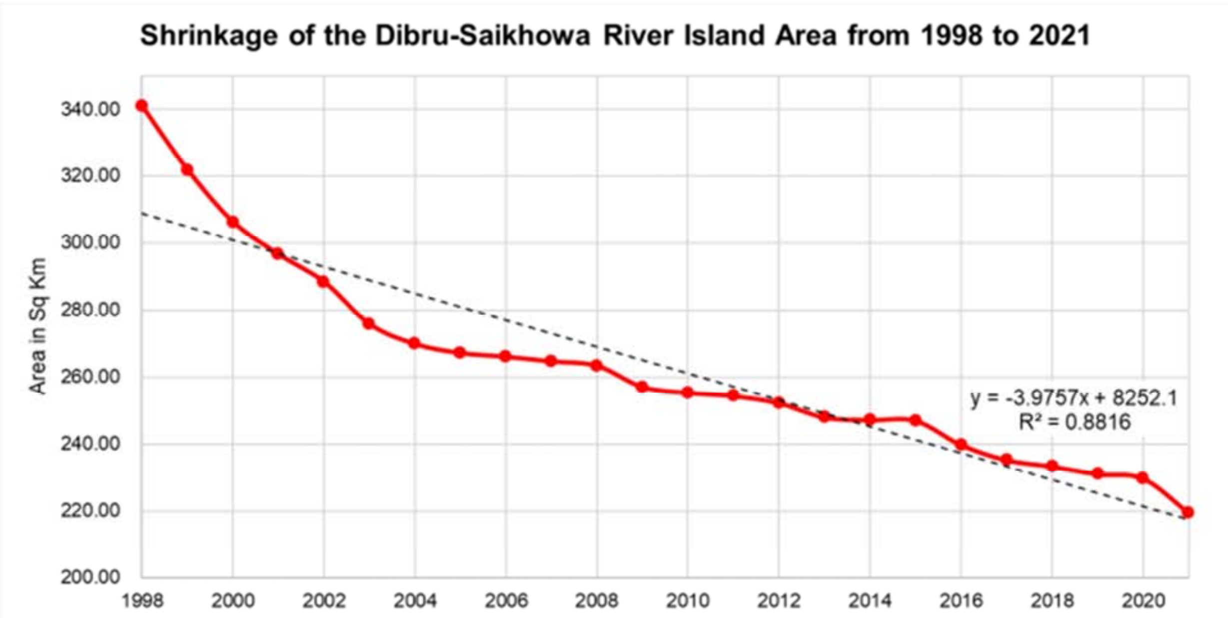


Figure 6. Shrinkage of the Dibru-Saikhowa River Island Area from 1998 to 2021.

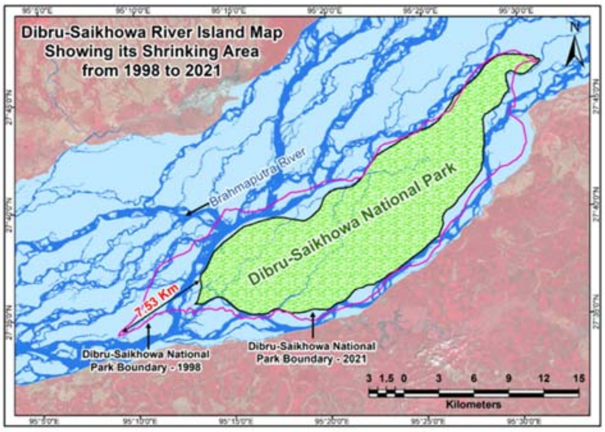


Figure 7. Dibru-Saikhowa River Island Map Showing its Shrinking Area from 1998 to 2021.

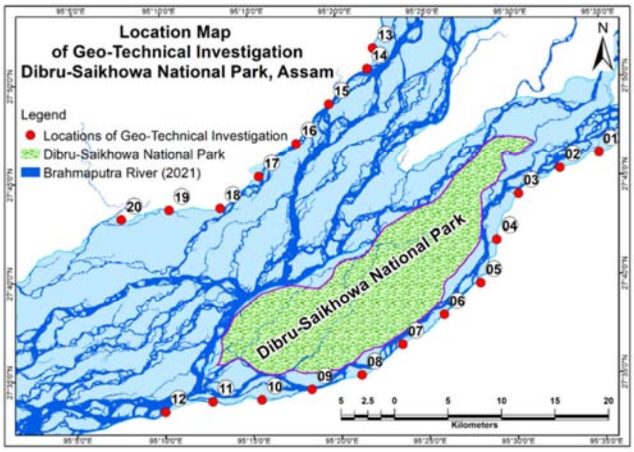


Figure 8. Location Map of Sub-Soil Exploration and Geo-Technical Investigation.

