Channel Dynamics and Bankline Shift of the Brahmaputra River in Morigaon District, Assam

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Abstract

The Brahmaputra River, one of the biggest rivers in the world, has been alternating between its two banks in north-south path of Assam, like a meandering river. Assam's agro-climatic zones, particularly in districts like Morigaon, are largely influenced by the River Brahmaputra, which causes regular flooding and bank erosion. This research aims to evaluate channel change and bank line shifting of the River Brahmaputra over 41 years, from 1980 to 2021, as well as the status and impact of bank degradation from 2001 to 2021. The research is conducted using SOI toposheets and LANDSAT satellite imagery from 1980, 2001 and 2021. To further evaluate the effects of bank erosion, secondary data has been gathered from the District Disaster Management Authority (DDMA) and the Revenue Circles (RC) of the districts. As per the records, out of the five revenue circles (RC) of Morigaon district, the Bhuragaon RC, Mayong RC and Laharighat RC have been facing bank erosion from 1980 onwards.

The Brahmaputra river channel is migrating more towards left direction than towards right direction and the south bank line has been moving south in the district. The three regions with the greatest bank line movement between 1980 and 2021 are Mayong RC (5.34 km), Laharighat RC (5.32 km) and Bhuragaon RC (4.95 km). During the course of twenty years, from 2001 to 2021, 3386.14 hectares of land in Laharighat RC were lost to erosion, affecting 2583 households, of them 1427 lived on their own land and 1156 on Government land. The erosion of 2499.90 hectares of land in Bhuragaon RC has an impact on 2447 households who live on their own land. Similarly, 1520.1 hectares of land were lost in Mayong RC, affecting 3749 families in total, 200 living on government land and 3549 on private land.

Keywords: Bank erosion, Channel migration, Remote sensing, GIS, Brahmaputra.

Introduction

Rivers are dynamic in nature and their changes are also significant. A river goes through three phases of erosion, transportation and deposition for which river systems or fluvial processes are called “three-phase work” systems. The shifting of river which is a process of fluvial dynamics, involves the lateral migration process. River course undergoes various fluvial changes at larger or smaller extents. Changes in river course are due to erosion and depositional works of rivers[1]. A river becomes sluggish, meandering or braided when it enters the middle course and these oscillations cause bank erosion[22].

Riverbank erosion, which is regarded as a global problem, is a dynamic and complex fluvial process. Factors like the size of the river, morphology of riverbeds, water flow characteristics, heavy rainfall, flood and human activities like the construction of reservoirs, sand and gravel extraction from riverbeds alter the hydrology of rivers and thereby aggravate the process of bank erosion. Moreover, the main factors intensifying bank erosion of rivers are daily flow regulations, incision, re-distribution of annual runoff and reduction of sediment load[2]. When riverbank erosion occurs, land resources get lost and people are left homeless and forced to migrate to other places.

According to Rashtriya Barh Ayog 1980, the Indian subcontinent can be divided geomorphologically into two fluvial systems, the Himalayan system, where all the large rivers along with their tributaries head in the Himalayas and the Deccan system, where the rivers drain the Deccan. Dynamic river flow processes in the Himalayan environment have significantly impacted the geomorphology leading to channel migration, abnormal flow patterns, meander growth and avulsion[17]. Countries like Bangladesh experience river bank erosion hazards especially in the flood plains due to sudden and rapid channel shifting compelling millions of populations to be displaced from their place of origin[13,14].

In India, rivers like the Ganga and Brahmaputra are characterized by a process of high erosion, which impacts human lives and livelihood. Assam is a flood-prone and erosion-prone State in India. The mighty river Brahmaputra is considered the lifeline of Assam. Still, it also acts as a sorrow of Assam due to its recurring flood events and bank erosion almost every year. During the monsoon period i.e. from May to September, heavy rainfall causes floods in the State. The Brahmaputra being the most dynamic and extensively braided river in the world[4] is characterized by large flow, enormous volume of sediment load, continuous changes in channel morphology, rapid bed aggradations etc.[1]

In addition, the Brahmaputra River, being the fourth largest river in the world by discharge, discharges a very high sediment load at the mouth with a flow of 19,839 m^3s^{-1} and is the second largest in terms of sediment transport per unit drainage area[16]. The total length of the Brahmaputra River in India is 880km (about 546.81 mi), out of which 720km

(about 447.39 mi) lies in Assam alone. The rest 160 km (about 99.42 mi) lies in Arunachal Pradesh. The main causes of flood in the State are seasonal heavy rainfall and melting of snow in the Himalayas, meander growth, channel migration, avulsion and failure of landslide-induced dams, hydrological factors like drainage congestion at the mouth of the tributaries and breaching of embankments[10]. Since 1916, the Brahmaputra river bed has widened significantly and appears to be shifting more towards the south than towards the north[10].

Bank erosion along with floods has become a serious problem in the State. Goswami et al[12] in their study on the Brahmaputra River stated two possible causes of erosion, either due to the undercutting of upper bank materials during severe floods or due to the migration of thalweg closer to the bank leading to over steepening of bank materials. In the recent past, many studies on channel changes and bank erosion have been carried out through remote sensing which is considered as the most ideal technique for such spatio-temporal studies. In the context of N.E India, NASA (1980) has studied flood and river migration of the Brahmaputra using airborne scanner. Likewise, the Space Application Centre and Brahmaputra Board of Assam (1996) studied on bank erosion of Brahmaputra at the world's largest riverine island Majuli using temporal satellite images.

Sarma and Basumallick[19] carried out a study on bank line migration of the Burhi Dihing river using topographical maps. Goswami et al[12] studied channel migration of the Subansiri River using topographical maps and satellite imageries. However, a major contribution has been made by the Department of Water Resources Development and Management (IIT, Roorkee) by studying the erosion of Brahmaputra and its control measures in the year 2012 using remote sensing technology. Continuing the trend of bank erosion and bank line migration studies, researchers across the Nation have been carrying out such studies. In Assam, bank erosion and channel changes studies have been made on the Barak River[5], the Brahmaputra River and its tributaries like Burhi Dihing, Dhansiri, Subansiri, Jia Bhareli, Pagladiya, Puthimari etc.[9,11,12,18-21].

Keeping these facts into considerations, the objective is to study the channel change and migration of Brahmaputra river along with the shifting of the south bank line of the Brahmaputra River for a period of 41 years i.e. from 1980 to 2021 and the status and impact of bank erosion in the Morigaon district of Assam.

Study Area

Morigaon is one of the most flood-affected districts of Assam and flood is the most destructive geomorphic process in the district. In Morigaon, bank erosion is mainly caused by the Brahmaputra River. Breaching of embankments also creates manifold problems for the villagers living nearby. The northern part of the district is highly prone to erosion because the Brahmaputra lies in the northern part of the district. Many villages of the district are eroded by Brahmaputra partially or fully. Out of 629 villages in the district, 94 villages are fully eroded and 31 villages are partially eroded as per the record of the Revenue Circle office and District Disaster Management Authority, Morigaon (DDMA, 2021).

There are five revenue circles in the district, of which three are more vulnerable to flood and bank erosion namely the Bhuragaon Revenue Circle, Laharighat Revenue Circle and Mayong Revenue Circle.

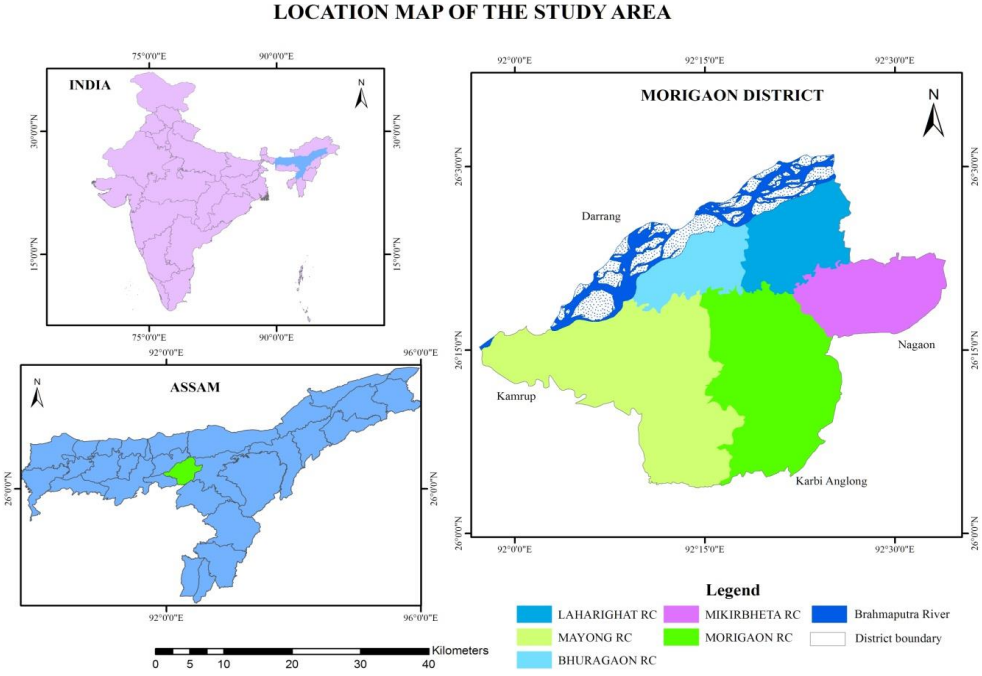

Figure 1: Location of Morigaon district, Assam, India

Table 1
Satellite images used to study the bank line migration

Image	Year	Spatial Resolution	Source
Landsat 1-5 MSS	01-02-1980	30m	USGS
Landsat 4-5 TM	07-02-2001	30m	USGS
Landsat OLI	27-04-2021	30m	USGS

The bank line of Brahmaputra in the district is migrating towards the south gradually. The Brahmaputra and its tributaries Kopili, Kolong, Pokoriya and Sonai govern the fluvial regime of the district. Figure 1 shows the location map of the study area.

Material and Methods

Data: The basic data used in this study are toposheets and satellite imageries along with secondary data collected from the District Disaster Management Authority (DDMA) and Revenue Circle offices. The location map of Morigaon is delineated from SOI (Survey of India) toposheets bearing the numbers 78N/15, N/16, 83 (B03, B04, B06, B07, B08 and B12) at the scale 1:50000. Table 1 shows the satellite images used to study the bank line erosion in this study.

Methodology: Channel shifting analysis has been made on River Brahmaputra along the stipulated reach length of 54.7 km. The water channel of the Brahmaputra has been digitized from the Landsat satellite imageries for the year 1980, 2001 and 2021 in GIS environment. Only the presence of water area have been considered excluding the sediment deposited area such as the sandbars. All the three layers of river Brahmaputra has been overlayed in GIS and the base map of channel shifting of Brahmaputra has been prepared. In addition, in order to estimate the erosion and accretion of Brahmaputra channel for the three different time period in a time span of 41 years, reach wise analysis has been made. The reach length AB has been divided into four reaches named as reach 1, reach 2, reach 3 and reach 4 and the erosion and accretion analysis has been done reach wise.

The analysis of 'unchanged area' i.e. the presence of river water between two time periods has been obtained by using the Arc GIS geoprocessing tool 'intersect' and using the river layer of 1980 and 2001, 2001 and 2021 as input. The formula to estimate the unchanged area is given in formula 1. Moreover, to calculate the eroded area, formula 2 has been used. The accretion area is estimated from previous year and unchanged area as given in formula 3.

$$Unchanged\ area = Intersect\ of\ next\ year\ and\ previous\ year \quad (1)$$

$$Erosion = Next\ year - unchanged \quad (2)$$

$$Accretion = Previous\ year - unchnaged \quad (3)$$

In addition to channel change analysis, the shifting or migration of the Brahmaputra has also been analysed in Arc GIS using the 'Channel Migration Toolbox' which was introduced by Department of Ecology, State of Washington. For migration analysis, the river centre line of the Brahmaputra river for the years 1980, 2001 and 2021 is generated through the 'midpoint' editing tool in GIS. After generating the river centre line for three years taking 1980 as the base year, the 'Reach Average Channel Migration Tool' is used to generate the migration of the river channel. Afterward transect lines were generated taking 1km distance between transects, thereby 62 auto-generated transects and observation points were obtained. A few of the auto-generated transects were manually edited for better results. Thus, a total of 62 observation points and transects are obtained, which indicate the direction of channel migration from 1980 to 2021. The distance of each transect from the base year i.e. 1980 to 2021 is statistically measured and graphically presented.

