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EVALUATION OF GEO-FLUVIAL CHARACTERISTICS AND ITS IMPACT ON LAND AND PEOPLE USING GEOSPATIAL TOOLS IN MIDDLE BRAHMAPUTRA RIVER BASIN

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Abstract
While landforms in a drainage basin have been the basic ingredient for land use, floods in some basins are seen to act partly as boons in the midst of their many faceted problems as well as the anthropogenic actions and results. The river is an active agent on landforms that controlled the entire study area. The geo-fluvial [1]characteristic of a river basin has been dominated by the morphology and the hydrological regimes of the river. The middle Brahmaputra River basin in the hub of the North East India below the high standing Bhutan Himalaya has since the last 4-5 decades been observed to create the flood menace to not only standing crops, human habitation but also to other kinds of land uses in the area under the river's domain. The middle part of the basin has its peculiar landform characteristics that can be well counted through surficial relief, slope, dissection, drainage net, vegetational cover along with soil types and their capabilities yielding characteristic combination of land uses. Over the analyzed period the geo- fluvial parameters are frequently changed under the spatio-temporal domain. Hydro-morphological aspects are influenced by the river basin parameters including channel shifting rate, braiding index, sinuosity index, etc. The middle part of the basin being flooded frequently due to high storm rainfall in its catchment uses to cause the high damage to land including river planform, people and environment. The terrain characteristics of the region influenced the hydraulic parameters and their impact on the landform. The Brahmaputra River frequently changed the thalweg causing drastic change on sand bar location. In the dynamically substitute landforms that are formed island and sandbars, it is beneficial for the riparian vegetation and agricultural land. Therefore, there has been an outmost need to evolve the area specific strategies for mitigation of fluvio-geomorphologically associated problems in order to protect and progress land use pattern on the one hand and the human society on the other.
Keywords: Fluvial-geomorphic, channel shifting, GIS, river braided, hydrological aspects

Introduction

A drainage basin being the best unit for hydro-physical studies among many (Horton, 1945, Chorley, 1969), bears a great significance in today's fluvio-geomorphological investigation of

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channel network and drainage morphology along with flood events and their relationship with land, water and man (Chorley,1969b).Bank erosion and channel shifting are the main problems of the river Brahmaputra as it carries the huge amount of sediment from its catchment area on the one hand and river width is another reason for the channel shifting in the other. Being in a constant process of changes, river basins are always subjected to the forces carried out in ecological, economic, social and cultural aspects i.e., the so-called 'driving forces' of land use and land cover (LULC) change (Verburg et al., 2006). The role of river basins as repositories of natural, environmental, and cultural resources along with capturing, channeling, regulating, and storing the freshwater for anthropogenic uses, makes them multifunctional units in all perspectives i.e., hydrological, biophysical, socio-economic, etc. (Dawei and Jingsheng, 2001; Wagner et al., 2002). Bank erosion and its effects on channel evolution are essential geomorphic research problems with relevance to many scientific and engineering fields (Sarkar etal. 2011), drastically change runoff and sediment transport of rivers. These changes in hydraulic conditions will have the great impacts on the economic development, the safety of urban areas, and the ecological environment of rivers. Thus, it is of great significance to study the impact of climate change on the topography and ecological environment of rivers (Wang et al.,2020). River morphology describes the concept of geographic form, the river channel classification, edges of the river, and geomorphic analysis. River morphology is a significant analysis of the physical principles of hydraulic flow and sediment transport (Chang 2008). The degradation of mountains by streams recognized that not all of the material removed by streams was immediately carried to the sea but that a considerable part of it went into the building of floodplains (Guetthard, 1715-1786). In case of river Brahmaputra, it carries a huge amount of bed load and suspended load from its catchment as the Brahmaputra valley is basically composed with alluvial soil (Goswami, 1985). A channel pattern is a result of factors such as river discharge, water velocity, thickness, and depth of the channel, which are interrelated to each other (Matsuda,2004) A combination of human-induced activities causes a decline in river levee, high sedimentation rates, and adverse channel gradients, which results in avulsion (Sharma et al. 2010; Heyvaert et al. 2012). Seasonality and high variability are noteworthy features of the Brahmaputra's flow. A significant characteristic of the river's flow regime is the significantly large variations in its daily discharge in different seasons (Pradhan et al., 2021). Stream bank erosion and its effects on channel evolution are essential geomorphic research problems with relevance to many scientific and engineering fields (Sarkar et al., 2011).

Methodology

The entire part of the middle Brahmaputra River basin area is identified by using toposheet and satellite image. The data collected from the website of USGS earth explorer and from the satellite imagery -Landsat-5 for years of 1990, 1995, 2000, 2005 2010, and Landsat-8 data used for the years of 2015, 2020. The data used to calculate the river Sinuosity Index, Channel Index, Valley Index, Hydraulic Sinuosity Index, Topographic Sinuosity Index and the Braiding Index and measures the rate of erosion and deposition. For the measures of height, depth and three-dimensional model of the study area prepared using the ASTER DEM. The DEM data collect from the website of Earth data which are analyzed with the help of ArcGIS 10.3 software and

Golden Surfer software. TWI, SPI, STI and elevation map prepared and calculate with the help of DEM data. For the calculation purposes are used formula as follows-

1) Topographic Wetness Index (TWI) = In $(\frac{a}{\tan\beta})$, (Beven and kirkby,1979) where, a is the local upslope area draining through a certain point per unit contour length; and tan β indicates local slope.

2) Sediment Transport Index (STI) = $(A_s/22.13)^{0.6}$ x $(\sin\beta/0.0896)^{1.3}$ (Moore and Burch,1986), where, A_s is the unit contributing area (in m^2/m) and β is the slope angle (in degrees) at a given pixel.

3) Stream Power Index (SPI) = In (Dai) *tan (Gi), (Bagnold.1996) where, SPI is the Stream Power Index at grid cell i, DA is the upstream drainage area (flow accumulation at grid cell I multiplied by grid cell area), and G is the slope at a grid cell I radians.

4) Slope in degree = Rise / run (O' Brien, 1844)

5) Sinuosity Index (SI) =L_{cmax} / L_R, (Leopold & Miller, 1964) where, L_{omax} is the mid channel length, L_R is the straight length.