4.2. Geo-technical Investigations

Geo-technical investigations and sub-soil explorations have been conducted at 20 various location in an area around Dibru-Saikhowa National Park, Assam. Geo-technical investigations, also variously known as foundation analysis, soil analysis / testing / mechanics and subsurface investigation, are carried out to acquire information regarding the physical characteristics of soil and underlying rocks. A geo-technical examination includes surface and sub-surface exploration, soil sampling, and laboratory analysis. Here, the purpose of geo-technical investigations is to obtain physical properties of the soils, and sub-soils.

The geo-technical investigations and sub-surface explorations have been carried-out for collection of strength information of the Dibru-Saikhowa National Park. The depth of each borehole is around 10 m. Out of 20 geo-technical investigation locations, 10 locations are situated on north bank of Brahmaputra river, and 10 locations are situated on south of Dihing river / Sursa river. The location map of sub-soil exploration and geo-technical Investigation is shown in Figure 8.

Representative soil samples were collected from the drilled boreholes, tightly sealed, and was taken for the laboratory tests. The (i) natural moisture content, (ii) bulk density, (iii) grain size distribution (sieve), (iv) grain size distribution (hydrometer), (v) liquid limits and plastics limits, (vi) free swell index, (vii) specific gravity, (viii) unconfined compression test (UCS), and (ix) direct shear test (DS) laboratory tests have been carried out.

According to twenty borehole logs of an area around Dibru-Saikhowa National Park, Assam, 0 to 4.5 m below the ground level the brown to grayish silty clay soil is found in most of the borehole. Mostly sandy, and mixture of clay and sandy soil is found between 4.5 to 7.0 m below the ground level. 7.0 m to 10.50 m below the ground level, the mixture of clay and sandy soil is found in most of the borehole. Details of 20 boreholes is shown from Figure 9 to Figure 11. A typical photograph showing the soil layer is shown in Figure 12.

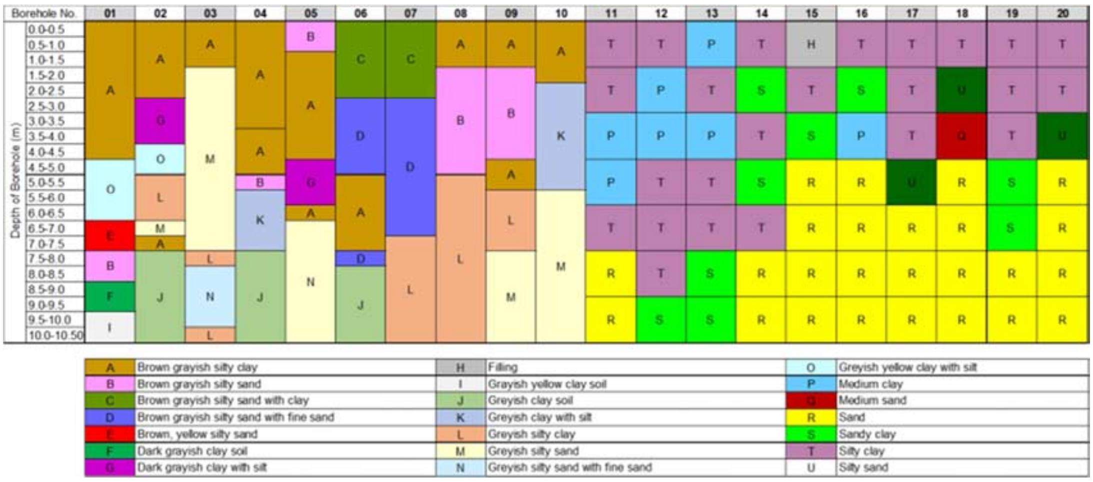


Figure 9. Borehole Log showing the Details of Soil Layers of Twenty Boreholes.

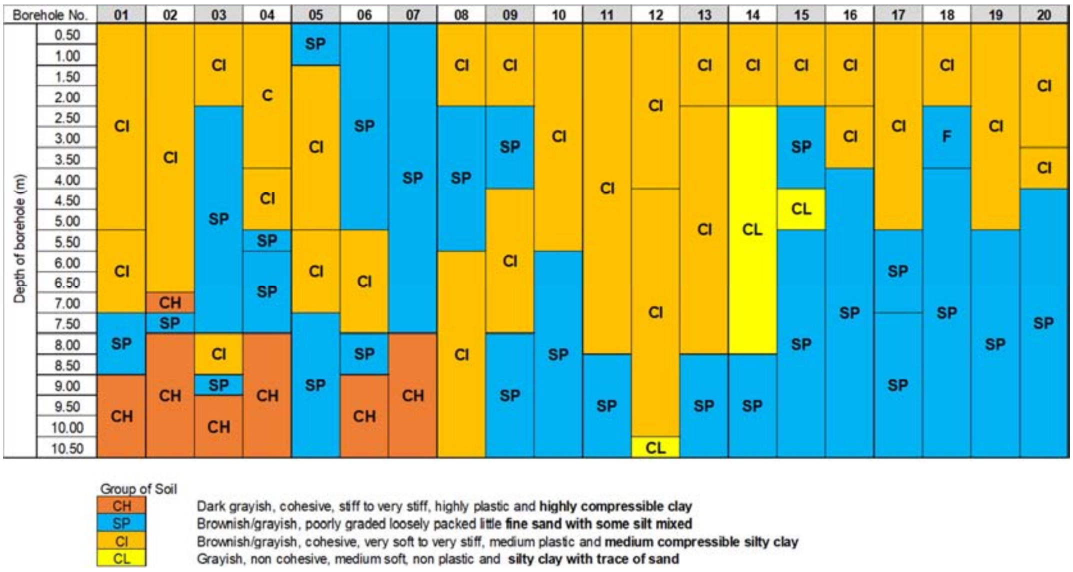


Figure 10. Borehole Log showing the Group of Soil of Twenty Boreholes.

