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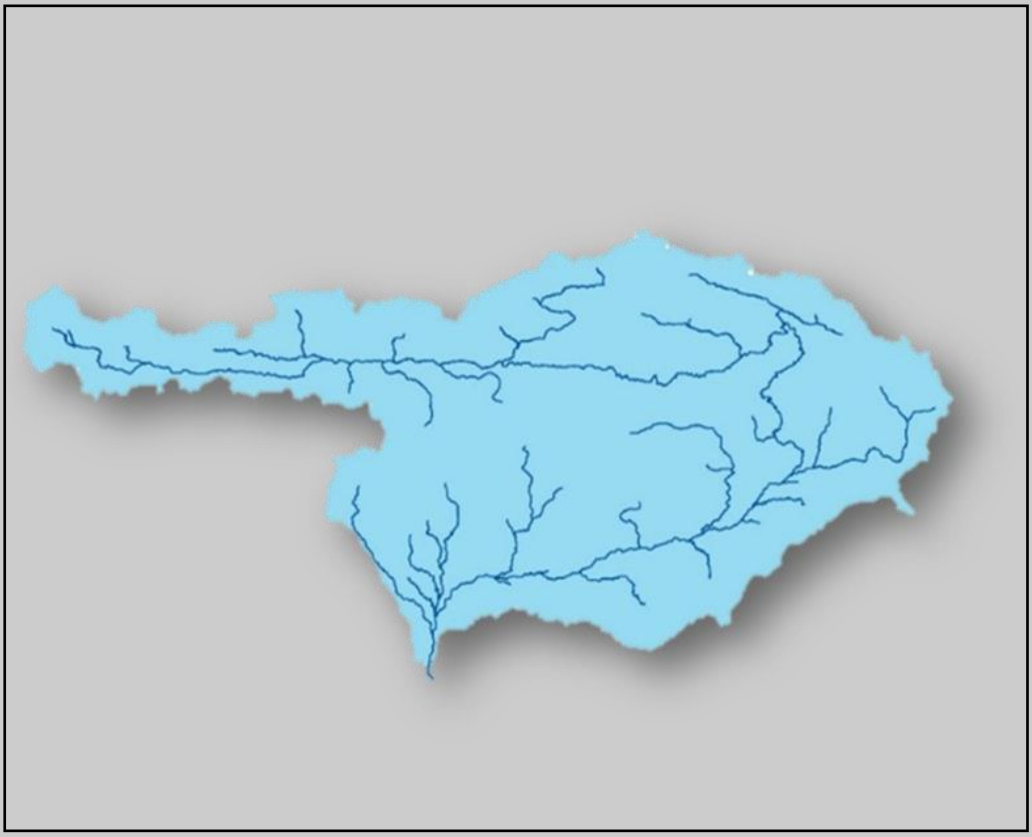
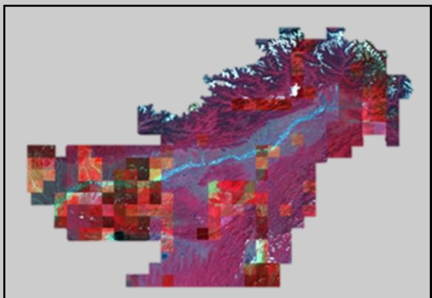
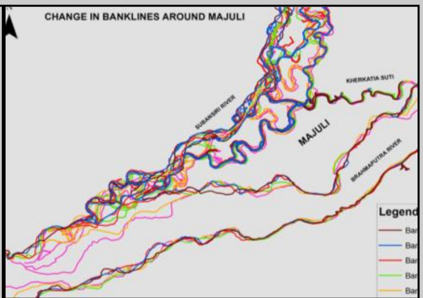
FINAL REPORT

MORPHOLOGICAL STUDY OF RIVER BRAHMAPUTRA USING REMOTE SENSING TECHNIQUE







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Final Report

on

Morphological Studies of River Brahmaputra using Remote Sensing Technique

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Executive Summary

1. Fluvial morphology is the broad area of hydraulic engineering which describes the temporal changes of the river in its planform. Rivers are the extreme dynamic medium of transportation and deposition of sediments which often carries a great problem to the hydraulic engineers during the planning and design of hydraulic structures. In the implementation of any structural and non-structural measures on a river, a knowledge of fluvial morphology is an indispensable part. Morphological changes of a river generally deal with the shifting of the banklines, aggradation and degradation, channel dimensions, cross-sectional changes, the formation of ox-bow lakes, cutoff, etc. A comprehensive study is thus essential to understand the river characteristics. With this motive CWC, New Delhi is interested to understand the morphological study of the major rivers in India. Thus, a project entitled “Morphological Studies of Rivers Brahmaputra, Subansiri and Pagladiya using Remote Sensing Techniques” was given to IIT Guwahati. This report contains **Morphological Study of River Brahmaputra using Remote Sensing Techniques.**

2. Broad objectives of the study can briefly be stated as:

    i. To prepare river drainage map showing major hydraulic structures in GIS.
    ii. To study course shifting and plan form change from 1973-2010 in 10-year interval.
    iii. To study Landuse/Land-cover to explore its impact on the river morphology.
    iv. To analyze channel evolution in upper and flood plain reaches.
    v. To estimate bank erosion/deposition w.r.t. base year at 50 km interval.
    vi. To identify critical reaches by confirming through ground reconnaissance.
    vii. To determine Impacts of major hydraulic structures on river morphology.
    viii. To evaluate braiding using Plan Form Index (PFI) and their classification.
    ix. To compile information on flood affected areas prepared by NRSC.
    x. To prepare probability curve to show flow rates for 1.5 and 2.0 years Return Period.

(May-October) contributes 82% of its mean annual flow at Pandu. On examination of the annual isohyetal map of this region prepared by India Meteorological Department (IMD, 1986) it can be seen that maximum rainfall (about 250–500 cm) occurs in the northwestern and southwestern parts of this basin with a minimum of about 150 cm in the southeastern side of the basin in the Lanka-Dimapur area.

4. The Brahmaputra basin extends between the geographical bounds of 26.03°N to 27.48°N latitude and 90.00°E to 95.00°E longitude. The reach of the Brahmaputra river falling under the Indian Territory has been considered for this study.

5. **Methodology in brief:** SOI Toposheets of 1973-74 and satellite data of different resolutions as per availability with decadal interval are collected covering the basin area within India. Efficiency and accuracy of different techniques for bank-line delineation were examined and the most suitable one is used for delineating the river bank line. Field visit has been made to all important locations for ground truthing. LULC maps were prepared/collected as per availability. Planform and topographic analyses have been carried out in GIS environment to determine Fluvio-morphological and geomorphological parameters of the river. Hydrological and cross sectional data have been collected from CWC and flood frequency and other statistical analysis are carried out. Impact of hydraulic structures on the morphological changes has been investigated and summarized. Vulnerable reaches have been identified based on the satellite data and locational importance. A vulnerability index has also been developed based on factors of vulnerability identified in this study. Due weightage to each of these factors were given by considering expert opinion of different stakeholders. A special chapter on morphological changes of Majuli island is included based on the request made during draft final report presentation. Combining all these information vulnerable locations needing immediate attention were identified and management strategies have been suggested. Need and scope of further study for better management of the river has also been highlighted.

6. In this study, 1 set of SOI toposheets of 1973-74 and 4 sets of satellite data for the period 1976-80, 1993-95, 2003-04 and 2008-11 at around 10 years interval were used. For vulnerable reach identification another set of Resourcesat-2 LISS 4 data of 2016-17 has

also been used in this study. Hydrological data viz. daily and 10 daily gauge, discharge, silt and x-section data were collected for different stations of river Brahmaputra from CWC Upper Brahmaputra Division, Middle Brahmaputra Division and Lower Brahmaputra Division. LULC data for the years 2005-06 and 2011-12 were collected from North Eastern Space Applications Centre (NESAC), DOS, Umiam, Meghalaya.

7. Following conclusions are drawn from this study:

   I. Between 1976-80 and 1993-95, a significant morphological change took place in the Lohit channel after its confluence with the Brahmaputra near Dibru-Saikhowa National Park. At this point, before 1993-95 the Lohit channel was used to meet the main Brahmaputra channel ahead of the Dibru-Saikhowa National Park flowing through the northern boundary of the Park. However, in the 1993-95 imagery, an avulsion was observed in the channel and the channel started flowing to the south of Dibru-Saikhowa and meeting the main Brahmaputra again near Rahmoria.

   II. Major planform changes were observed near Majuli, once the largest inhabited river island of the world, where the right bank of the river Brahmaputra was migrating northward owing to the continuous process of erosion over the years. The northward erosion is happening in different locations with different degrees of severity. Details of these are given in the chapter 14 on Majuli Island.

   III. The slope of the Brahmaputra River in Assam is relatively flatter. The river has a braided nature when it flows through the alluvium of Assam except at Pandu where the channel flows as a single channel of around 1.2 km.

   IV. From the erosion-deposition analysis it has been found that on the right bank, Barpeta district is more prone to erosion while on the left bank Morigaon district is more erosion prone. In 2016-17 the erosion area in Barpeta district is found to be around 1527.74 sq.km from the base year i.e. 1973-74 and the amount of erosion in Morigaon district is found to be 628.07 sq.km from the base year to 2016-17. The maximum length of erosion from the base year to the recent year has been observed in Dhemaji district.

V. It has also been observed that on the left bank, the decadal rate of erosion is increasing in most of the reaches causing severe erosion at present times whereas on the right bank except at reach no. 4 (Majuli area), in all other reaches the decadal rate of erosion is decreasing resulting in deposition in those reaches.

VI. From the Planform Index (PFI) analysis, it has been found in the extreme upstream and extreme downstream portion within India, the river is highly braided in nature while the middle portion of the river is moderately braided. However, from 2003-04 onwards braiding in the middle portion of the river has also increased.

VII. Morphometric parameter analysis indicates that the shape of the basin is elongated; although the delineated basin area of Brahmaputra appears to be more of circular in nature. It is because, there exists a ridge line separating the whole basin into the Tibetan part and the Indian part. Also, the bifurcation ratio for the highest order stream is the lowest due to larger no. of segments in the higher order (as several 1^{st} order tributaries join the main channel directly in the downstream) which results in flooding in the downstream area.

VIII. From the analysis of LULC change for the years 1973-74, 2005-06 and 2011-12, it has been observed that there is a conversion of landuse from Agriculture, Dense Forest, and Wetland/Marshy land to Built-up area, Open Forest and Sandbar/Dry riverbed. This reduction in the Wetland/Marshy land and increase in the Sandbar/Dry riverbed area might have contributed to the increase in both riverine and flash flood in the region.

IX. Flooding in the Brahmaputra basin occurs primarily due to breaching of the embankments at different locations. Therefore, an area not getting flooded in the flood inundation maps prepared by NRSC (based on observed inundation data) may also get affected by severe flood if embankment protecting that area suffers failure. Similarly, an area experiencing flood may not experience it with the same intensity if relevant embankment is repaired or reconstructed to protect that area.

These facts need to be considered while preparing policies for flood relief, insurance, etc.

X. From the cross-section analysis of Brahmaputra it has been found that there exists a cycle of 7-10 years after which the river undergoing changes reaches the same form at a particular section. A detail study in this direction will be helpful for deciding river management strategy.

XI. It has been found that the average width of the river Brahmaputra is increasing over the time while the average hydraulic depth of the river is found to be varying in different years. In the year 1973-74 the average width of the river is estimated to be 8.04 km. while in 2008-11 the average width is found to be 9.97 km.

XII. From the morphological analysis of Majuli, it has been observed that there is a northward shift in the Brahmaputra right bank towards Tekeliphuta embankment. It is also evident that presently, the Kherkatia Suti i.e. the channel flowing on the northern boundary of the Majuli island, is not as active as it was before 1960s. This is because of construction of the closing dyke i.e. the Tekeliphuta embankment on the channel to mitigate the flood hazard in the northern part of Majuli.

XIII. Also, an enormous shift (around 15 km) has been observed at the Brahmaputra-Subansiri confluence point. These shifting in the river banklines over time has resulted in massive erosion in the western and eastern boundary of Majuli island. Also, in the southern part of Majuli, continuous process of erosion has been observed near Sumoimari village. However, some amount of deposition has also been observed at upstream of Salmara, i.e., near Sukan Suti Miri village.

XIV. From the decadal analysis of change in total area of Majuli, it is found that although there is a decrease in the total area of Majuli from the base year i.e. 1973-74 to 2016-17 while in the recent decades the total area almost remains same. However, this does not indicate that no erosion has occurred in the recent times rather this might be owed to the fact that there exists a continuous process of erosion-deposition around the landmass.

XV. In this study six critical/vulnerable reaches were identified based on the shift in river course/bankline and its proximity to flood/erosion protection structures as envisaged from the satellite imageries. These reaches include confluence of the

Simen river with Brahmaputra in Dhemaji, Tekeliphuta embankment in Majuli, reach near Na-bazar, Biswanath, reach near Niz Rangamati, Darrang and Lahorighat, Morigaon, reach near Balidhari (right bank) and Kadulimari (left bank) in Barpeta and possible avulsion of Manas river at the border of the Barpeta and Bongaigaon districts

XVI. From the Vulnerability Index calculation, it has been observed that except for reach no. 4, 7, 11 and 13 in all other reaches of Brahmaputra, the vulnerability to erosion in the Left Bank is more than the right bank at the present stage. The highest vulnerability in the left bank is found to be in Reach 9 where the city of Guwahati and LGBI Airport exist. The highest vulnerability for the right bank is found to be in Reach 4 where the Majuli island resides.

XVII. It has also been observed that at many locations of the river protective structures were constructed which have reduced the problem of erosion locally; however, these structures have also contributed to the alterations in the channel's natural morphology.

XVIII. The potential water resource of Brahmaputra basin is enormous but the basin is devoid of major hydraulic structures for harnessing water resources. The bridges, embankment, spurs etc. are the major hydraulic structure that exist on this river. Existing bridges has affected the river morphology to some extent. It has been observed from the delineated river banklines that at the immediate downstream of Saraighat and Pancharatna bridges, there is widening of the river Brahmaputra, which might be caused by the construction of the bridges on the river.

XIX. From this study it can be ascertained that the construction of the closing dyke on Kherkatia Suti has forced the river to move towards southern part causing severe erosion in Nematighat and at the southern bank of Majuli.

8. Following are the recommendations for future study:

   I. From this study and the responses of the various stakeholders during the Dissemination Workshop, it is clear that morphological studies of rivers are important for flood management, navigation development and selecting sites for river training works. Therefore, further studies can be made by incorporating tectonic studies, using higher resolution satellite data and latest technology like drones, etc. and the data should be made available in public domain so that it can be used by researchers.

II. To have more clarity on flood risk, inundation map can be prepared by running a hydrodynamic model in the river without considering the existence of embankments. Areas coming under flood in such simulations may be designated as Potential Flood Prone Area (PFPA) and policy decision may be taken for relief, insurance, etc. by considering if the areas fall under PFPA.

III. As river cross-sections influence the flow of the river and its hydrodynamics significantly, therefore a more reliable statistical model, if can be developed, to derive river cross section in future time will be quite helpful in river management. Therefore, a project in this direction can be taken up for all available cross sections of Brahmaputra River.

IV. Management of the catchment through Ecological Management Practices (EMP) including afforestation, small cascade reservoir etc. can be taken up with detail study. Visible impact of such approach of course may take some time. Such EMP project will also yield revenue to pay back the invested amount though 5 to 10 years may be necessary to reach the breakeven point.

V. Removal of bed sediments through dredging may be applied to divert the main flow from hitting the river bank at few locations. A model study carried out at Department of Civil Engineering, IIT Guwahati in 2011, indicated that the dredging of a sand bar in Morigaon reach along with construction of spurs to push the river away from the bank could mitigate the severe erosion problem of Morigaon as per simulation result. Such projects can be taken out to identify strategic solution for the vulnerable reaches.