To assess the bank line shifting, the Brahmaputra River part lying in Morigaon district has been divided into 10 reaches of equal spacing of approximately 6 km each and a total of 11 cross sections have been drawn in such a way that each reach covers a cross-section either in the middle of the reach or in the border line of the reach depending upon the suitability. Only the south bank line of the river which lies within the district has been considered. The study has delineated the bank line shift for three years 1980, 2001 and 2021. The bank line of 1980 has been considered as the baseline.

Delineation of river bank line: The Normalized Difference Water Index (NDWI) is the dominant method to delineate the river bank line. In the study area, where there are either recent or ancient deposits along the riverbank, there seems to be some confusion regarding the interpretation of the active water channel at some. Some distant patches from the active channel have higher moisture and appear in a dark tone in the satellite images. This suggests that the land was either recently flooded or the river was passing through that section. Therefore, the NDWI has assisted in defining the bank line and these places are regarded as being a part of the river. GIS software was used to digitise the identified bank line and three bank lines for the years 1980, 2001 and 2021 were created.

Results and Discussion

Geospatial analysis of channel change of Brahmaputra River, 1980-2001: The base map of channel shifting of Brahmaputra from 1980 to 2001 is presented in figure 2. The erosion, accretion or deposition and unchanged areas were estimated through channel change analysis in a reach length of 57.40 km presented in figures 3 and 4. The estimated values are shown in table 2. Reach 1 (3061.2 hectares) had highest erosion, followed by reach 2 (306.4 hectares), reach

3 (2251.0 hectares) and reach 4 (1288.5 hectares), according to reach-wise analysis. Between 1980 and 2001, reach 2 (3938.3 hectares) had the most soil accretion, followed by reach 3 (2327.3 hectares), reach 1 (2101.1 hectares) and reach 4 (1549.7 hectares). The estimated values are graphically plotted in figure 5.

Geospatial analysis of channel change of Brahmaputra river, 2001-2021: The base map of channel shifting of Brahmaputra from 2001 to 2021 is presented in figure 6. The analysis conducted on the Brahmaputra River's (Reach length 57.40 km) erosion and accretion processes during 2001–2021 produced estimates of the river's erosion, accretion, or deposition and remaining unchanged area, which are shown in figures 7 and 8. The estimated values are shown in table 3.

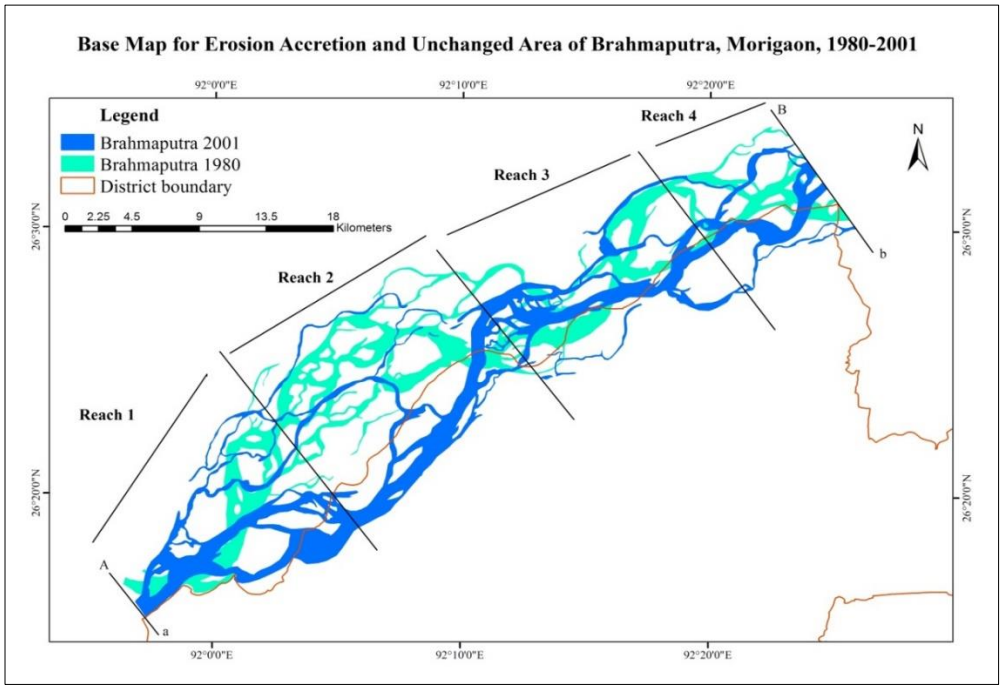

Figure 2: Channel shifting of Brahmaputra river in Morigaon, 1980-2001

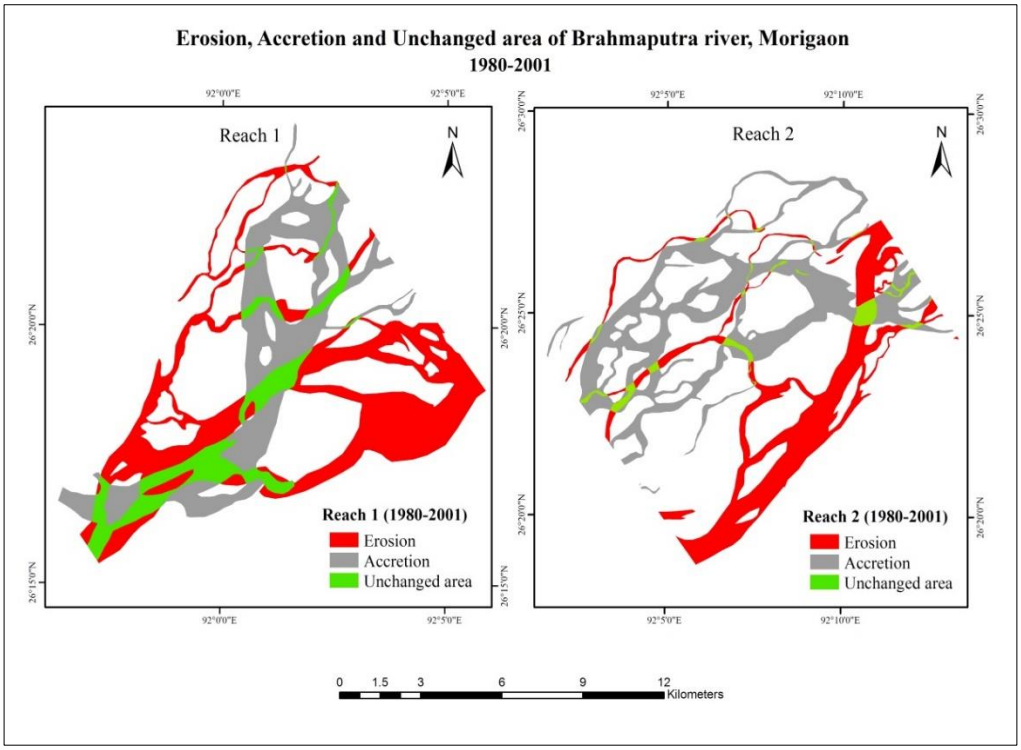

Figure 3: The area eroded, accreted and remaining unchanged area of Brahmaputra river in reach 1and 2 during 1980-2001

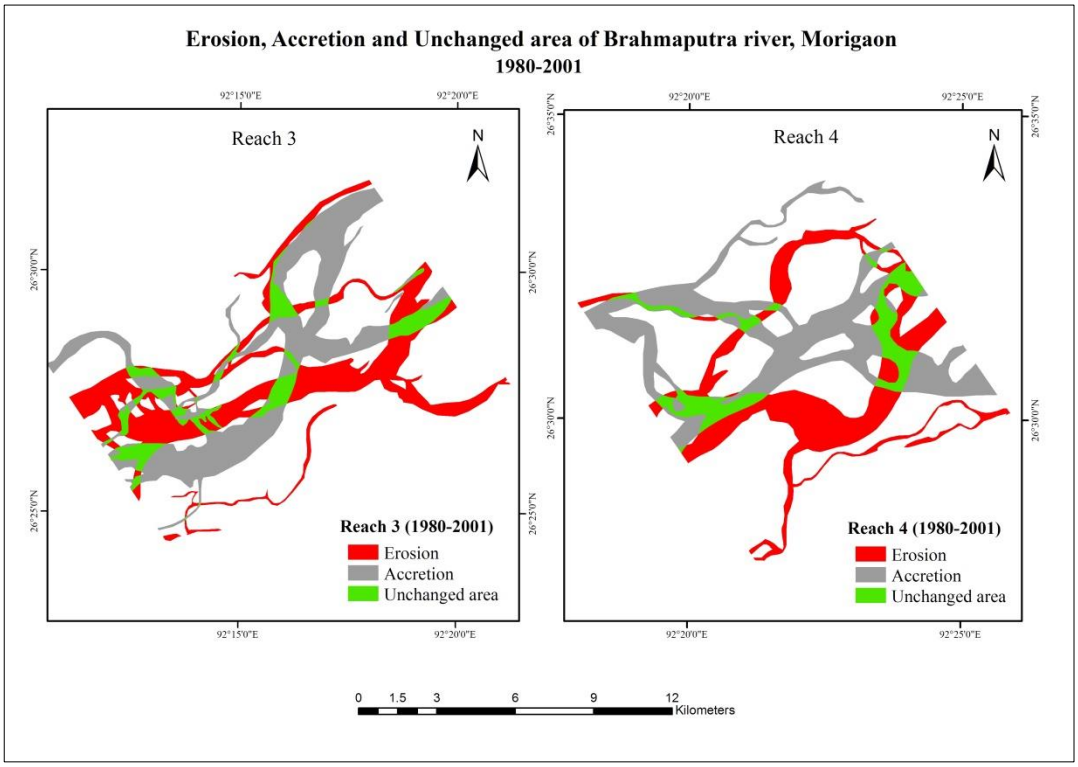

Figure 4: The area eroded, accreted and remaining unchanged area of Brahmaputra river in reach 3 and 4 during 1980-2001

Table 2
Statistics of reach wise total channel area, erosion, accretion and unchanged area, 1980-2001

Reach	Area in 1980 (ha)	Area in 2001 (ha)	Erosion (ha)	Accretion (ha)	Unchanged area (ha)
1	3071.3	4031.3	3061.2	2101.1	970.1
2	4276.9	3345.0	3006.4	3938.3	338.6
3	3055.8	2979.5	2251.0	2327.3	728.5
4	2007.5	1746.4	1288.5	1549.7	457.9

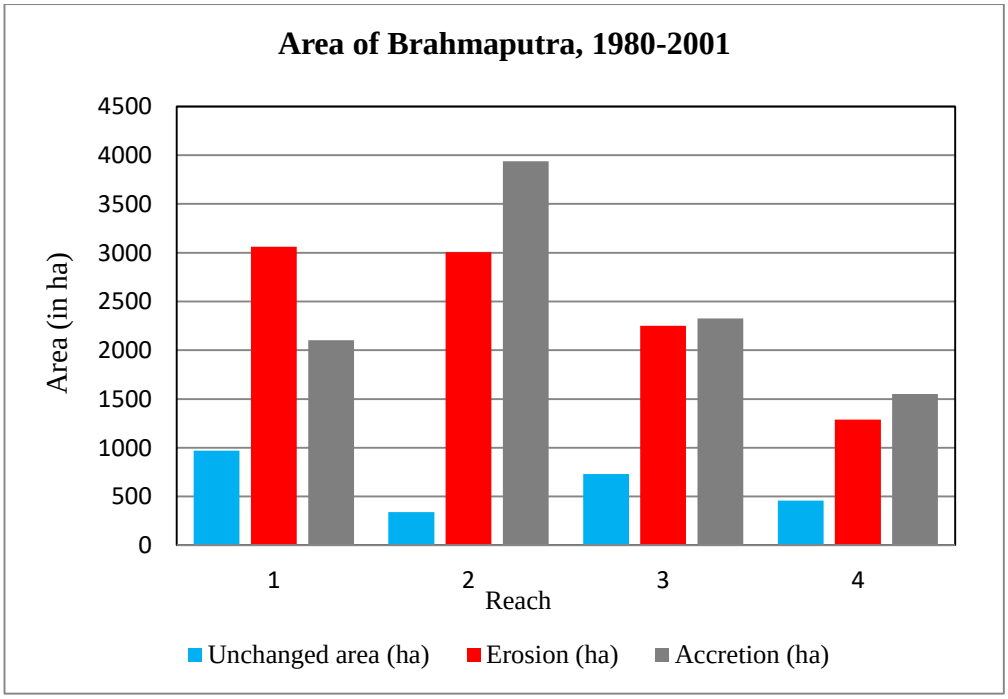

Figure 5: Erosion, accretion and unchanged area of Brahmaputra river channel during 1980 to 2001