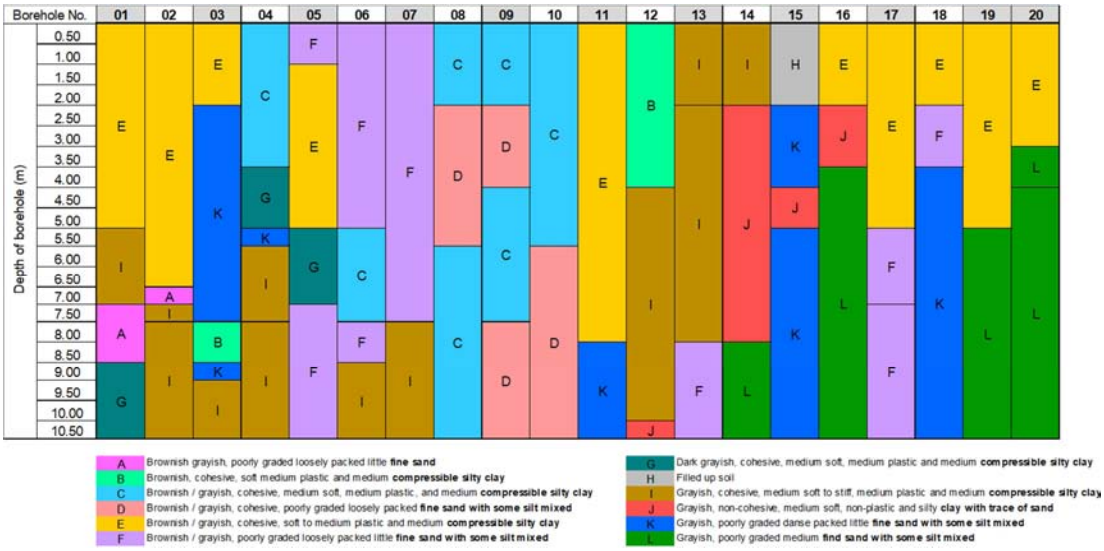


Figure 11. Borehole Log showing the Stratification / Description of the Sub-soil Encountered of Twenty Boreholes.

Figure 12. Photograph showing the Various Soil Layers in an Area around Dibru-Saikhowa National Park, Assam.

Soil permeability is the property of the soil to transmit water and air and is one of the most important qualities to consider for fish culture. The coefficient of permeability of a soil describes how easily a liquid will move through a soil. It is also commonly referred to as the hydraulic conductivity of a soil. This factor can be affected by the viscosity, or thickness (fluidity) of a liquid and its density. Borehole wise coefficient of permeability is shown in Table 3. The average coefficient of permeability of the pilot area is 0.0597 cm / sec.

Table 3. Coefficient of Permeability of Soil of Twenty Boreholes.

BH No.	Coefficient of Permeability (cm / sec)		BH No.	Coefficient of Permeability (cm/sec)	
01	1.09×10^{-1}	0.109	11	1.06×10^{-1}	0.106
02	1.37×10^{-3}	0.001	12	1.15×10^{-1}	0.115
03	1.21×10^{-3}	0.001	13	1.01×10^{-1}	0.101
04	1.11×10^{-1}	0.111	14	1.07×10^{-1}	0.107
05	1.09×10^{-1}	0.109	15	1.46×10^{-3}	0.001
06	1.36×10^{-3}	0.001	16	1.39×10^{-3}	0.001
07	1.41×10^{-3}	0.001	17	1.33×10^{-3}	0.001
08	1.12×10^{-1}	0.112	18	1.45×10^{-3}	0.001
09	1.02×10^{-1}	0.102	19	1.02×10^{-1}	0.102
10	1.07×10^{-1}	0.107	20	1.37×10^{-3}	0.001

4.3. Geology

A general lithological map can help understanding of the geomorphology of an area. Published geological district resource maps (http://www.portal.gsi.gov.in) from Geological Survey of India (GSI) have been used for the preparation of a geological map of Dibru-Saikhowa National Park, Assam. This geological map has been updating through the using Landsat-8 OLI satellite imagery (30 m spatial resolution), SRTM DEM data (30 m spatial resolution) with slope map, and landform map, and Survey of India (SoI) topographical maps (1: 50,000 scale) with limited field check. A geological map of Dibru-Saikhowa National Park, Assam is show in Figure 13.

