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EFFECT OF CLIMATE CHANGE ON MORPHOLOGY OF RIVER BRAHMAPUTRA USING GIS

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Abstract - *Assam is extremely vulnerable to climate change due to both, its geographic proximity to the delta region and poor socio-economic conditions. Rise in average global temperatures have led to no rain for long periods and then a sudden burst of excessive rainfall causing extreme weather events, particularly floods. Climate change is expected to affect flooding through a range of mechanism including rainfall, temperature, sea level and river channel changes. The main issues of climate change that may affect morphological processes are i)changes in flood regime due to changes in precipitation pattern ii)changes in sediment load due to changes in precipitation iii)change in base level due to sea level rise. Changes of flow introduced by climate change would have impact on morphology of rivers during monsoon. The present study has been taken up to understand the impact of climate change on morphology of River Brahmaputra. Geographic Information System [GIS] techniques are used for mapping and measurement of morphology analysis. The bank-lines of River Brahmaputra in the year 1984, 1994, 2004, 2014 and 2019 from satellite images of Google Earth are studied. The channel positions are superimposed and the change is studied by measuring the width of the River at different longitudes. By studying the satellite images from 1984-2019, a conclusion is made that maximum erosion is being observed at South Bank in Morigaon district with an increase of 5277.75metres of width and maximum deposition is being observed at North Bank in Darrang district with a decrease of 3737.56metres of width.*

Key Words: **Climate change, morphology, Erosion, Deposition, Satellite images, GIS**

1. INTRODUCTION

The Brahmaputra River originates from the Himalaya (Kailash ranges) and flows through southern Tibet and enters into eastern India and lastly joins with the River Ganga in Bangladesh. The basin lies between 23°N to 32°N latitude and 82°E to 97°50'E longitude. River basin experiences with alteration in flow transport of sediment and channel configuration. However, in the rainy season, floods are a common phenomenon in the plain areas of India due to heavy discharge of Brahmaputra River.

Northeastern States of India are highly vulnerable to climate change which has led to floods, droughts and melting of glaciers. The climate is humid sub-tropical with hot summers, severe monsoons and mild winters. In Northeast, monsoon season leads to frequent floods due to melting of Himalayan snow and torrential rains which feed into Brahmaputra River. Due to climate change rainfall is becoming unpredictable and erratic.

River morphology refers to channel alignment, bed topography, bank erosion or deposition etc. The variables determining river morphology are: geology, paleo-climatology, relief, valley dimensions, climate, vegetation, hydrology, channel morphology, water discharge and sediment discharge and flow hydraulics. Climate change leads to change in upstream by changing rainfall intensity and at downstream by raising the level of sea. Changes of flow introduced by climate change would have impact on morphology of Rivers during monsoon.

Flugel et al., (2008) have observed that the average temperature of upper Brahmaputra River basin has increased by 0.28°C per decade from 1961 to 2005. The extensive physical assessment of the Brahmaputra River basin has been carried out by Mahanta et al., (2014)45. The authors expected that the temperature might increase from 1.3°C to 2.4°C by 2050, followed by 2.0°C to 4.5°C by 2100 in the Brahmaputra River basin. Monthly evapotranspiration is likely to increase 5% to 18% by 2050 followed by 7% to 36% by 2100. Through a future projected model which suggests that the variation in rainfall to be 14% decrease to 15 % increase by 2050 and 28 % decrease to 22 % increase by 2100 respectively. The overall result by authors showed that climate change might lead to alteration in the physical characteristics of Brahmaputra River basin shortly. S.Hossain, I.Jahan, S.AYeham(2014) plotted the bank line positions of Meghna River from the years 1980, 1989, 2000 in the satellite images and the change in bank-line is analyzed. Field visit was also carried out at Baidder Bazaar of Meghna River at a reach of approximately 1km and visit to Meghna Ferry Ghat was also made. They made a conclusion that Meghna River is in a meandering

stage for a particular range of flow and depth. Masum Ur Rahman, Sarwat Jahan, Mir Mostafa Kamal(2010) assessed the morphological changes for an average flood event by applying two dimensional morphological modeling(2-D) system, MIKE21C and boundary for 2-D morphological model has been generated simulating the one dimensional (1-D) flow modeling system MIKE11. Manash pratim Gogoi, Bikash Gogoi, Swapnil Hazarika, Prince Borgohain(2012) carried out a GIS based study in upper Assam by delineating the fluvio-morphological changes that took placed in the confluences of Dihang, Dibang and Lohit rivers and in increasing valley width of the River Brahmaputra. TM+ and MSS 25 years' time gapped satellite imageries of year 1986 and 2011 were studied Changes have roughly doubled the width of original drainage system contributing about 846 km^2 area captured or lost. Muniraja K(2011) analyzed the image of the old Brahmaputra River, located under the district of Mymensingh, Bangladesh in the year 1997 and 2004, it was found that remarkable change occurred in north east part of Mymensingh sadar upazila and less change was found in the lower part which is close to the Mymensingh town.). The river course-changing pattern due to sedimentation is measured 168.34 ha.

2. OBJECTIVE OF STUDY

To study the change in morphology of the River Brahmaputra due to climate change which in turn bring changes in rainfall pattern and discharge of the Brahmaputra River. This can be carried out by processes like-

- Observation of width of the river at various longitudes on daily, monthly or yearly basis
- With help of GIS techniques using satellite imageries

2.1 AVAILABLE DATA AND ANALYSIS

2.1.1 Discharge and Water level Data: Discharge and Water level data for Pandu Gauge Site of Brahmaputra River collected from Water Resources Department, Assam during the year 2008-2017, it is showing an increasing trend which can be referred due to climate change.

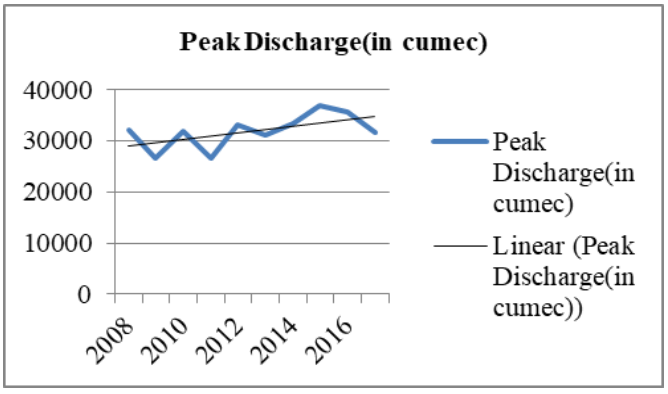

Chart 1: Variation of peak discharge with time (Refer Data from Water resources department, Assam)

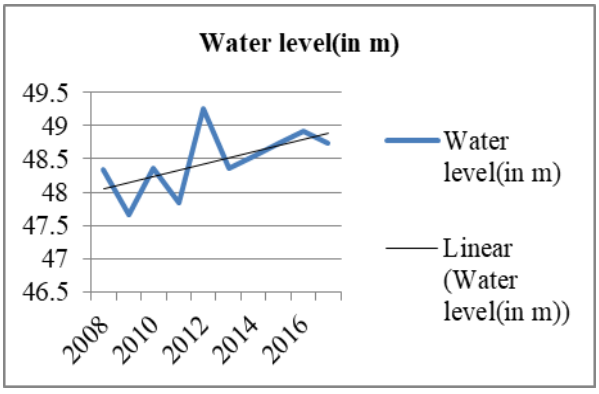

Chart 2: Variation of water level with time (Refer data from Water resources department, Assam)

2.1.2 Satellite Images: Google Earth Satellite images of River Brahmaputra of the years 1984, 1994, 2004, 2014 and 2019 are used to plot the bank lines and study the change in morphology of the River Brahmaputra.

3. METHODOLOGY

Satellite images of River Brahmaputra in the years 1984, 1994, 2004, 2014 and 2019 were used to plot the bank lines and study the morphology of the River. Then the bank-lines are overlapped and the difference in bank line positions is studied. The satellite images of about 35years are studied and the change is noted.