6) Channel Index (CI)= CL/Air, (Mueller,1968)

7) Valley Index (VI) I= VL/Air, (Mueller, 1968)

8) Hydraulic Sinuosity Index (HSI) =% equivalent (Cl-Vl)/(Cl-1), (Mueller,1968)

9) Topographic Sinuosity Index (TSI) =% equivalent (Vl-1)/(Cl-1), (Mueller, 1968) According to Mueller formula where, CL is the length of the channel(Thalweg) in the stream under study, VL is the valley length along a stream, the length of a line which is everywhere midway between the base of the valley walls (in this case one half of total length of right and left banks of a reach) and Air is the shortest air distance between the source and mouth of the stream (in this case shortest air length of a reach)

10) Braiding Index (BI) =2ΣLb/Lm,(Brice, 1964) where, 2ΣLb is the sum of the length of islands/ bars, Lm is the length of the reach

Leopold et al. (1964), Mueller (1968), Friend and Sinha (1993) are used the sinuosity index and the Braiding Index method for the analysis of the river parameters

Study Area

The mean elevation of the study area is 50 meters from the mean sea level however, in the hilly area it is up to 600 meters from the mean sea level. The region is located between$26^0 11^/.11.798^{//}$N to$26^0 37^/ 29.666^{//}$N latitude and $92^0 57^/ 22.077^{//}$E to $92^0 37^/ 29.666^{//}$N longitude. The part of the middle Brahmaputra River lies in the north eastern part of India extending up to two districts namely Kamrup(M) and Sonitpur, as the total length is 133 km from east to west. The study area has been regularly washed by the flood water both the south and north banks along with two reserved forests (Laokhowa Wildlife Sanctuary and Orang National Park). The basin being dominated by incessantly occurred storm rainfalls during the summer season all over the basin, more specifically on the foothills, creates often flood havocs of low to very high intensities and the durations which is accelerated by the basin morphology. The basin, which has been entangled with topographic peculiarities under geomorphic, hydrologic edaphic and anthropogenic domains, suffers from problems like soil erosion, floods, channel shifting, abandonment of channels, drainage congestions etc. which bear a strong negative impact on landform and land uses. Many tributary rivers are deposited their load to the middle Brahmaputra River causing the high congestions in the channel morphology. The major tributaries are Jia Bharalu, Puthimari, and Dhansiri in the north and the south bank tributaries are- Kulsi, Kapili, Kalang etc. The region therefore, needs to investigate the characteristics of present landform and landuses in order to formulate strategies to overcome the geomorphic and hydrologic problems. On the rationale behind such a feature in the middle Brahmaputra River, the authors have intended to investigate some of the vital determinants to manage the flood problems by using geospatial tools and techniques covered by remote sensing and GIS.

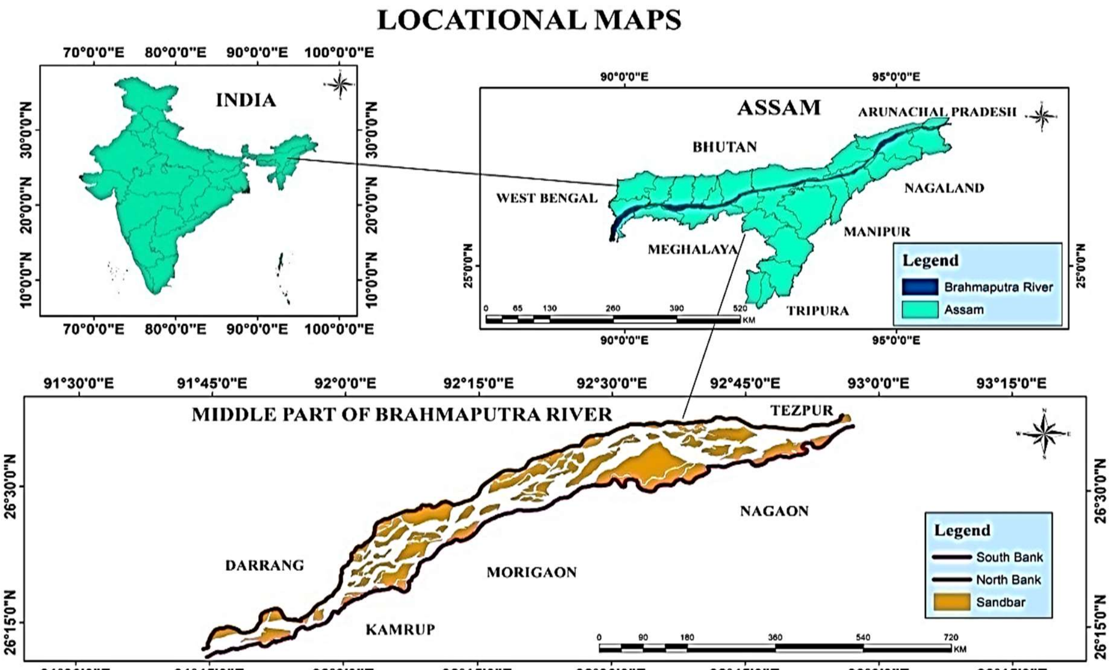


Fig. 1The Locational Map. (Braided pattern of Brahmaputra River with island and sandbars of both banks).

Morphology of Middle Brahmaputra Valley

Morphology is primarily concerned with exogenous processes as they mold the surface of the earth, but the internal forces cannot be disregarded when one considers fundamental concepts of the origin and development of landforms (Leopold et al., 1995). Geomorphology is the interpretative description of the relief features of the earth (Worcester,1965). Morphological facets of the study area define the hydro-morphological pattern and characteristics of the river basin. In the study area, the river pattern is braided, and the aggregate of the surface area is a gentle slope which is almost covered with flood plain. During the monsoon period almost, entire sandbars are submerged and often prone to a severe flood for three to four times in a year. The resultant morphometric developments and assemblages of basin landforms (F) in the middle Brahmaputra have been caused by the dynamic process (P) on the characteristic material composition (M) of the basin since the inception and coming under geomorphic processes till date (dT). As such the whole geomorphic phenomenon can be contained in the Gregorian geomorphic process model of F=f (M.P) dT (Gregory, 1976). While going to examine the morphometric determinants, it is observed that in the hill and foothill portion in north of the basin for a very constricted area there lie the geological structure and rock composition akin to Himalayan origin. In the plains below the hills alluvial deposits carried from the Himalayan region by fluvial agents have formed material base. In the upper part of the plain, there is the dominance of old alluvium in the Bhabar and Tarai zone while in the built up and floodplain areas recent and sub-recent alluvium composed of fine sand, silt, and clay dominate. Numerous studies have shown how the shape of the land surface can affect the lateral migration and accumulation of water, sediments, and other constituents (e.g., Moore et al. 1988).

Aerial Aspects

To evaluate the fluvio-morphological characteristics of an area four major aspects are need to examine. Among them one is aerial aspects. The areal aspects of an area determined the two-dimensional features of an area. The middle Brahmaputra River basin is extended from Tezpur to Kamrup districts having total length of 340 km. As the river carries huge amount of sediment load, therefore, from 1990 to 2020 the maximum sand bar area was 632km^2 (1990) and the minimum 383.11 km^2 (2020). On the other hand, the height of braiding index was 5.83 km^2 and the lowest braiding index was 3.76 km^2 in both the year. The areal aspect indicates that unstability of the geo-fluvial characteristics of study area.