Various geologists have contributed to diverse geological aspects of the study area. Notable among these are: [33-35], and others etc. They have recorded the principal rock formations as described in Table 4.

Table 4. Lithostratigraphic succession of Dibru-Saikhowa National Park, Assam.

Notation	Lithology	Formation	Group	Age
Q2b2	Unoxidized sand, silt clay with occasional pebbles and carbonaceous matter	Barpeta –II (=Sisimukh-II)	Newer Alluvium	Recent
Q2b1	Unoxidized well sorted fine to medium sand, silt, and clay with carbonaceous matter	Barpeta –I (=Sisimukh-I)	Newer Alluvium	Holocene to recent
Q2h	Unoxidized alternate sand, silt, clay with carbonized wood and minor pebbles	Hauli (=Dhemaji)	Newer Alluvium	Holocene
Q12s	Oxidized brownish grey to greyish sand, silt clay with occasional pebbles and cobbles	Sorbhog (=Sunpura) (=Dimow)	Older Alluvium	Pleistocene to Holocene

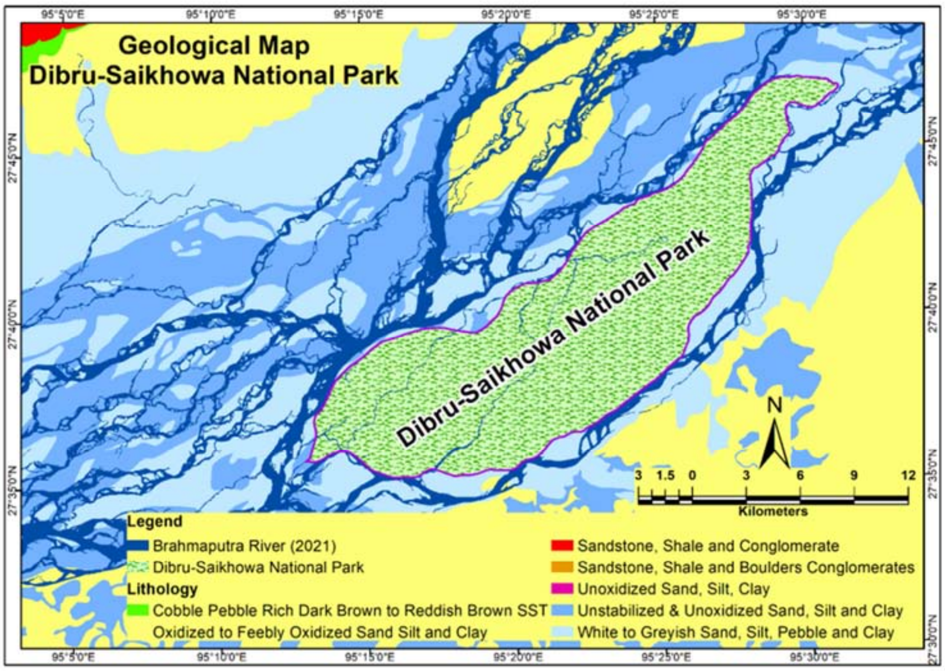


Figure 13. Geological Map of Dibru-Saikhowa National Park, Assam.

Geological Survey of India (GSI) has been identified the four landform units in the area on the basis of the geomorphology, lithology and pedological characters, such as morphology, relief, slope, drainage pattern, degree of dissection, nature of soil cover, type of vegetation and land use pattern. They have named of these morpho-stratigraphic units after the villages where they are best developed.

The Quaternary sediments uncomfortably overlie the Tertiary rocks. Sorbhog formation is the next older surface forming a part of the flat alluvium plain bordering and at places surrounded by Hauli formation. It is generally an erosional surface occupying the area from east to west and some part of north. Hauli formation is exposed in the northern and eastern parts of district and characterized by unoxidized alternate sand, silt, and clay sequence with carbonized wood. The youngest formation Barpeta is composed of sand and silt. This is divided into two units namely Barpeta formation-I and II. The notable morphological elements of the Barpeta formation-I are recent flood plain with meander loops, scrolls, abandoned channel etc. whereas the Barpeta formation-II consist of active river channel point bar, channel bar.

The Quaternary sediments in the area have been classified as Dimow formation, Dhemaji formation and Sisimukh-I formation and Sisimukh-II formation. The Dimow formation is mainly confined between 120 to 140 m contour level and extends up to 160 m contour height in the north-eastern part of the area. This formation exhibits slightly undulatory topography with a southerly slope. It is well dissected by the southerly flowing rivers and streams. It is marked by high degree of oxidation and shows occurrence of yellow ochre. The Dimow surface shows onlap relationship with the overlaying Dhemaji surface. The Dhemaji formation occurs beyond the southern limit of the Dimow formation. It exhibits a vast flat area and merges with the recent flood plain of the Brahmaputra river. It is dissected by the southerly flowing river and streams. Due to meandering nature of the river, it shows frequent shifting tendency resulting in heavy silt discharge during the flooding. It is characterized by unoxidized alternate sand, silt, clay sequence with carbonized wood and minor pebble.