3.1 CHANNEL POSITIONS OF RIVER BRAHMAPUTRA

Fig 1: Channel position of River Brahmaputra in the year 1984 according to Google Earth Satellite images (Refer Google Earth, Imagery date=12/31/1984)

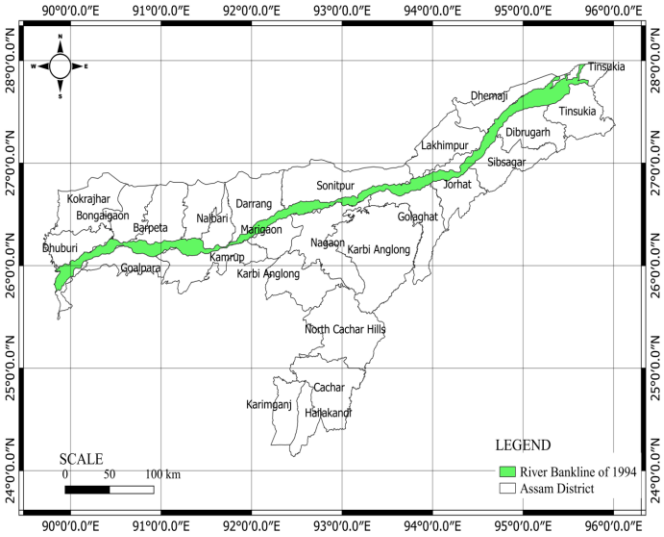

Fig 2: Channel position of River Brahmaputra in the year 1994 according to Google Earth Satellite (Refer Google Earth, Imagery date=12/31/1994)

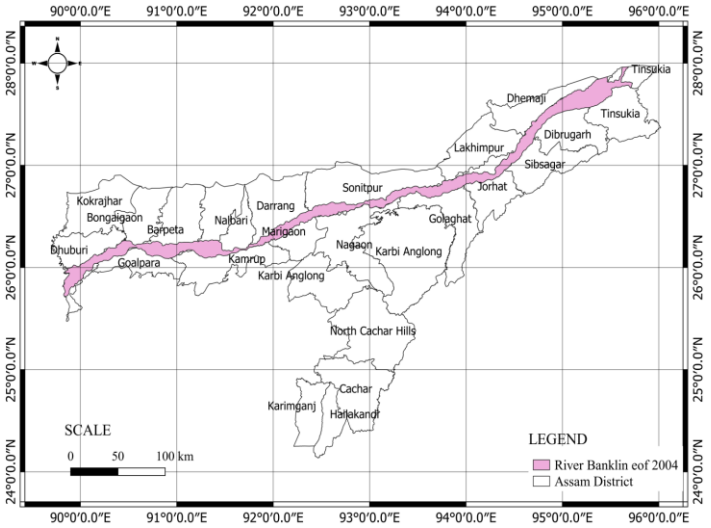

Fig 3: Channel position of River Brahmaputra in the year 2004 according to Google Earth Satellite images (Refer Google Earth, Imagery date=12/31/2004)

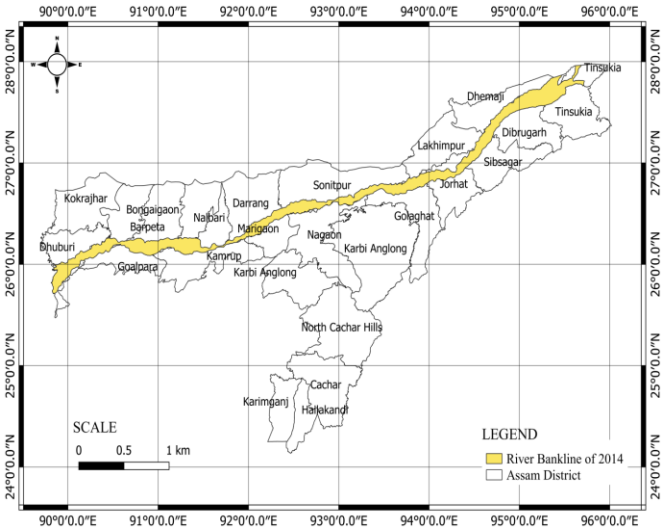

Fig 4: Channel position of River Brahmaputra in the year 2014 according to Google Earth images (Refer Google Earth, Imagery date=12/31/2014)

Fig 5: Channel position of River Brahmaputra in the year 2019 according to Google Earth satellite images (Refer Google Earth, Imagery date=12/31/2019)

3.2 PLAN FORM CHANGES OF RIVER BRAHMAPUTRA: The changes in the bank-line positions of River Brahmaputra in the years 1984,1994,2004,2014 and 2019 are analyzed in GIS and their respective width is measured. For accuracy the area is divided into ten sections and the change in width in each of these sections are studied.

Table 1: Different sections of the River Brahmaputra

Section	Coordinates	Location
1	89°54'E-90°36'E	Dhubri to Goalpara
2	90°38'E-91°34'E	Goalpara to Sualkuchi
3	91°36'E-92°24'E	Sualkuchi to Moirabari
4	92°26'E-92°46'E	Moirabari to Tezpur
5	92°48'E-93°10'E	Tezpur to Biswanath Town
6	93°12'E-93°36'E	Biswanath Town to Gohpur
7	93°38'E-94°12'E	Gohpur to Jorhat
8	94°14'E-94°36'E	Jorhat to Dhemaji
9	94°38'E-95°10'E	Dhemaji to Chabua
10	95°12'E-95°40'E	Chabua to Sadiya