Table 1. Areal aspects of the Middle part of the Brahmaputra River

Relief Aspects

Start Point	$92^{0}57^{/}22.077^{//}$E $26^{0}37^{/}29.66^{//}$N				Tezpur		
End Point	$91^{0}43^{/}11.152^{//}$E $26^{0}11^{/}11.798^{//}$N				Kamrup		
Total Length	340 km^2						
Year	1990	1995	2000	2005	2010	2015	2020
Total Bar area (Km^2)	456.76	632	492	563	502.8	383.11	390.8
Braiding Index	5.27	5.01	5.37	4.23	5.84	5.53	3.76

Relief aspects of the study area play a vital role in the fluvial geomorphology of the middle Brahmaputra River. Relief characteristics on an area are defined by the measurement of the XYZ attribute. The relief facets of the area are very significant because of a huge amount of sediment deposition in the river basin area. In the present context, three important parameters are considered, they are slope, profile graph, and elevation map. Slope defines the rate of inclination of an area. The river activities like sediment transportation, erosion capacity, and water velocity depends upon the slope gradients of an area. The study area slope map (fig.3) shows the 0-2.5 (very low) indicates the river and wetland area. Low slope 2.51-6.04-degree inclination area covered the almost entire area. The area is very helpful for sediment deposition. The high area situated in the 11.83-21.64 degree and 21.64-64.15-degree inclination area which is prone to erosion.

The profile graph visualizes the surface elevation of an area. The area measures 3-dimensional continuous line change over the distance. The A-B profile line shows the almost equal height but often changes the continuation of height. The profile graph C-D shows both the side east and west comparatively high but the mid area height between the 40 to 60 meters height. The almost entire study area has been covered with the alluvial floodplains in the height from the mean sea level in about 50 meters and only in south east portion near gohaingaon of the study area covered by the hilly areas in the about 600 meters from the mean sea level. The hilly area's vulnerability to erosion is high. The erosion and deposition of an area in the context of fluvial geomorphology are very important and the factors control the terrain characteristics of an area.

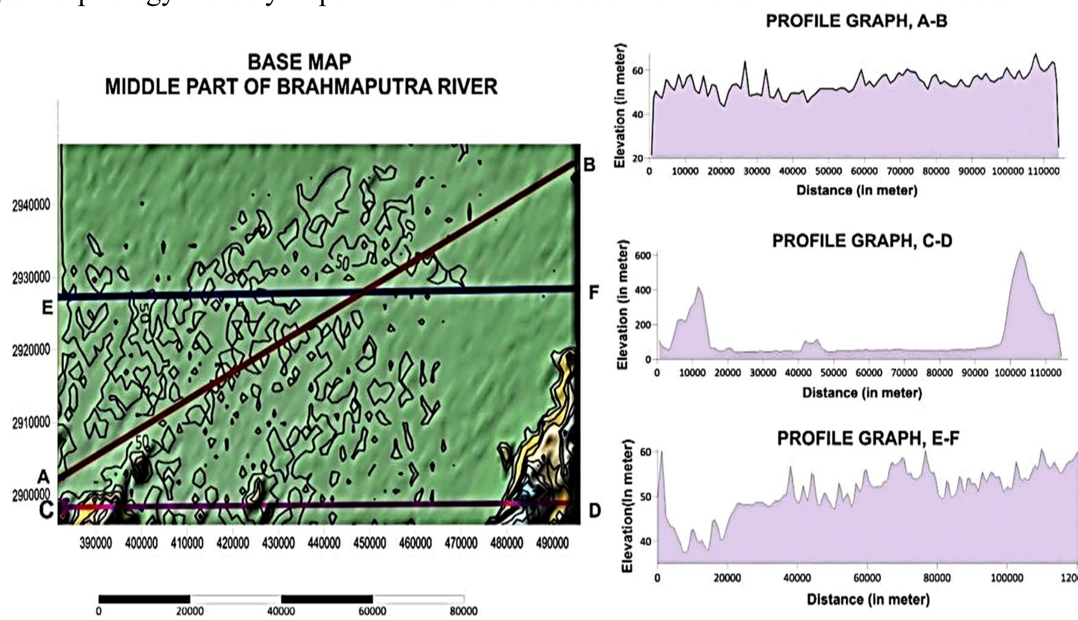


Fig 2. Topographic Profile showing the terrain condition of middle Brahmaputra River cross section A-B (Kharghuli NC to Silghat town), C-D (Kharghuli gaon to Raita gaon), E-F (Bagachala to Gohaingaon)

Table 2. Principal Component Analysis (Data Calculated from the Elevation Map).

	PC1	PC2	PC3
X:	6.64277645969e-07	6.64277645969e-07	-0.000496322793057
Y:	0.99999944439	0.99999944439	0.00105414449447
Z:	-0.00105414429461	-0.00105414429461	0.00105414449447
Lambda:	1102107976.89	234072361.09	3982.45856849

Here, the Principal Component Analysis technique is used to simplify the data set. The final outcome result is 9 bytes = 3 x3, which indicates the geometrical plotting in 3 dimensional spaces (fig. 3). The three-dimensional river morphological areas calculated based on the X, Y and Z values. The X, Y denotes the coordinate system where the Z value denotes the height of the area. The calculated PC1, PC2 and PC3 data set are well sustained and having good relationship between X, Y and Z values (table 2).

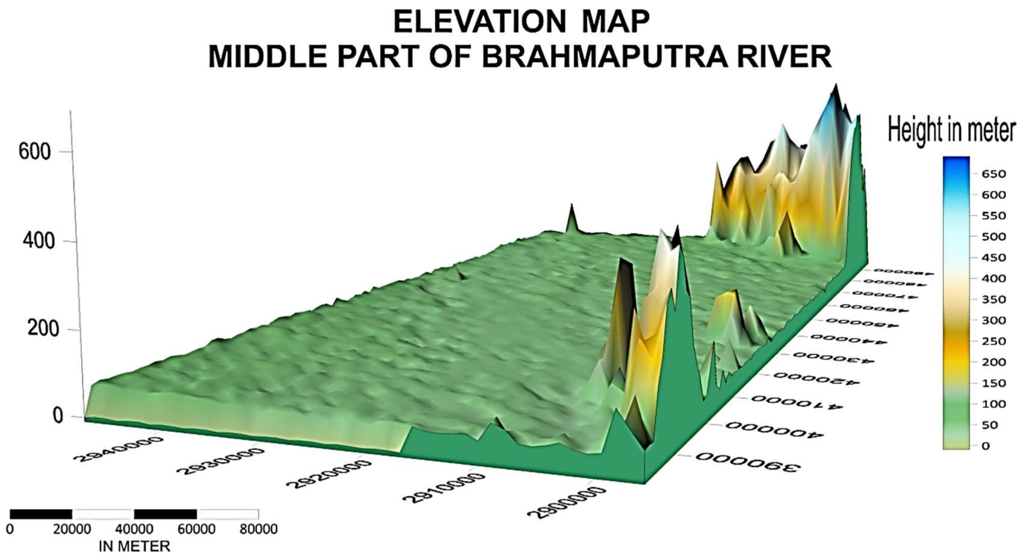


Fig.3 Elevation Map of Middle Brahmaputra River Valley (Showing elevation of various parts through 3D Model)

The entire area of the middle Brahmaputra River almost covered height between 50-100 meter, only Kharghuli area in Kamrup metropolitan district and Ratia Gaon area in Karbi-Anglong district height between 200-650 meters from the mean sea level as found in the elevation map.