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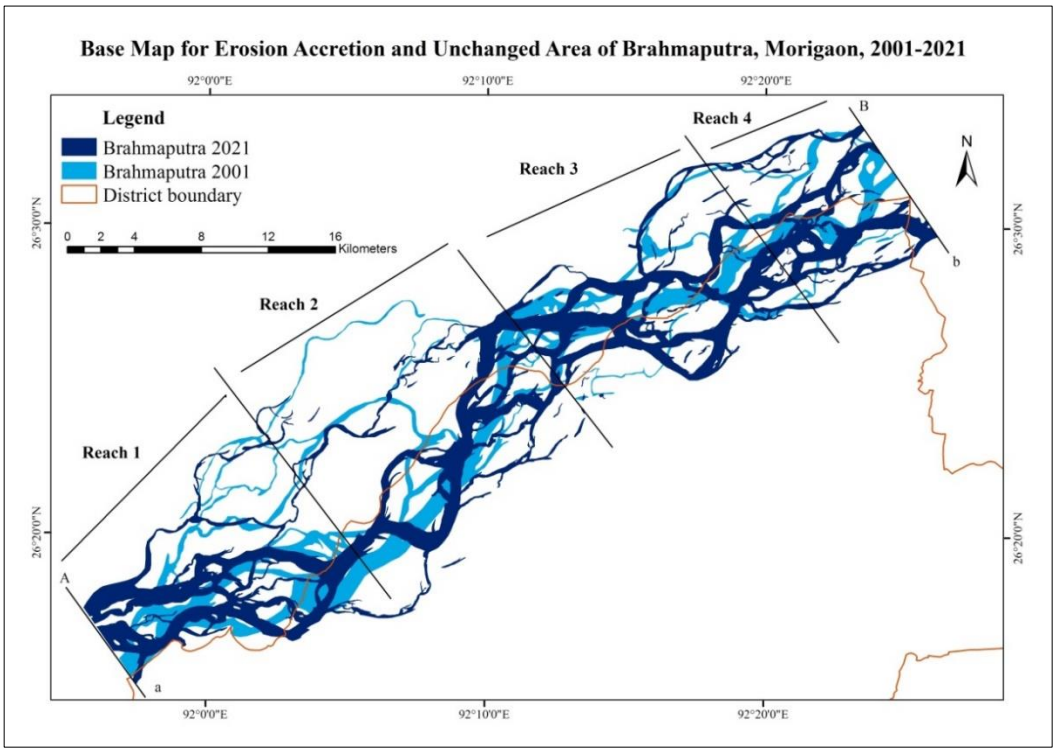


Figure 6: Channel shifting of Brahmaputra river in Morigaon, 2001-2021

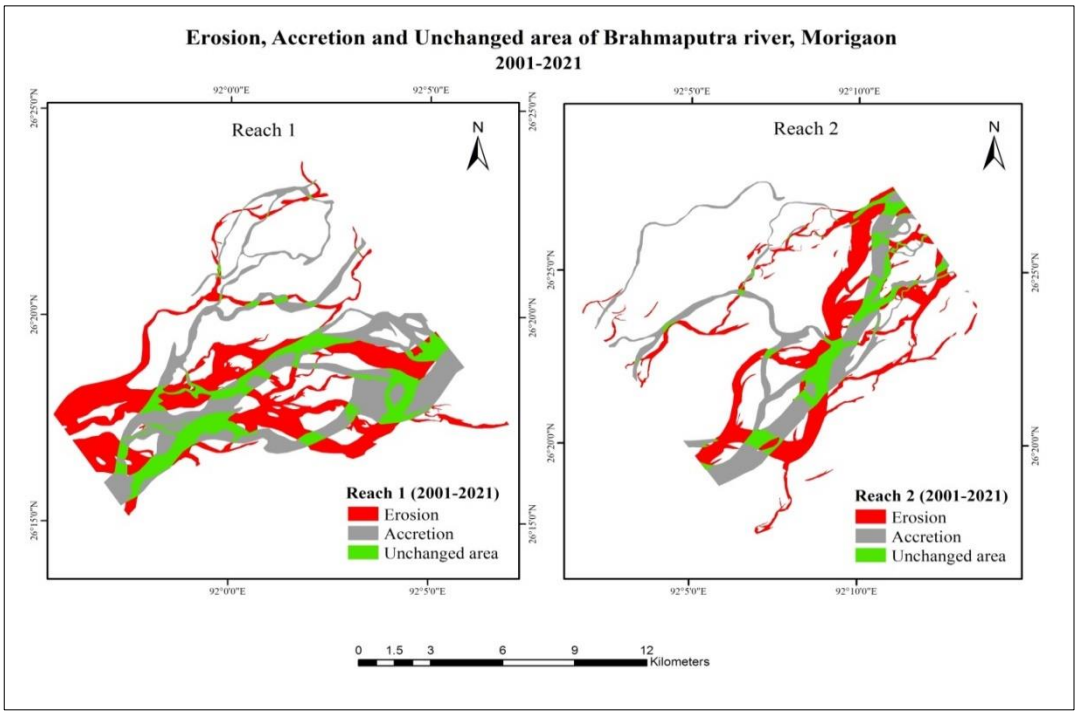


Figure 7: The area eroded, accreted and remaining unchanged area of Brahmaputra river in reach 1and 2 during 2001-2021

Table 3
Statistics of reach wise total channel area, erosion, accretion and unchanged area, 2001-2021

Reach	Area in 2001 (ha)	Area in 2021 (ha)	Erosion (ha)	Accretion (ha)	Unchanged area (ha)
1	4031.3	4397.4	3043.9	2677.8	1353.5
2	3345.0	3909.7	2917.8	2353.1	991.9
3	2979.5	4260.2	3227.2	1946.4	1033.1
4	1746.4	2748.4	2209.0	1207.0	539.4

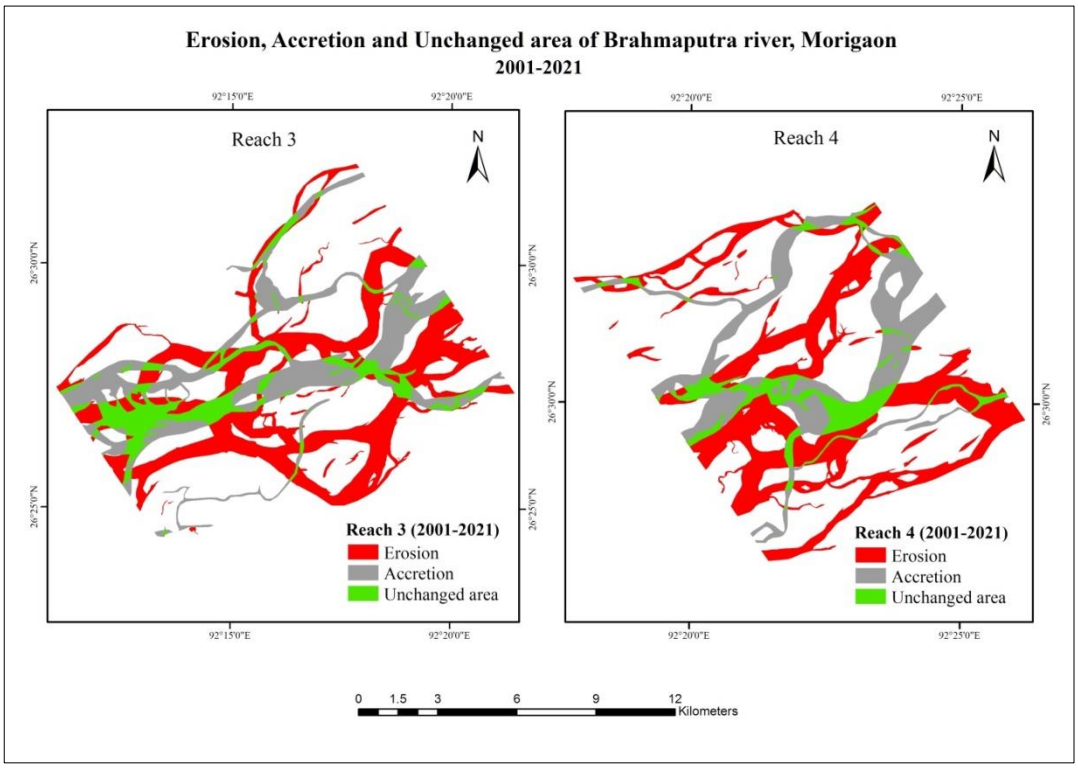


Figure 8: The area eroded, accreted and remaining unchanged area of Brahmaputra River in reach 3 and 4 during 2001-2021

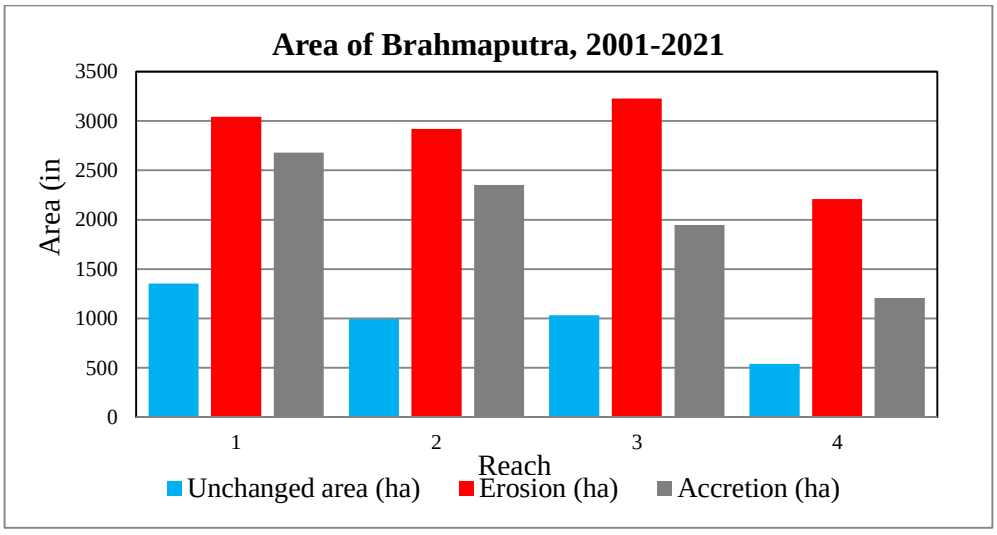


Figure 9: Erosion, accretion and unchanged area of Brahmaputra river channel during 2001-2021

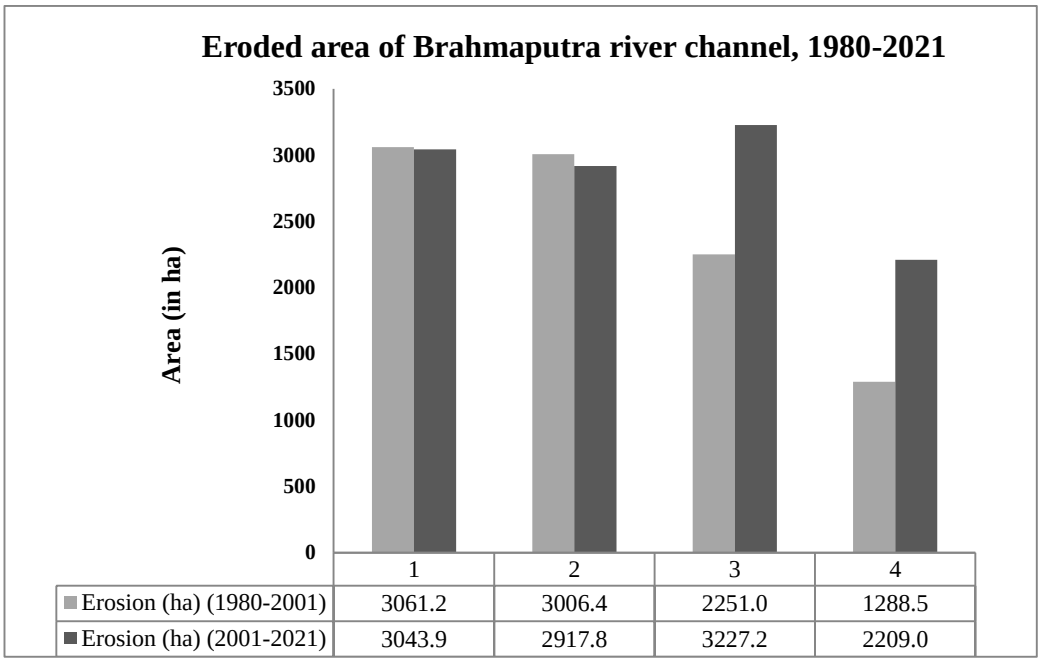
The reach wise analysis reveals that from 2001 to 2021, erosion was maximum in reach 3 (3227.2 hectares) followed by reach 1 (3043.9 hectares), reach 2 (2917.8 hectares) and reach 4 (2209.0 hectares). Soil accretion or deposition was maximum in reach 1 (2677.8 hectares) followed by reach 2 (2353.1 hectares), reach 3 (1946.4 hectares) and reach 4 (1207.0 hectares). The estimated values are graphically presented in figure 9.