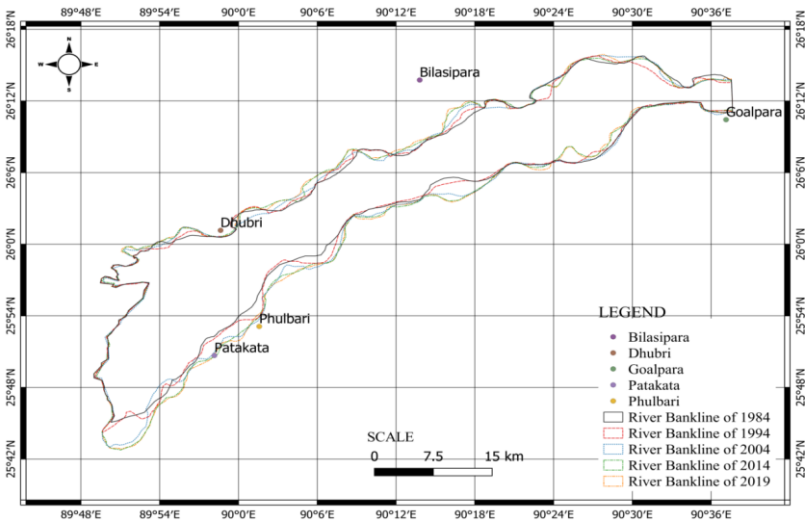

Fig 6: Superimposed Channel position of Section-1

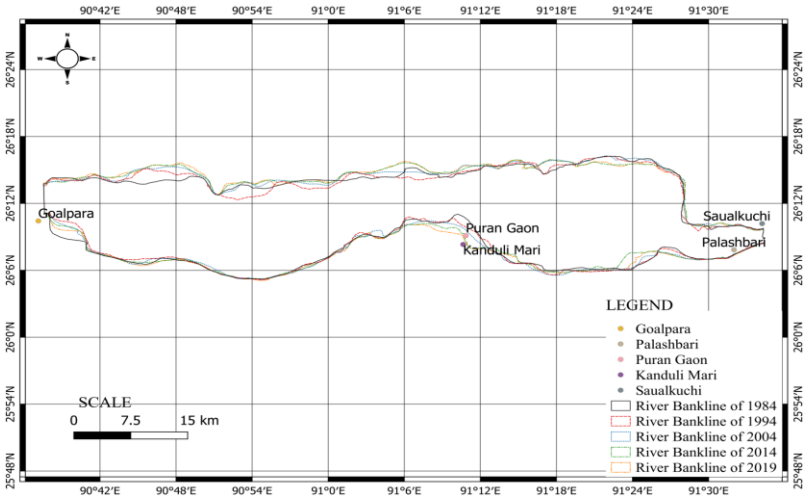

Fig 7: Superimposed Channel position of Section-2

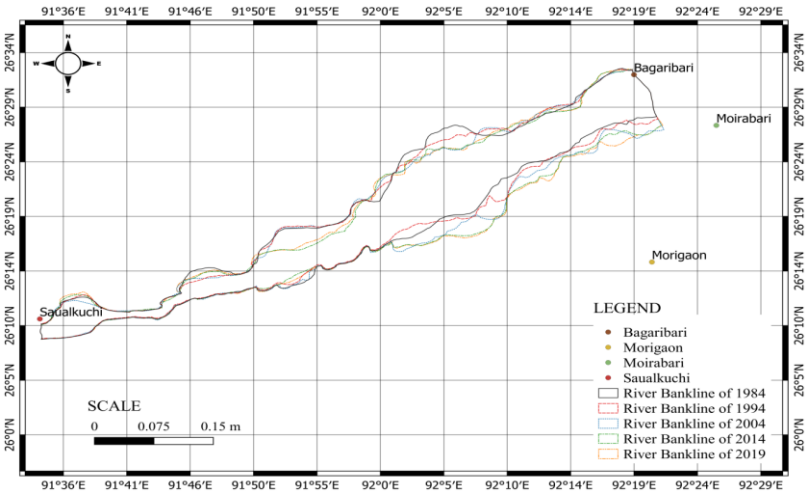

Fig 8: Superimposed Channel position of Section-3

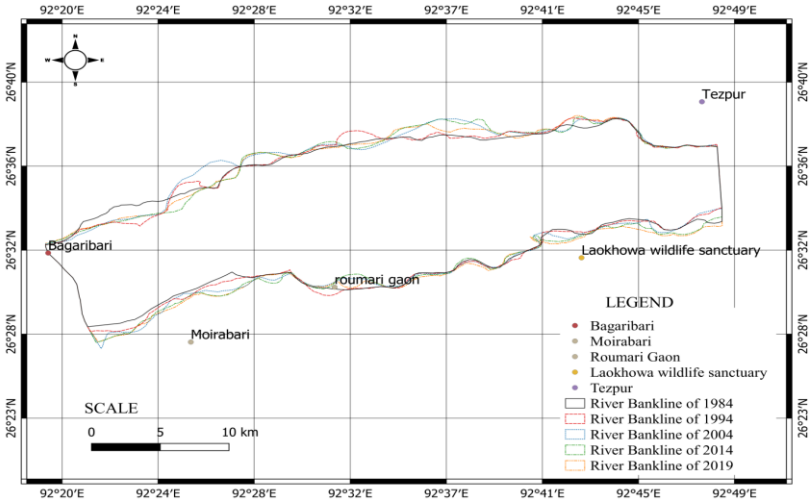

Fig 9: Superimposed Channel position of Section-4

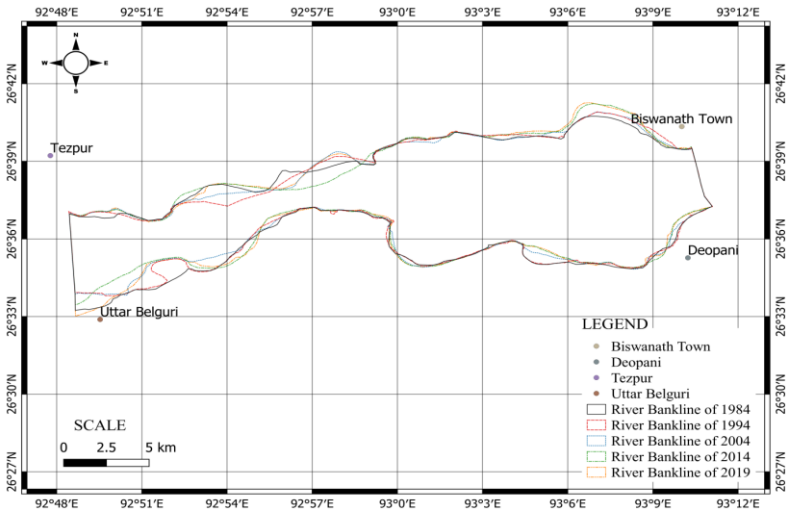

Fig 10: Superimposed Channel position of Section-5

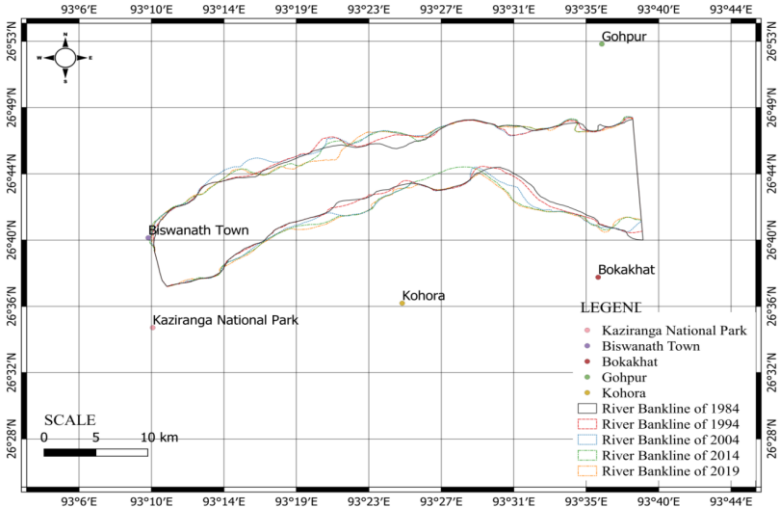

Fig 11: Superimposed Channel position of Section-6

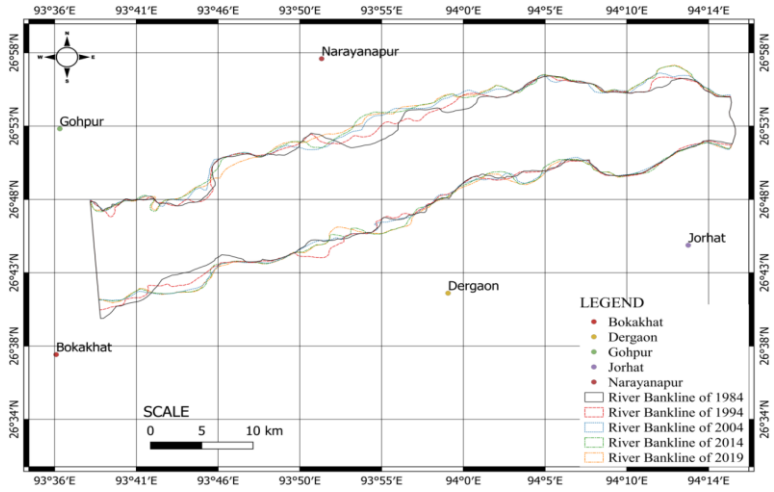

Fig 12: Superimposed Channel position of Section-7

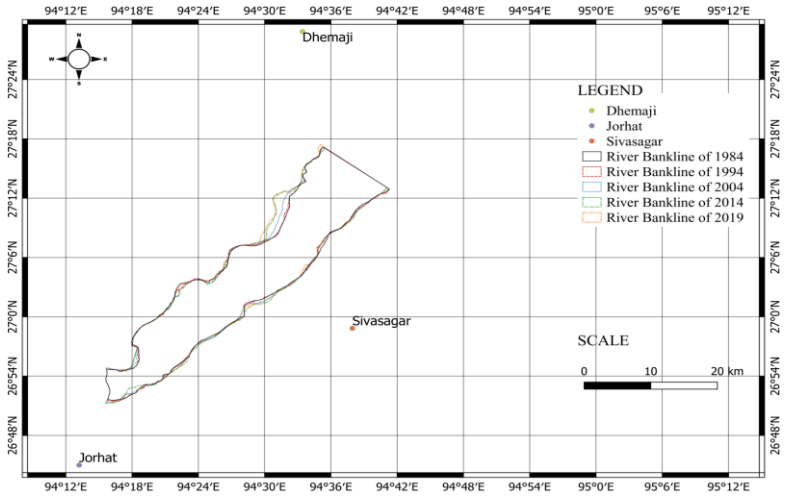

Fig 13: Superimposed Channel position of Section-8

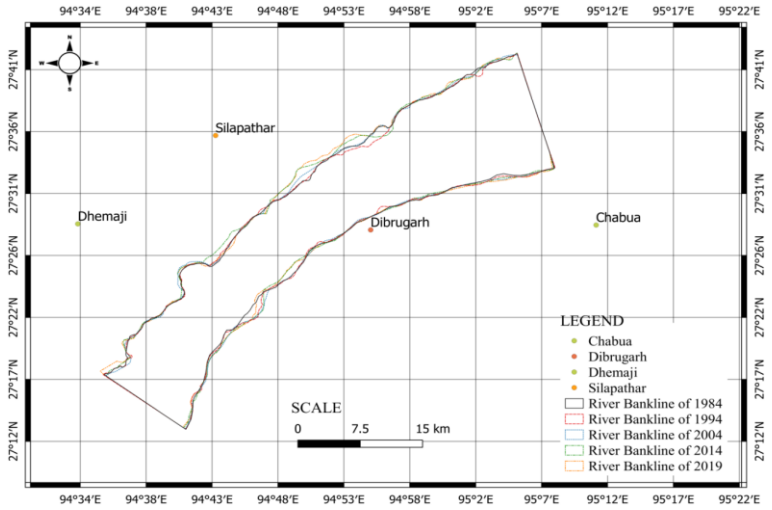

Fig 14: Superimposed Channel position of Section-9

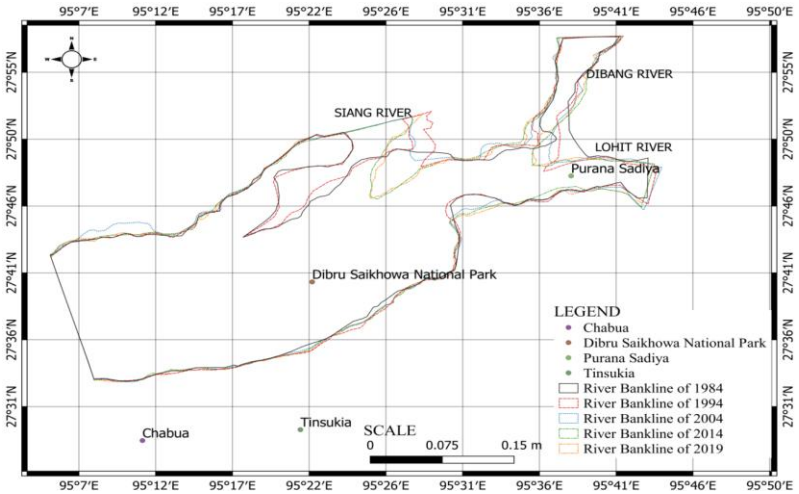

Fig 15: Superimposed Channel position of Section10

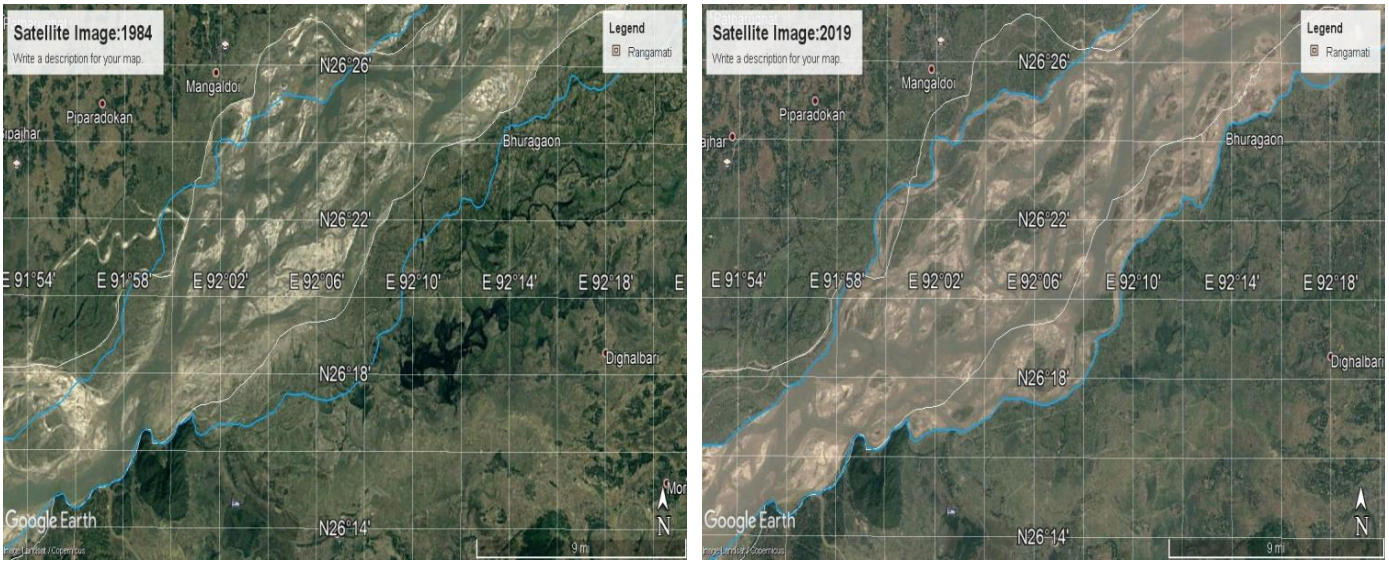

Fig 16: Satellite images of 1984 and 2019 showing maximum change of width of the River Brahmaputra. Maximum deposition is being observed at 92°06'E longitude of North Bank and maximum erosion is being observed at 92°08'E longitude of South Bank.

4. RESULTS AND DISCUSSIONS

The width of the river in 1984, 1994, 2004, 2014 and 2019 are measured at different longitudes and then analyzed. The migration of the river from 1984-2019 at different longitudes in north bank and south bank is measured and change due to erosion and deposition is noted.