Linear Aspects

Linear aspects of the basins are closely linked with the channel patterns of the drainage networks wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed (Hajam, 2013). The morphometric parameters – Channel index, Valley index, Sinuosity index, Topographic sinuosity index, and Hydraulic sinuosity index assessment outcomes indicate the circumstances of the geo-fluvial characteristics of the river Brahmaputra. The factors of sediment load, discharge carrying capacity, stream velocity, deposition, and erosion all are interrelated with the linear aspects of the river. The output shows the highest channel index 1.32 (2020) and the lowest channel index 1.13(1990). The calculate maximum valley index 1.14 (1990) and minimum valley index 1.18 (2020). The sinuosity index is calculated by dividing the total length of the river by the total air length of the valley. The Brahmaputra River channel pattern is a sinuous type of river. The calculated table (table.3) shows the characteristics of the river.

Table 3 Linear Aspects of the Middle Brahmaputra River Valley

	Year						
	1990	1995	2000	2005	2010	2015	2020
Channel Index	1.13	1.14	1.16	1.15	1.16	1.16	1.32
Valley Index	1.14	1.15	1.16	1.17	1.21	1.18	1.19
Sinuosity Index	1.14	1.18	1.18	1.18	1.21	1.20	1.15
Topographic Sinuosity Index	107	107	0	113	131	113	59

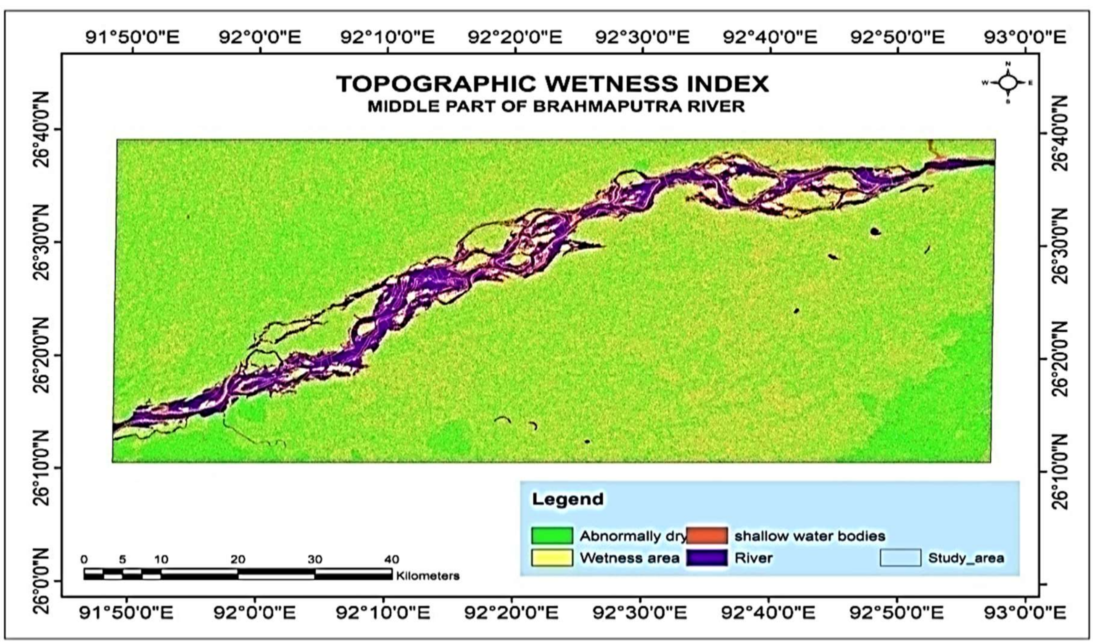
Hydraulic Sinuosity Index	7	7	0	13	31	13	41

Source: Results calculate using the Landsat-5, Landsat-7 and Landsat-8 satellite imagery

Fluvio-Hydrological Aspects

The water regime of the river is very fluctuating in nature all over the year. In the monsoon season, the water level perpetually rises and is overwhelmed on the river bank generate low to high magnitude floods in the river valley areas. In the monsoon season, the Brahmaputra River water level frequently goes up to the danger level and sometimes crosses it. When the river water level is high the rate of erosion and deposition is increased and often interchangeably changed their riverbank towards the right and left bank. Due to sediment deposition, on the river bed, some segment becomes very shallow and prone to bank erosion in the monsoon season. The submerged sandbar is exposed during the winter season and the river water level goes down. The water velocity, river load transportation capacity, and supply of the sediment from the basin area all power tremendously lose the river due to the climatic variation's river basin.

Hydrological aspects are most important for the geo-fluvial condition of an area. Hydrology is the main factor that changed land cover of an area. The topographical wetness index is used for the measurement of soil moisture conditions in an area. The present study area soil moisture unevenly distributed depends upon the moisture condition the area categorized into four major areas –Abnormally dry area (247 km^2), wetness area (241 km^2), shallow water bodies (96km^2),



and River (41 km^2).

Fig 4. The whole area covered with abnormally dry and wetness area only river thalwag and shallow water bodies covered Brahmaputra River area in the wetness index map.

Stream power index map has been calculated from the ASTER DEM. The negative threshold value indicates potential depositional areas and the positive values indicate the potential erosive area. In the context of the middle Brahmaputra River, negative value shows the frequent flood affecting areas where soil most important component humus accumulates due to flood and this area formed with new alluvial soils. The positive threshold value shows the comparatively hilly areas where flood affects chance is less as well depositional capacity is less but active in the erosional process. Where highly erosional the area covers the 6.20km^2, erosional area 81 km^2, the depositional area comes under 187 km^2 and the highly depositional area is covered with 353 km^2.