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Chapter 1
INTRODUCTION

1.1 Background

A river is an integrated system of water and carried along sediments. Any alterations in the atmospheric and terrestrial systems of a watershed are integrated and manifested in the river system. As the river flows, the dynamics of the exchange between its water and sediment load along with the geology and the hydrology of the landscape creates a complex network of processes, resulting in a given physical form of the river system. River morphology and its synonym fluvial geomorphology are basically the changes in shape, direction, orientation over the time. The morphology of a river channel is a function of a number of processes and environmental conditions. The composition and erodibility of bed and banks due to river current are some important parameters for the study and analysis of fluvial geomorphology. Sedimentation is another such process that impinges the fluvial system. Availability of the sediment, size and composition of the sediment materials are some important ingredients that require attention for the analysis. Due to changes in the surface profile a river is found to migrate from its original course. There are various hydrodynamic and geological inferences for such changes. Human interventions can also alter the morphology of river which can impinge the entire basin. Erosion predominates in the upper reach area of a drainage basin. The materials brought to the lower reaches in a channel are sediment load. Weathering of the rocks composing slopes is the main cause of production of sediment load. Sediment load is deposited to form an alluvial plain. Three basic channel patterns are detected in alluvial plains. They are braided, meandering and straight. River morphology is explained by channel patterns and channel forms and is decided by such factors as discharge, water surface slope, water velocity, depth and width of the channel, and river bed materials, etc. Morphometric analysis of a river basin provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins.

1.2 Importance of river morphology

River morphodynamics is a consequence of channel dimensions, gradient, channel adjusted by erosion deposition process (Church and Ferguson, 2015). The alluvial rivers are characterized by the sediment transported from its bed and bank. Most of the alluvial rivers in India like Ganga and Brahmaputra show erratic behavior both during the lean period and flow period. The planform of these alluvial rivers are constantly changing and are extremely dynamic in nature. Equilibrium can be at best a statistical phenomenon since there must be local erosion and deposition as flow changes (Leopold and Maddock, 1953). River channel behavior often needs to be studied for its natural state and responses to human activities (Chang, 2008). The humanitarian activities which include the artificial alignment, construction of dams, urban effects, industrialization, etc. are some of the factors that can be attributed to the change of river morphology to a great extent. To understand the river morphology and its characteristics a sustainable approach towards proper planning and management is prerequisite.

Recent advancement in space science made possible the improvements in remote sensing and GIS technology which is currently in vogue as an efficient application in water resources. Aerial photographs and satellite imageries are powerful means that can detect the large planform change of a river. Remote Sensing and GIS technology also helped to extract information from such remote areas where field survey is inaccessible. The remote sensing and the field survey data are may be useful in calibration and validation with numerical models. Thus, remote sensing based study is fundamental in morphological studies of the rivers.

1.3 Objectives

The specific objectives of works are:

1. To compile and complete the river drainage map in GIS by integrating available Secondary maps in WRIS of CWC. Also, to collect additional required information on major flood protection structures, existing water resources projects, important. Cities/towns, CWC H.O sites, airport, island etc., and to integrate them with the final river Drainage maps.
2. To study the shifting of the river course and also assess the changes in its plan form from the base year (1973) till 2010, by collecting 4 sets of satellite imageries at around 10 years interval in addition to one set of Survey of India toposheets for the base year on a scale of 1:50,000.
3. To compile changes in the Land use/Land cover over the years, and study its impact of the river morphology.
4. To analyze the channel evolution in order to describe the status of the river channel. The analysis of the channel dimension, pattern and the longitudinal profile identifying distinct river reaches i.e. the channel in the upper reaches, channel in flood plain with bank erosion etc. This segregation of the reaches is to be determined by using channel evolution analysis.
5. To estimate the rate of bank erosion/deposition in term of erosion length and erosion are w.r.t. base year at 50 km interval.
6. To assess the present condition of the critical reaches of the main channel of river by conducting ground reconnaissance. Field recon trips may be taken, if required.
7. To evaluate the impacts of the major hydraulic structures on morphological behavior of the river course and its impacts on the river morphology.
8. To evaluate the braiding pattern of the river by using Plan Form Index (PFI) criteria along with its threshold classifications.
9. To compile information (if any) on flood affected areas in the vicinity of the river course prepared by NRSC using multi-temporal satellite data of IRS WiFS (188 m)

10. To plot probability curve (Exceedance Probability Vs Flow rate) so as to show the flow rates corresponding to the return period of 1.5 year and 2 years for different CWC H.O. locations.
11. To relate the morphological changes in the river on the basis of available peak discharges of different years in the time domain considered in the study. Also to study the impact of changes in annual rainfall in the basin on river morphology.
12. To identify crucial and other vulnerable reaches, locations. Also to analyze the respective rate of river course shifting and based on it, future prediction of river course behaviors.
13. To suggest suitable river training works for restoration of critical reaches depending on site conditions.

1.4 Detailed Scope

I. The required inventory of one set of Survey of India (SOI) toposheets in respect of reference time datum on a scale of 1:50,000 is to be procured from SOI by the consultant. The inventory of satellite imageries having spatial resolution of 23.5 m, IRS LISS-I, LISS-II, LISS –III, may be worked out covering the area and to be procured from NRSC.

II. One set of SOI toposheet (say year 1970) and digital satellite imageries of IRS LISS-I, LISS-II, LISS-III sensors, comprising scenes for the year 1980, 1990, 2000, 2010 are to be used for present study. In case of non-availability of above data, the foreign satellite data of similar resolution may be used. The maps and imageries are registered and geo-referenced with respect to Survey of India (1:50,000 scale) toposheet w.r.t. base year by using standard technique & GIS tools.

III. Delineation of river bank line, river center line, along with generation of important GIS layer of river banks, major hydraulic structure, embankment/levees, railway bridge line, islands, airport, cities/towns/villages, and important monuments etc. located in the vicinity of the river bank for selected year of studies are to be part of studies.

IV. Estimations of left and right bank shifting amount(s) w.r.t. base year & appropriate graphical plotting of these shifting.

V. Evaluation of braiding of different river course reaches by using Plan Form Index (PFI) criteria along with its threshold classification wherever required.

VI. Estimation and comparison of each bank erosion for different reaches in terms of erosion length and erosion area of river w.r.t. base year by using appropriate GIS tool, accordingly vulnerability index for different reaches may be evolved & prioritized along with causative factor details for the erosion may be worked out.

VII. Comparison of delineated different river course on the same graphical plot on A0 size, and all plots may be arranged in separate volume.

VIII. The most critical reaches may be shown separately with appropriated suitable stream reach(s) restoration with a recommendation of suitable bank stabilization technique(s) depending upon the channel planform and condition.

IX. The cross-section data available may be used for identifying riffle locations and measures topography changes. The cross-sectional data provided may be used to extract necessary information to analyze the channel, which ultimately led to identifying channel stage or conditions.

X. The plan view of various stream may be used to define the geometric relationship that may quantitatively define through measurement of meander wavelength, radius of curvature, amplitude and belt width. It may be done by separation river reaches based on change in valley slope into different RDs, estimation of sinuosity, number of bends for different RDs, average radius of curvature for each segment of river defined. Based on this channel pattern analysis, proper interpretation may be given.

XI. River channel dimensions; river channel width and the representative cross section are a function of the channel hydrograph, suspended sediments, bed load, and bank materials, etc. The future river channel dimensions may be evaluated based on the available cross section details for vulnerable/critical reaches of rivers.

XII. Maximum Flow Probability curve at CWC H.O. sites located on concern river, may be developed to predict the channel discharge corresponding to 1.5 years and 2 years Return Interval (RI). These values i.e. 2 years RI is widely accepted as “Channel forming Discharge” or “Bankfull”. These are the flows that contribute most to the channel dimensions. These parameters may be used to determine the Channel Evolution Stage based on the Channel Evolution Analysis. Comparison of channel forming discharge and maximum channel capacity may be done, accordingly interpretation about the channel carrying capacity is to be presented.

XIII. Channel profile: Channel profile is commonly referred to channel slope or gradient. The channel profile may be developed for river reach under consideration. The proper interpretation w.r.t. bed formations, aggradation, degradation etc. may be part of studies.

XIV. Impaired steam analysis; as a part of the scope of work, part of impaired stream to be identified along with the cause and source of consultant. Based on the cause of stream impairment, stream restoration mechanism/method to be recommended. While stream restoration and bank improvement techniques do improve water quality, land use practices may also be discussed, which is typically the main culprit of chemical pollution.

XV. Results & Recommendations is to be separate chapter. A proper discussion about results in respect of different reaches i.e. upper reach, middle reach and lower reach of river along with appropriate suggestion to be given.

XVI. Collection of additional information like Topography, Climate, Soil, Geology and Hydrology etc. required to be incorporated in the Morphological report.

XVII. Analysis of shifting of left and right banks at about 50 km interval as well as covering critical reaches of river irrespective of river RDs interval.

XVIII. Identification of flood affected area in the vicinity of river course which have experienced frequent flooding in the past and suggesting suitable remedial measures for flood proofing for river reaches. It was informed by NRSE representative that NRSC derived inundation from 10 years of multi-temporal satellite data (1998-2007). Based on frequency and extent of inundation, the flood hazard is categorized into 5 classes- very high, high, moderate, low, and very low. This helps the concerned authorities in planning developmental works in these areas. NRSE multi-temporal satellite data of IRS-WiFS (188) & Radarsat Scan SAR Wide & Narrow (100m & 50m) for flood images. The flood hazard along with flood annual layer mapping has been done for Assam and Bihar. It include complete flood hazard statistics district wise. This published information can be utilized by IIT Guwahati to cover flood affected aspects in the study.

XIX. The entire satellite data used in the study by IIT Guwahati, all analysis, result maps, charts etc. and the subsequent reports prepared shall be the exclusive property of CWC and IIT Guwahati has no right what so ever to divulge the information/data to others without specific written permission of CWC.

XX. In order to ensure the desired quality of the generated outputs as well as to ensure that the GIS layers are hydrologically, hydraulically and scientifically reasonable approximation. It was decided that the standard used for WRIS, as well as "Standards for Geomorphological Mapping Project" and "Standard for Land Degradation Mapping Project" given in manuals of NRSC may be referred.

XXI. The compilation of challenges in Land use/ Land cover, and study of its impact on river Morphology is to be incorporated in the study report. The NRSC's published information about land use and land cover maps under NRSC Bhuvan thematic service on a scale of 1:50,000 as well as 1:2,50,000 for all states can be used for this purpose.

2.2 Morphological studies on Brahmaputra River

Coleman, J. M. (1969) did some pioneering work on the channel processes and sedimentation in Brahmaputra River and identified the high discharge and heavy sediment load as the main factors for extreme instability of the river. According to Coleman, the Brahmaputra shifted its route 60 miles to the west only in 200 years. He also remarked that the preferred migration of the Brahmaputra River is westward and these movements are controlled by the major faults or fractures in the Earth's crust. In plan view, Brahmaputra forms a braiding pattern and short-term channel migration is very common in this river. The rate of rise and fall of the river, the number and position of major channels active during flood, the formation and movement of large bedforms, cohesion and variability in composition of bank material and intensity of bank slumping are some of the factors responsible for controlling the bankline configuration and movement. During the falling stage of the river, modification in the bankline is most significant due to deposition of excess sediments as bars within the channel which results in changes in the local flow direction and migration of the thalweg. He also studied the bedform patterns and migration and found that during a single flood cycle the bed configuration undergoes a definite sequence of changes. As mentioned by Coleman, the maximum discharge recorded for Brahmaputra was 2,519,000 cusecs in 1958, whereas the lowest flow measured was 116,000 cusecs in 1960. From the discharge hydrograph, the author marked two or three major flood peaks: the first peak, if present, occurs during mid-June and is characterized by an extremely rapid increase in discharge. After this rapid initial rise the river level generally falls slightly, and then in the latter part of July or the first part of August, the major flood peak occurs. This flood period generally last for nearly a month, and then the river again drops slightly. During the first part of September, a third flood peak occurs. In the latter part of September or first of October, the river stage begins to subside. The water-level hydrographs too illustrate these rapid rise and fall of water levels associated with the flood stage. The river Brahmaputra, even in its lower flow (900,000 cusecs) carries over 1,640,000 tons of suspended material a day. According to the author, this heavy silt load might be the result of seismic disturbances in the lower Himalayas and Assam Hills in 1950, which partially clogged the Brahmaputra and undoubtedly subjected the hill regions to increased runoff and erosion.

Goswami, D. C. (1985), studied the physiography, basin denudation and channel aggradation processes of Brahmaputra river. In his study, he found that the river Brahmaputra experienced a secular period of aggradation from 1971 to 1979. Based on the suspended load budget, he mentioned an overall aggradation of 16 cm for the 607 km Assam reach of the Brahmaputra between Ranaghat and Jogighopa during the period 1971 -79, with about 70% of the suspended sediment inflow into the reach being retained in the channel. The author used another alternative method of evaluating aggradation based on measurement of cross sections for a 145 km reach of the Brahmaputra between Kobo and Bessamora and found a degradation of about 21 cm during 1971-1977. From the study, it was found that there were phases of rapid aggradation in the river followed by periods of slower degradation. The author also estimated the rate of denudation for the eastern Himalayas and found as 73-157 cm/1000 years. He remarked that the high rate of denudation of the Himalayas may be due to the rapid uplift of the mountain system, earthquake activities of 1950 and high susceptibility of geologic formations to erosion by running water coupled with effectiveness of the monsoonal rainfall regime.

Kotoky et. al. (2003) studied the nature of bank erosion processes in a part of the river Brahmaputra covering two important sites viz. Majuli, world’s largest inhabited river island, and the the Kaziranga National Park. Their study revealed that the mechanisms involved and responsible for riverbank erosion in that stretch were basically related to liquefaction of the bank materials worsened by their inhomogeneity, over-steepening and associated sub-aerial processes of weathering and weakening in relation to soil moisture content. The study also observed that the extent of erosion and deposition is not same for the period 1914–75 and 1975–98. The authors considered different scale and nature of shear failure as the main factors responsible for bank erosion processes.

Sarkar et. al (2012) carried out a RS-GIS based assessment of the river dynamics of the Brahmaputra river for the period 1990-2008. They used two sets of optical satellite imageries for the the years 1990 and 2008 respectively. In the study, the authors marked sharp changes in the fluvial landform that lead to considerable loss in inhabited land. The authors also observed that the river has eroded both the banks throughout its course except at few constriction points where the banks are well defined due to presence of rocks. The study found the utility and application

13 of satellite remote sensing to be very effective in detailed spatio-temporal assessment of river channel changes and associated erosion/deposition processes.

Gogoi et. al. (2012) did a GIS based study on fluvio-morphology of the river Brahmaputra in Upper Assam. The study was carried out using satellite imageries for the year 1986 and 2011.Their study elucidates that within that period the main stream of Lohit was diverted along Dangori River and presently flowing along the south of Dibru-saikhowa. As a result of this, the confluence point is shifted towards southwestern side of Dibru-saikhowa about 59.76 km. They further added that the confluence between Dibang and Dihang shifted westward about 8.84 km from the Kobo Chapori. The total loss was estimated as 846 km2 area due to migration of river banklines. Their study revealed that the average rate of bank line migration was about 115 m/yr.

2.3 Meandering Parameters

A meander, in general, is a bend in a sinuous watercourse or river. A meander is formed when the moving water in a stream erodes the outer banks and widens its valley and the inner part of the river has less energy and deposits what it is carrying. A stream of any volume may assume a meandering course, alternately eroding sediments from the outside of a bend and depositing them on the inside. The presence of meanders allows the stream to adjust the length to equilibrium energy per unit length in which the stream carries away all the sediment that it produces (Punmia, 2009). The meandering parameters are described below:-

- Meander Length (ML): It is the air distance along the river between tangent point of one curve and tangent point of other curve of same order.
- Meander Belt Width (Mb): It is the transverse distance between the apex point of one curve and apex point on reverse curve.
- Bank full Width (W): It is the width where the maximum change in slope of the channel cross sections occurs or where the first significant break in slope occurs.

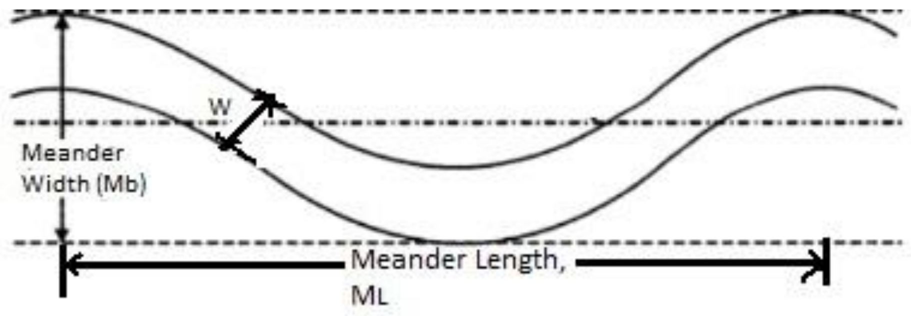

Figure 1: Meandering of a river

2.3.1 Meander Width Ratio

Meander width ratio depends on the lateral confinement of a stream as well as the width of the channel. Mathematically it is defined as:

$$\text{Meander Width Ratio (MWR)} = \frac{\text{Meander belt width (Mb)}}{\text{Bankfull width (W)}}$$

The value of MWR ranges from 1 to 20 signifying straight course of a channel as 1 and values above 10 representing a meandering course.