Table 2: Migration of north bank and south bank during the years 1984-2019 in section 1 in meters

	BANK	1984-1994	1994-2004	2004-2014	2014-2019	1984-2019	NB+SB
89°54'E	NB	-1035.76	381.82	593.93	105.5	45.49	
	SB	528.78	-2597.26	2965.92	-119.45	777.99	823.48
89°56'E	NB	610.84	953.69	-203.42	124.24	1485.35	
	SB	-331.45	1389.19	0	761.32	1819.06	3304.41
89°58'E	NB	-16.59	40.74	52.45	-89.11	-12.51	
	SB	504.12	2261.82	473.13	0	3239.07	3226.56
90°00'E	NB	72.33	-1572.88	-197.03	1486.23	-211.35	
	SB	671.66	2430.95	-357.97	959.06	3703.7	3492.35
90°02'E	NB	79.41	-632.42	984.55	-348.85	82.69	
	SB	-342.04	2344.22	1258.48	-1427.81	1832.85	1915.54
90°03'E	NB	-26.47	682.66	786.24	-28.33	1414.1	
	SB	-354.94	2450.57	-205.67	548.98	2438.94	3853.04
90°04'E	NB	445.29	425.06	-160.91	141.04	850.48	
	SB	45.73	712.64	1232.29	153.12	2143.78	2994.26
90°06'E	NB	56.22	-276.82	868.81	38.87	687.08	
	SB	1155.39	569.42	-550.53	207.88	1382.16	2069.24
90°08'E	NB	735.95	507.46	351.02	-139.52	1454.91	
	SB	185.33	486.88	1840.34	-532.3	1980.25	3435.16
90°10'E	NB	-126.84	-1237.61	254.87	-64.86	-1142.58	
	SB	12.17	1091.4	125.47	322.54	1551.58	377.14
90°12'E	NB	121.59	185.69	49.57	428.56	785.41	
	SB	-169.33	492.04	313.14	-376.29	259.56	1044.97
90°14'E	NB	-34.21	58.99	346.38	205.77	576.93	
	SB	-168.05	381.67	68.5	-231.82	50.3	627.23
90°16'E	NB	271.95	670.4	1650.74	744.45	3361.24	7013.42