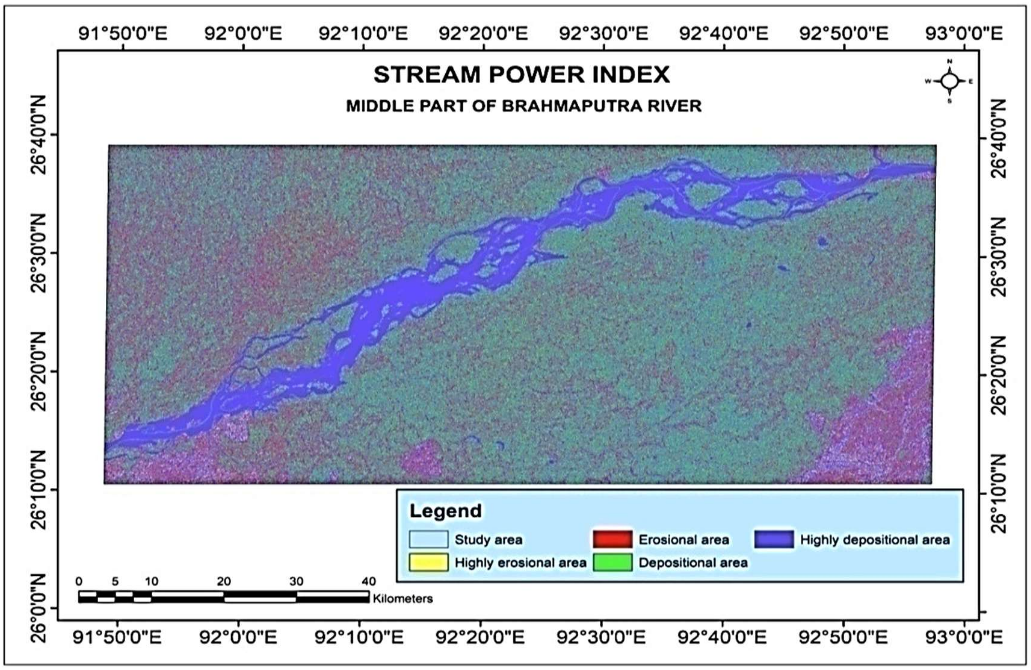


Fig 5. The stream power capacity high in the Brahmaputra River and near kharghuli gaon in the southwest area and ratia gaon in the southeast area is slightly high it shows in the Stream Power Index map.

The river Brahmaputra rank first in terms of sediment carrying among the other rivers of the world. The Brahmaputra River basin is surrounded by newly formed hilly tracks, as a result the area covered with soft material which is easily erodible by the droplets of the rain and other biological activities. The sediment transport index map indicates the different ranges of sediment transportation zone; the sediment carries through rainfall and floods. This zone is categorized based on their calculated threshold value and the value is divided into four different zones like- the very high potential area covered 603.31 km^2, the second high area has been 21.47 km^2, low area 1.54km^{2,} and very low 0.15 km^2. Almost the entire study area is prone to very high sediment transportation area causes low slope and structural position of the area.

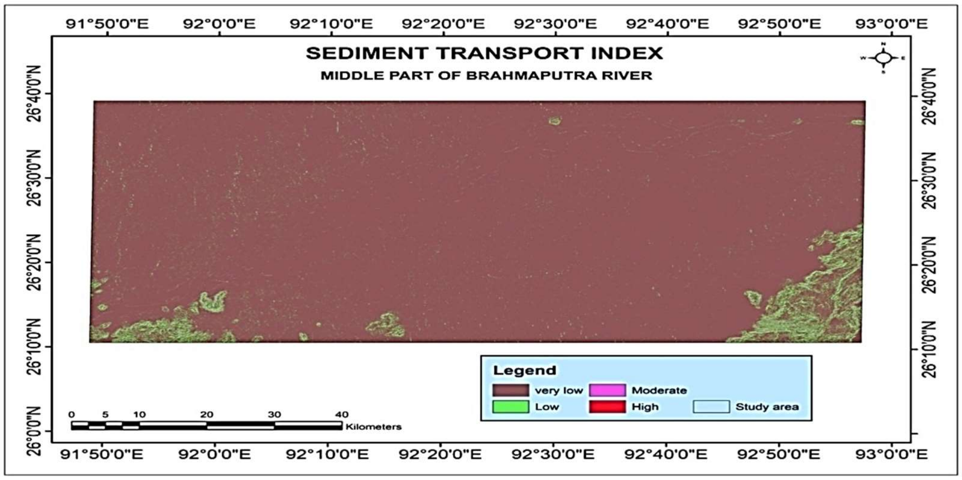


Fig 6. The entire area sediment transport capacity is low, in the southeast area (Ratia gaon) and southwest (Kharguli gaon) area slightly high compare to the entire study area.

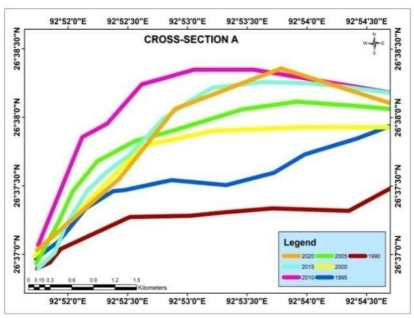
Channel Shifting

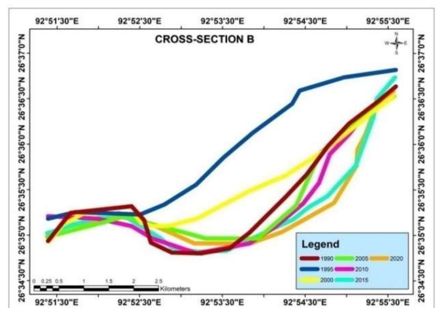
Channel shifting is a common problem of river Brahmaputra and its tributaries. The channel especially middle part is highly unstable due to aggradations and degradation of the river bed. On the river bed, formations of sand bars are the chief factor for the diversion of river thalweg. During the last 5 years the Brahmaputra River shifted his channel in the both banks, which is more frequent than the other years. Based on the satellite imagery of different time periods, it has been found that the erosion and deposition are the common factor of the valley. At the cross-section B in Katiachapari, Kaliabor in Nagaon district the left bank eroded 0.66 km and right at the Nadirpar, Darrang the river bank eroded 0.38 km in the years between 1990 to 1995 (fig.7). In the years in between 1995 to 2000 left bank katiachapari, Kaliabor in Nagaon again eroded 0.78 km and in the right bank Mowamari, Mangaldai, Darrang eroded 2.73 km. From the analysis of satellite imagery, it has been observed that the years 2000 to 2005 left bank Baralimari no.1, Morigaon district maximum eroded 0.46 km and in the right bank Bhoikhowa gaon Tezpur district eroded total 1.01 km length of riverine area. The valley shifted in the years between 2005 to 2010 in the left bank Katiapari, Kaliabor, Nagon district, where erosion rate was 0.80 km. In the right bank Mowamari Mangaldai, Darrang shifted 1.02 km. During the time periods of 2010 to 2015 the river bank eroded in the left Katiachapari, kaliabor, Nagaon 0.42 km and in the right bank maximum eroded 0.63km at Nadirpar, Darrang district. For the years of 2015 to 2020 maximum shifted towards the left bank at the Batabori, Laharighat, Morigaon area where erosion rate was 2.17 km. The right bank at the Nadirpar, Darrang shifted at the rate of 0.42 km within the 5 years. In the figure.7 shows the maximum shifted rate in between 1990 to 2020 towards the left shifted rate due to erosion is 1.57 km and in the right bank shifted rate is 4.18 km. Table 4. shows the cross-section site and the table 5 shows the details about the maximum erosion rate in the left and right bank in different cross section site A,B,C,D,E,F,G,H,I and J . The shifted rate is not constant due to the soil structure, river characteristics, climatic condition and land cover of the area.