Fig. 10 represents a comparison of the total eroded areas of the Brahmaputra river channel. In all four reaches of Brahmaputra channel, erosion was high from 2001 to2021 as compared to 1980 to 2001. This indicates high erosion from 2001 to 2021 which resulted into the widening of the river channel and shifting respectively.

Table 4 indicates the change statistics of the Brahmaputra River channel in the study area from 1980 to 2021. The total channel area of Brahmaputra in 1980 was 12411.5 hectares, which decreased by 309.3 hectares in 2001. This indicates a 2.49% decrease in channel area in 2001. The total channel area in 2021 was 15315.8 hectares, showing a 26.55% growth in channel area over 2001. Similarly, in 1980, the area of sandbars in the Brahmaputra Reach was 19688.07 hectares; this rose by 16904.36 hectares, indicating an 85.86% increase in area.

Similarly, in 1980, the area of sandbars in the Brahmaputra Reach was 19688.07 hectares; which increased by 16904.36 hectares, indicating an 85.86% increase in 2001. Table 4 shows that the overall area of sandbars has expanded by 3213.6 hectares in 2021, or 4.07%, from 2001 to 2021. Overall, between 1980 and 2021, the river channel extended by 23.4%, while the area of sandbars increased by 93.4%, suggesting further channel widening and sandbar deposition in the river bed.

Channel Migration of Brahmaputra River (1980-2021): The channel shifting of the Brahmaputra River was analysed for the time span of 41 years which indicates a migration of the river channel. Channel migration is a natural process of a river. It describes how a river channel moves or changes its flow path over time. Brahmaputra River is mostly braided in nature, however, some reaches are meandering or anastomosed[3]. In order to understand the migration direction of the river channel, a base map has been prepared and the directions and the respective distances are generated (Figure 11). Through channel migration analysis, the generated statistics have been presented in table 5 and graphically presented in figure 12 and 13.



	1	2	3	4
Erosion (ha) (1980-2001)	3061.2	3006.4	2251.0	1288.5
Erosion (ha) (2001-2021)	3043.9	2917.8	3227.2	2209.0

Figure 10: Reach-wise comparison of total area eroded from 1980 to 2021

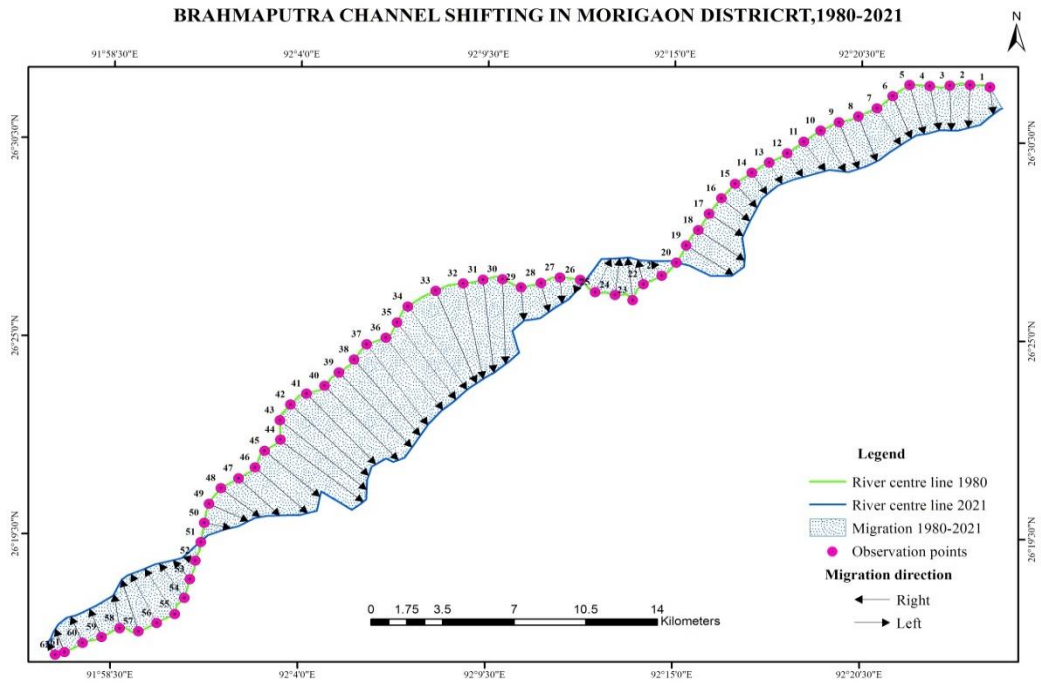


Figure 11: Channel migration of Brahmaputra in Morigaon district, 1980-2021

Table 4
Total increase and decrease of channel area and its percentage

Year	Channel area (ha) (A)	Sandbars area (ha) (B)	Increase / Decrease (A)	Increase / Decrease (B)	Increase / Decrease % of A	Increase / Decrease % of B
1980	12411.5	19688.07	0	0	0	0
2001	12102.2	36592.44	-309.3	16904.36	-2.49	85.86
2021	15315.8	38083.65	3213.6	1491.21	26.55	4.07

Table 5
Migration direction and distance of Brahmaputra channel from 1980 to 2021

Observation points	Migration Direction	Distance (in km)	Observation points	Migration Direction	Distance (in km)
1	L	1.40	32	L	5.00
2	L	2.21	33	L	5.14
3	L	2.30	34	L	5.16
4	L	2.31	35	L	4.89
5	L	2.62	36	L	4.62
6	L	2.35	37	L	5.10
7	L	2.21	38	L	5.06
8	L	2.47	39	L	5.23
9	L	2.57	40	L	5.24
10	L	2.43	41	L	4.96
11	L	1.83	42	L	5.27
12	L	1.43	43	L	5.54
13	L	1.26	44	L	5.14
14	L	1.33	45	L	3.58
15	L	1.62	46	L	3.47
16	L	1.82	47	L	2.78
17	L	2.02	48	L	2.42
18	L	2.74	49	L	2.12
19	L	2.74	50	L	1.33
20	R	0.02	51	R	0.04
21	R	0.92	52	R	0.63
22	R	1.29	53	R	1.28
23	R	2.20	54	R	2.15
24	R	1.90	55	R	2.74
25	R	1.89	56	R	2.81
26	L	0.75	57	R	2.77
27	L	1.32	58	R	1.78
28	L	1.54	59	R	1.56
28	L	1.71	60	R	1.46
30	L	4.35	61	R	1.27
31	L	4.79	62	R	0.73

*L= left, R= right

Table 5 clearly demonstrates that out of 62 observation points, 44 indicate leftward channel migration whereas 18 indicate rightward migration. This definitively shows a predominant tendency toward migration to the left. However, from all the migration distances, the highest distance is found to be 5.54 km and the lowest distance is 0.02 km. There are total 10 observation points which have migration distance more than 5 km (observation points 32, 33, 34, 37, 38, 39, 40, 42, 43, 44). When analyzing the migration directions of the channel, it is clear that migration to the left occurs more frequently than migration to the right. In fact, the maximum observed distance in the right direction is only 2.81 km (observation point 56). It can be seen that observation points 23, 54, 55, 56 and 57 have more migration distances. Figure 12 clearly indicates that the distance increases from points 30 to 43, followed by a decrease from points 44 to 50. These points are situated in the Bhuragaon RC area of the district which has been grappling with severe erosion for decades.

This persistent erosion underscores the urgent need for effective intervention measures. Left direction migration

distance is greater in Bhuragaon RC and Mayong RC as compared to Laharighat RC.

Figure 13 reveals that in the right direction of migration, distance increases from points 21 to 25, then decreases and then again increases from 53 to 57 and again decreases accordingly. The Brahmaputra River channel clearly demonstrates a more pronounced leftward migration than rightward, confirming a significant southward shift of its bankline.

Geo-spatial analysis of bank line: The Brahmaputra shifts its bank line in north and south directions alternately like a meandering river. From 1912 to 1996, in Assam, there was a loss of about 868 km^2 of area along the entire river length. In addition, the net shift of the north bank line of Brahmaputra towards the north direction was 7.74 km whereas towards the south direction was 8.75km. Likewise, the shifting of the south bank line of Brahmaputra towards the south direction was 7.09 km whereas towards the north direction was 6.37 km[21]. The Brahmaputra River brings huge amounts of sediments, which are deposited in the river beds after entering into the plains of Assam. In this present study, the bank line shifting map has been prepared from Landsat satellite imageries using geospatial tools.

Bank line shifting in Morigaon district from 1980-2001: Figure 14 shows the shifting of the bank line of the Brahmaputra in the Morigaon district and table 6 represents the length of each cross section depicting the shifting of the bank line.

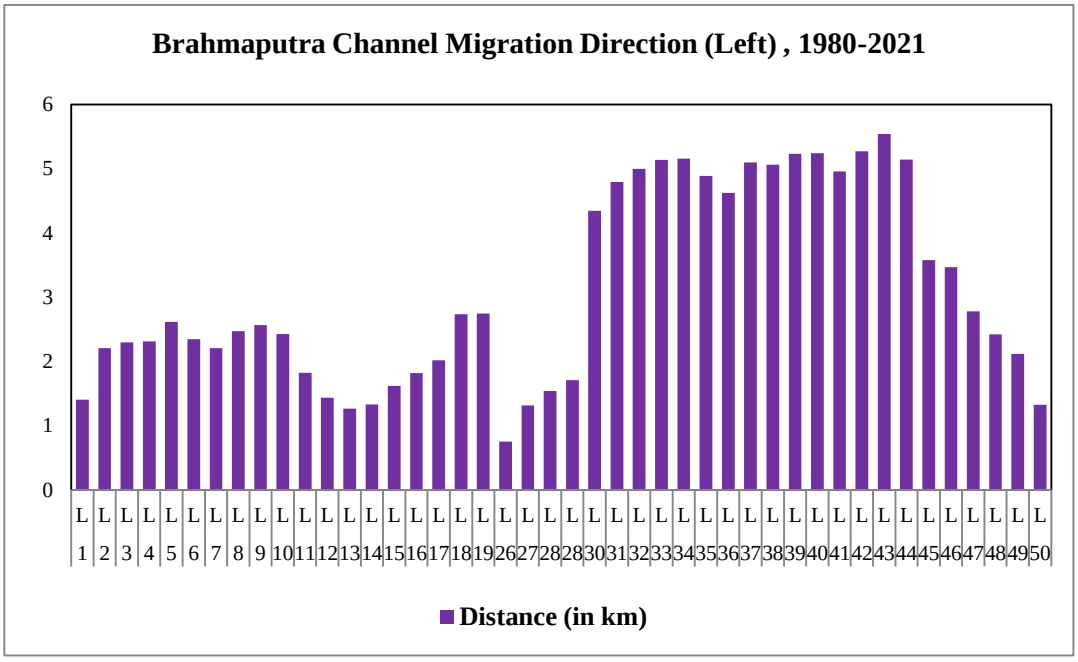


Figure 12: Left direction migration along with observation points of Brahmaputra River, 1980-2021