2.3.2 Sinuosity Index

Sinuosity index is a means of quantifying how much a river or stream meanders (how much its course deviates from the shortest possible path). Sinuosity indices explain the hydrological and topological characteristics of drainage basin. It is usually calculated as the length of the stream divided by the length of the valley. A perfectly straight river would have a meander ratio of 1 (it would be the same length as its valley), while the higher this ratio is above 1, the more the river meanders. Sinuosity Index categories alluvial river patterns as:

1. Straight rivers: Sinuosity index <1.1
2. Sinuous rivers: Sinuosity index between 1.1 - 1.5
3. Meandering rivers: Sinuosity index > 1.5

Different researchers have defined sinuosity index in different but almost similar ways.

According to P.F. Friend and R. Sinha (1993), the sinuosity parameter P is defined as,

$$P = L_{cmax} / L_r$$

Where, L_r = overall length of the channel belt and L_{cmax} = mid-channel length for same reach or mid-channel length of widest channel. Channel length has been measured along a line that runs mid-way between channel banks. This allows measurement readily from aerial photographs and satellite images. Also, channel length is unlikely to change in a major way with changes of river water level.

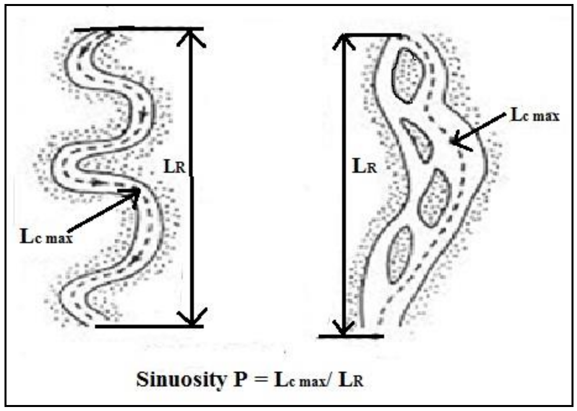

Figure 2: Sinuosity Index in a channel by P.F. Friend and R.Sinha (1993)

2.3.2.1 Mueller's Sinuosity Index (1968)

The major attractiveness of Mueller's component of sinuosity index is that it accounts for what percentage of a stream channel's departure from a straight line course is due to either hydraulic factor within the valley or topographic interference (Ezizshi, 1999). Mueller (1968) has redefined the index to incorporate hydraulic sinuosity (i.e. that freely developed by the channel uninfluenced by valley-wall alignment) and topographic sinuosity (i.e. imparted by the geometry of the channel).

Parameters taken for Mueller's Sinuosity Index:

CL= the length of the channel (thalweg) in the stream under study

VL= the valley length along a stream, the length of a line which is everywhere midway between the base of the valley walls.

Air= the shortest air distance between the source and mouth of the stream.

CI (Channel Index) = CL / Air

VI (Valley Index) = VL / Air

HSI (Hydraulic Sinuosity Index) = % equivalent of (CI – VI) / (CI – 1)

TSI (Topographic Sinuosity Index) = % equivalent of (VI – 1) / (CI – 1)

SSI (Standard Sinuosity Index) = CI / VI

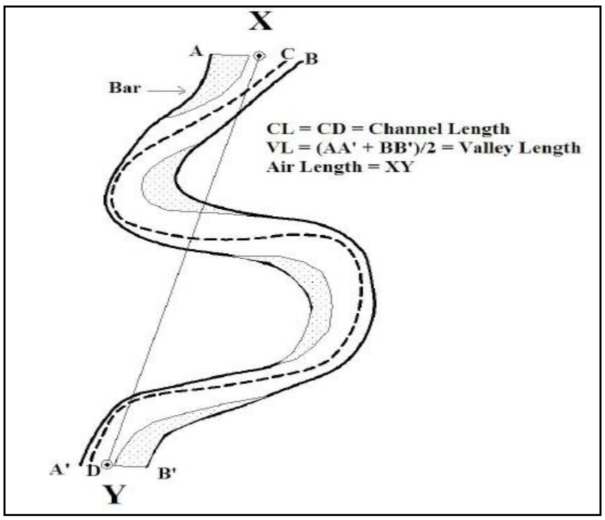

Figure 3: Sinuosity index given by Mueller (1968)

2.4 Braiding Parameters

2.4.1 Braiding index

Braiding is strongly influenced by high availability of bed load sediment relative to suspended load sediment. Slope and discharge determine on their own whether a river is braided or meandering.

Brice (1964), used a Braiding index (BI), defined as follows:

$$B.I. = 2 (\sum L_i)/ L_r$$

Where, $\sum Li$ = length of all islands/bars in a reach

L_r = length of reach measured midway b/w banks of channel belt.

Brice rationalized this definition as a measure of the total amount of bank length, where most islands or bars have a significantly greater length than width so that the total bank length is approximated by doubling the island or bar length.

Rust (1978), measured the braiding parameter as:

$$Bp = \sum L_b / L_m$$

Where, $\sum L_b$ = sum in the reach of the braid lengths between channel thalweg divergences and confluence.

L_m = mean of meander wavelengths in a reach of channel belt.

Rust was concerned about the variations of apparent island length that might be caused by fluctuations of water levels. He proposed that channel talwegs be used to define a "braid length" from upstream divergence to downstream convergence.

According to P.F. Friend and R. Sinha, braiding parameter,

$$B = L_{ctot} / L_{cmax}$$

Where, L_{ctot} = sum of mid channel lengths of all the segments of primary channel in a reach.

L_{cmax} = mid-channel length of the widest channel through the reach.

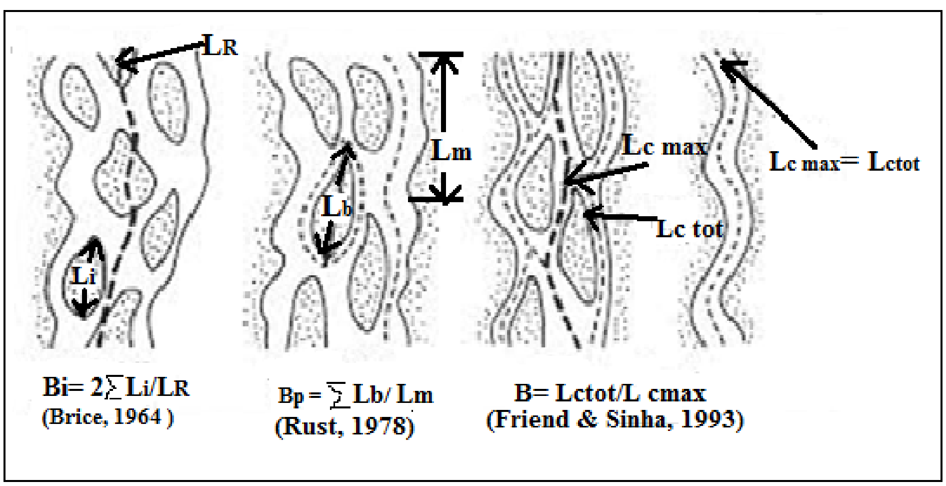

Figure 4: Diagram representing the calculation of the braiding indices of Brice (1964), Rust (1978), Friend and Sinha (1993)

2.4.2 Plan Form Index

Sharma (1995) developed Plan Form Index (PFI) for identifying the degree of braiding of highly braided river. PFI reflects the fluvial landform disposition with respect to a given water level and its lower value is indicative of higher degree of braiding.

$$\text{Plan Form Index} = \frac{T \times 100}{B \times N}$$

where, T = flow top width; B= overall width of the channel ; N = number of braided channels.

For providing a broad range of classification of the braiding phenomenon, the following threshold values for PFI are proposed by Sharma (2004).

Highly Braided: PFI < 4
Moderately Braided: 19 > PFI > 4
Low Braided: PFI > 19

2.5 Bifurcation Ratio

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in the next higher order (Schumn, 1956).

$$R_b = \frac{N_\mu}{N_{\mu+1}}$$

Where, R_b= Bifurcation ratio, N_μ= Number of streams of a given order, $N_{\mu+1}$ = Number of streams of the next higher order.

If the bifurcation ratio of a river network is low, there is a higher chance of flooding. The bifurcation ratio can also show which parts of a drainage basin is more likely to flood, comparatively, by looking at the separate ratios.

2.5.1 Drainage Density

It is the measure of the length of stream channel per unit area of drainage basin. Mathematically it is expressed as: Drainage density = stream length / basin area.

If $\sum L_u$ be the total channel segment lengths cumulated for all orders, A be the basin area projected to the horizontal, then drainage density is

$$D_d = \frac{\sum L_u}{A} \text{ (km/sq km).}$$

It is a measure of the texture of the network, and indicates the balance between the erosive power of overland flow and the resistance of surface soils and rocks.

2.5.2 Stream frequency

If $\sum N_u$ be the number of stream segments of all orders then stream frequency is,

$$F_s = \sum N_u / A \text{ (km}^{-2}\text{) where A is the area of the basin}$$

2.5.3 Basin shape factor (L_1)

Basin shape factor is given by

$$L_1 = (LL_{ca})^{0.3}$$

Where L is the length of watershed in miles, L_{ca} is the distance measured along the main channel from basin outlet to the point on the main channel opposite to the centre of area.

Shape factor is the best descriptor of peak discharge. It is negatively correlated with peak discharge.

2.5.4 Form Factor (F_f)

Form factor was given by Horton (1932)

$$F_f = A / L_b^2$$

Where A is the basin area in km and L_b is the length in km.

Form factor was introduced by Horton which shows the shape of a basin. There is a low form factor in a basin that indicates less intense rainfall simultaneously over its entire area than an area of equal size with large form factor.

2.5.5 Drainage factor (D_f)

$$D_f = F_s/D_d^2$$

Where Fs is the stream frequency, D_d is the drainage density

2.5.9 Circulatory Ratio (R_c)

It was given by Miller (1953),

$$R_c = 12.57 * (A/P^2)$$

Where *P* and *A* are the perimeter and area of watershed respectively

It is concerned mainly with the length and frequency of streams, geological structures, land use land cover, climate relief and shape of the basin.

2.5.10 Elongation Ratio (R_e)

It was given by Schumm (1956) as,

$$R_e = \frac{2}{L_m\sqrt{\frac{A}{\pi}}}$$

Where L_m is the maximum basin length parallel to principal drainage.

It indicates the shape of basin deviating from a circle. It is an index to mark the shape of drainage basin.

Chapter 3
STUDY AREA

3.1 Study area

The Brahmaputra basin extends between the geographical bounds of 26.03°N to 27.48°N latitude and 90.00°E to 95.00°E longitude. It is bounded on the north by the Himalayas, on the east by the Patkai range of hills running along the Assam-Burma border, on the south by the Assam range of hills and on the west by the Himalayas and the ridge separating it from Ganga sub-basin. With an average width of 8 km, the river Brahmaputra flows through the seismically unstable valley in Assam and occupies about one-tenth of the valley. In India, it passes through a length of 278 km in the state of Arunachal Pradesh and 720 km in Assam (Akhtar et al., 2011). In terms of discharge, Brahmaputra ranks fifth in the world and monsoonal rain (May-October) contributes 82% of its mean annual flow at Pandu (Goswami, 1985). On examination of the annual isohyetal map of this region prepared by India Meteorological Department (IMD, 1986) it can be seen that maximum rainfall (about 250–500 cm) occurs in the northwestern and southwestern parts of this basin with a minimum of about 150 cm in the southeastern side of the basin in the Lanka-Dimapur area Due to such large extent and complex geo-tectonic setting, the river Brahmaputra is associated with the problems of erosion-deposition of sediments, rapid bed aggradations, drainage congestions and flooding (Sarkar et al., 2012). Alluvial rivers are mostly associated with flood, erosion along with sedimentation. Brahmaputra River is no more exception in these problems. Every year flood and erosion problem is a major cause of concern in Assam, Arunachal Pradesh and other states of North East India. Thousands of hectares of agricultural land of Brahmaputra basin has been facing the problem of erosion at an alarming rate annually.

2.1.1 Climate

The Brahmaputra basin experience an atypical climate with temperature and rainfall variation. The climate of Brahmaputra basin is humid and high rainfall. It is mainly influenced by both south-west monsoon from the Bay of Bengal and the surrounding hills of Assam Himalayas, lower Himalayas and the Assam plateau. The basin is characterized by fairly good amount of rainfall during five months from May to September. The pre-monsoon i.e from March –May, the weather is characterized by gradual rise in the temperature. The rainfall varies from 20% -30% of the total precipitation. The post-monsoon season (September-November) is characterized by fair weather with fall in temperature and rainfall. The monsoon season from June-August is characterized by cloudy weather, high humidity. The rainfall ranges from 60% -70% of the total annual rainfall. The eastern region is characterized with mean annual rainfall of 2,452 mm followed by the western and middle region with mean annual rainfall of 1,982 and 1,527 mm respectively [Bhattacharyya and Sidhu,1984]. The average minimum temperature of the Brahmaputra valley is about 10^0C in December/January and a maximum of about 35^0C in July/August The mean annual temperature of eastern, western and middle regions are 23.5^0C, 24.5^0C and 24^0C respectively [Talukdar et.al ,2004]

2.1.2 Geology

The Brahmaputra Basin lies in one of the most seismically active regions of the world. Rao(1975) emphasized a scientific and rational study of the basin which includes geological base, tectonic events, geomorphology, sedimentation ,geophysics, geomorphology. In the high plateau of Tibet Brahmaputra known as Tsangpo drains turbidites and ophiolites mostly.This region mostly comprised of evaporate deposits and saline lakes[Pascoe, 1963; Hu et al., 1982; Pande et al., 1994]. The region where Tsangpo river makes a U turn is known as The Eastern Syntaxis [Singh,2007]. Quartzites, phyllites and marbles are some of the major constituents of this region.The two tributaries Lohit and Dibang flow through Mishmi hills. The lithology of which includes calc-alkaline diorite-tonalite-granodiorite complexes and tholeiitic metavolcanic rocks of island-arc affinity (Kumar, 1997).The principal rocks in the Meghalayan Plateau are granite and gneisses. Conglomerate beds are mostly found at the foot of hills. The Brahmaputra valley in Assam is basically alluvial in nature consisting of sand, sandstones, pebbles, clay and sometimes mixture of sand and clay with decomposed matter [Ojha and Singh, 2004]. Occurrence of fragile rocks and frequent landslides in Arunachal Pradesh results in increased input of sediment load in the river. Sediment laden streams are prone to the phenomenon of braiding. The flood plains of Brahmaputra valley are subjected to alluvial features like levees, pointbars, ox-bow lake, channel bars etc.[Goswami, 1998].

2.1.3 Tributaries

A number of tributaries joins the Tsangpo river both in the left bank and the right bank . Some important tributaries include Nau Chhu, Tsa Chhu, Chaktak Tsangpo, Raga Tsangpo, Tong Chhu etc on the left bank. On the right bank there are Kubi, Kyang, Sakya Trom Chhu, Nyang Chhu, Yearlang Chhu etc [Datta,2004]. While traversing through the mountainous region of Arunachal Pradesh Tsangpo named as Siang meet Lohit and Dibang in Assam. In the north the principal tributaries are Simen, Subansiri, Buroi, Bargang, Jiabharali, Dhansiri (North), Jia Bharali, Gabharu, Barnadi, Puthimari, Pagladia, Manas-Aie- Beki, Champamati, Godadhar etc. Again Ranganadi, Dikrong, Jiadhol are the major tributaries of Subansiri. The southern tributaries of Brahmaputra includes Burhi Dihing, Disang, Dikhow, Jhanzi, Bhogdoi, Dhansiri (South),Kopili, Kulsi, Krishnai, Jinari etc.