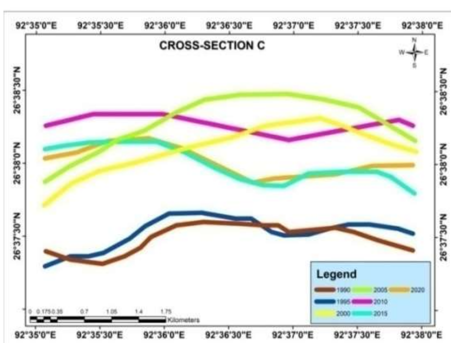
Table 4. Location of the Channel Shifting of the Middle part of Brahmaputra River

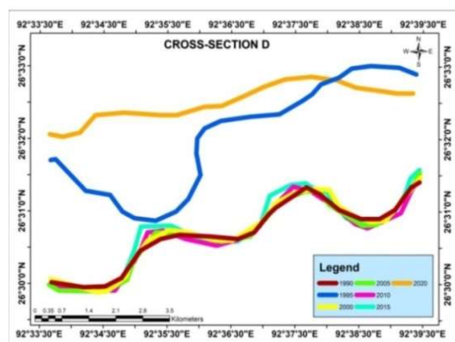
Cross-section	Latitude/longitude	Area	Districts
A	$92^{0}53^{/}2.335^{//}$E $26^{0}38^{/}37.966^{//}$N	Bhoi khowa gaon	Tezpur
B	$92^{0}54^{/}7.612^{//}$E $26^{0}34^{/}44.089^{//}$N	Katiachapari	Kaliabor, Nagaon
C	$92^{0}36^{/}49.971^{//}$E $26^{0}38^{/}43.129^{//}$N	Siparia chapari	Dhekiajuli, Sonitpur
D	$92^{0}36^{/}47.853^{//}$E $26^{0}30^{/}13.994^{//}$N	Baralimari No.1	Morigaon
E	$92^{0}17^{/}20.706^{//}$E $26^{0}32^{/}58.064^{//}$N	Nadirpar	Darrang
F	$92^{0}18^{/}21.114^{//}$E $26^{0}24^{/}32.861^{//}$N	Batabori	Laharighat, Morigaon
G	$92^{0}2^{/}41.036^{//}$E $26^{0}25^{/}11.98^{//}$N	Mowamari	Mangaldoi, Darrang
H	$92^{0}4^{/}43.309^{//}$E $26^{0}17^{/}7.75^{//}$N	Garubandha	Dhing, Nagaon
I	$91^{0}49^{/}21.414^{//}$E $26^{0}14^{/}33.098^{//}$N	Dakhin kuruah	Sipajhar, Darrang
J	$91^{0}49^{/}30.39^{//}$E $26^{0}12^{/}19.018^{//}$N	Kharghuli N.C	Guwahati, Kamrup(m)

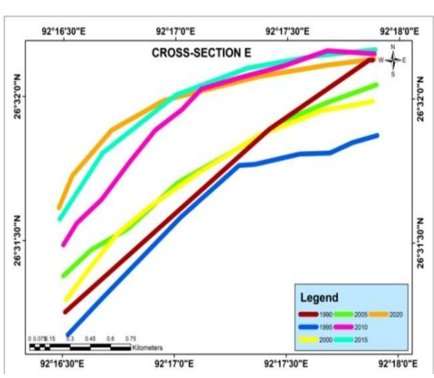
Source: ArcGIS map and Google Earth, 2020

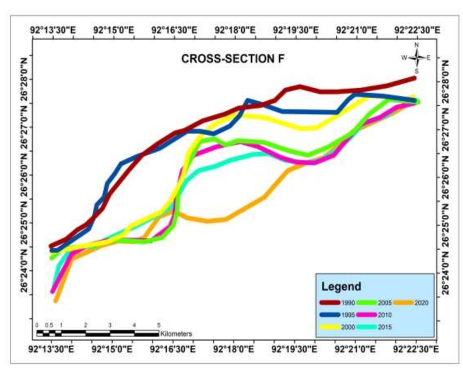












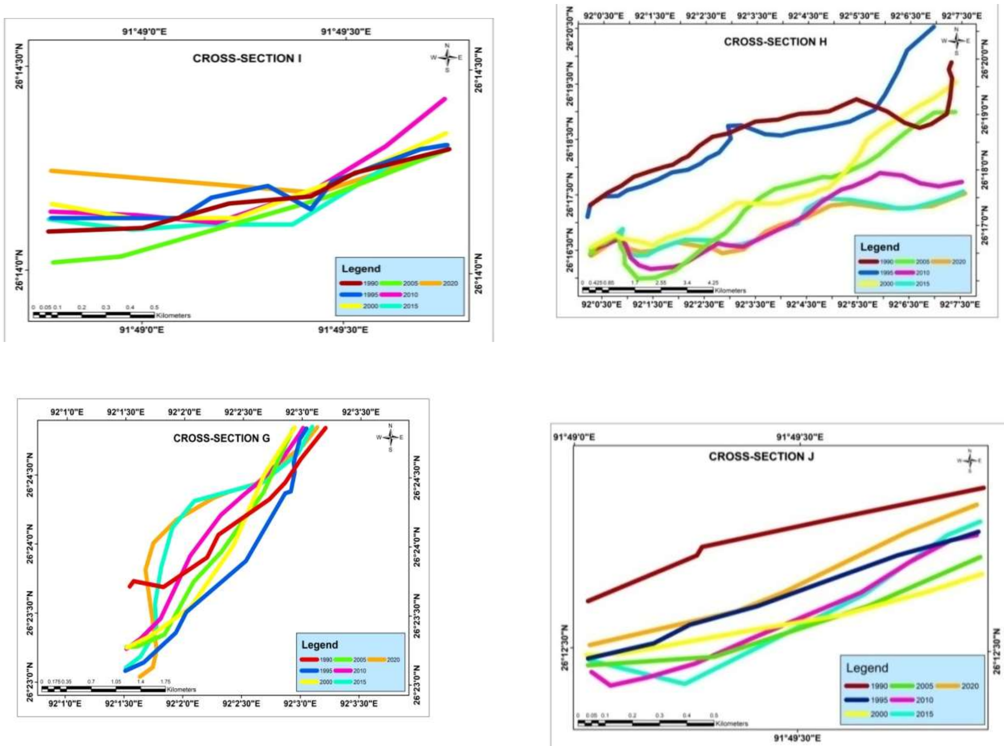
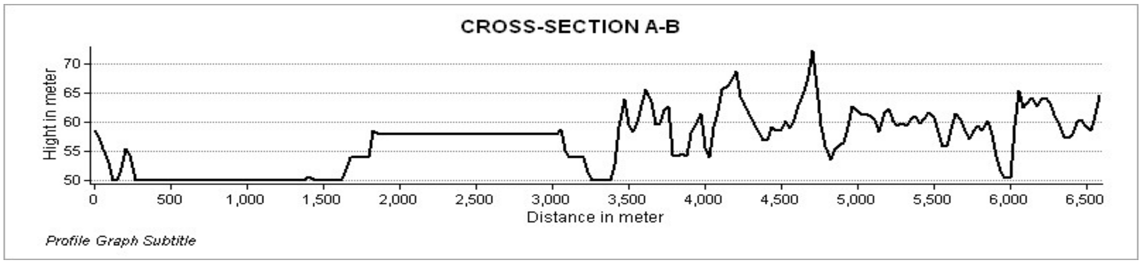