The Barpeta formation-I (Sisimukh formation-I) represents the youngest landform with active depositional process by the present river system. It represents the active flood plain of the Brahmaputra river and its tributaries and comprises point bars, channel bar, stabilized channel bar, bills etc. It is characterized by unoxidized well sorted fine to medium sand silt and clay with carbonaceous matter. Whereas the Sisimukh formation-II consists of active river channel and point bar. Exposure of unit's equivalent of Sorbhong formation of lower Assam occupies a major part of the area. It comprises yellowish brown silty clay with micaceous particles. The equivalent of Hauli formation is exposed in the northern part of the area. It is mainly composed of unoxidized grey colored sand, silt, and clay. Sediment equivalent to Barpeta-I formation comprises alluvial sediments of unoxidized grey colored micaceous silty clay, clay at the top and micaceous sand at the bottom admixed with pebbles and the equivalent Barpeta-II formation is characterized by unoxidized fine sand, silty clay with occasional pebbles and carbonaceous matter.

The thick tertiary sediments have been buckled and over thrusted because of the forces generated during the tertiary period directed towards the south from the Himalayas and to the North west from Shan-Burma plateau consequent upon the upheavals. This resulted in the formation of several parallel imbricating thrusts viz Naga thrust passing along the northern edge of the Joypur-Tipam-Digboi range hills in the southern part of the area.

4.4. Geomorphology

Geomorphology is the scientific study of landforms in relation to genetic evolution, evolution and processes of their origin, form, and mass [1]. It is an investigation into the relationship between land development and the processes that shape and configure these landforms with tectonic movements, volcanoes, erosion, and deposition cycles [36-38]. Landforms are the most distinguishing features on the surface of the Earth.

Remote sensing data is an important resource in the preparation of geomorphological maps. A detailed geomorphological map of the Dibru-Saikhowa national park has been prepared by using visual image interpretation of Landsat-8 OLI satellite imagery (30 m spatial resolution), SRTM DEM data (30 m spatial resolution) with slope map, and landform map, district resource maps with structural and lithological maps from Geological Survey of India (GSI) (1: 250,000 scale), and Survey of India (SoI) topographical maps (1: 50,000 scale) with limited field check (Figure 14). The various geomorphic units and their components of primary classification, secondary classification and 3rd geomorphic classification were identified and mapped. Important geomorphic units of the Dibru-Saikhowa National Park study area are given in Table 5.

Table 5. Important Geomorphic Units of the Dibru-Saikhowa National Park, Assam.

S. No.	Primary Classification	Secondary Classification	3rd Geomorphological Classification
1	Structural Origin	Highly Dissected Hills and Valleys	Structural Origin - Highly Dissected Hills and Valleys
2	Structural Origin	Moderately Dissected Hills and Valleys	Structural Origin - Moderately Dissected Hills and Valleys
3	Denudational Origin	Piedmont Slope	Denudational Origin - Piedmont Slope
4	Fluvial Origin	Piedmont Alluvial Plain	Fluvial Origin - Piedmont Alluvial Plain
5	Fluvial Origin	Younger Alluvial Plain	Fluvial Origin - Younger Alluvial Plain
6	Fluvial Origin	Active Floodplain	Fluvial Origin - Active Floodplain
7	Fluvial Origin	Older Flood Plain	Fluvial Origin - Older Flood Plain
8	Fluvial Origin	Palaeo Channel	Palaeo Channel
9	Fluvial Origin	Abandoned Channel	Abandoned Channel
10	Fluvial Origin	Natural Levee	Natural Levee
11	Fluvial Origin	Back Swamp	Back Swamp
12	Fluvial Origin	Crevasse Splay	Crevasse Splay
13	Fluvial Origin	Channel Island	Channel Island
14	Fluvial Origin	Braid Bar	Braid Bar
15	Fluvial Origin	Channel Bar	Channel Bar
16	Fluvial Origin	Lateral Bar	Lateral Bar
17	Fluvial Origin	Rivers	Rivers