There are three Trans-Himalyan tributaries on the north bank which includes Subansiri, Jia-Bharali and Manas. The drainage areas of these three rivers are more than 10000 sq kms. The south bank tributaries namely Dhansiri and Kopili have areas more than 10000 sq kms. The Manas River combines with Aie and Beki river and forms the biggest catchment of around 42000 sq.kms [Bora, 2004]. There is a marked difference in terms of fluvio-geomorphic characteristics between the north bank and south bank tributaries. The variations includes geology, geomorphology, precipitation, relief etc. There is a notable difference between the tributaries of Brahmaputra of both the banks in terms of the sediment characteristics. The northern tributaries have very steep slope as compared to the south bank tributaries.

2.1.4 Soil

There is a great diversity in the physical-chemical aspect of the soils of Brahmaputra basin. The soil characteristic of Brahmaputra basin is somewhat similar to the soil characteristic of Indo-Gangetic plains.The soils of the flood plain of Brahmaputra basin contains higher percentage of sand at lower depths [Chakravarty et al., 1978; Karmakar,1985]. Sand content of upland soils is less than 28% at the surface and decreases at further depths. The silt content ranges from 30-75% in the basin.The clay content increases from a depth of 28 to 49 cm in soil of middle, eastern and western part of the basin with increase of rainfall [Talukdar et al, 2004].The organic matter content of the soils of the Brahmaputra basin increases with the increase in the amount of rainfall and decreases with the increase of the temperature [Chakravarty et al., 1978]. Illite and kaolinite are the major minerals present in clay fractions of the soils of the basin [Karmakar, 1985].Silt fractions of the flood plain soils have quartz, feldspar, micas, amphiboles, calcite, chlorite and kaolinite.

2.1.5 Agriculture

Agriculture is the major income source of Brahmaputra Valley. Cultivation of cereals is the basic feature of cropping in Brahmaputra basin. Among all crops rice is the dominant crop which contributes around 80% of the net cropped area. The climatological attributes including rainfall, temperature, soil characteristics etc. are the determinants of rice cultivation in Brahmaputra Valley. The average annual rainfall is 2000mm which provide adequate standing water for the growth of rice throughout the year [Talukdar et al, 2004]. Pulses are another important crops that are grown basically in Rabi season in Assam. However certain other pulses are also grown in Kharif season in some other districts. The major pulses grown in Assam are black gram, green gram, linseed, lentil, peas, beans etc. Other crops such as jute, pea, potato, wheat and vegetables are also grown under different cropping methodologies. Assam constitutes around 52 % of tea production of India [Laskar and Thapa, 2018].

2.1.6 Navigation and Transport

The use of rivers for transportation of goods from one place to another has been widely used in India since time immemorial. Transportation from one part of the bank to the other part of the bank is a part of daily life in Assam. The width of the Brahmaputra in Assam varies from place to place. In some stretches like the width is around 1.2 kms whereas in some other stretches it is around 20 km. So, the construction of bridges in these large stretches is uneconomical. About 32 % of the country's water resources flows through Brahmaputra and Barak [Das, 2004]. A total of 1983 navigable waterways with a density of 2.53 (sq.km waterways per 100 sq.km of area) of waterways. The Dhubri-Sadiya stretch of around 891 km has been declared as National Waterway in 1988. The sediment inflow of order of 800 million tons annually together with flat gradient are among the various factors contributes its braiding nature. These factors are necessary for smooth navigation.

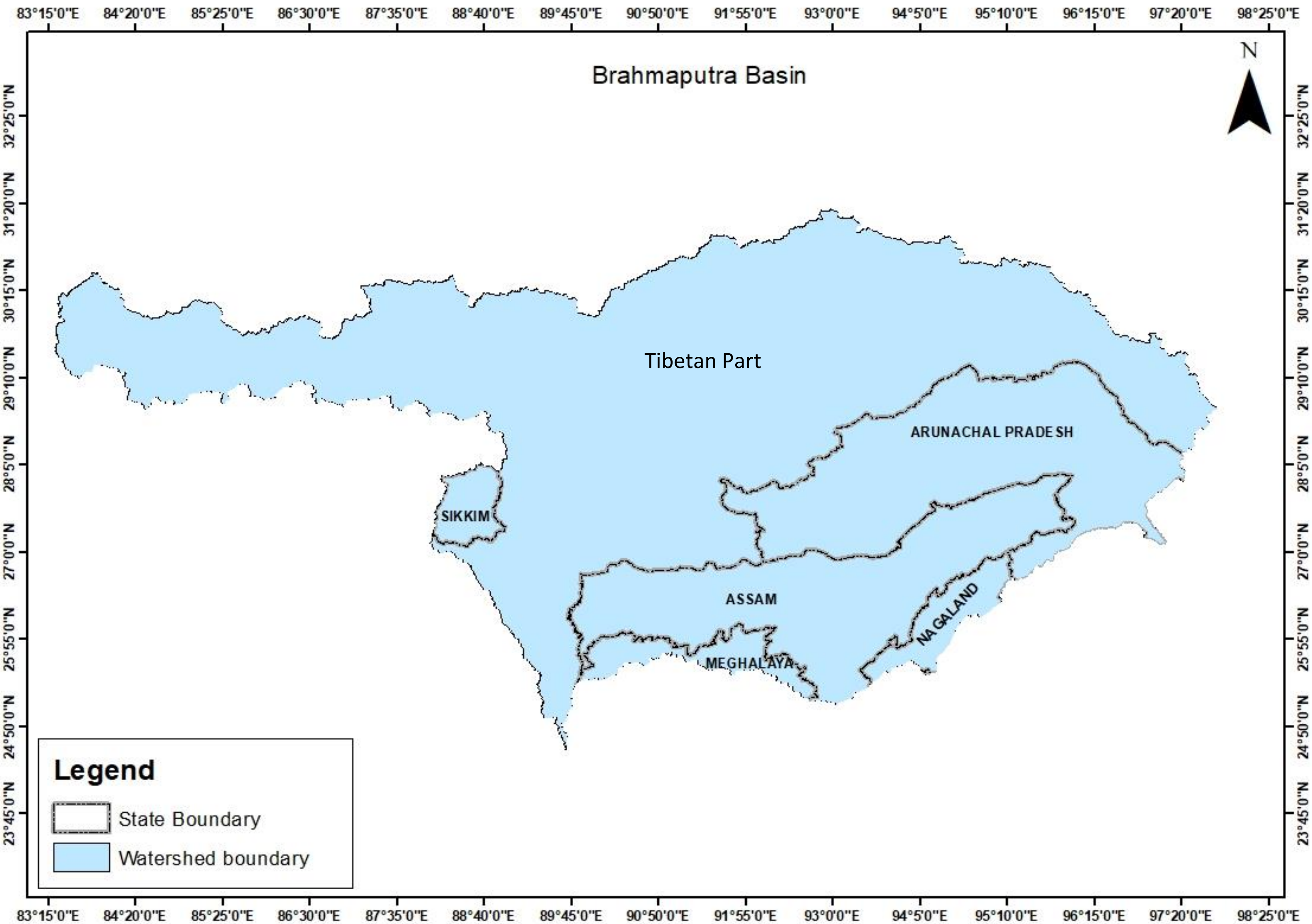

Figure 5: Map of the Study Area

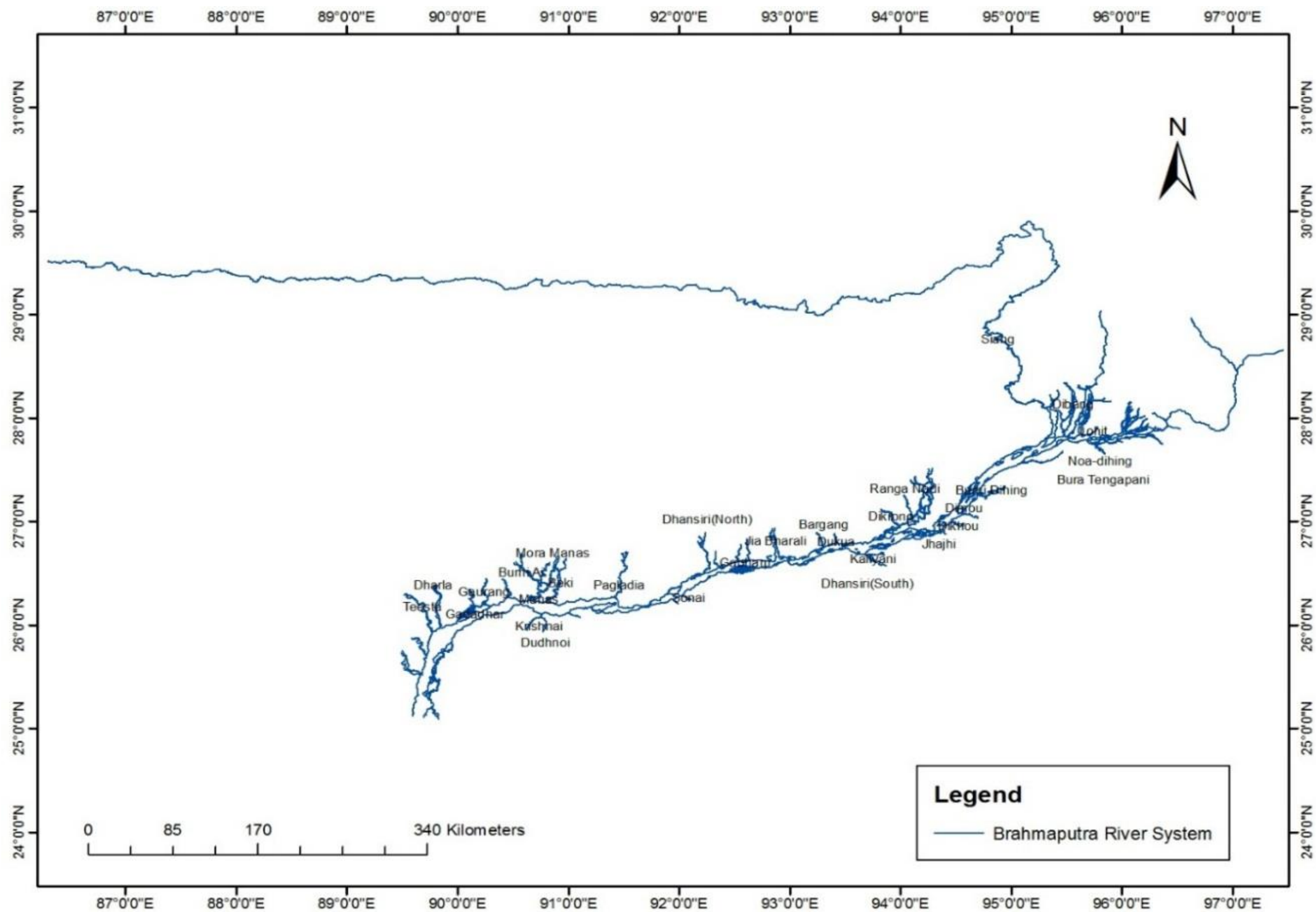

Figure 6: Brahmaputra main stem indicating confluence of important tributaries in India

Chapter 4
METHODOLOGY

Based on the objectives and feasibility analysis, along with literature survey, a methodology was formulated to carry out the study. Also, dataset to be used for the study were identified and an inception report was prepared and submitted to CWC, New Delhi which was approved by CWC, New Delhi and the methodology was then finalized as follows:

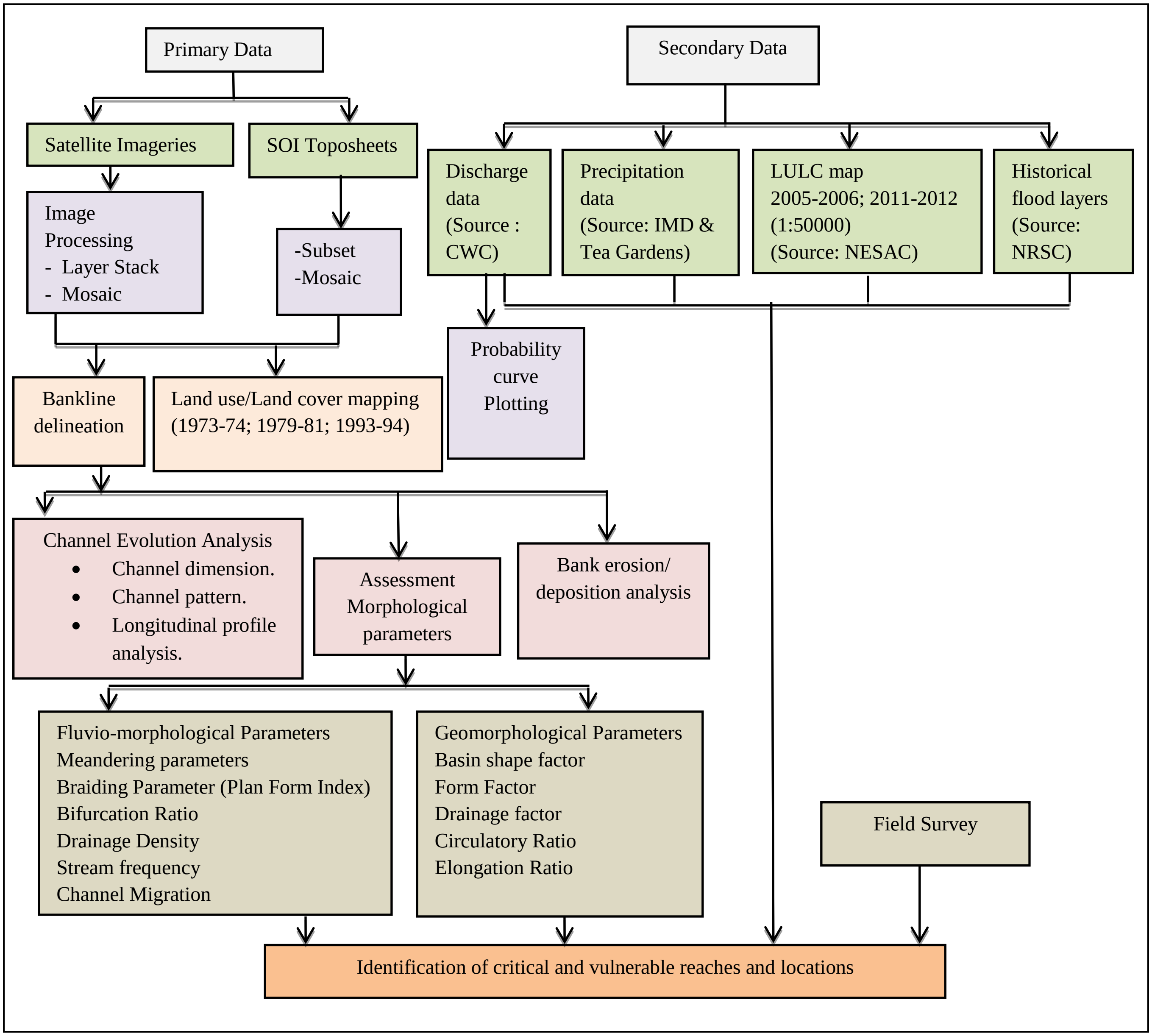

Figure 7: Methodology Flow Chart

Chapter 5

DATA COLLECTION & IMAGE PROCESSING

5.1 Geospatial Data

In this study, 1 set of SOI toposheets of 1973-74 and 4 sets of satellite data for the period 1976-80, 1993-95, 2003-04 and 2008-11 at around 10 years interval were used. Out of these 5 datasets, few toposheets and the satellite imageries of 2008-11 (Resourcesat-1, LISS 3) were already available with IITG. Toposheets which were not available with IITG were procured from SOI during the project period. For vulnerable reach identification another set of Resourcesat-2 LISS 4 data of 2016-17 has also been used in this study. The SOI toposheets were georeferenced using 1st Order Polynomial Model in Erdas Imagine 2015 and keeping the total RMS error less than 1. The subset of the georeferenced toposheets were then taken out and mosaicked to cover the entire watershed. Also, mosaicking had been performed for the 2008-11 LISS 3. Georeferenced Landsat MSS imageries of 1976-80 were downloaded from the USGS website and then layer stacking and mosaicking of the dataset was carried out using ERDAS Imagine 2015 software. Georeferenced satellite imageries for the periods 1993-95 (IRS 1B, LISS 1) and 2003-04 (IRS P6, LISS 3) and 2016-17 (Resourcesat-2 LISS 4) were procured from NRSC, Hyderabad and layer stacking and mosaicking of these datasets were done in ERDAS. Few geo-referencing errors were encountered in the 2003-04 dataset which had been corrected subsequently. The details regarding the geospatial data used in the study are given in Annexure-I and the specifications of the sensors are given in Table-1.