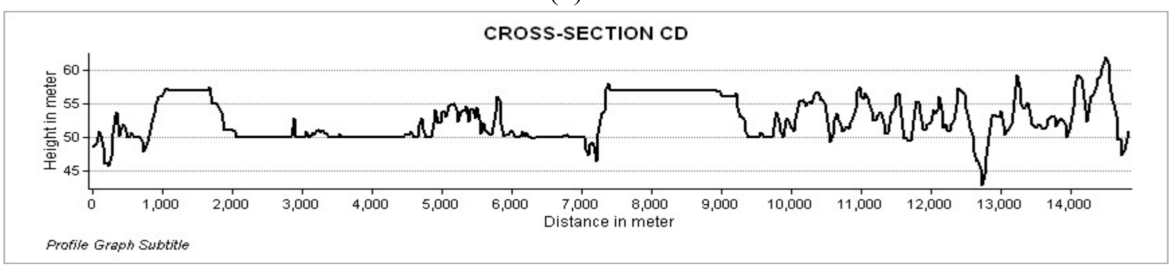
Fig 7. Temporal morphology changes due to channel shifting (1990-2020) towards Right and Left bank at the Cross-section A- Bhoikhowa gaon, B- Katiachapari, C-Siparia chapari, D-Baralimari no-1, E- Nadirpar, F- Batabori, G- Mowamari, H- Garubandha, I- Dakhin kutuah, J- Kharghuli NC area at the Middle part of Brahmaputra River.

As a river moves laterally, sediment is deposited within or below the level of the bank full stage on the point bar, while at overflow stages the sediment is deposited on both the point bar and over the adjacent flood plain (leopold et al,1964 p.322). The present deposition rate calculated based on the overflow stages while the river deposited sediment on both the point bar and over the adjacent flood plain area. Depend upon the satellite imagery in different time periods-1990, 1995, 2000, 2005, 2010, 2015 and 2020 measured the deposition rate of the study area. In the years 1990 to 1995 in the left bank at the Barlimari no.1, Morigaon district deposited 0.05 km^2 and right bank maximum deposited rate are 3.15 km^2 in the Siperia chapari, Dhekiajuli, Sonitpur. Within the 5 years in between 1995 to 2000 maximum deposition on the Barlimari No.1 Morigaon area is 0.06 km^2. And in the year's 2000 to 2005 deposition rate at the place Batabori, Laharighat, Morigaon districts is 1.07 km^2. Right bank of the river in the area siperia chapari, Dhekiajuli, sonitpur district in between 2005 to 2010 deposition rate is 0.09 km^2. The observed satellite imagery provided the depositional rate in between the years 2010 to 2015 in the place Barlimari no.1 Morigaon for cross- section D deposition rate is 0.63 km^2 where the right bank in the area Mowamari, Mangaldai, Darrang deposited 0.13 km^2. In the years 2015 to 2020 maximum deposition 0.15 km^2 in the Kharghuli N.C Guwahati, Kamrup at the left bank side and in the right bank in the cross-section site I maximum all the observed time periods is 3.74 km^2 in the place Dakshin kurah sipajhar, darrang districts. The entire observed area depositional rate descriptive based on the table 6.

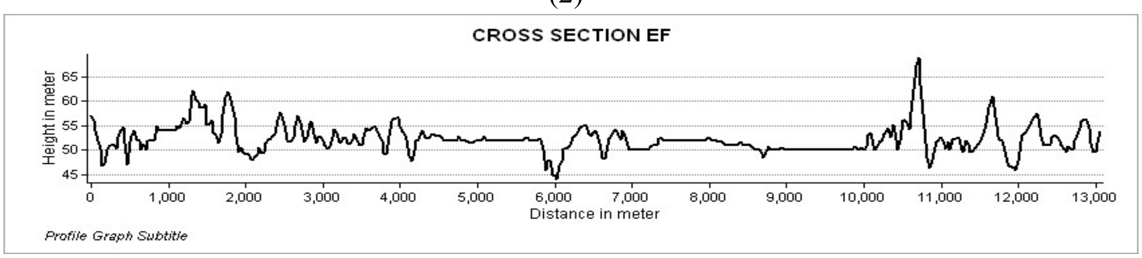
Remote sensing can provide ground information from local to global scales based on the reflected and emitted radiation from measured objectives (Read and Tarrado,2009). The cross-section measures by the use of vertical height bed to the river bank and horizontal distance of river width. The shallow river bed defines the more erosion-prone and depth river bed refers to the low intensity of erosion. In this context, the middle part of Brahmaputra River sediment transport capacity is low, as well as the collection of the sediment amount, is high. The cross-section A-B, C-D, and G-H observed the shallow river bed and the cross-section E-F, and I-J comparatively river bed is depth.