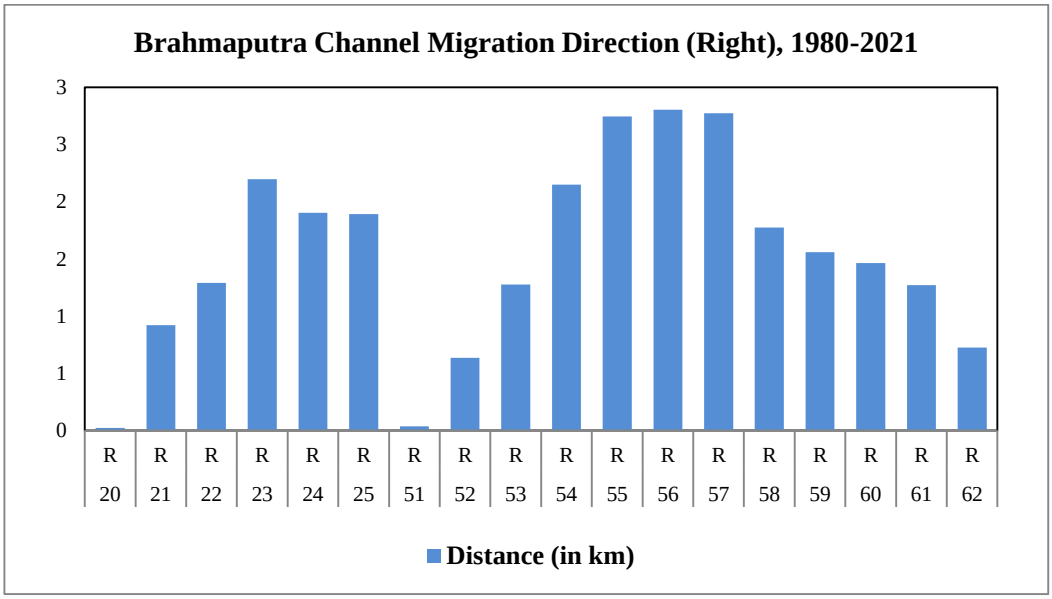


Figure 13: Right direction migration along with observation points of Brahmaputra River, 1980-2021

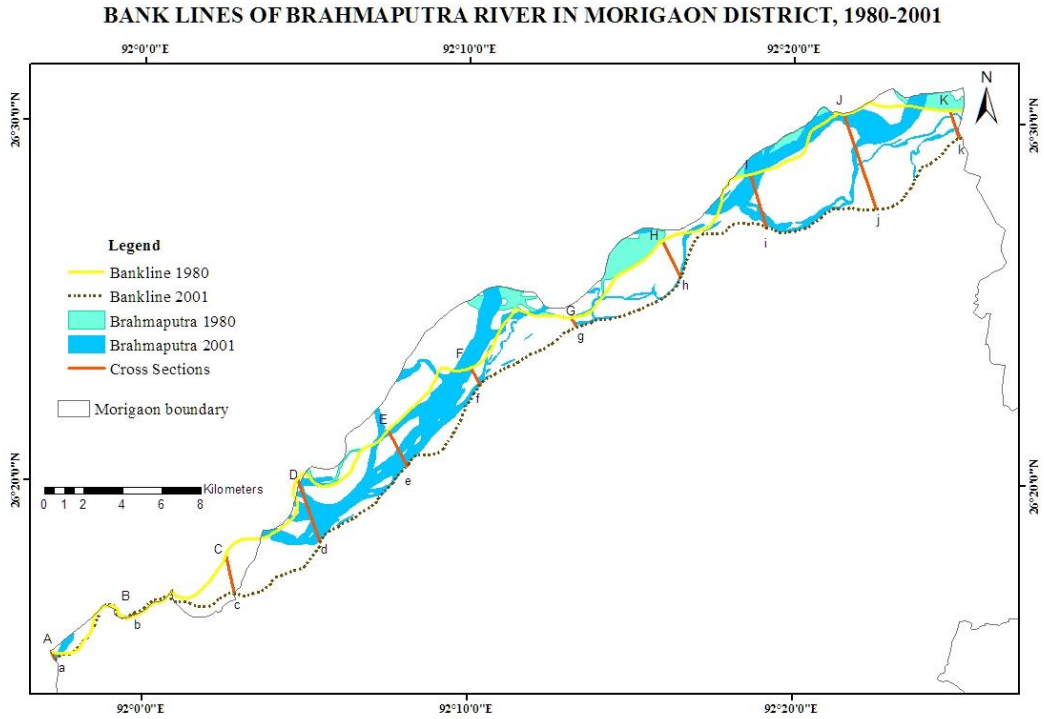


Figure 14: Cross-sections of bank line shifting of the Brahmaputra River, 1980-2001

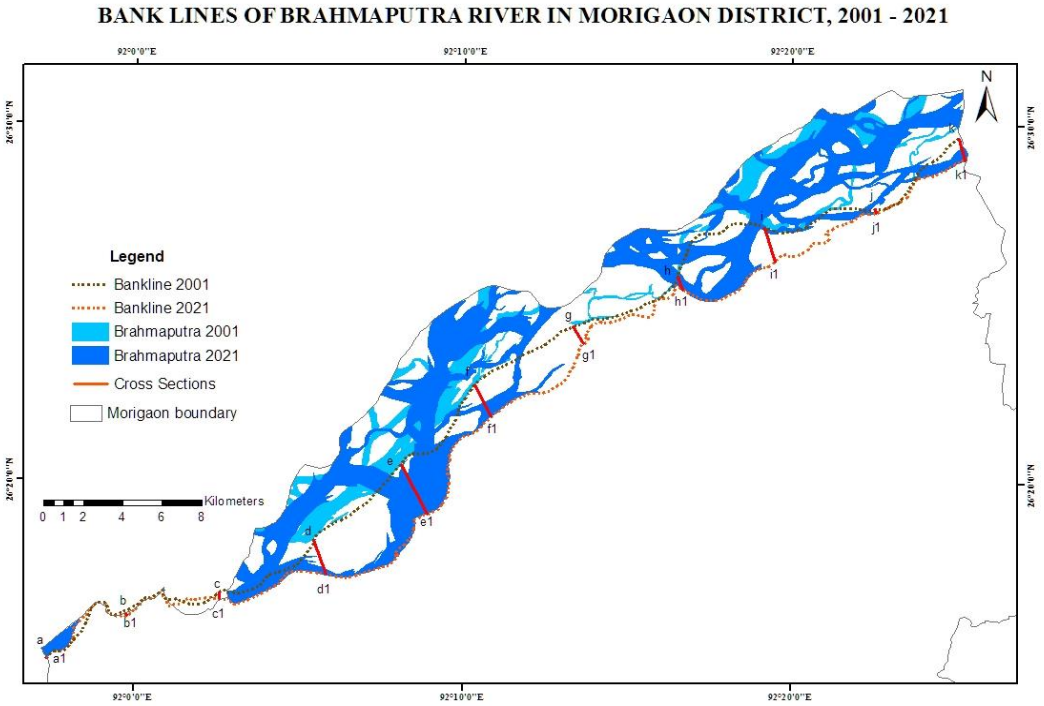


Figure 15: Cross-sections of bank line shifting of The Brahmaputra River, 2001 and 2021

Table 6 indicates that cross section *'Jj'* had a maximum shift in the south bank line of about 5.142 km in a span of 21 years (1980 to 2001). This lies in the Laharighat revenue circle which is the most flood and erosion affected area in the district. In the cross section *'Cc'*, *'Ee'*, *'Hh'* and *'Ii'*, the shifting of the bank line was 2.03, 2.07, 2.09 and 2.83 km respectively. Cross-sections *'Aa'*, *'Bb'* and *'Gg'* had the minimum shifting of only 0.45, 0.24 and 0.63 km respectively. Bank line migration was less in cross sections *'Aa'* and *'Bb'* due to the structural control of hillocks like Burha Mayong and Govardhan Pahar. Cross sections *'Ff'* and *'Kk'* had 1.11 and 1.39 km shifts respectively. The bank line shifting in the northern part of Morigaon district from 1980 to 2001 can be related to the 33 major floods from 1980-1989[19].

Bank line shifting in Morigaon from 2001-2021: Figure 15 shows the shifting of the south bankline of Brahmaputra from 2001 to 2021 and table 7 shows the cross-section wise length and direction of shifting. From 2001 to 2021, the cross sections *'ee1'* had a maximum shift of 2.88 towards the south followed by ff1 (1.87km), dd1 (1.86km), ii1 (1.83km) respectively (Table 7).

Table 6
Shifting of south bank line along various cross-sections, 1980-2001

Cross Sections	Length in km	Direction
	1980-2001	
Aa	0.451	South
Bb	0.140	North
Cc	2.040	South
Dd	3.474	South
Ee	2.073	South
Ff	1.022	South
Gg	0.592	South
Hh	2.093	South
Ii	2.834	South
Jj	5.142	South
Kk	1.505	South

Table 7
Shifting of south bank line along various cross-sections, 2001-2021

Cross Sections	Length in km	Direction
	2001-2021	
aa1	0.017	South
bb1	0.126	South
cc1	0.301	South
dd1	1.869	South
ee1	2.884	South
ff1	1.871	South
gg1	1.016	South
hh1	0.685	South
ii1	1.839	South
jj1	0.182	South
kk1	1.156	South

Table 8
Measurement along various cross-sections, 1980-2021

Cross Sections	Length in km	Cross Sections	Length in km	Total shift
	1980-2001		2001-2021	1980-2021
A-a	0.451	a-a1	0.017	0.468
B-b	0.14	b-b1	0.126	0.266
C-c	2.04	c-c1	0.301	2.341
D-d	3.474	d-d1	1.869	5.343
E-e	2.073	e-e1	2.884	4.957
F-f	1.022	f-f1	1.871	2.893
G-g	0.592	g-g1	1.016	1.608
H-h	2.093	h-h1	0.685	2.778
I-i	2.834	i-i1	1.839	4.673
J-j	5.142	j-j1	0.182	5.324
K-k	1.505	k-k1	1.156	2.661