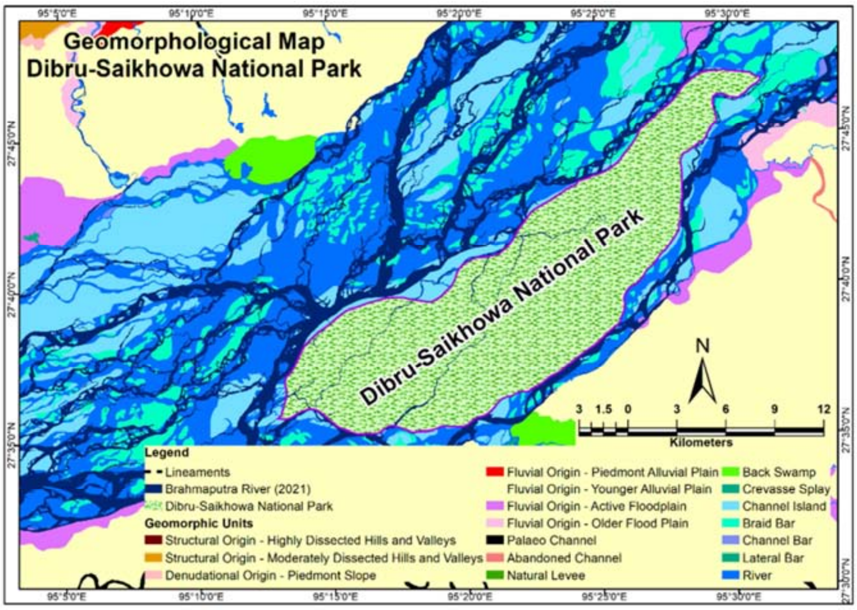


Figure 14. Geomorphological Map of Dibru-Saikhowa National Park, Assam.

The area drained by the river Brahmaputra flowing from NE to SW direction with its tributaries Dibru and Burhi-Dihing from Naga-Patkai hill range in the south. All these rivers carry huge quantities of water and sediment during rainy season and cause submergence of the low-lying areas. The area is characterized by a flat monotonous thick alluvial plain. The area forms a part of the Assam-Arakan geological domain. The area predominantly comprises vast tracts of thick Quaternary alluvial sediments deposited by the Brahmaputra river. Physiographically, the area is more or less flat and the area can be divided into high level plain and low-lying flood plain area. A number of perennial streams which originates in the northern hill ranges flow through the area from north to south and join the Brahmaputra river. The major streams that drain the area are Subansiri, Kumotia, Gai, Kanibil, Sisi, Simem, Dikrai and Reyang. Because of very high rainfall in the catchment area, these rivers bring huge amount of sediment and cause flash floods during monsoon. Environmental problems of the area include annual flooding of terraces, low lying area, riverbank erosion, water logging in area around tals and palaeo channels, and bad land formation in some area during high floods in the rainy season.

4.5. Gravity and Groundwater Storage Change

Gravity Recovery and Climate Experiment (GRACE) twin satellites made detailed measurements of Earth's gravity field and improved investigations about Earth's water reservoirs, over land, ice, and oceans. NASA's GRACE mission provides the first opportunity to directly measure groundwater changes from space. By observing changes in the Earth's gravity field, scientists can estimate changes in the amount of water stored in a region, which cause changes in gravity. GRACE provides a more than 10 year-long data record for scientific analysis. This makes a huge difference for scientists and water managers who want to understand trends in how our resources are being consumed over the long term. GRACE has returned data on some of the world's biggest aquifers and how their water storage is changing [39-41]. Using estimates of changes in snow and surface soil moisture, scientists can calculate an exact change in groundwater in volume over a given time period.

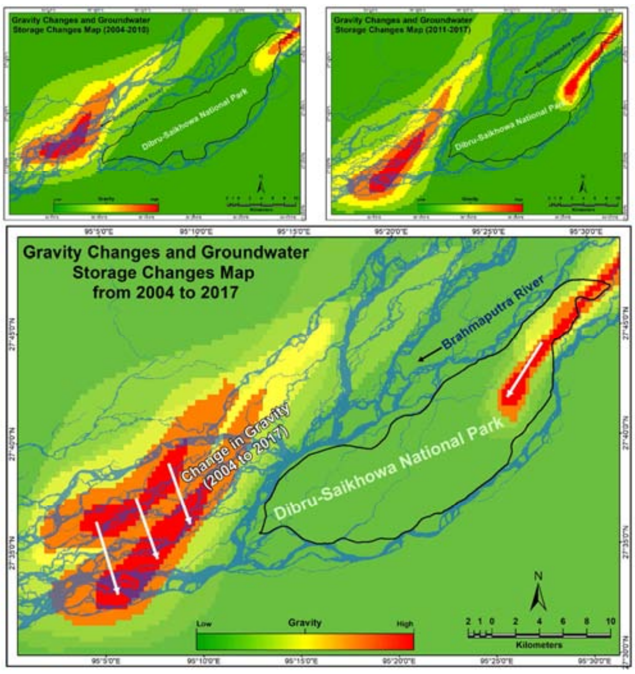


Figure 1. Gravity Changes and Groundwater Storage Changes Map (2004-2017).