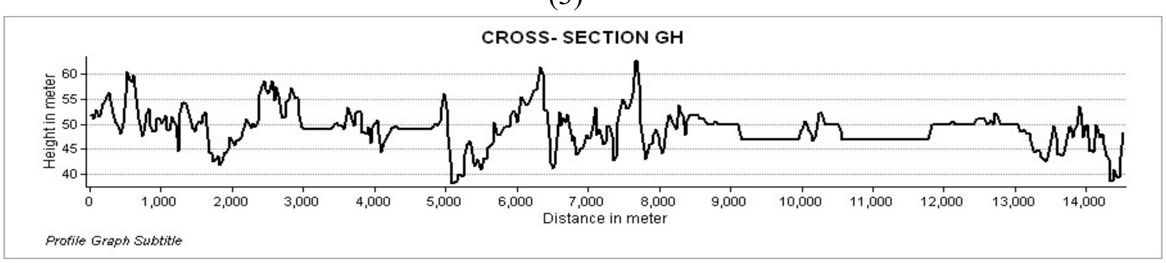
(1)



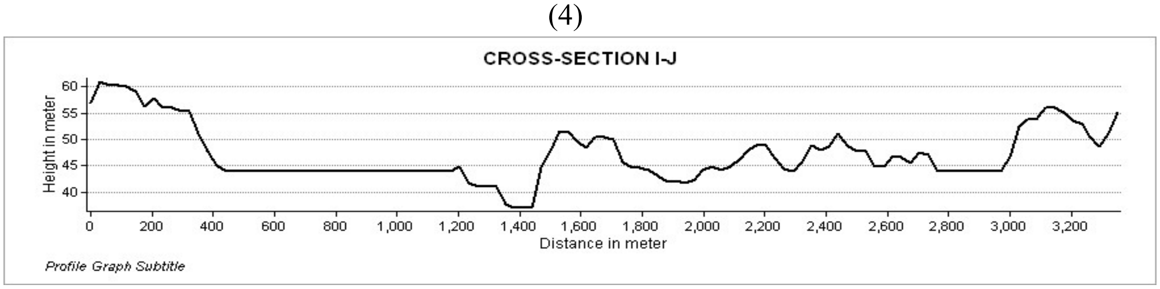
(2)



(3)



(4)



(5)

Fig 8. Cross- section show the river depth distribution at the river bed of middle Brahmaputra river AB- Bhoikhowa to Katiapara, CD- Siparia chapari to Baralimari no.1, EF-Nadipar to Batabori, GH- Mowamari to Garubandha, IJ- Dakhin kuruah to kharghuli.

Table 5. Details the Erosion Rate During the Period 1990-2020

	Erosion Rate in (km^2)									
	Cross-section A-B		Cross-section C-D		Cross-section E-F		Cross- Section G-H		Cross-Section I-J	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
1990-1995	0.38	0	0	0	0.19	0.66	0.19	0.54	0	0.23
1995-2000	0.78	0.63	1.36	0.06	0.17	0.25	0.66	2.73	0	0.36
2000-2005	0.21	1.01	0.46	0.08	0	0	0.15	0	0.04	0
2005-2010	0.80	0	0.51	0	0.41	0	0	1.02	0.04	0
2010-2015	0.42	0	0	0.07	0.08	0.63	0.06	0	0	0.01
2015-2020	0	0	0.03	0	2.17	0.42	0.21	0.31	0	0.04
1990-2020	1.57	0.39	0.58	0	0.42	4.18	0.31	3.46	0.04	0

Source: Result calculate using the satellite imagery Landsat-5, Landsat-7 and; and Landsat-8

Table 6. The Deposition rate of the Middle Brahmaputra River during the Period 1990-2020.

	The depositional rate in km^2									
	Cross-section A-B		Cross-section C-D		Cross -section E-F		Cross-section G-H		Cross-section I-J	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
1990-1995	0	1.73	0.05	3.15	0	0	0	0	0	0
1995-2000	0	0	0.06	0	0	0	0	0	0	0
2000-2005	0	0	0	0	1.07	0	0.56	0	0	0
2005-2010	0	0	0	0.09	0	0	0	0	0	0.08
2010-2015	0	0	0.63	0	0	0	0	0.13	0.11	0

2015-2020	0.04	0.08	0	3.74	0.07	0	0	0	0.15	0
1990-2020	0	0	0	3.75	0	0	0	0	0	0.19

Source: Result calculate using the satellite imagery Landsat-5, Landsat-7 and; and Landsat-8

Impact on Land and People

Erosion and deposition are the two major processes which are related to the changing geomorphological features of an area. The riverbank shifted towards the north and sometimes towards the south bank. The feature is most important for the river ecology. Sandbar plays a significant role in river like Brahmaputra diverted into many streams which often changed their shape, size, area, and location.

It is observed that during the high flood and bank erosion in the middle part of the Brahmaputra valley in their fluvio-geomorphologically significant points and places. Due to such a kind of regular bank erosion, the mostly flood generating rivers like, Subansiri, Gabharu, Kalong have shifted their bank and channel by about 500meters during the last 4 or 5 decades. Again, thus metamorphosis of rivers has been most conspicuous in the river morphology of the area. The main characteristics of the river Brahmaputra are the erratic behavior like channel shifting posing threat to human properties as well as public utilities and lines of communication. Due to channel shifting lots of agricultural fields, towns, and villages are affected at mostly the cross-section sites A, B, C, D and J. Villages like Bhoi khowa gaon, katiachapari, Siparia chapari, Baralimari No.1, and Kharghuli N.C are mostly affected due to bank erosion and channel shifting. Sedimentation on agricultural lands converted to the barren soils.

Impact on Environment

The southern slope of the Himalayas in Bhutan, Arunachal Pradesh and northern foothill zone of Assam receives high amount of rainfall (annually) ranging between 2500 mm and 5000 mm. This high rainfall coincides with the zone of entrance of the major northern tributaries to the plains of Assam. The tributaries have their short courses over the plains i.e., from the foot hills up to the Brahmaputra, which eventually give rise high floods waves and levels. These flood waves of characteristically high magnitude have devastating dimensions highly affecting the environment. In the study area, most of the wetlands, ponds and rivers as well as are now studded with siltation and sand deposits. The river carries huge amount of sediment and deposit the same in the low-lying areas. In summer the bed of the rivers is covered by vast sheet of rushing and foaming water, while in winter the beds have only trickle of water flowing with winding courses a amidst vast sand deposits. Although the accretion due to lateral erosion by rivers has its role on the modification of the floodplain, overbank flows also develop the topographic features such as levees, crevasse, splays and flood basin in the floodplain. Such features are specially found in the southern part of the study area.

Conclusion

Morphological characteristics of the Brahmaputra River play a very significant role in Assam, India. The analysis of all the aspects relating to the fluvial and morphological parameters indicates highly unstable nature of the river channel. The stream power index, topographic wetness index, and sediment transport index are related to the elevation of the area. The sediment deposition capacity, power of erosion capacity, and channel shifting rate are also reflects the typical characteristics of the river. The middle part of the Brahmaputra River is sinuous in shape and the cross-section also sustained the shallow and wide river bed. The cross-section I-J river bed is narrow and depth. For maintenance and proper planning, the middle part of Brahmaputra, a well-planned monitoring system is the best way. To reduce the hazard damage intensity and precaution for future threats, morphological and fluvial characteristics of the river analysis will be the most important and fruitful. Using remote sensing and GIS is very helpful to identify the vulnerable zone for the future plan of river basin like Brahmaputra.

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