	SB	832.79	1631.43	1145.25	42.71	3652.18	
90°18'E	NB	726.79	520.71	286.4	-71.88	1462.02	
	SB	0	1590.13	-100.4	151.62	1641.35	3103.37
90°20'E	NB	120.69	-968.12	1050.61	-65.85	137.33	
	SB	-66.73	446.76	-185.15	0	194.88	332.21
90°22'E	NB	17.5	-30.88	18.45	98.45	103.52	
	SB	-83.28	-78.25	392.99	64.47	295.93	399.45
90°24'E	NB	-397.03	2706.85	-3367.07	-87.19	-1144.44	
	SB	0	155.58	-144.11	84.94	96.41	-1048.03
90°25'12" E	NB	182.53	1138.68	-823.5	267.51	765.22	
	SB	78.14	0	-2489.33	0	2587.72	3352.94
90°26'E	NB	100.02	-35.22	-98.76	138.78	104.82	
	SB	-154.45	44.93	-1177.86	170.18	-1117.2	-1012.38
90°28'E	NB	546.17	530.9	-721.91	780.96	1136.12	
	SB	-151.7	457.64	-778.14	-419.36	-891.56	244.56
90°30'E	NB	422.02	-447.69	-455.2	517.14	36.27	
	SB	-205.49	-372.37	347.18	-778.71	-1009.39	-973.12
90°32'E	NB	-1522.64	1757.65	-96.61	-232.07	-93.67	
	SB	73.21	25.6	131.39	-131.39	98.81	5.14
90°34'E	NB	-13.91	92.76	-85.95	48.65	41.55	
	SB	168.94	-138.94	97.68	-177.9	-47.9	-8.15
90°36'E	NB	-789.51	41.74	66.75	66.97	-614.05	
	SB	-123.9	331.43	-282.56	-14.44	-75.03	-689.08
TOTAL CHANGE IN WIDTH OF THE RIVER							**37883.71**

Table 3: Migration of north bank and south bank during the years 1984-2019 in section 2 in meters

	BANK	1984-1994	1994-2004	2004-2014	2014-2019	1984-2019	NB+SB
90°38'E	NB	-212.16	-254.19	6.03	466.18	5.86	-257.92
	SB	-268.64	129.59	701.06	-825.79	-263.78	
90°40'E	NB	-293.51	68.11	267.28	97.8	139.68	-194.68
	SB	-1626.05	839.99	119.92	331.78	-334.36	
90°42'E	NB	316.91	109.95	0	-22.36	404.5	437.89
	SB	-215.83	78.4	94.49	76.33	33.39	
90°44'E	NB	358.78	26.49	529.3	389.27	1303.84	1501.75
	SB	-218.2	265.71	25.01	125.39	197.91	
90°46'E	NB	2173.01	135.43	454.02	37.21	2799.67	2999.89
	SB	-772.46	115.37	506.82	350.49	200.22	
90°48'E	NB	970.98	1274.81	230.6	212.12	2688.51	2664.64
	SB	-429.53	185.58	112.24	107.84	-23.87	
90°50'E	NB	32.59	233.92	149.03	351.9	767.44	609.69
	SB	-16.23	-401.32	361.44	-101.64	-157.75	
90°52'E	NB	-1209.79	905.24	922.59	394.78	1012.82	939.98
	SB	10.72	-107.56	46.39	-22.39	-72.84	
90°54'E	NB	-1535.14	2139.94	42.41	108.69	755.9	820.02
	SB	24.9	-113.64	64.03	88.83	64.12	
90°56'E	NB	500.41	402.58	-322.51	-494.5	85.98	64.42
	SB	-56.18	-52.98	-32.63	120.23	-21.56	

90°58'E	NB	-1275.46	833.73	251.55	232.96	42.78	320.06
	SB	0	552.39	-22.81	-252.3	277.28	
91°00'E	NB	-1232.66	419.26	362.63	139.8	-310.97	-127.92
	SB	153.36	-234.39	152.44	111.64	183.05	
91°02'E	NB	1042.38	0	113.47	-31.95	1123.9	1281.11
	SB	-441.79	46.47	358.25	194.28	157.21	
91°04'E	NB	28.46	753.38	420.05	-61.53	1140.36	1477.27
	SB	186.43	-1233.51	1262.1	121.89	336.91	
91°06'E	NB	-904.07	904.07	1577.97	177.76	1755.73	2310.52
	SB	-266.49	821.39	228.73	-228.84	554.79	
91°08'E	NB	-636.71	804.21	249.93	28.55	445.98	1117.68
	SB	-53.76	-191.78	476.75	440.49	671.7	
91°10'E	NB	200.68	327.04	-25.88	202.14	703.98	3779.99
	SB	742.61	872.5	512.37	948.53	3076.01	
91°10'48" E	NB	291.47	1002.46	-478.62	436.21	1251.52	5223.61
	SB	1517.03	452.94	1910.66	91.46	3972.09	
91°12"E	NB	248.23	375.6	100.01	-23.25	700.59	2700.99
	SB	294.4	852.81	801.8	51.39	2000.4	
91°14'E	NB	253.58	-60.03	99.64	-32.33	260.86	-384.89
	SB	258.39	196.03	-1272.31	172.14	-645.75	
91°16'E	NB	256.63	-478.51	-368.24	157.66	-432.46	-103.62
	SB	103.63	741.09	-577.38	61.5	328.84	
91°18'E	NB	733.56	827.85	-134.64	13.97	1440.74	1729.26
	SB	606.3	98.59	-496.39	80.02	288.52	
91°20'E	NB	274.05	-70.22	-633.65	-15.32	-445.14	186.56
	SB	671.1	-322.49	197.95	85.14	631.7	
91°22'E	NB	-74.75	106.94	-1395.31	343.64	-1019.48	-903.1
	SB	408.49	-100.32	-2559.32	2367.53	116.38	
91°24'E	NB	23.73	542.07	-936.07	21.58	-348.69	-1312.25
	SB	-33.89	-194.75	-2488.42	1753.5	-963.56	
91°26'E	NB	-315.62	31.57	470.21	-263.24	-77.08	122.07
	SB	296.14	-26.1	-317.55	246.66	199.15	
91°28'E	NB	0	0	0	0	0	664.76
	SB	145.17	425.91	93.68	0	664.76	
91°30'E	NB	-472.77	869.86	-399.75	40.66	38	71
	SB	41.44	-11.33	-18.28	21.17	33	
91°32'E	NB	40.91	77.11	0	-77.11	40.91	200.82
	SB	55.88	-132.46	163.59	72.9	159.91	
91°34'E	NB	-59.83	127.13	-183.08	16.95	-98.83	-98.83
	SB	-77.34	-51.65	85.55	43.44	0	
TOTAL CHANGE IN WIDTH OF THE RIVER							**27840.77**

Table 4: Migration of north bank and south bank during the years 1984-2019 in section 3 in meters