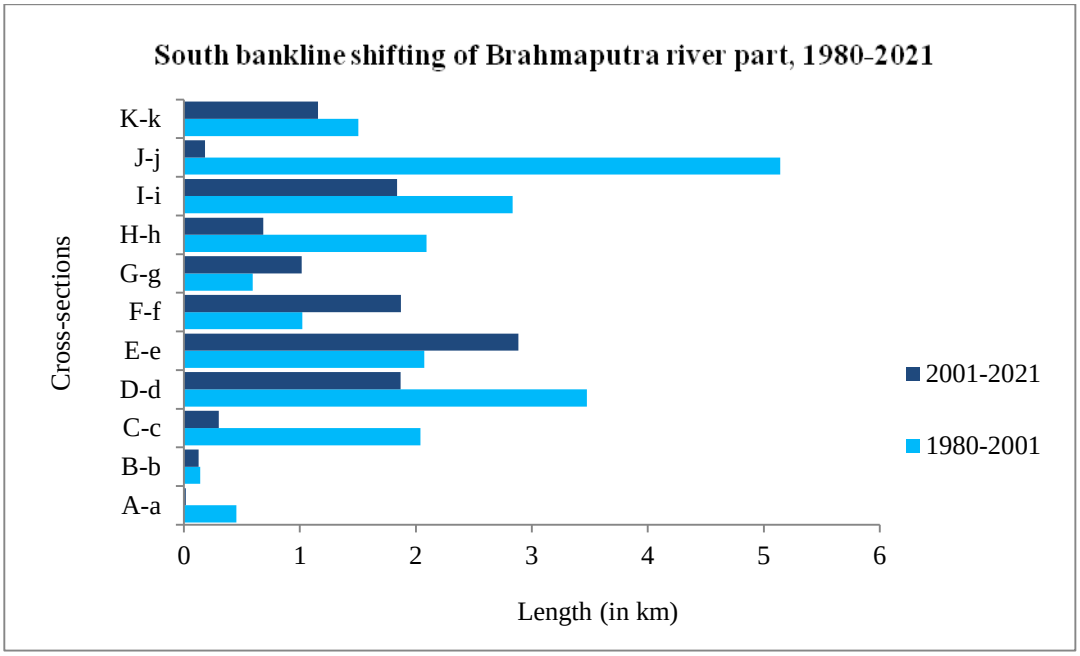


Figure 16: South bank line shifting, Morigaon, 1980 to 2021

Table 9
Cross section wise villages and its eroding years, 1980-2021

Cross-sections	Total shift (in km)	Village	Eroded year	Revenue Circle
Dd-d1	5.34	Tengatuli	1984, 1990	Bhuragaon
		Pakariguri	1988, 1992	Bhuragaon
		Phaliamari	2008	Mayong
		Khandakhati	2008	Mayong
Ee-ee1	4.96	Haibar Pathar	1988, 1992	Bhuragaon
		Rupahi beel	2000	Bhuragaon
		Baralimari	2016, 2017	Bhuragaon
		Bahakajari	2004	Mayong
Ff-ff1	2.89	Bihabari beel	1988, 1992	Bhuragaon
		Saharigaon	1991, 2004	Bhuragaon
		Durabandhi	1988, 1990	Bhuragaon
		Jengpori	1998, 2009	Bhuragaon
Gg-gg1	1.61	Pabhakhati	1981, 1992	Bhuragaon
		Bhuragaon	1985, 2015	Bhuragaon
		Baruakati	2001, 2015	Bhuragaon
Hh-hh1	2.78	Kahitoli	1981, 1990	Bhuragaon
		Haloakanda	1992, 2001	Bhuragaon
		Kapurpora	2012, 2016	Bhuragaon
Ii-ii1	4.67	Kaurhagi	1982	Laharighat
		Tengagurigaon	1984	Laharighat
		Sialmarigaon	1990	Laharighat
		Garakhiakhuti	1999	Laharighat
		Harangtoli	2003	Laharighat
		Chutiagaon	2004	Laharighat
Jj-jj1	5.32	Goroimari	1983	Laharighat
		Modarguri	1989	Laharighat
		Bhajakhati	1984	Laharighat
		Ulubari	2002, 2007	Laharighat
Kk-kk1	2.66	Leruamukh	1989	Laharighat

Source: GIS analysis along with secondary data from DDMA

Bank erosion in the district was first recorded by the DDMA in 1982 in the Laharighat RC. In Bhuragaon RC and Mayong RC, erosion was recorded for the first time in 1984 and 1998 respectively. As bank erosion is not considered a disaster, records of erosion were not found before 1980. As stated by Valdiya[23] in his study on the Brahmaputra River, the major flood of 1998 with four shocking waves deluged about 38200 km^2 or 48.65% of the geographical area of Assam thereby creating havoc to almost 15 million people.

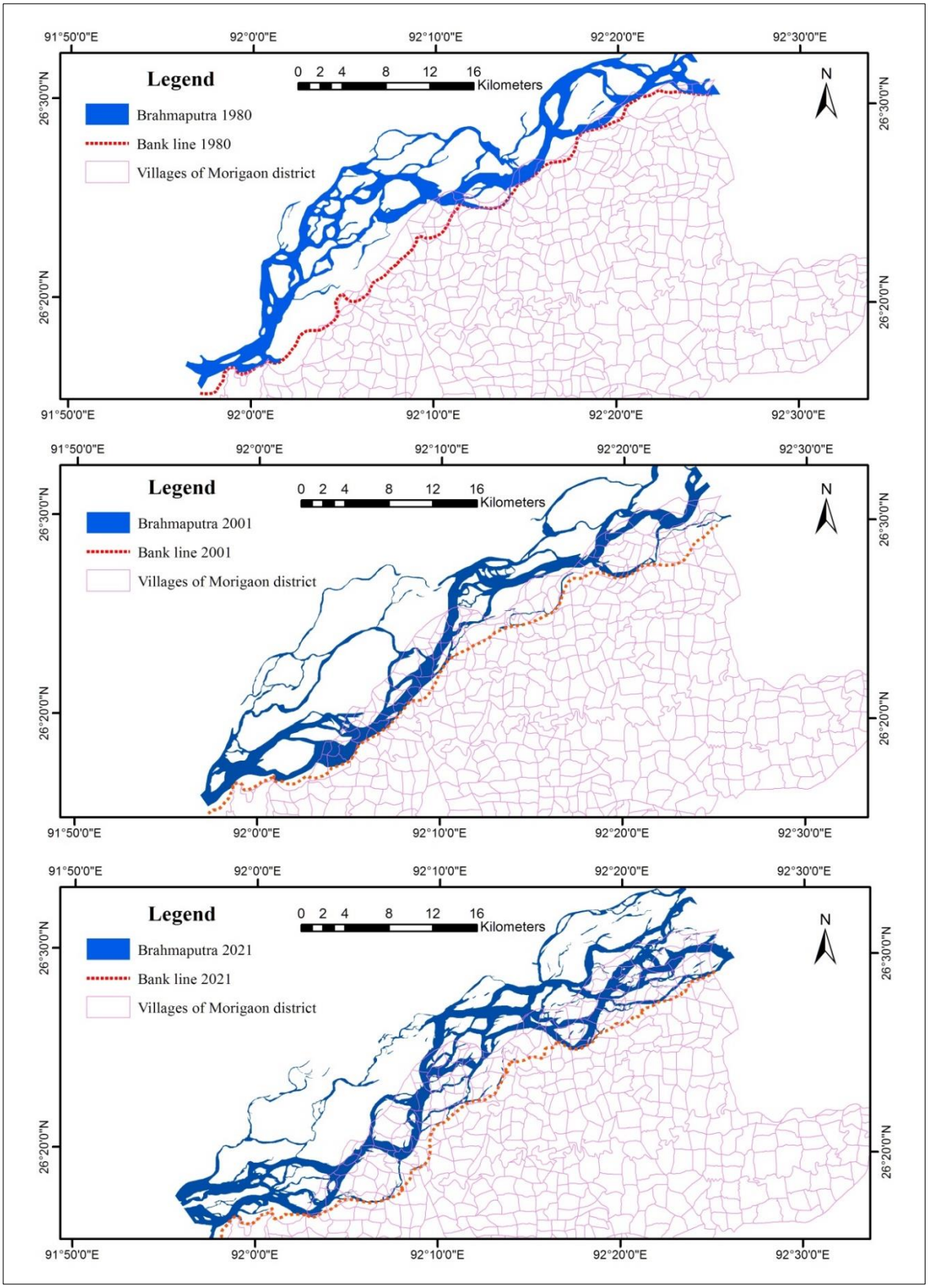


Figure 17: Overlay of south bank lines of Brahmaputra for the three different periods (1980, 2001 and 2021) on villages of the district.

By combining the bank lines of 1980, 2001 and 2021 with the village map of the district in GIS environment, the eroded villages have been identified (Figure 17). Additionally, by repeating the process, it is possible to identify the specific villages that fall within the cross-sections. By using this method, the villages were identified and verified against secondary data obtained from the District Disaster Management Authority, Morigaon (Figure 17 and table 9).

As evident in the bank line shifting map (Figure 14) of Brahmaputra River in Morigaon and table 8, for the period 1980 to 2001, the cross section *'Dd'* has a shift of 3.47 km which falls within two villages of Bhuragaon RC namely Tengatuli village which was eroded in the year 1984 and 1990 and Pakariguri village which was eroded in the year 1988 and 1992. Likewise, the cross section *'Ee'* for the period 1980-2001 had a shift of 2.073 km. This falls within Haibur Pathar village and Rupahi beel. Haibur Pathar village was first eroded in the year 1988 and second time again in 1992 and Rupahi beel was partially eroded in the year 2000.

During that same period, cross section '*Ff*' indicated a total shift of 1.112 km which lies within Bihabari beel, first eroded in 1988 and then again in 1992; Saharia Gaon was eroded in 1991; Jengpori village was eroded in 1998 and Durabandhi village of Bhuragaoon RC was eroded in 1988 and again in 1990. The cross-section *'Hh'* had a bank line shifting of 2.093 km from 1980 to 2001 and lies within Kahitoli village of Bhuragaon RC, which was first eroded in 1984 and again in 1990. The Haloakanda village of Bhuragaon RC eroded in 1992 for the first time. Cross-section 'Ii' has a bank line shifting of 2.834 km from 1980 to 2001 and lies in Laharighat RC where Kaurhagi village was eroded in 1982, Tengagurigaon village was eroded in 1984, Sialmarigaon was eroded in 1990 and Garakhiakhuti village was eroded in 1999.

From 1980-2001, cross-section *'Jj'* had a bank line shifting of 5.14km. Goroimari village eroded in 1983, Goroimari and Modarguri village eroded in 1989 and Bhajakhati Gaon eroded in 1984. Cross-section Kk indicates bank line shifting of 1.39 km from 1980 to 2001, which lies within Leruamukh village of Laharighat RC which was eroded in 1989. Again from 2001 to 2021, cross-section kk1 shows a shifting of 1.13km which lies within Bongrai no.1 and Bongrai no.2 villages of Laharighat RC (Table 9). The data from DDMA also validates the erosion of the above-mentioned villages in the respective years.

Between 2001 and 2021 (Figure 15 and table 8), the cross section *'dd1'* indicates a total shift of 1.869 km. Phaliamari and Khandakhati villages of Mayong RC falling along this cross section were eroded for the first time in 2008. During the same period, in the cross section 'ee1' the bank line shifted by 2.884 km, which lies in Baralimari beel of Bhuragaon RC which was first eroded in 2016 and again in 2017. Bahakajari village of Mayong RC along the same cross section was also eroded in 2004. In figure 15, the cross-section *'ff1'* had a total shift of 2.451 km which lies within Saharia Gaon of Bhuragaon RC. This village was eroded again in 2004; Jengpori village eroded again in 2009. In the cross section '*Gg',*

Pabhakhati village was eroded for the first time in 1988 and again in 1992 and Bhuragaon village was eroded for the first time in 1985. Cross section *'gg1'* lies within Bhuragaon village which was again eroded in 2015; Baruakati village of Bhuragaon RC was eroded in 2001 and again in 2015. From 2001 to 2021, cross-section *'hh1'* had a bank line shifting of 0.89km where Haloakanda village was again eroded in 2001. Kapurpora village of Bhuragaon RC was eroded in 2001 and again in 2016. The cross section *'ii1'* indicates a bank line shifting of 1.84km and lies within Laharighat RC where Harangtoli village was eroded in 2003 and Chutiagaon village was eroded in 2004.

The cross-section *'jj1'* indicates a bank line shifting of 0.182km and lies within Ulubari village which was eroded in 2002 for the first time and again in 2007 (Table 9). However, cross sections Aa, aa1 and Cc, cc1 have a total shift of 0.468 km and 2.341 km respectively. Cross section Bb lies in Gamariguri village of Mayong RC and has a total shifting of 0.24 km from 1980 to 2001 and 0.12km from 2001 to 2021 km.

Impact of erosion on the people: Erosion of riverbanks is a natural fluvio-geomorphological phenomenon. But the question is who is at risk? Erosion takes away houses and homesteads land making people homeless, landless and assetless. The degree of bank erosion impacts the level and severity of poverty of affected populations since they are forced to fall into the trap of poverty[8]. Among the five revenue circles of the district, Bhuragaon RC, Laharighat RC and Mayong RC are the most vulnerable to bank erosion as many villages have already been completely eroded. Out of the total of 629 villages in the district, a total of 94 villages (14.94%) are fully eroded and 31 villages (4.93%) are partially eroded.

As per 2021 data from the district administration, there are 535 villages in the district (Table 10). In Assam, rural households have two types of agricultural land, one is homestead land and another is croplands or agricultural land. Households having ownership of lands are called 'patta' land or 'myadi' land in Assam. Those residing in non-patta land or '*khas*' land (local name) belong to the category of government land holdings. Erosion data including the number of affected families, total land area eroded and the number of families either residing in Government land or own land (patta land) that have become landless, were collected from the revenue circles and DDMA, Morigaon.