Table 1: Sensor Specifications

Specification	Landsat MSS	IRS 1B LISS 1	IRS P6 LISS 3	Resourcesat-1 LISS 3	Resourcesat-2 LISS 4
Spectral Bands	4	4	4	4	3
Spatial Resolution (m)	80	72.5	23.5	23.5	5.8
Swath (km)	185	148	141	141	70
Radiometric resolution (bits)	6	7	8	8	10

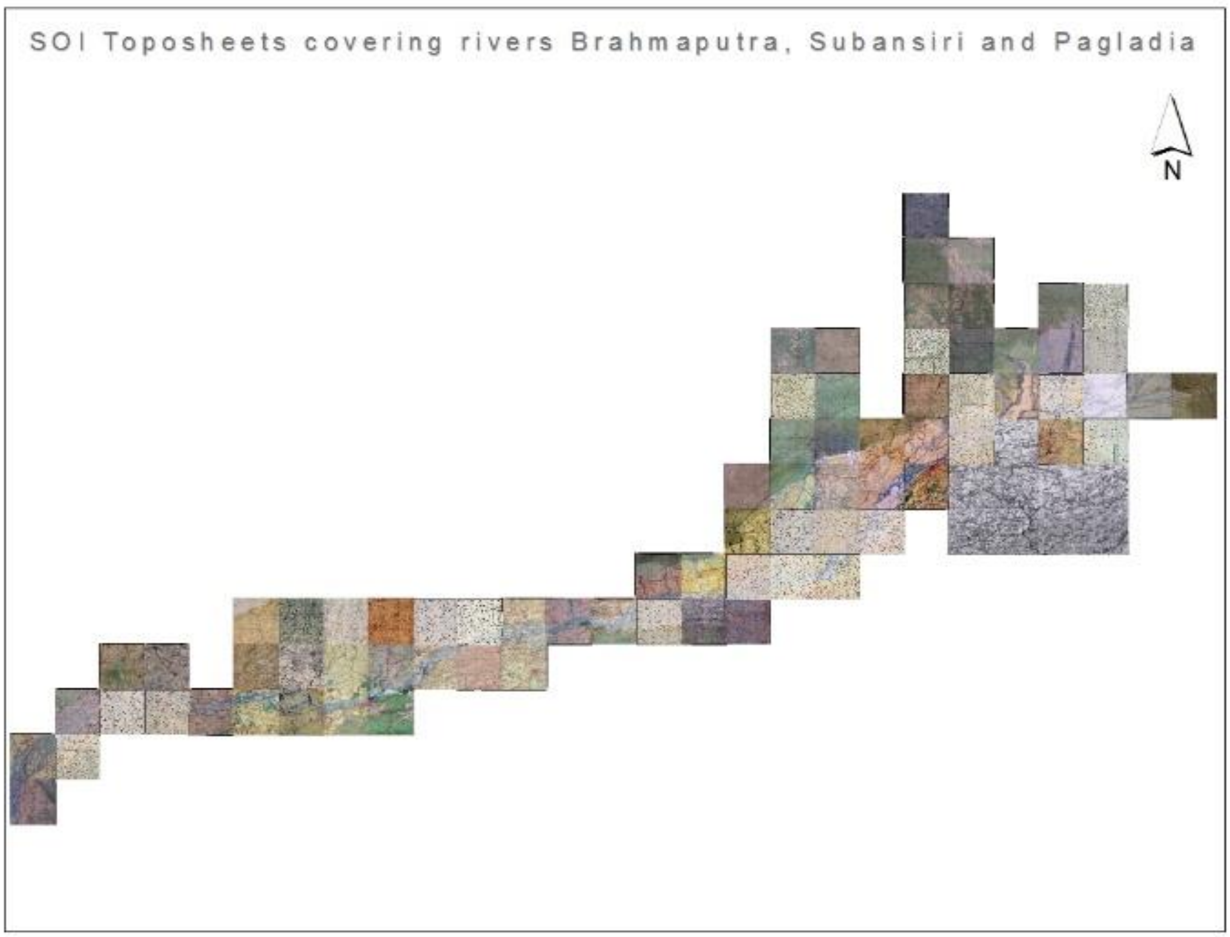

Figure 8: Mosaicked SOI toposheet covering Brahmaputra river (1973-74)