The observed monthly changes in gravity are caused by monthly changes in mass. The mass changes can be thought of as concentrated in a very thin layer of water thickness changes near the Earth's surface (i.e., in a layer up to several kilometers thick). In reality, most of the monthly gravity changes are indeed caused by changes in water storage in hydrologic reservoirs, by moving ocean, atmospheric and land ice masses, and by mass exchanges between these Earth system compartments. The surface mass change data from GRACE from 2004 to 2017 was used for that study. This dataset contains gridded monthly global water storage/height anomalies relative to a time-mean, derived from GRACE and GRACE-FO and processed at JPL using the Mascon approach (Version2/RL06) [42-43]. These data are providing a quantity of available terrestrial water storage and combining the soil moisture from Global Land Data Assimilation System (GLDAS) offering estimation of groundwater storage changes for a region in a single data file in netCDF format. These datasets have been processed by python script. The GRACE data has been divided in two group (2004-2010, and 2011-2017) to see the gravity changes, and groundwater storage changes in the study area, which is shown in Figure 15. Referring to Figure 15, the gravity and groundwater storage have been shifted approx. 5 Km from NW to SE during the period of 2004-2017.

4.6. Bathymetry Analysis

The Hemisphere Vector-V113 was used for the current bathymetric survey for horizontal positioning. It is well known for its heading performance. The rugged IPX6 design housing of it is sealed for the harshest environments. A single beam transducer coupled with Hydrotech-II echo sounder was used for sounding operations. The digital output from the echo sounder was logged in using HYPACK data logging software on a real-time basis during the survey. Data was acquired applying a frequency of 200 kHz. Checks were done daily before commencing the sounding operation and at completion. In shallow regions, the depth soundings were cross-checked against demarcated sounding poles throughout the survey. The sounding lines were carried out using survey boat at 5 Km interval in 13 cross-sections line. The cross-section lines were established perpendicular to the current riverbanks (year 2020). The location map for bathymetry survey is shown in Figure 16. The currents and bathymetry collected simultaneously for 13 cross-sections line is shown in Figure 17.

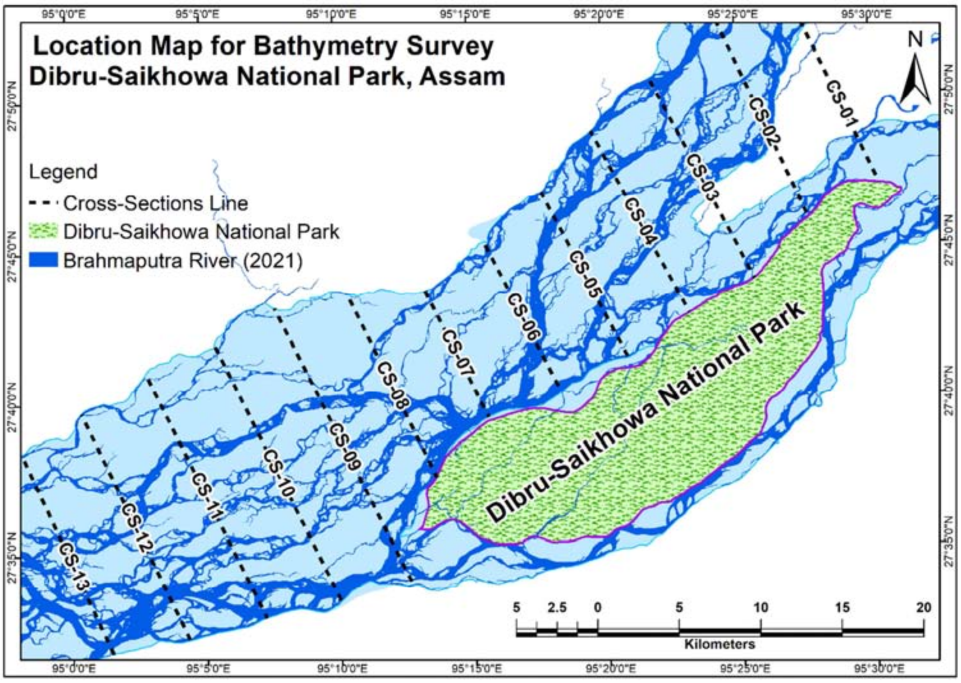


Figure 16. Location Map for Bathymetry Survey.

To address questions concerning on-going geomorphic processes in an area around Dibru-Saikhowa national park (Brahmaputra river), selected bathymetric datasets of year 2020 was analyzed. The high-resolution datasets of bathymetry covering the upper river indicate a highly variable, active environment. Although statistical and spatial analysis of the bathymetric datasets show that some changes to the channel size and shape have taken place. The limitation of only one year dataset, and accuracy of available data was not great enough to reliably detect the widespread geomorphic change throughout an area around Dibru-Saikhowa national park (Brahmaputra river) at the scale required, but it has cleared that the maximum depth of water has detected in the mainstem of Brahmaputra river, which is continuously moving from north-west to south-east direction due to gravity change over the study period.