	BANK	1984-1994	1994-2004	2004-2014	2014-2019	1984-2019	NB+SB
91°36'E	NB	-98.99	-46.93	540.63	375.7	770.41	752.78
	SB	-52.5	87.32	-37.51	-14.94	-17.63	
91°38'E	NB	259.19	-1101.63	917.18	266.99	341.73	298.93
	SB	-75.37	-101.49	155.4	-21.34	-42.8	
91°40'E	NB	45.89	17.85	-69.08	23.22	17.88	51.25
	SB	-91.93	114.99	22.35	-12.04	33.37	
91°42'E	NB	58.94	-35.64	156.75	-137.9	42.15	11.84
	SB	-115.87	6.61	74.03	4.92	-30.31	
91°44'E	NB	-52.92	20.17	-410.43	366.4	-76.78	-169.55
	SB	-283.22	42.93	115.71	31.81	-92.77	
91°46'E	NB	-1773.35	432.63	235.25	235.01	-870.46	-861.97
	SB	-52.27	0	35.17	25.59	8.49	
91°48'E	NB	-807.06	-57.32	552.45	178.49	-133.44	-248.24
	SB	-103.05	-103.41	188.13	-96.47	-114.8	
91°50'E	NB	57.59	129.93	251.31	-302.69	136.14	323.54
	SB	72.83	45.1	33.41	36.06	187.4	
91°52'E	NB	175.32	248.21	-2702.87	-67.24	-2346.58	-2295.15
	SB	-228.73	264.85	60.15	-44.84	51.43	
91°54'E	NB	326.56	-141.78	-3607.18	612.91	-2809.49	-3977.12
	SB	-1030.75	512.15	-1260.92	611.89	-1167.63	
91°56'E	NB	109.27	-92.84	-1792.48	510.11	-1265.94	-1261.95
	SB	-175.21	160.25	-116.31	135.26	3.99	
91°58'E	NB	78.57	345.67	-2734.65	1404.65	-905.76	-853.46
	SB	-112.67	0	27.27	137.7	52.3	
92°00'E	NB	2131.25	681.39	631.3	111.65	3555.59	3774.97
	SB	-246.36	222.38	206.03	37.33	219.38	
92°02'E	NB	-1693.39	-726.69	994.8	184.4	-1240.88	-145.43
	SB	-1513.44	3177.92	-627	57.97	1095.45	
92°04'E	NB	-1680.69	-1233.55	211.47	-267.32	-2970.09	-70.79
	SB	-387.7	2820.59	385.89	80.52	2899.3	
92°06'E	NB	-1398.78	-2393.71	85.97	-31.04	-3737.56	-129.24
	SB	583.14	935.61	1820.88	268.69	3608.32	
92°08'E	NB	1005.72	235.7	-1696.79	167.25	-288.12	4989.63
	SB	1157.31	2217.36	1735.21	167.87	5277.75	
92°10'E	NB	-39.68	132.7	736.74	253.62	1083.38	3777.63
	SB	1140.34	469.1	1006.6	78.21	2694.25	
92°12'E	NB	237.38	280.65	-692.46	796.81	622.38	3564.73
	SB	829.36	636.72	1244.17	232.1	2942.35	
92°14'E	NB	414.28	-159.36	-887.92	75.45	-557.55	221.25

	SB	110.93	431.89	181.86	54.12	778.8	
92°16'E	NB	0	-11.91	167	88.07	243.16	2815.36
	SB	1575.54	1705.71	-962.07	253.02	2572.2	
92°18'E	NB	-36.53	-388.88	12.26	218.67	-194.48	3392.69
	SB	171.24	1108.33	344.32	1963.28	3587.17	
92°20'E	NB	-16.92	-125.76	307.74	103.59	268.65	3100.43
	SB	1054.8	1634.91	158.4	-16.33	2831.78	
92°22'E	NB	-1379.35	156.09	-177.79	91.51	-1309.54	-120.99
	SB	678.85	75.3	415.21	19.19	1188.55	
92°24'E	NB	-1336.55	170.91	-182.28	104.58	-1243.34	-472.47
	SB	225.08	615.12	-267.04	197.71	770.87	
TOTAL CHANGE IN WIDTH OF THE RIVER							**16468.13**

Table 5: Migration of north bank and south bank during the years 1984-2019 in section 4 in meters

		1984-1994	**1994-2004**	**2004-2014**	**2014-2019**	**1984-2019**	**NB+SB**
92°26'E	NB	92.32	1873.56	-2068.71	41.34	-61.49	769.38
	SB	226.33	315.31	245.81	43.42	830.87	
92°28'E	NB	-71.51	902.37	191.3	-57.62	964.54	1469.36
	SB	-56.34	555.79	152.98	-147.61	504.82	
92°30'E	NB	20.2	-45.67	-74.88	-95.57	-195.92	-168.74
	SB	-80.3	26.19	-82.85	164.14	27.18	
92°32'E	NB	981.81	-962.39	98.37	-191.12	-73.33	-507.73
	SB	144.72	-1161.62	-96.52	679.02	-434.4	
92°34'E	NB	-94.6	-205.92	243.21	142.3	84.99	75.94
	SB	-10.78	-70.34	-2.76	74.83	-9.05	
92°36'E	NB	283.95	1179.17	-32.37	-509.46	921.29	1151.67
	SB	24.3	75.37	73.63	57.08	230.38	
92°38'E	NB	252.31	1121.75	530.06	-921.85	982.27	1365.11
	SB	93.27	46.19	-190.74	434.12	382.84	
92°40'E	NB	243.52	-81.59	91.55	-91.55	161.93	105.34
	SB	24.3	-67.93	33.82	-46.78	-56.59	
92°42'E	NB	582.03	-955.22	84.87	94.81	-193.51	861.83
	SB	114.61	630	135.13	175.6	1055.34	
92°44'E	NB	71.69	5.63	-45.13	86.84	119.03	636.7
	SB	161.15	62.08	336.87	-42.43	517.67	
92°46'E	NB	-53.37	-25.57	-19.58	145.28	46.76	818.18
	SB	48.26	441.95	145.33	135.88	771.42	
92°25'30"E	NB	729.07	614.73	-1869.26	122.44	-403.02	180.3
	SB	438.51	-144.04	102.69	186.16	583.32	
TOTAL CHANGE IN RIVER WIDTH							**6757.34**

Table 6: Migration of north bank and south bank during the years 1984-2019 in section 5 in meters

	BANK	1984-1994	1994-2004	2004-2014	2014-2019	1984-2019	NB+SB
92°48'E	NB	-47.09	55.19	-26.3	3.56	-14.64	350.43
	SB	-780.45	-220.14	952.84	412.82	365.07	
92°50'E	NB	289.11	304.47	-61.27	129.71	662.02	554.16
	SB	-214.82	-99.69	-981.88	1188.53	-107.86	
92°52'E	NB	-110.85	-173.81	216.72	-84.23	-152.17	-1691.12
	SB	-1538.32	-65.99	-34.39	99.75	-1538.95	
92°54'E	NB	-1503.22	904.21	693.47	-6.45	88.01	322.24
	SB	-42.74	-451.61	866.74	-138.16	234.23	
92°56'E	NB	-800.35	-495.82	-58.9	126.06	-1229.01	-1378.87
	SB	-25.49	-23.02	-207.37	106.02	-149.86	
92°58'E	NB	522.86	321.35	-1610.87	1484.75	718.09	714.33
	SB	13.61	-27.92	12.21	-1.66	-3.76	
93°00'E	NB	-32.44	15.56	-13.9	29.96	-0.82	40.61
	SB	4.84	0	36.59	0	41.43	
93°02'E	NB	73.21	-15.38	-28.27	16.44	46	83.54
	SB	8.01	-2.9	40.78	-8.35	37.54	
93°04'E	NB	239.98	-298.47	291.38	85.47	318.36	373.25
	SB	-35.47	40.15	-10.78	60.99	54.89	
93°06'E	NB	-28.82	28.82	296.6	139.36	435.96	564.38
	SB	-65.83	157.1	-77.81	114.96	128.42	
93°08'E	NB	403.26	28.21	463.69	-89.16	806	771.45
	SB	-49.31	48.16	-78.58	45.18	-34.55	
93°10'E	NB	22.89	-25.72	39.81	67.79	104.77	-448.09
	SB	-72.93	-295.88	-206.53	22.48	-552.86	
TOTAL CHANGE IN WIDTH OF THE RIVER							**172.77**

Table 7: Migration of north bank and south bank during the years 1984-2019 in section 6 in meters

	BANK	1984-1994	1994-2004	2004-2014	2014-2019	1984-2019	NB+SB
93°12'E	NB	31.55	77.36	49	-24.23	133.68	-87.16
	SB	-23.31	-3.1	23.65	-218.08	-220.84	
93°14'E	NB	-7.71	863.8	-999.5	105.66	-37.75	101.67
	SB	77.08	-20.47	105.16	-22.35	139.42	
93°16'E	NB	266.6	1846.69	-1545.64	-126.29	441.36	1201.65
	SB	64.42	341.24	188.09	166.54	760.29	
93°18'E	NB	269.65	-15.07	-567.22	-407.31	-719.95	-95.5
	SB	68.29	409.4	202.1	-55.34	624.45	
93°20'E	NB	990.19	-1175.56	-78.71	-1103.99	-1368.07	-127.85
	SB	104.35	-33.06	957.5	211.43	1240.22	
93°22'E	NB	163.83	398.09	84.19	302.16	948.27	2713.53