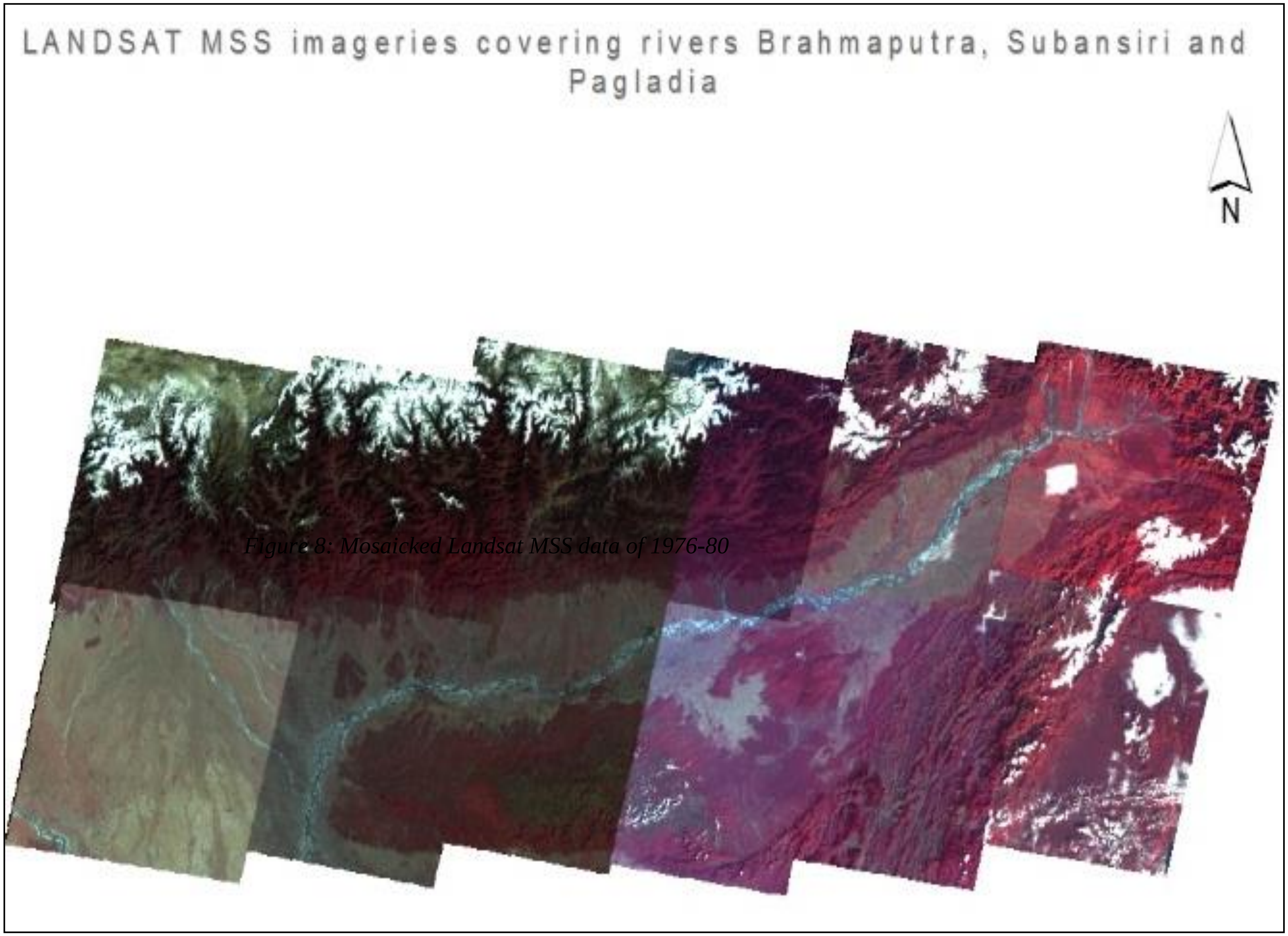

Figure 9: Mosaicked LANDSAT MSS imagery of 1976-80

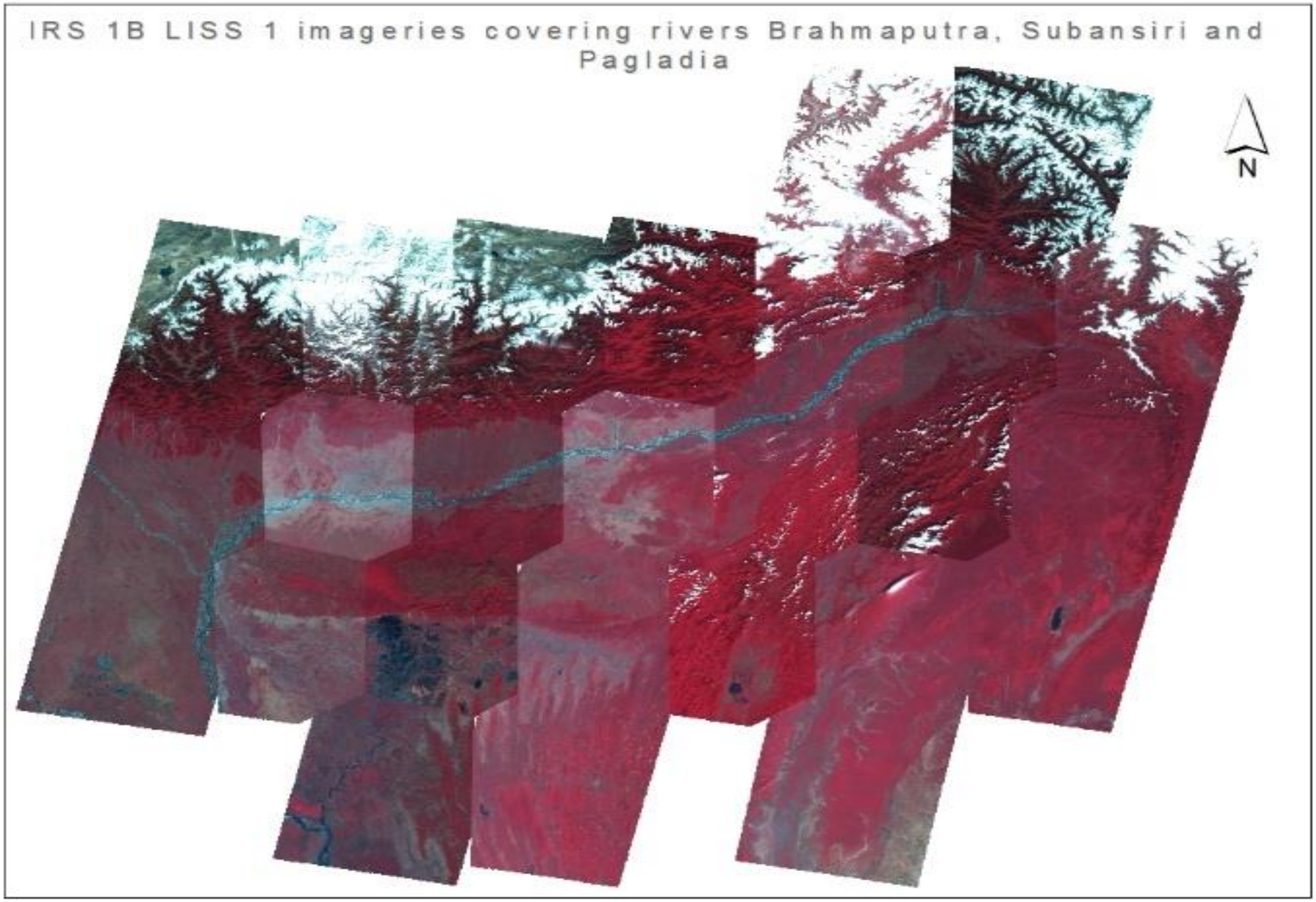

Figure 10: Mosaicked IRS 1B LISS 1 data of 1993-95

Figure 11: Mosaicked IRS P6 LISS 3 data of 2003-04

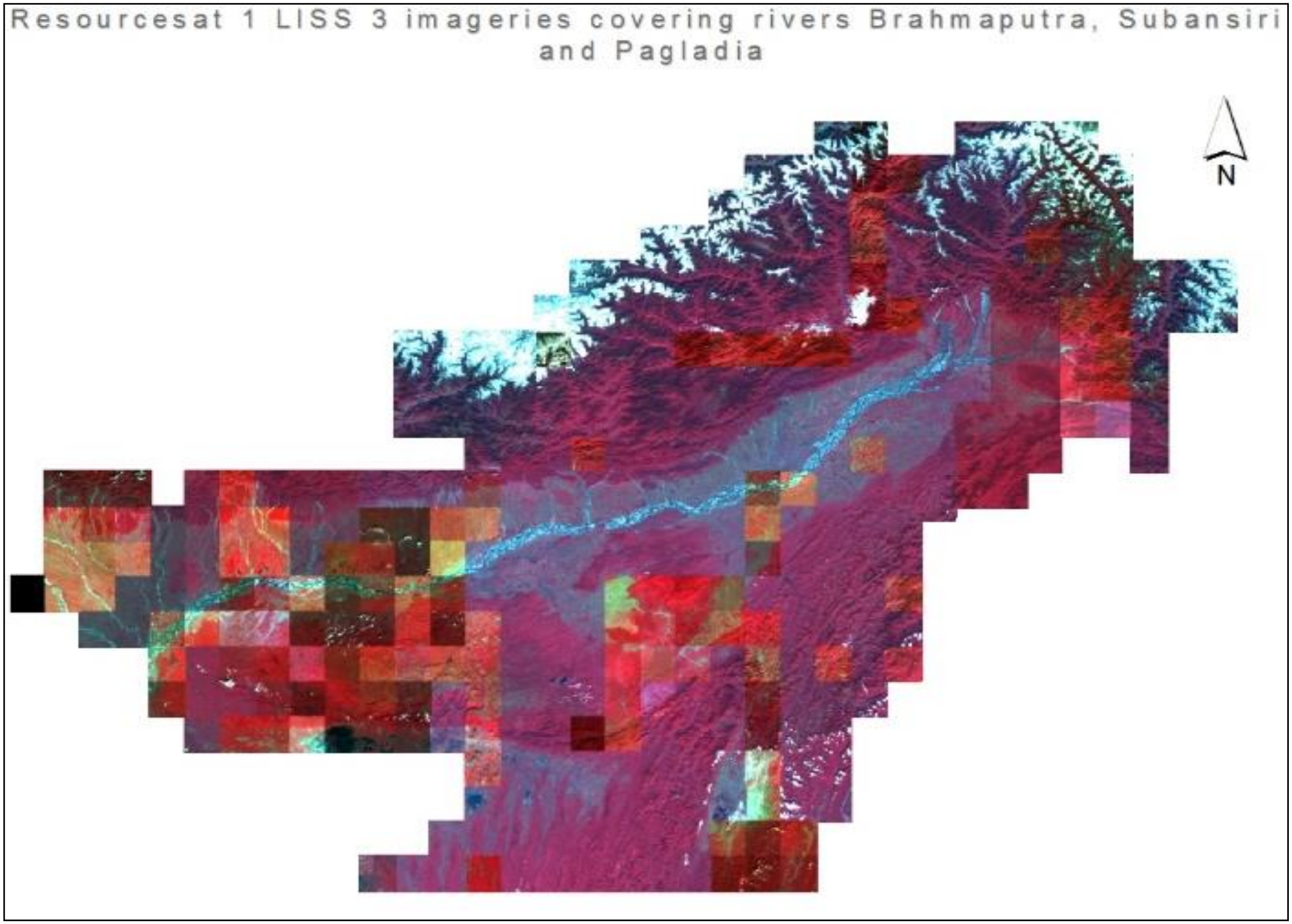

Figure 12: Mosaicked RESOURCESAT-1 LISS 3 data of 2008-11

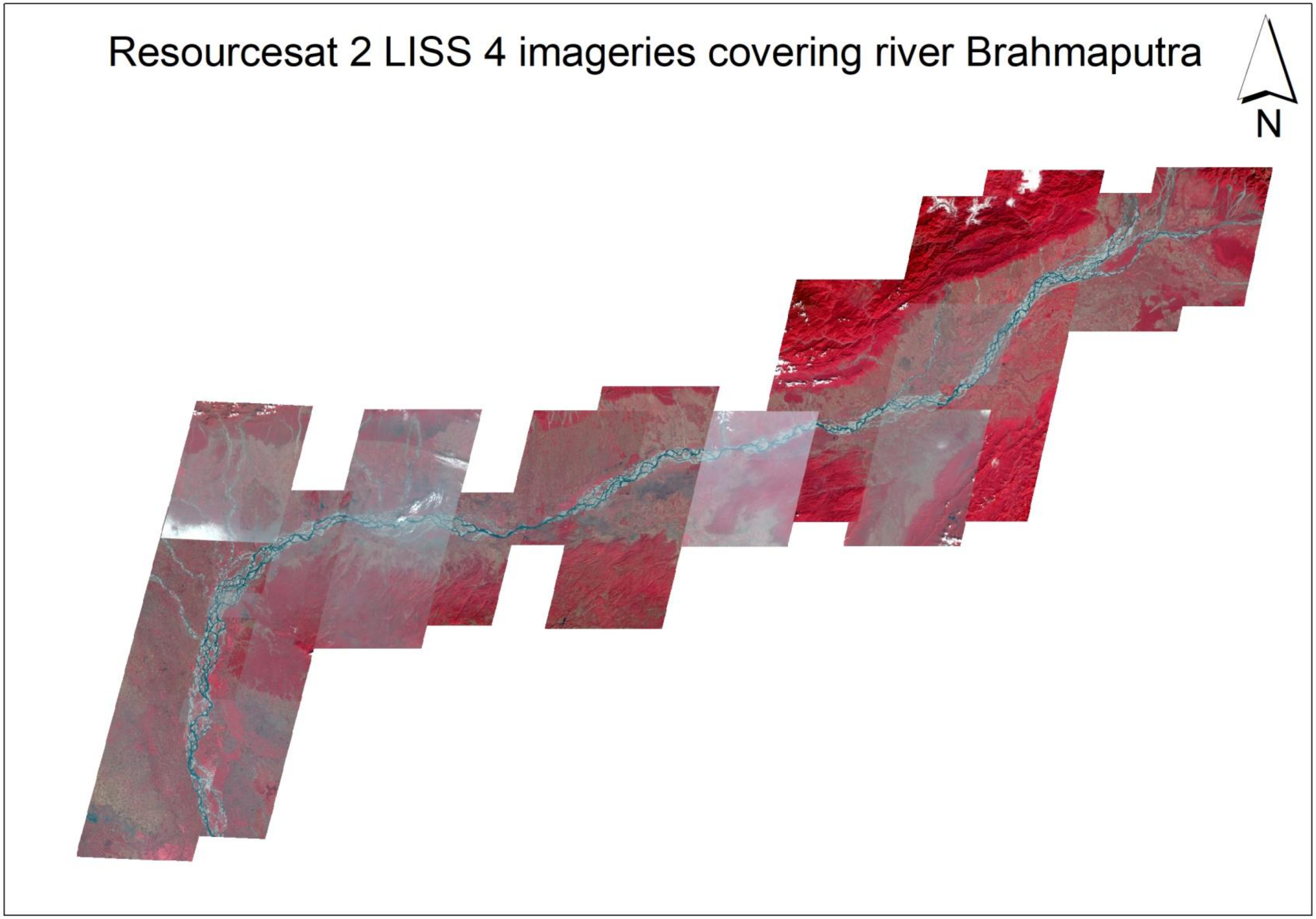

Figure 13: Mosaicked RESOURCESAT-2 LISS 4 data of 2016-17

4.2 DEM

SRTM DEM of 90m resolution were downloaded from the CGIAR website (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp) covering the Brahmaputra basin. The DEM tiles were then mosaicked and further used for Brahmaputra basin delineation using ArcGIS 10.1.

4.3 Hydrological Data

Hydrological data viz. daily and 10 daily gauge, discharge, silt and x-section data were collected for different stations of river Brahmaputra from CWC Upper Brahmaputra Division, Middle Brahmaputra Division and Lower Brahmaputra Division. Details of the hydrological data collected are given as Annexure II.

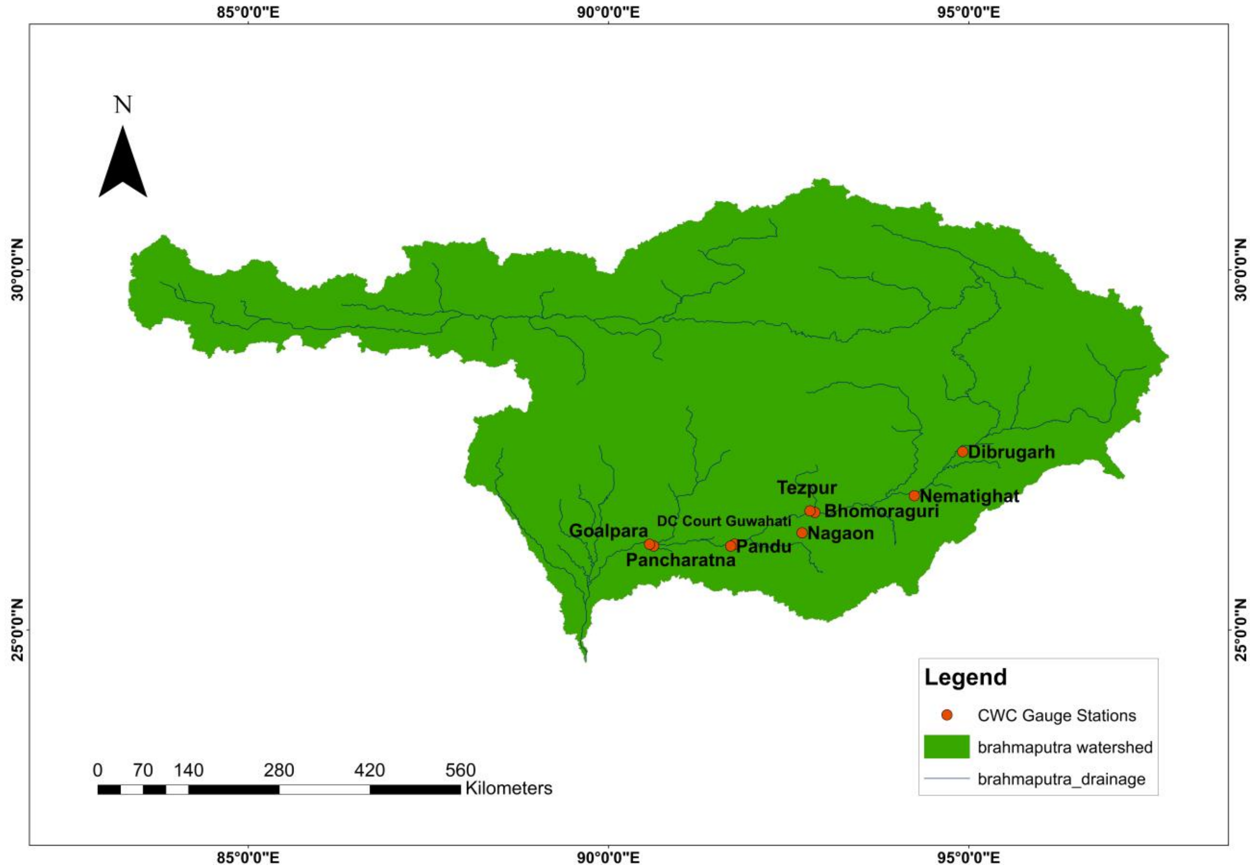

Figure 14: Location map of CWC Hydrological observation sites

Chapter 6
BANKLINE DELINEATION

The recent advancement in remote sensing and GIS helped in the identification and demarcation of river banklines upto a great extent. An easy and relatively accurate method of analyzing channel migration and erosion-depositional analysis is to compare the overlaid existing survey maps, satellite imageries, etc. Accuracy of the analysis is dependent on the temporal resolutions of the datasets and also on the expertise interpreter. Identifying and delineating banklines is often dependent on the resolution and skill of an interpreter. High- resolution satellite imageries allow the user to identify the banklines features more easily. An analysis was carried out to compare the automatic delineation and manual delineation techniques for bankline demarcation.

5.1 Automatic delineation of river bankline using band ratios

Every object on the earth surface has a characteristic spectral signature. Based on this spectral signature of the objects, different band ratios or spectral indices were derived to study the health of vegetation, water body extraction, presence or absence of moisture in vegetation or soil etc. McFeeters (1996), first proposed the Normalized Difference Water Index (NDWI) to detect surface waters in wetland environments and measured the surface water extent. Water shows a strong absorption at NIR and SWIR region in the electromagnetic spectrum and absorbs relatively little energy in the visible region. This results in high transmittance in the blue-green portion of the EM spectrum.

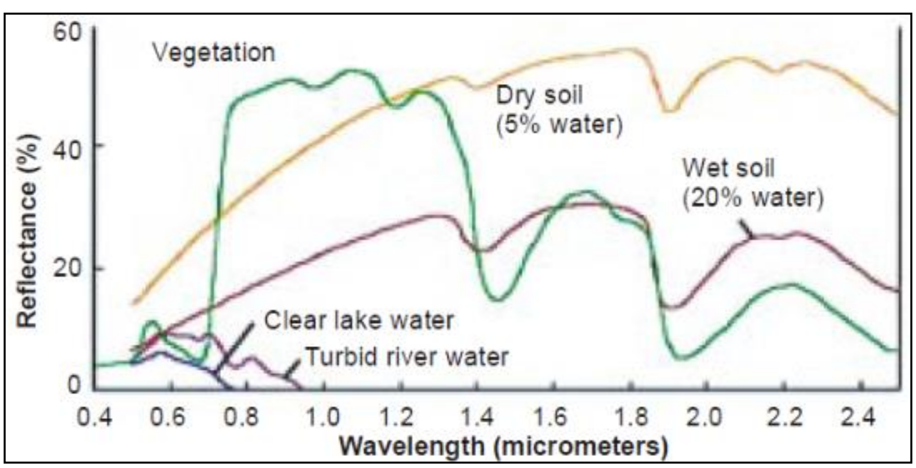

Figure 15: Spectral reflectance curves for different objects

The SWIR reflectance indicates changes in soil and vegetation water content. Based on these reflectance characteristics of water, NDWI is calculated using the following band ratios:

For LISS III imagery NDWI is calculated as,

$$\text{NDWI} = \frac{NIR - SWIR}{NIR + SWIR}$$

For TM imagery NDWI is calculated as,

$$\text{NDWI} = \frac{NIR - Green}{NIR + Green}$$

In the NDWI output image (Figure 16 & 18), the values of the water bodies and moist soil ranges between -1 and < 0. To delineate the water bodies based on the NDWI values a threshold is used and the output is assigned as Unsigned 1Bit (Figure 17 & 19). The model used for NDWI and automatic delineation of water bodies in ERDAS is shown in Figure 22.

The Normalized Differential Vegetation Index (NDVI) is also generated to extract the water bodies from LISS IV imagery. In the NDVI output, value of the water bodies ranges between -1 to 0, bare soil has a value of 0 and that of soil with vegetation ranges between 0 to 1 (Figure 20 & 21).

NDVI is calculated as,

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}$$

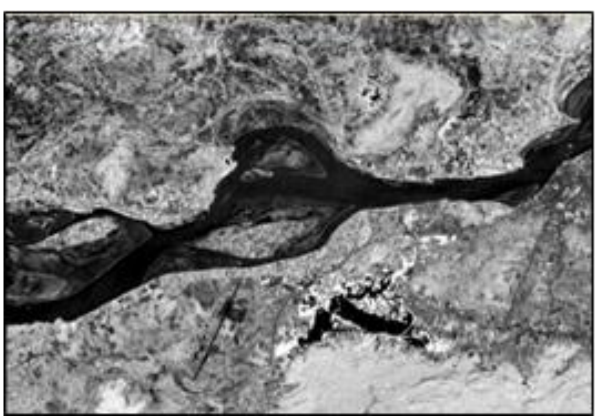

Figure 16 NDWI image derived from LISS 3 imagery using NIR (band 4) and SWIR (band 5) band ratio

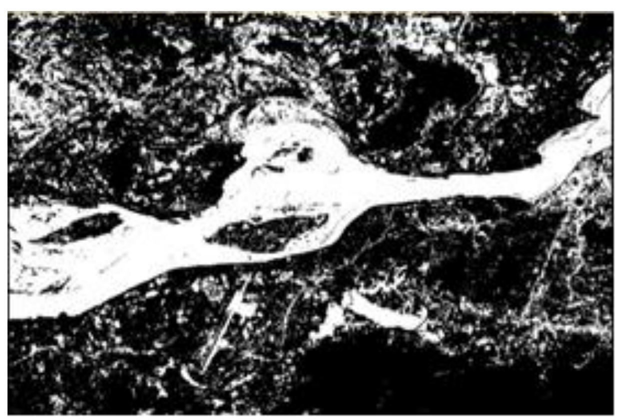

Figure 17: Automatic delineation of water bodies based on NDWI generated form LISS 3 imagery

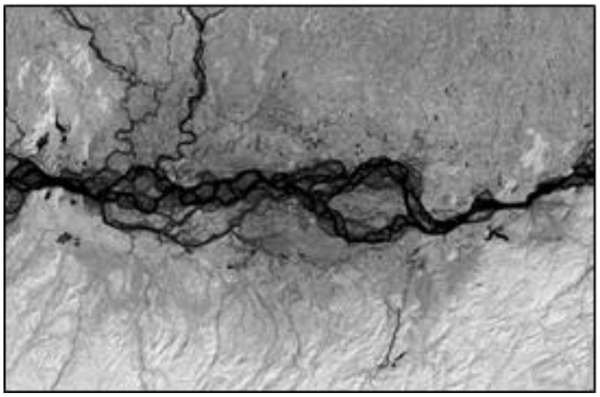

Figure 18: NDWI image derived from TM imagery using NIR (band 4) and Green (band 2) band ratio

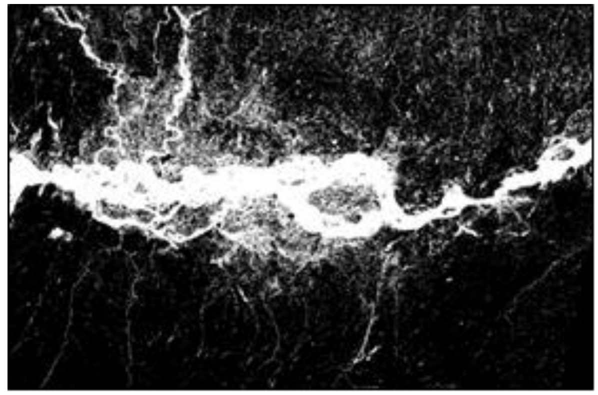

Figure 19: Automatic delineation of water bodies based on NDWI generated from TM imagery

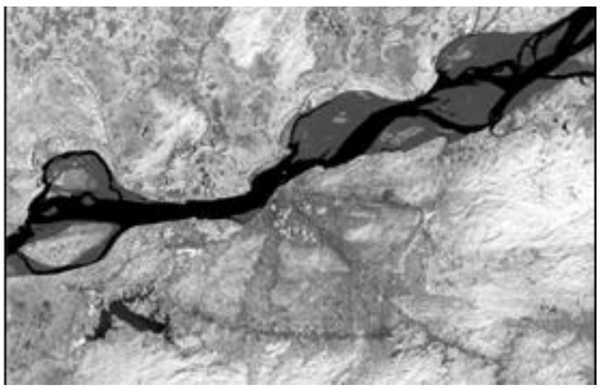

Figure 20: NDVI image derived from LISS 4 imagery using NIR (band 4) and Red (band 3) band ratio

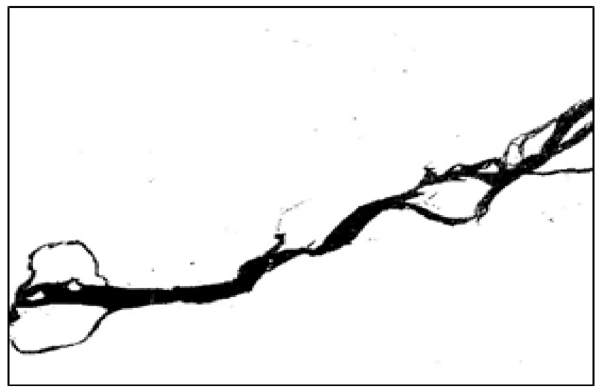

Figure 21: Automatic delineation of water bodies based on NDVI generated from LISS 4 imagery