Bank erosion in Bhuragaon Revenue Circle (RC): Figure 18 shows the erosion map of Bhuragaon RC. Table 10 indicates the number of families affected by erosion from the

year 2000 to 2020. The number of affected families was high in the year 2004 due to the major flood in 2004. A total of 1392.98 hectares of land were eroded. There was no bank erosion from the year 2005 to 2016. However, in 2017 due to the high flood, bank erosion occurred and 1109 families were affected and a total of 1072.49 hectares of land got eroded in the revenue circle. In the year 2019, a total of 120 families lost their land and in the year 2020, a total of 115 families were affected (Fig. 19).

Table 10
Erosion data of revenue circles, Morigaon

Revenue circle	No. of villages	Total eroded village	Fully eroded village	Partially eroded village	Present village (2021)
Mayong	177	17	7	10	170
Bhuragaon	122	70	58	12	52
Laharighat	103	38	29	9	74
Morigaon	162	Nil	Nil	Nil	162
Mikirbheta	65	Nil	Nil	Nil	65
TOTAL	629	125	94	31	535

Source: Revenue Circle Office, Morigaon and DDMA, Morigaon, 2021

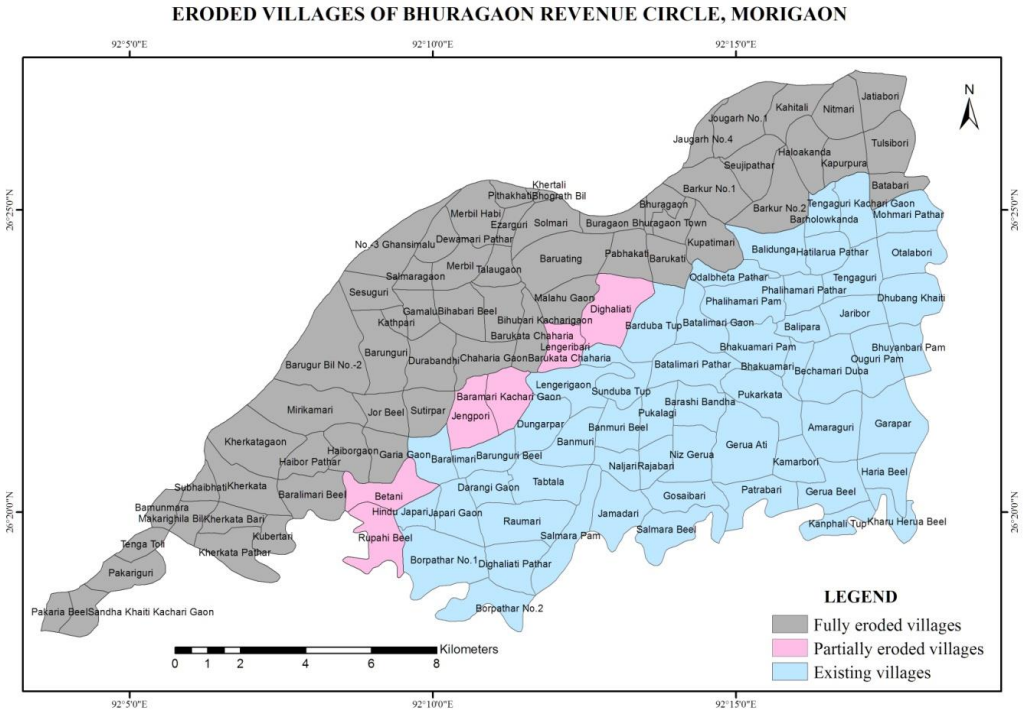


Figure 18: Map showing eroded villages of Bhuragaon RC
(Data source for village boundary: Administrative Atlas of India 2011)

Table 11
Erosion data from 2000 to 2020, Bhuragaon RC

Name of Revenue Circle	Year	No. of Family affected by erosion	Total area eroded (in hectares)	No of families become landless	
				Govt Land	Own Land
Bhuragaon	2000-2003	0	0	0	0
	2004	1103	1392.98	0	1103
	2005-2016	0	0	0	0
	2017	1109	1072.49	0	1109
	2018	0	0	0	0
	2019	120	16.07	0	120
	2020	115	18.28	0	115
TOTAL		**2447**	**2499.82**	**0**	**2447**

Source: District Disaster Management Authority (DDMA), Morigaon

Though the extent of bank erosion was less as compared to 2004 and 2017, it is a recurring process. It is evident from the data that within a period of 20 years i.e. from 2000 to 2020, a total of 2447 families were affected by bank erosion and a total of 2499.82 hectares of land was eroded in the revenue circle.

Bank erosion in Laharighat Revenue Circle (RC): Figure 20 shows the partially eroded and fully eroded villages of the Laharighat RC. It is evident from table 12 that within a period of 20 years i.e. from 2000 to 2020, Laharighat RC experienced recurring bank erosion. Like the Bhuragaon RC, the number of affected families was higher in the year 2004, when 128 families inhabited Government land and 298 families inhabited in own land (myadi patta) rendered homeless. However, in the year 2002, bank erosion occurred twice. Though bank erosion did not occur from 2005 to 2016 in Bhuragaon RC, in Laharighat RC, bank erosion affected a total of 104 families and eroded 97.55 hectares of land in the year 2006. A total of 117 families were affected and 127.33 hectares of land were eroded in the year 2007. From 2008 to 2011, the erosion process was a standstill in the revenue circle.

However, in 2012 again 117 families with own land and 28 families living on Government land were affected by bank erosion and a total of 29.73 hectares of land was eroded. From the year 2017, bank erosion has been a recurring phenomenon in the circle. It is observed that the number of affected families was high in 2018. In the year 2017, the size of eroded land was the highest (333.94 hectares). Within twenty years, a total of 2583 families were affected by bank erosion and rendered landless and homeless of which 1156 families resided on Government land and 1427 families had own land or patta land (Fig. 21). The total land lost was 3386.14 hectares.

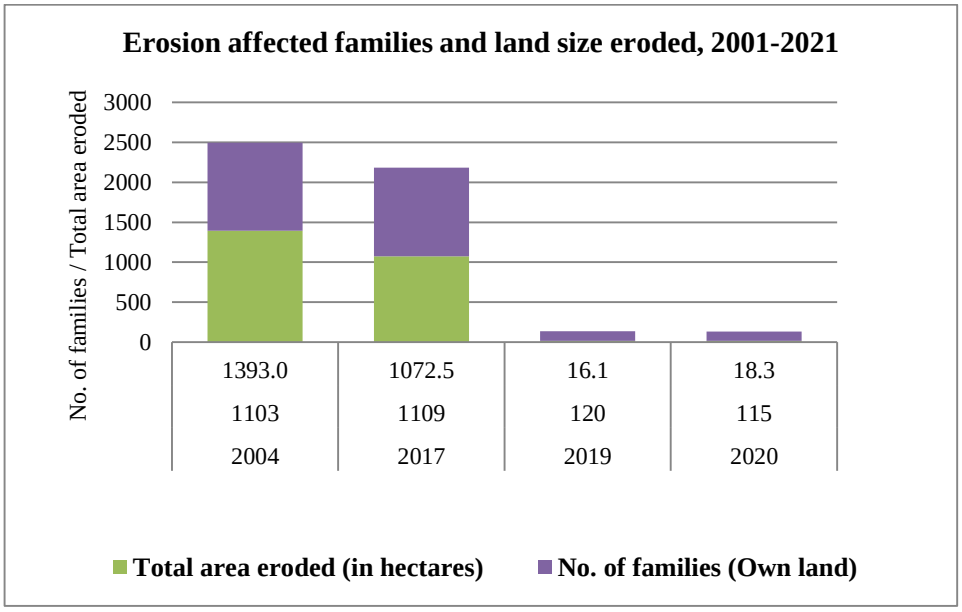


Figure 19: Families affected by erosion in Bhuragaon RC, 2000-2021.

Table 12
Details of erosion data from 2000 to 2020, Laharighat RC

Year	No. of affected families	Total area eroded (in hectares)	No. of landless families	
			Govt. land	Own land
2001	136	109.04	21	115
2002	116	183.43	13	103
2002	300	244.2	72	228
2003	121	66.44	45	106
2004	426	243.95	128	298
2006	104	97.55	35	69
2007	117	127.33	41	76
2012	145	29.73	28	117
2017	264	333.94	76	188
2018	450	200.72	389	61
2019	204	33.58	168	36
2020	170	92.04	140	30
TOTAL	**2583**	**3386.14**	**1156**	**1427**

Source: District Disaster Management Authority (DDMA), Morigaon

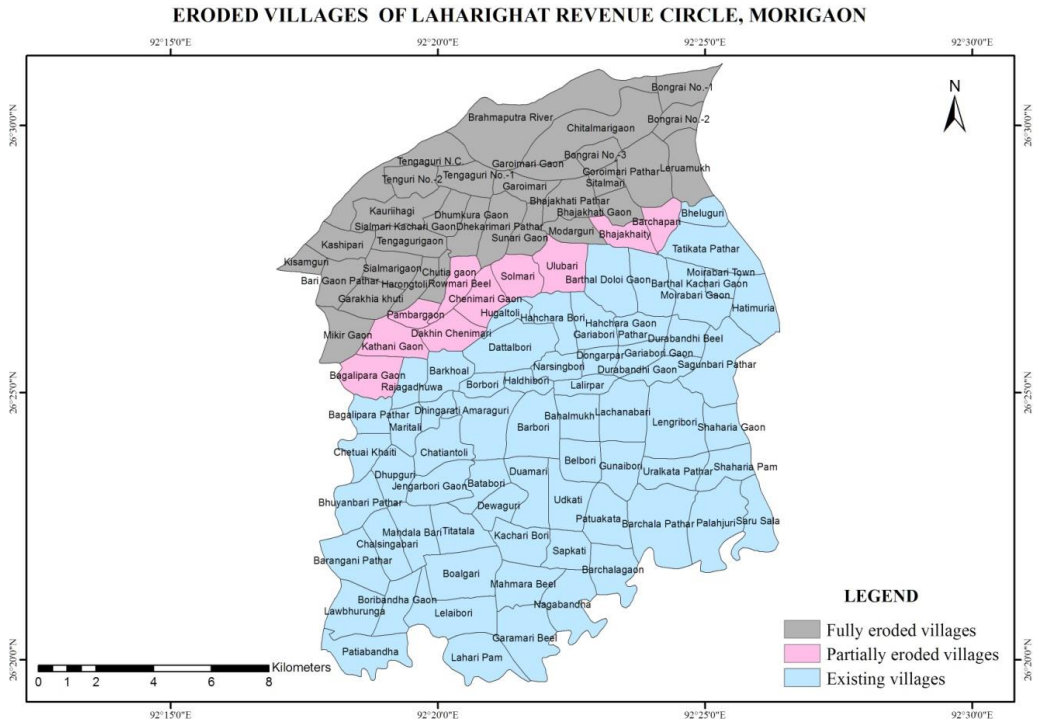


Figure 20: Map showing eroded villages of Laharighat RC
(Data source for village boundary: Administrative Atlas of India 2011)