	SB	242.52	1452.35	74.1	-3.71	1765.26	
93°24'E	NB	1289.62	559.12	-18.57	-90.24	1739.93	2450.2
	SB	170.96	476.89	0	62.42	710.27	
93°26'E	NB	330.99	191.99	-387.89	375.02	510.11	534.92
	SB	67.44	42.83	-865.81	780.35	24.81	
93°28'E	NB	-52.89	66.05	-66.05	21.3	-31.59	-1.03
	SB	119.53	28.17	-2271.71	2154.57	30.56	
93°30'E	NB	41.87	-7.1	-52.76	61.76	43.77	1778.79
	SB	34.72	1067.4	366.26	266.64	1735.02	
93°32'E	NB	-391.73	-12	635.75	35.8	267.82	3251.32
	SB	642.17	1686.14	537.62	117.57	2983.5	
93°34'E	NB	104.04	123.18	-14.09	-41.19	171.94	940.62
	SB	606.15	122.9	60.7	-21.07	768.68	
93°36'E	NB	-95.95	-12.33	92.24	-3.67	-19.71	608.12
	SB	177.2	554.83	-135.46	31.26	627.83	
TOTAL CHANGE IN WIDTH OF THE RIVER							**13269.28**

Table 8: Migration of north bank and south bank during the years 1984-2019 in section 7 in meters

	BANK	**1984-1994**	**1994-2004**	**2004-2014**	**2014-2019**	**1984-2019**	**NB+SB**
93°38'E	NB	223.14	57.79	-23.12	-114.92	142.89	-2223.76
	SB	-583.82	-356.92	-1425.91	0	-2366.65	
93°40'E	NB	33.49	-37.55	-61.98	-33.56	-99.6	-789.94
	SB	-117.87	-577.63	-16.36	21.52	-690.34	
93°42'E	NB	-17.21	0	-923.52	164.78	-775.95	89.62
	SB	-100.57	974.88	-70.08	61.34	865.57	
93°44'E	NB	219.13	695.16	332.95	157.41	1404.65	3908.25
	SB	1452.24	740.41	301.13	9.82	2503.6	
93°46'E	NB	28.46	-3.84	-112.12	-1481.29	-1568.79	-342.69
	SB	903.08	59.94	24.49	238.59	1226.1	
93°48'E	NB	174.71	0	-70.4	-114.73	-10.42	223.91
	SB	39.92	78.9	111.58	3.93	234.33	
93°50'E	NB	569.3	-96.74	655.42	-77.12	1050.86	943.43
	SB	15.07	-24.68	-14.04	-83.78	-107.43	
93°52'E	NB	-603.03	-357.2	282.13	1189.3	511.2	748.3
	SB	1842.63	-1898.71	236.96	56.22	237.1	
93°54'E	NB	1141.36	809.99	1533.51	-809.17	2675.69	2494.91
	SB	6.2	0	-463.71	276.73	-180.78	
93°56'E	NB	925.05	1834.26	-443.11	89.93	2406.13	3537.82
	SB	-231.01	268.03	1112.38	-17.71	1131.69	
93°58'E	NB	-383	598.3	473.39	-33	655.69	920.99
	SB	-106.84	65.47	133.29	173.38	265.3	
94°00'E	NB	1691.15	386.21	-685.34	261.01	1653.03	2163.32
	SB	35.15	39.49	271.52	164.13	510.29	
94°02'E	NB	43.72	980.59	430.43	45.12	1499.86	1060.26
	SB	267.31	-118.59	-885.3	296.98	-439.6	
94°04'E	NB	-130.84	-129.94	-127.07	194.08	-193.77	1286.68
	SB	183.2	1109.75	65.95	121.55	1480.45	
94°06'E	NB	-188.7	23.32	320.61	-232.03	-76.8	-187.32

	SB	151.96	-309.05	-50.01	96.58	-110.52	
94°08'E	NB	-222.46	-415.49	300.21	56.66	-281.08	-202.98
	SB	73.98	-111.76	59.68	56.2	78.1	
94°10'E	NB	-5.57	362.84	323.11	-59.54	620.84	646.44
	SB	92.55	-207.13	57.31	82.87	25.6	
94°12'E	NB	900.6	312.8	1005.02	21.88	2240.3	2261.66
	SB	-7.6	-22.79	-69.62	121.37	21.36	
TOTAL CHANGE IN WIDTH OF THE RIVER							**16538.9**

Table 9: Migration of north bank and south bank during the years 1984-2019 in section 8 in meters

	BANK	**1984-1994**	**1994-2004**	**2004-2014**	**2014-2019**	**1984-2019**	**NB+SB**
94°14'E	NB	-217.54	272.35	-74.04	-52.98	-72.21	63.46
	SB	48.68	23.04	130.3	-66.35	135.67	
94°16''E	NB	50.72	126.07	-173.95	2.86	5.7	514.53
	SB	174.71	302.13	79.75	-47.76	508.83	
94°18'E	NB	65.91	188.76	454.38	-68.72	640.33	594.38
	SB	-27.99	-221.12	-1006.47	1209.63	-45.95	
94°20'E	NB	-46.82	10.89	-57.61	9.57	-83.97	-305.07
	SB	-60.85	18.27	-226.3	47.78	-221.1	
94°22'E	NB	-348.28	-831.18	-149.71	803.33	-525.84	126.13
	SB	173.57	-33.31	414.35	97.36	651.97	
94°24'E	NB	118.76	-232.8	30.3	-45.54	-129.28	31.81
	SB	70.62	90.47	323.28	-323.28	161.09	
94°26'E	NB	-394.7	157.45	21.35	136.77	-79.13	134.94
	SB	-16.21	301.31	-55.51	-15.52	214.07	
94°28'E	NB	23.84	-44.66	41.17	-61.25	-40.9	-1016.05
	SB	36.09	-1300.34	1510.88	-1221.78	-975.15	
94°30'E	NB	226.21	61.61	150.3	1725.35	2163.47	2691.26
	SB	-172.49	696.01	410.34	-406.07	527.79	
94°32'E	NB	588.61	2829.22	599.92	-317.71	3700.04	3747.16
	SB	66.45	-117.62	313.04	-214.75	47.12	
94°34'E	NB	28.04	4.14	-201.25	166.11	-2.96	-83.8
	SB	336.94	-380.7	133.54	-170.62	-80.84	
94°36'E	NB	0	-400.94	414.44	838.91	852.41	702.18
	SB	-188.87	126.28	188.21	-275.85	-150.23	
TOTAL CHANGE IN WIDTH OF THE RIVER							**7200.93**

Table 10: Migration of north bank and south bank during the years 1984-2019 in section 9 in meters

	BANK	**1984-1994**	**1994-2004**	**2004-2014**	**2014-2019**	**1984-2019**	**NB+SB**
94°38'E	NB	16.26	48.98	256.93	5.75	327.92	114.36
	SB	-409.31	149.11	730.58	-683.94	-213.56	
94°40'E	NB	75.55	-83.2	-31.2	162.57	123.72	85.49
	SB	74.92	-50.63	-24.88	-37.64	-38.23	