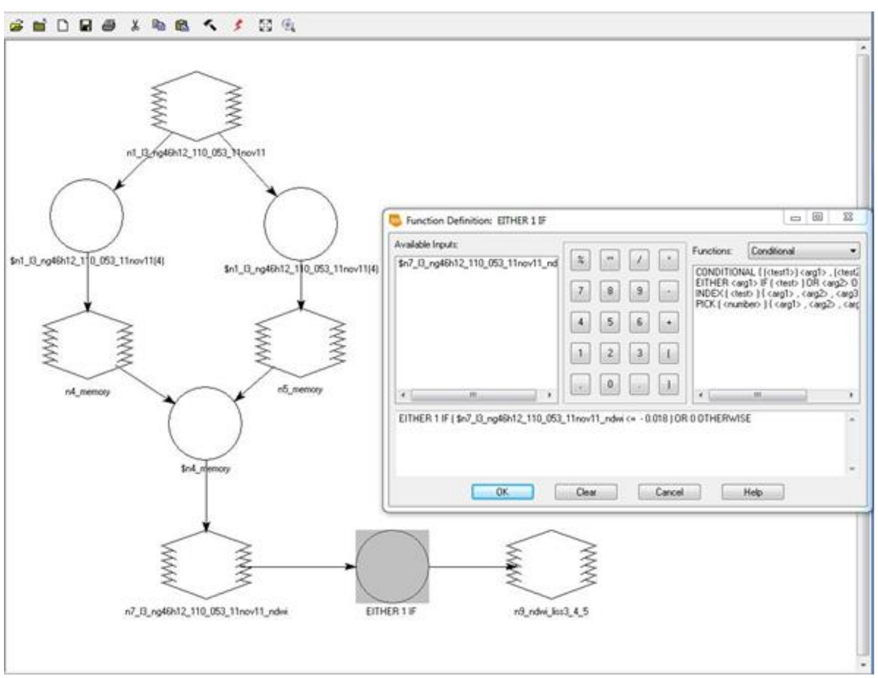

Figure 22: Erdas model used for auto delineation of water bodies

6.2 Comparison between auto delineation and manual delineation methods for bankline demarcation

A comparison had been made between the auto delineated river bankline and the actual river bankline that can be perceived from the visual interpretation of optical image (Figure 20a. & 20b.). From the comparison it was apparent that the automatic delineation method was not effective in delineating the river bankline near lateral bare sandbars or vegetated sandbars as it is based on the pixel values only. However, in manual digitization method it is easy for the interpreter to demarcate the bankline due to visual differences between the lateral sandbars and the bank landmass.

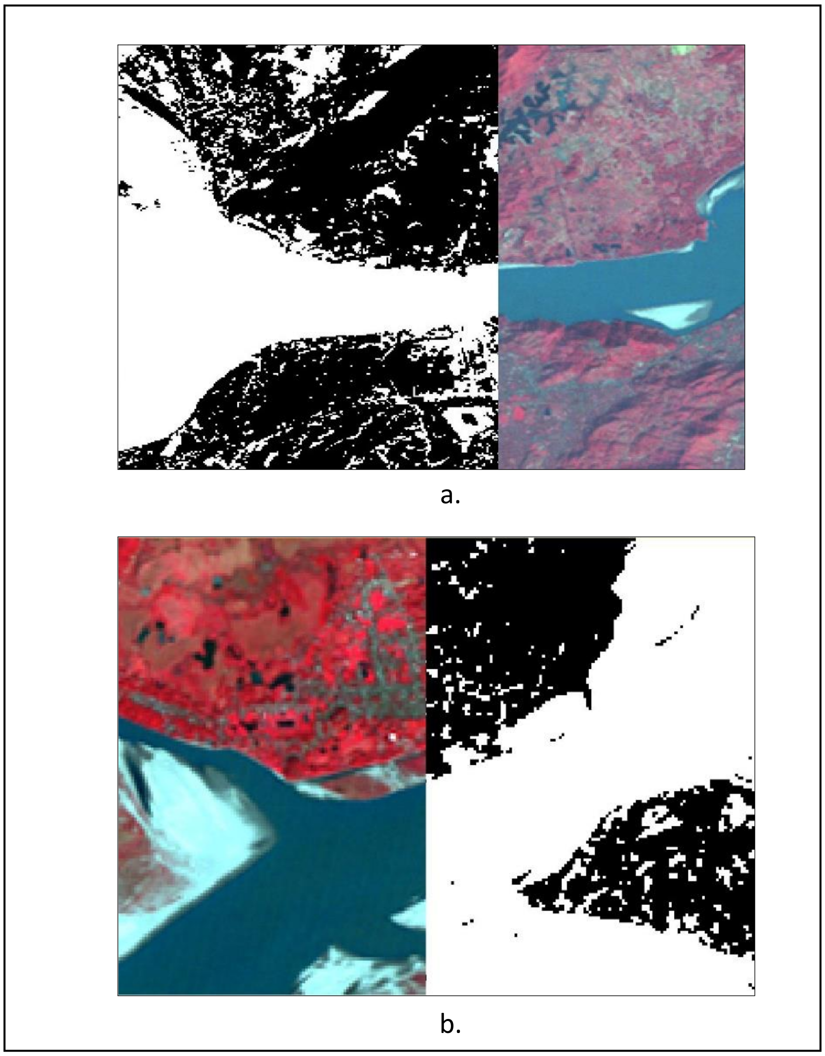

Figure 23: Comparison between real bankline and auto delineated river bankline for two different sensors (a. LISS 3; b. TM)

6.3 Manual delineation of river banklines

The dynamic nature of the fluvial rivers results in the formation of various geomorphic features (viz. floodplains, sandbars, point bars, river terraces, cut-off meanders, levees, ox-bow lakes, water bodies, river islands, meander scrolls etc.) that ultimately leads to the shifting in river bankline [Mallick, S., 2016]. Thus, delineation of river bankline is one of the important aspects in morphological studies of rivers. It is used extensively in hydraulic modelling, floodplain analysis, channel evolution study, hydraulic geometry [Mount et. al., 2003; Tate et. al., 2002; Merwade et. al., 2004]. In this study, manual digitization of the banklines of river Brahmaputra has been done for different years using ArcGIS 9.3. The delineated banklines are used to study the channel shifting, channel evolution, quantification of erosion-deposition and analysis of various morphological parameters.

6.3.1Methodology

The entire Brahmaputra River system with the confluence of important tributaries from Sadiya to Dhubri (near Bangladesh border) was delineated from satellite imagery (Figure 21). The bankline of river Brahmaputra for the selected time periods i.e. 1973-74, 1976-80, 1993-95, 2003-04 and 2008-11 were delineated from SOI Toposheet (1:50K), LANDSAT MSS (80m), IRS 1B LISS 1 (72.5m), IRS P6 LISS 3 (23.5m) and RESOURCESAT-1 LISS 3 (23.5m) respectively using visual interpretation technique in ArcGIS platform at 1:50K scale (Figure 22). For river bankline delineation, polyline shapefiles were created for each time period and digitization was done following standard digitizing procedure. The delineated banklines were then analyzed to quantify the erosion-deposition along the banks, channel evolution process and to study various morphological parameters.

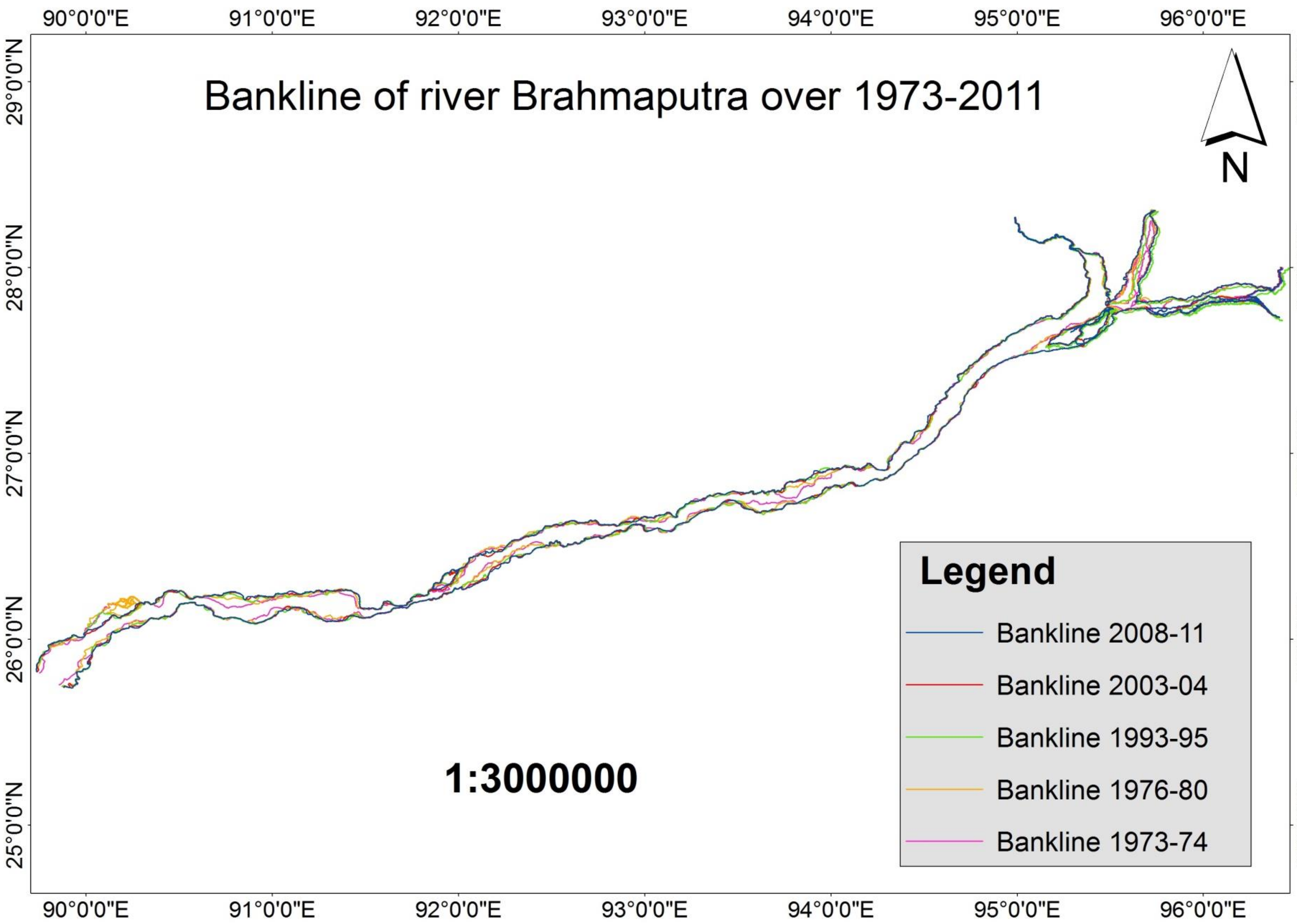

Figure 24: Brahmaputra bankline at different time periods

Chapter 7
CHANNEL EVOLUTION

7.1 Channel Pattern

In alluvial floodplains, the process of erosion-deposition dominates the morphological changes in the river channel. Being a regular phenomenon in the Brahmaputra valley, the process of erosion-deposition plays a significant role in the morphological evolution of the channel resulting in channel widening, channel migration, planform change and avulsion.

To study the channel evolution of Brahmaputra, the delineated river banklines of different study periods were overlaid in ArcGIS and analyzed. From the analysis, it was evident that between 1976-80 and 1993-95, a significant change took place in the Lohit channel after its confluence with the Brahmaputra near Dibru-Saikhowa National Park. At this point, before 1993-95 the Lohit channel was used to meet the main Brahmaputra channel ahead of the Dibru-Saikhowa National Park flowing through the northern boundary of the Park. However, in the 1993-95 imagery, an avulsion was observed in the channel and the channel started flowing to the south of Dibru-Saikhowa and meeting the main Brahmaputra again near Rahmoria (Figure 25). Also some major planform changes were observed near Majuli, once the largest inhabited river island of the world, where the right bank of the river Brahmaputra was migrating northward owing to the continuous process of erosion over the years at the confluence of rivers Subansiri and Brahmaputra (Figure 26).

Some other morphological changes were also marked from the observations and presented below (Figure 27 & 28).

6.2 Channel dimension

To study the changes in channel dimension of river Brahmaputra, the entire river from Sadiya to Dhubri had been divided into sections of 10 km reach and then the width of the river at each section for all the study periods were measured. Also, the width at various nodal points of the river was measured and a plot of the width against each section was then plotted in excel (Figure 29).