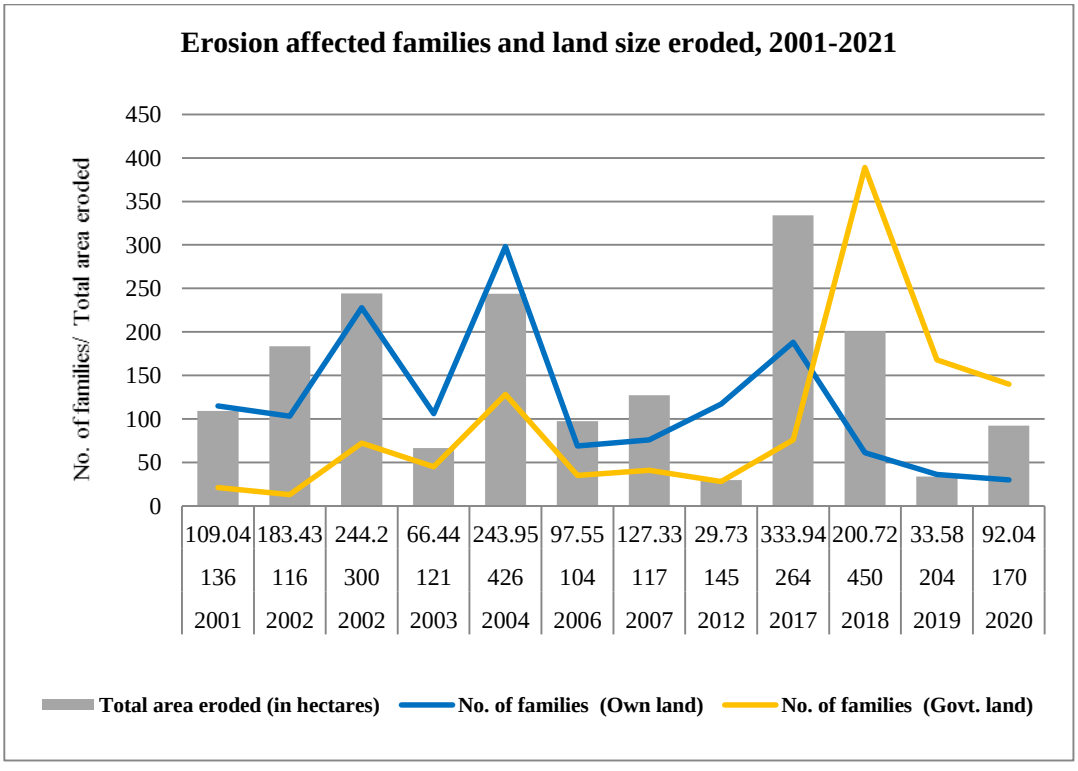


Figure 21: Families affected by erosion in Laharighat RC, 2000-2021

Bank erosion in Mayong Revenue Circle (RC): Unlike Bhuragaon and Laharighat RC, Mayong RC is less prone to erosion. Only 7 villages were fully eroded and 10 villages are partially eroded in the circle. The process of bank erosion was first recorded in the year 2004, which affected 30 families living on Government land and 496 families on their own land. The total area eroded was 249.34 hectares. Figure 22 shows the fully eroded and partially eroded villages of Mayong RC. From 2006 to 2009, bank erosion affected 2167 families of the revenue circle. Erosion was standstill from 2010 to 2012. However, in 2013, 2014 and 2017, the revenue circle was again affected by bank erosion. Total number of

affected families was the highest in 2008 and 2014 and lowest in the year 2017. From 2004 to 2017, a total of 3749 families were affected by bank erosion, out of which 200 families were living on Government land and 3549 families had their own land. Total land lost due to erosion was 1520.1 hectares (Table 13, figure 23).

The Brahmaputra channel has been changing over time resulting in erosion and deposition on both of its banks. The earthquake of 1897 (9.7 Richter) and the earthquake of 1950 (8.7 Richter) affected the gradient of River Brahmaputra accumulating large quantities of sediments in the channel which stopped the flow temporarily[23]. Bank line shifting and resulting bank erosion can be considered a major challenge in the district. River banks which are of recent deposits of silt and fine sands are highly susceptible to erosion and when a rapid flood occurs, it accelerates the proof of bank line shifting and erosion[4].

Bank erosion permanently displaces people and it has a long-term impact on human life by increasing their expenditure to maintain certain living conditions, well-being and education[6,7]. In Morigaon, erosion by the River Brahmaputra has been a recurring phenomenon. Moreover, North-East India experienced a total of 9 major earthquakes from 1980-2009, which resulted in major floods and erosion. The severe floods of 1987, 1988 and 1989 are associated with major earthquakes of 1987 (7.5 magnitude) and 1988 (7.0 magnitude)[15].

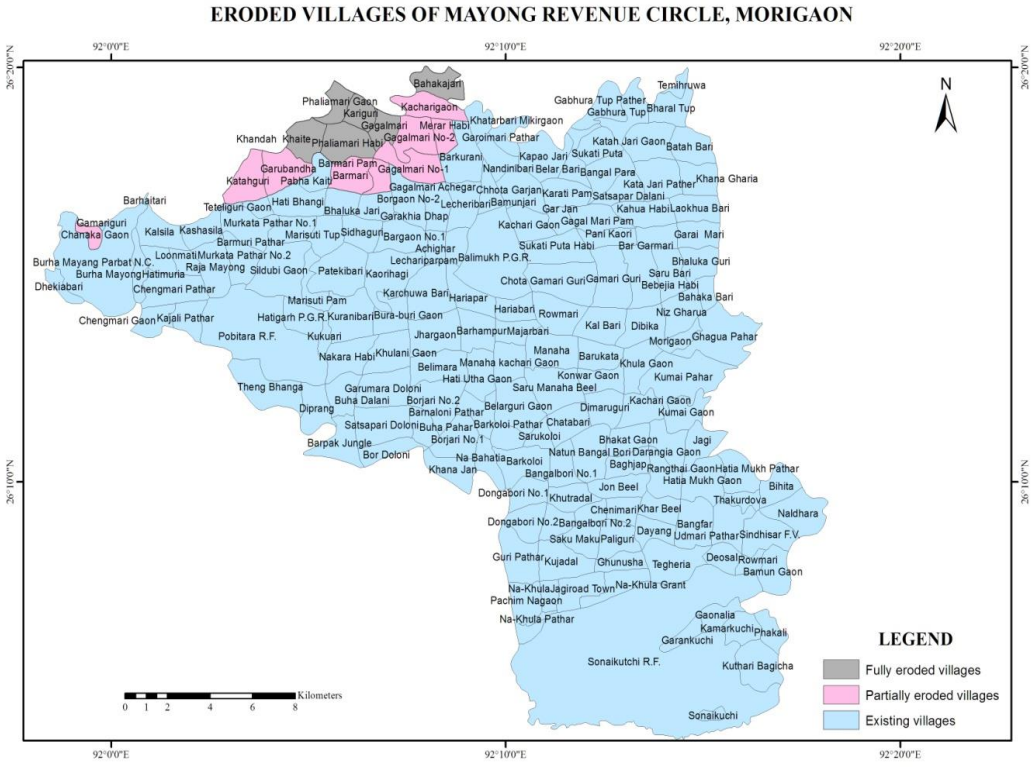


Figure 22: Map showing eroded villages of Mayong RC
(Data source for village boundary: Administrative Atlas of India 2011)

Table 13
Details of erosion data from 2000 to 2020, Mayong RC

Year	No. of affected families	Total area eroded (in hectares)	No. of landless families	
			Govt. land	Own land
2004	526	249.34	30	496
2006	480	210.37	20	460
2007	431	168.04	40	391
2008	938	712.13	50	888
2009	318	45.03	0	318
2013	267	27.84	20	247
2014	769	95.73	40	729
2017	20	11.62	0	20
Total	**3749**	**1520.1**	**200**	**3549**

Source: District Disaster Management Authority (DDMA), Morigaon

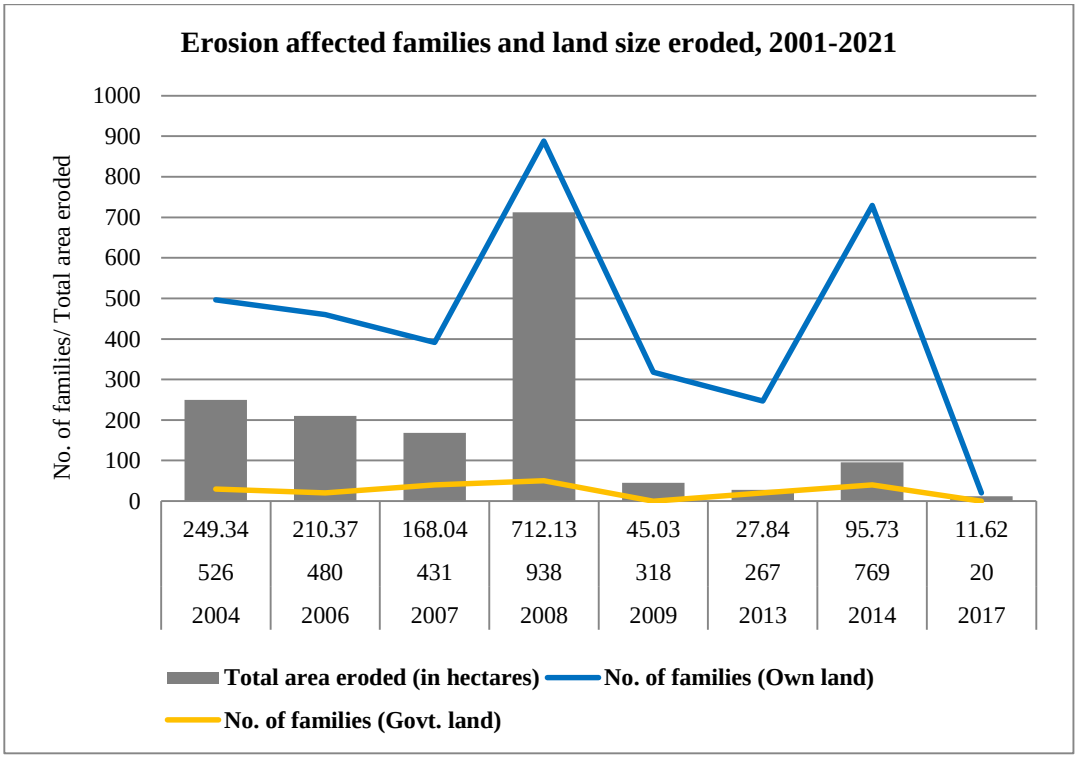


Figure 23: Families affected by erosion in Mayong RC, 2000-2021

There are many erosion management policies introduced in the State like 'Assam Disaster Management Act, 2005', 'Assam Disaster Management Policy, 2010', 'District Disaster Management Plans', 'Assam State Disaster Management Plan, 2022' etc. Although the State Government has adopted many anti-erosion measures, the problem of erosion has not been solved yet, only the frequency and intensity have reduced. Moreover, the State authority has also introduced land acquisition policies or laws for erosion management structures like 'The Assam Land and Revenue Regulation 1886'; 'Land Acquisition Act 1894', 'The Assam Embankment and Drainage Act 1953', 'Assam Acquisition of Land for Flood Control and Prevention of Erosion Act 1955' etc. The 'Chief Minister's Special Scheme for Rehabilitation of Erosion Affected Families in Assam' introduced on March 12, 2015, could not become operational and on 6th January 2021, the Government of Assam introduced 'Rehabilitation Policy for Erosion Affected Families of Assam 2020' (ASDMA). This is perhaps the first policy of the State that sought to provide compensation and rehabilitation to the erosion affected families.

The affected families are categorised into three categories, of which, category I includes those families who have lost all their lands both homesteads and agricultural lands; category II includes those families who have lost their homestead lands but not agricultural lands and category III includes those families who have lost all their agricultural lands, but have homestead lands. Based on these categories, it is proposed that compensation will be made and the rehabilitation package will include the erosion-affected families from the year 2014-15. From a geomorphological viewpoint, Assam is not comparable with any other State of India because of its unique geography characterised by a vast flood plain, prone to earthquakes, heavy rainfall, landslides and an elongated valley with the vast braided channel of the Brahmaputra River[15]. People have adopted different strategies to cope with bank erosion. In many villages of the district, small groups of villagers monitor the river banks during the advent of flood and depending upon their experiences and knowledge, they also initiate protective measures like placing sandbags or geo bags at the river bank.

Conclusion

Based on the analysis and findings of this research, it can be said that the Brahmaputra is one of the most dynamic rivers in Assam in terms of erosion and the overall scenario of channel migration along with its bankline shifting. Within a period of forty-one years (1980-2021), the total erosion of the Brahmaputra River in Morigaon district was 21005 ha where total accretion was 18100.7 ha and 6413 ha of area has remained unchanged. The channel has been shifting more towards the left direction than towards the right direction and the south bankline has a total shifting of 30.23km towards the south in the district. Due to channel shifting and bankline migration, the resultant erosion has affected 8779 families who lost their homestead and agricultural land due to the erosion of 7406.14 hectares of land in the three revenue circles of Morigaon district.

The process of bank erosion varies widely from river to river as it depends upon certain factors like bank material, variations in water level, bank flow velocities, river plan form and supply of sediment and water. In a State like Assam where natural disasters like floods and bank erosion occur

frequently, the primary policy concern should be addressing difficult questions like how prepared we are for disasters like floods and bank erosion, how advanced our mitigation plans are and how much we can lower the destruction level instead of focussing solely on the type of disaster.

Acknowledgement

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