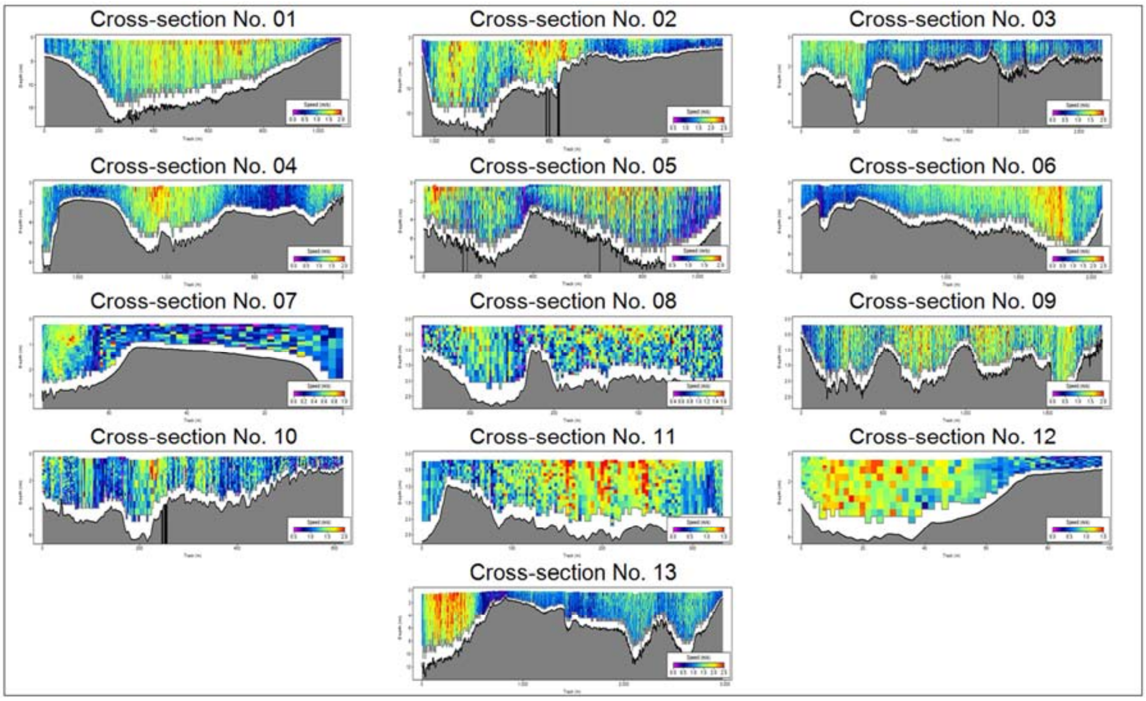


Figure 17. Currents and bathymetry (collected simultaneously) at the Study Area.

5. Conclusion

River width has been measured at 123 cross-sections of Brahmaputra river and observed that average river width is suddenly change from 13.03 Km in 1996 to 17.53 Km in 1997, when Dibru-Saikhowa National Park become an isolated patch of land forming as river island. The depositional areas on right bankline and left bankline is 77.51 Km^2, and 69.63 Km^2 respectively, while erosional areas on right bankline and left bankline is 112.83 Km^2, and 139.02 Km^2 respectively. The average depositional area from 1973 to 2021 on right bankline and left bankline is 3.23 Km^2, and 2.90 Km^2 respectively, while average erosional area from 1973 to 2021 on right bankline and left bankline is 4.70 Km^2, and 5.79 Km^2 respectively. The area around Dibru-Saikhowa National Park along Brahmaputra river has lost approximately 10.49 Km^2 of land per year and gained only 6.13 Km^2 per year. The erosion and deposition pattern of Brahmaputra river is showing a decreasing trend, which corresponds to the good flood management in that area over the last few years, but the erosion is quite expanded in the extreme flood year (1986, 1987, 1988, 1996, 1998, 2000, 2004, 2009, 2013, 2015, 2016, 2019) of both bankline of that area.

Dibru-Saikhowa river island has a total area of 340.79 Km^2 in 1998 but having lost significantly to erosion it has an area of 306.27 Km^2 in 2000, 267.25 Km^2 in 2005, 255.32 Km^2 in 2010, 246.98 Km^2 in 2015, and 219.60 Km^2 in 2021. The Dibru-Saikhowa river island is continuously shrinking due to heavy erosion and flooding, and it has lost its area around 121.18 Km^2 in last 23 years (1998-2021). In comparision to 1998, it has lost 35.56% of area, and average rate of land degradation is 5.27 Km^2 / year. Geo-technical investigation of an area around Dibru-Saikhowa National Park, Assam indicates 0 to 4.5 m below the ground level the brown to grayish silty clay soil most of the boreholes. Mostly sandy, and mixture of clay and sandy soil is found between 4.5 to 7.0 m below the ground level. 7.0 m to 10.50 m below the ground level, the mixture of clay and sandy soil is found in most of the borehole.

GRACE data are providing a quantity of available gravity and terrestrial water storage changes. The available datasets have been divided into two group 2004-2010, 2011-2017 and analyzed, and observed that the gravity and groundwater storage have been shifted approx. 5 Km from NW to SE direction during the period of 2004-2017. The same pattern has been also observed in the bathymetric data analysis. it has cleared that the maximum depth of water has detected in the mainstream of Brahmaputra river, which is continuously moving from north-west to south-east direction due to gravity change over the study period.

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