94°42'E	NB	42.12	302.45	-191.67	33.81	186.71	-123.3
	SB	-330.91	271.26	623.73	-874.09	-310.01	
94°44'E	NB	591.31	-591.31	1600.39	-1341.21	259.18	807.95
	SB	133.56	743.91	-246.87	-81.83	548.77	
94°46'E	NB	89.03	-153.83	39.66	-101.66	-126.8	1506.18
	SB	1505.22	39.51	-42.8	131.05	1632.98	
94°48'E	NB	0	24.86	715.02	46.13	786.01	453.58
	SB	-56.83	-90.69	-333.02	148.11	-332.43	
94°50'E	NB	57.51	963.45	1001.47	508.71	2531.14	2374.07
	SB	-208.97	125.31	-298.21	224.8	-157.07	
94°52'E	NB	-76.78	231.96	43.24	755.77	954.19	889.8
	SB	-99.29	-142.78	377.17	-199.49	-64.39	
94°54'E	NB	-314.27	424.84	1159.78	76	1346.35	1400.84
	SB	-191.77	-111.65	147.2	210.71	54.49	
94°56'E	NB	-536.54	453.13	-895.77	964.09	-15.09	-44.65
	SB	-175.61	274.31	102.58	-230.84	-29.56	
94°58'E	NB	70.76	-34.24	-131.01	226.66	132.17	102.55
	SB	-216.79	66.12	-149.21	270.26	-29.62	
95°00'E	NB	66.97	126.41	0	-262.99	-69.61	9.81
	SB	-40.16	50.24	-140.74	210.08	79.42	
95°02'E	NB	-28.03	-280.86	-95.75	-130.72	-535.36	-342.75
	SB	246.9	-278.24	122.56	101.39	192.61	
95°04'E	NB	59.02	159.52	95.3	135.55	449.39	1345.52
	SB	294.89	379.84	-100.41	321.81	896.13	
95°06'E	NB	-69.04	345.52	236.38	10.15	523.01	864.55
	SB	179.33	26.33	-104.47	240.35	341.54	
95°08'E	NB	83.82	1190.45	-1190.45	-275.14	-191.32	-74.6
	SB	-28.8	8.12	154.86	-17.46	116.72	
95°10'E	NB	25.22	1356.19	-1525.21	312.86	169.06	169.81
	SB	-2424.44	2446.5	-163.67	142.36	0.75	
TOTAL CHANGE IN WIDTH OF THE RIVER							**9539.21**

Table 11: Migration of north bank and south bank during the years 1984-2019 in section 10 in meters

	BANK	**1984-1994**	**1994-2004**	**2004-2014**	**2014-2019**	**1984-2019**	**NB+SB**
95°12'E	NB	160.77	224.75	-167.51	94.76	312.77	304.69
	SB	-2402.99	2341.42	-56.51	110	-8.08	
95°14'E	NB	-58.15	202.84	-266.57	280.62	158.74	203.79
	SB	-1168.26	1226.91	-134.97	121.37	45.05	
95°16'E	NB	-439.32	-332.39	1022.12	99.85	350.26	610.58
	SB	96.36	114.27	12.63	37.06	260.32	
95°18'E	NB	114.26	117.72	67.06	-14.42	284.62	364.47
	SB	387.24	-171.86	-144.82	9.29	79.85	
95°20'E	NB	474.22	71.35	1274.94	447.44	2267.95	2488.65

	SB	208.31	-116.5	79.99	48.9	220.7	
95°22'E	NB	0	0	0	0	0	663.61
	SB	733.89	-316.16	-108.08	353.96	663.61	
95°24'E	NB	0	0	0	0	0	236.07
	SB	814.66	-548.12	99.51	-129.98	236.07	
95°26'E	NB	0	0	0	0	0	679.59
	SB	1059.27	-419.32	202.89	-163.25	679.59	
95°28'E	NB	0	0	0	0	0	128.39
	SB	-179.98	419.77	-111.4	0	128.39	
95°30'E	NB	0	0	0	0	0	85.96
	SB	338.66	-252.7	0	0	85.96	
95°32'E	NB	-48.07	26.75	356.94	-178.96	156.66	2656.07
	SB	29.08	1901.77	249.03	319.53	2499.41	
95°34'E	NB	656.27	-105.07	280	-238.64	592.56	544.78
	SB	-82.12	174.87	-116.52	-24.01	-47.78	
95°36'E	NB	0	0	0	0	0	78.07
	SB	273.9	-188.47	-653.33	645.97	78.07	
95°38'E	NB	0	0	0	0	0	543.77
	SB	-57.74	271.47	-622.99	953.03	543.77	
95°40'E	NB	-149.02	-228.37	-82.09	40.91	-418.57	-38.08
	SB	32.33	151.58	206.55	-9.97	380.49	
TOTAL CHANGE IN WIDTH OF THE RIVER							**9550.41**

Table12: Maximum deposition and erosion that occurred during the years 1984-2019 at different sections in meters.

SECTION	PROCESS	LONGITUDE	BANK	LOCATION	MIGRATION
1	Erosion	90°00'E	South Bank	South Salmara tehsil of Dhubri district	3703.7
		90°16'E	South Bank	Lakhipur circle of Goalpara district	3652.18
	Deposition	90°26'E	South Bank	Chapar circle of Dhubri district	-1144.44
		90°10'E	North Bank	Lakhipur tehsil of Goalpara district	-1142.58
2	Erosion	91°10'48"E	South Bank	Chamaria tehsil of Kamrup district	3972.09
	Deposition	91°22'E	North Bank	Barkhetri tehsil of Nalbari district	-1019.48
3	Erosion	92°08'E	South Bank	Mayong tehsil of Morigaon district	5277.75
		92°00'E	North Bank	Mangaldoi circle of Darrang district	3555.59
		92°18'E	South Bank	Bhuragaon circle of Morigaon district(Tulsibori)	3587.17
	Deposition	92°06'E	North Bank	Mangaldoi circle of Darrang district	-3737.56

		91°54'E	North Bank	Sipajhar tehsil of Darrang district	-2809.49
4	Erosion	92°42'E	South Bank	Rupahi tehsil of Nagaon district, Laokhowa Wildlife Sanctuary	1055.34
	Deposition	92°32'E	South Bank	Dhing tehsil of Nagaon district	-434.4
5	Erosion	93°08'E	North Bank	Biswanath tehsil of Sonitpur district	806
	Deposition	92°52'E	South Bank	Kaliabor circle of Nagaon district	-1538.95
6	Erosion	93°32'E	South Bank	Golaghat district near Kaziranga National park	2983.5
	Deposition	93°20'E	North Bank	Biswanath tehsil of Sonitpur district	-1368.07
7	Erosion	93°54'E	North Bank	Majuli tehsil of Jorhat district	2675.69
	Deposition	93°38'E	South Bank	Bokakhat tehsil of Golaghat district	-2366.65
8	Erosion	94°32'E	North Bank	Dhakuakhana tehsil of Lakhimpur district	3700.04
	Deposition	94°28'E	South Bank	Sibsagar tehsil of Sivasagar district	-975.15
9	Erosion	94°50'E	North Bank	Sissibaragaon tehsil of Dhemaji district	2531.14
	Deposition	95°02'E	North Bank	Jonai tehsil of Dhemaji district	-535.36
10	Erosion	95°32'E	South Bank	Doomdooma tehsil of Tinsukia district	2470.33
	Deposition	95°40'E	North Bank	Sadiya tehsil of Tinsukia district	-418.57

4.1 LAND LOSS

Table 13: Land loss that took place during the years 1984-2019 due to erosion and deposition in River Brahmaputra

SECTION	COORDINATES	AVERAGE CHANGE IN RIVER WIDTH
1	89°54'E-90°36'E	37883.71meters
2	90°38'E-91°34'E	27840.77meters
3	91°36'E-92°24'E	16468.13meters
4	92°26'E-92°46'E	6757.34meters
5	92°48'E-93°10'E	172.77meters
6	93°12'E-93°36'E	13269.28meters
7	93°38'E-94°12'E	16538.9meters
8	94°14'E-94°36'E	7200.93meters
9	94°38'E-95°10'E	9531.29meters
10	95°12'E-95°40'E	9550.41meters
Average change in width of the River from 1984-2019		14521.353meters
Land loss = Average change in width of the River from 1984-2019×Length of the River in Assam		1.33×10^6 Hectares

Considering the huge land loss during the years 1984-2019, it is serious concern and it is necessary to take adequate measures to control the future erosion.

5. CONCLUSIONS

Maximum erosion is being observed at section-3(i.e Sualkuchi to Moirabari region) in Mayong tehsil of Morigaon district at South Bank in 92°08'E longitude, where the width increased by 5277.75 meters. Maximum deposition is being observed at section-3(i.e Sualkuchi to Moirabari region) in Mangaldoi circle of Darrang district at North Bank in 92°06'E longitude, where width decreased by 3737.56 meters. During analysis it was observed that land loss of approximately 1.33×10^6 Hectares took place during the year 1984-2019. So, it is important to take immediate erosion control measures so as to avoid further land loss. From above analysis, it is observed that the bank of the river Brahmaputra is quite unstable and changes its morphology due to change in discharge and sediment concentration level of water.

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