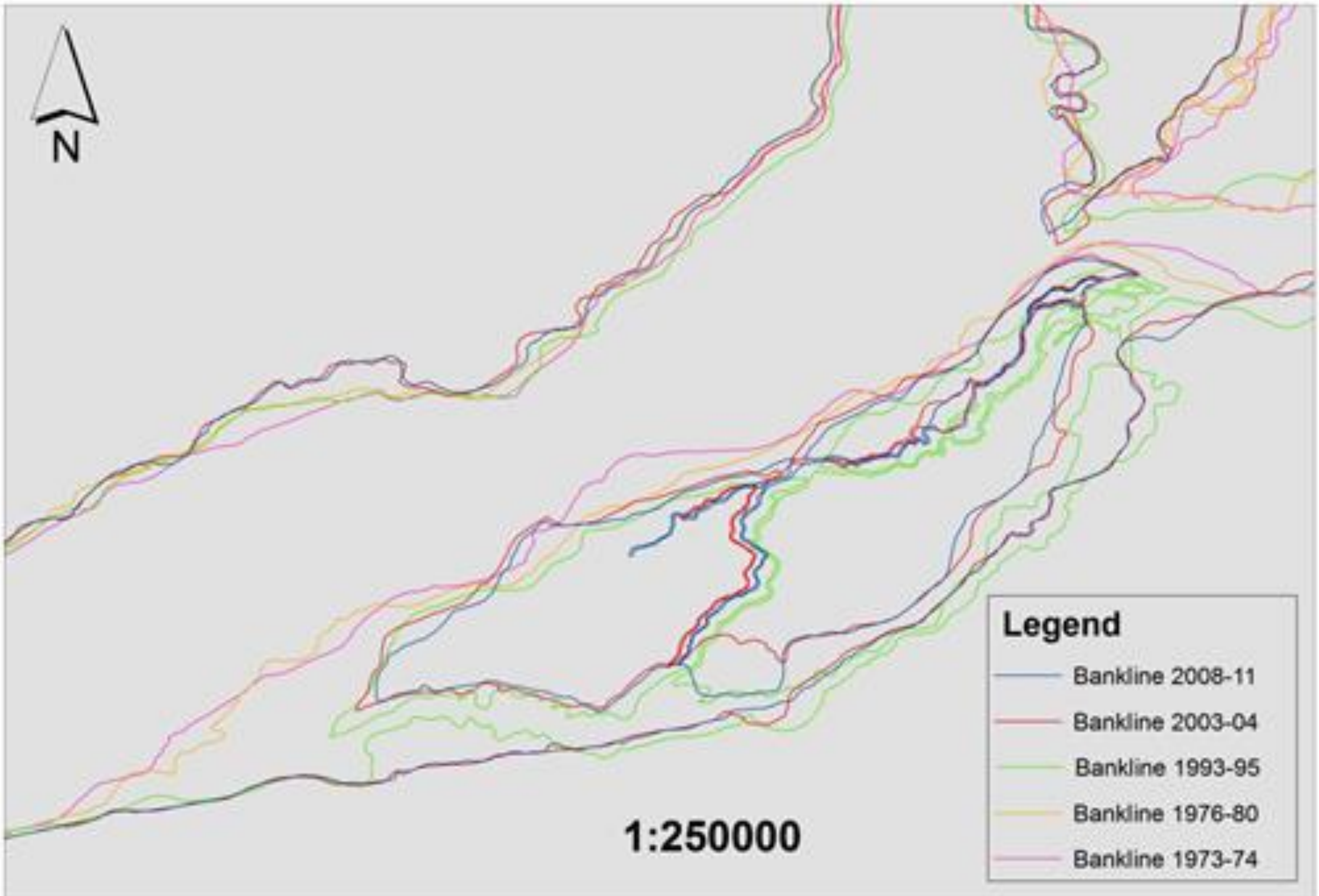

Figure 25: Avulsion of the Lohit channel

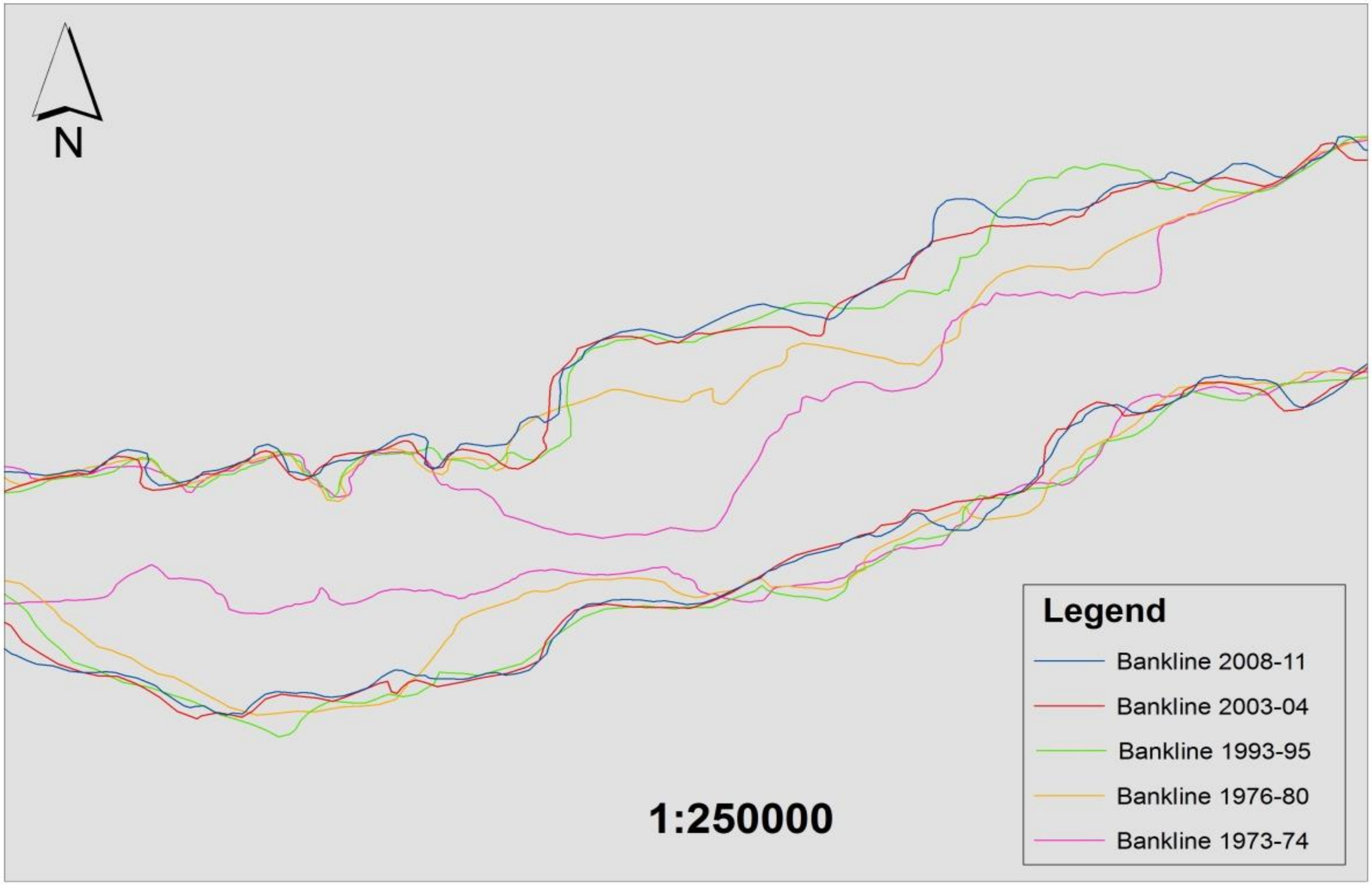

Figure 26: Change in the Brahmaputra-Subansiri confluence point due to severe erosion at Majuli

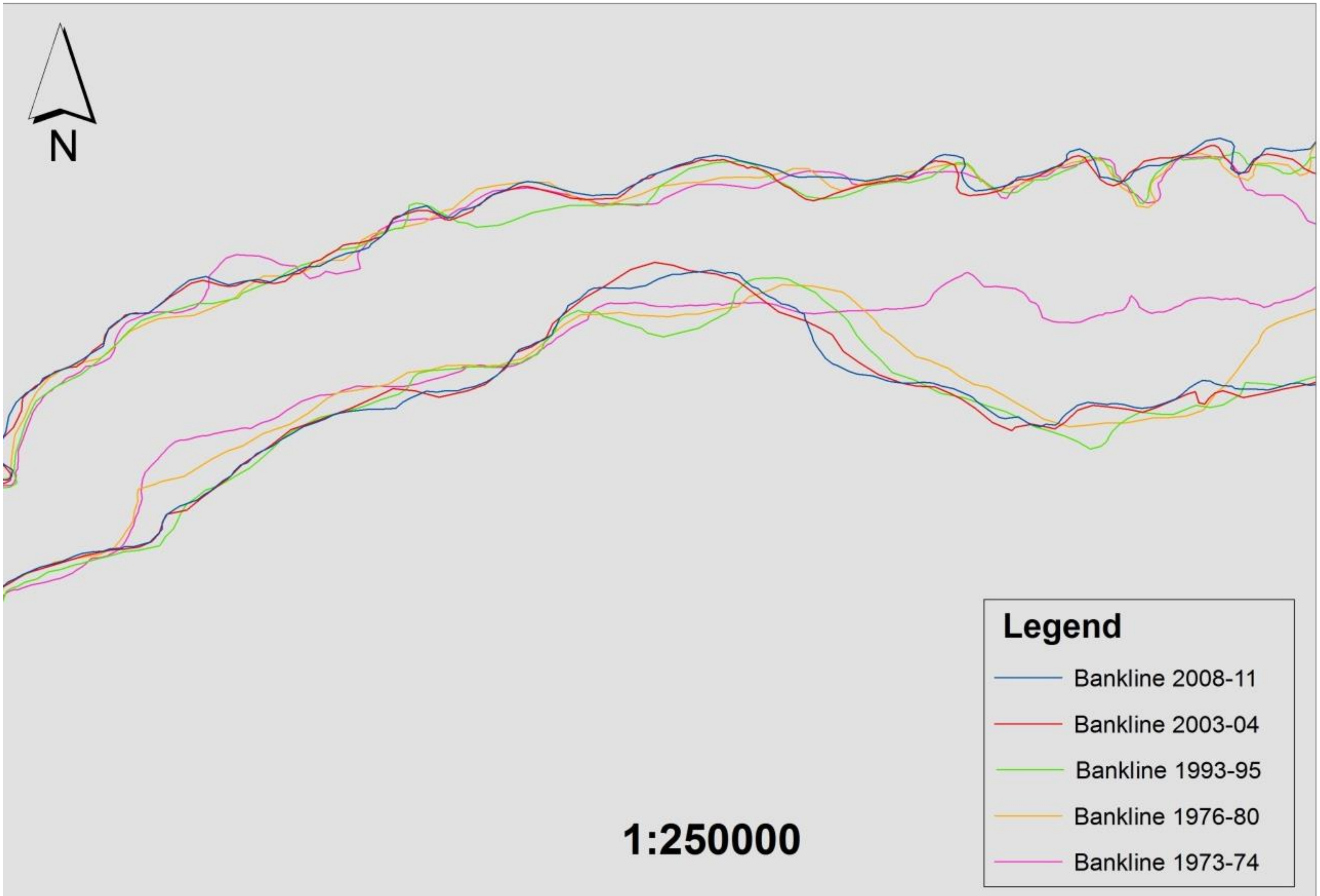

Figure 27: Northward migration of Brahmaputra near Sonitpur

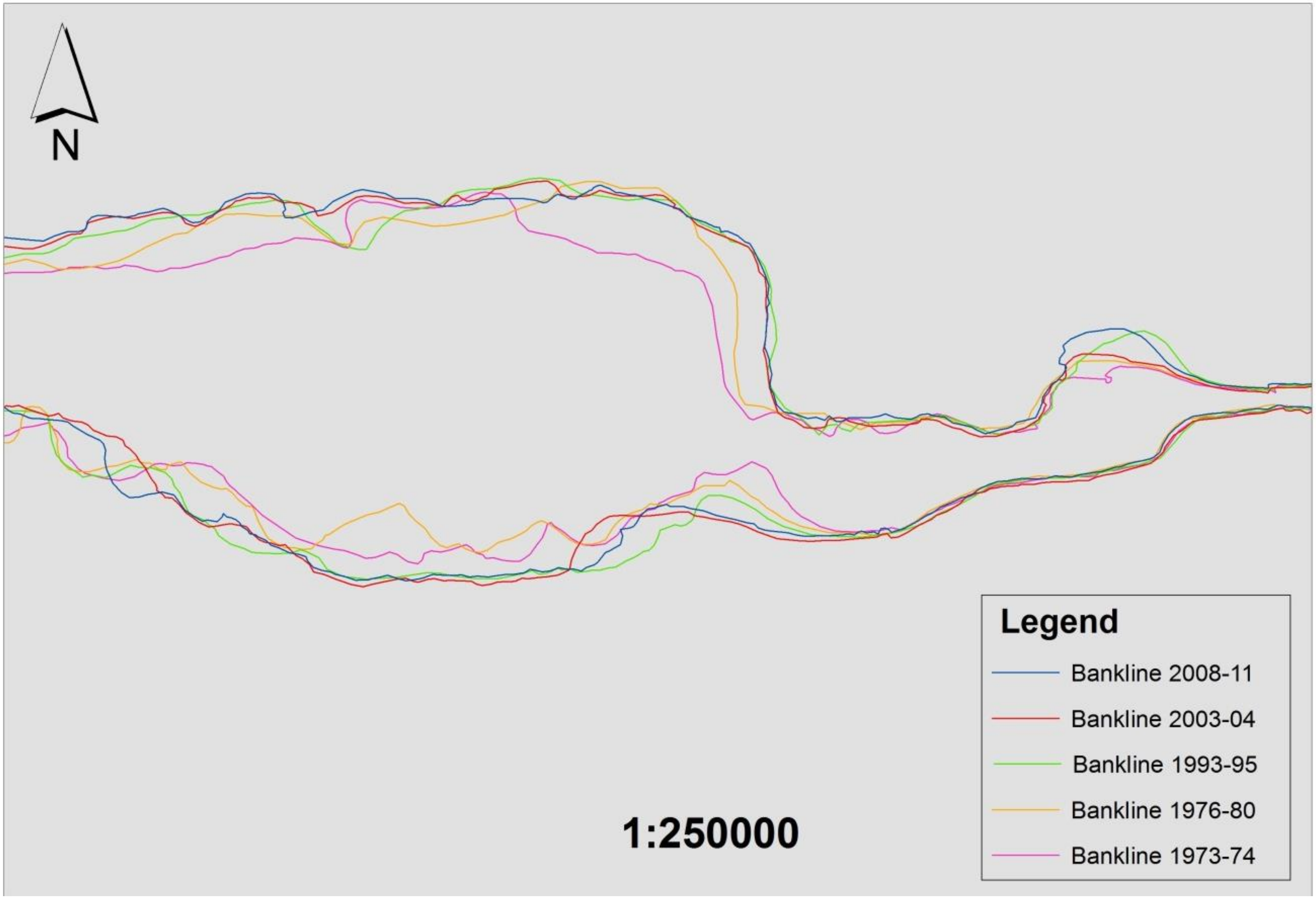

Figure 28: Widening of the channel due to severe erosion near Palashbari

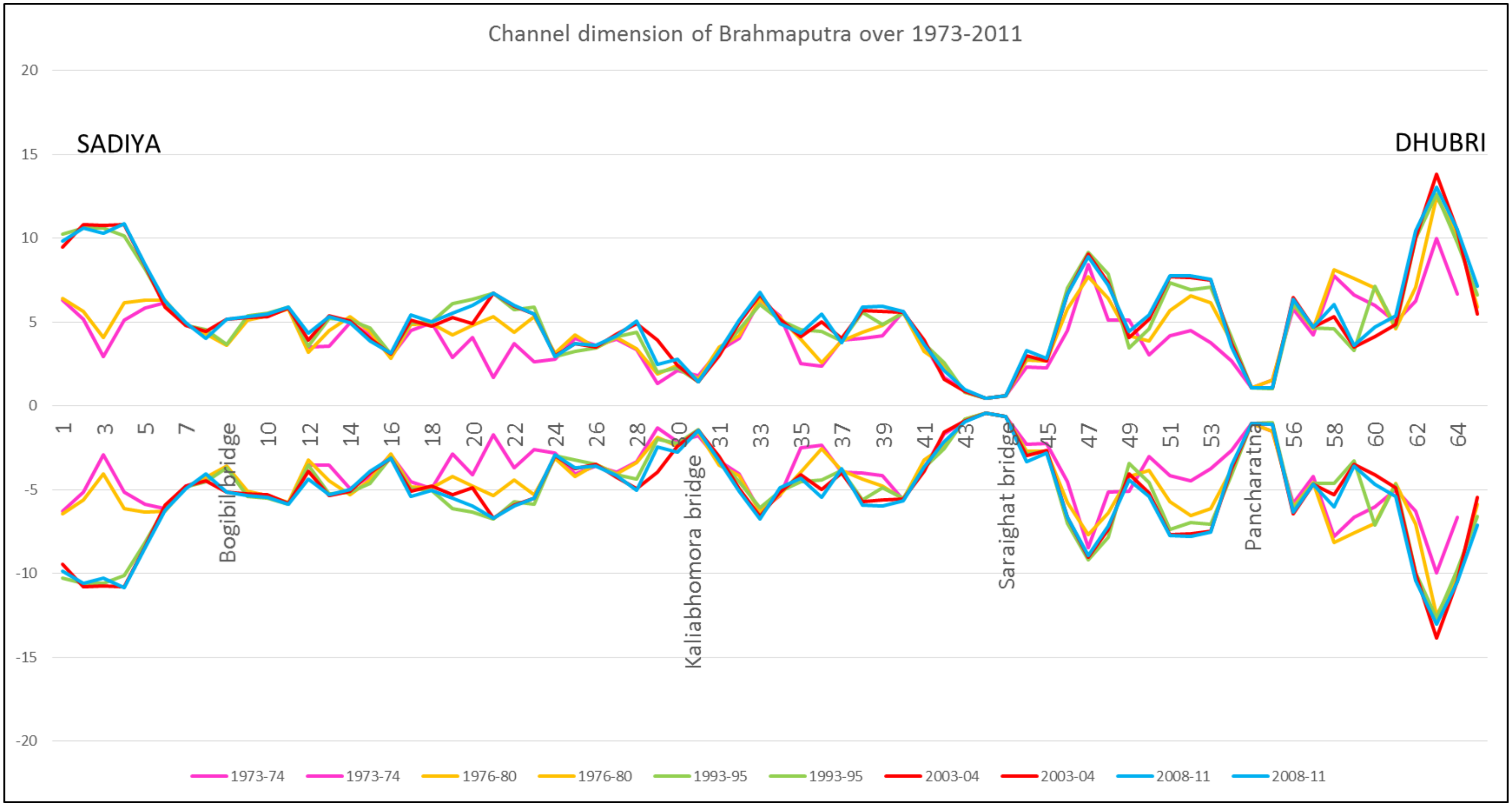

Figure 29: Change in Channel Dimension of Brahmaputra over time

7.3 Longitudinal Profile

In river hydraulics it is a plot of water surface elevation against upstream to downstream distances. It is the graphical represented of elevation versus distance. Analysis of longitudinal river profiles was first undertaken by Domenico Gugliemini over 300 years ago. The most striking phenomenon related to longitudinal profiles is their form. The plotting of these profiles shows altitude against distance downstream. The resulting form is a curve, more or less regular, the concavity of which increases towards the headwater area. Longitudinal profiles allow us to determine if channel incision exceeds, equals or is less than the influx of material into the drainage basin (Bishop 2007). The configuration of longitudinal profiles varies significantly across and within mountain ranges, with the relative length of the low gradient downstream segment being one of the most important expressions of longitudinal profile variance (Tippet and Hovius 2000).The longitudinal profiles of rivers reflect the diverse effects of sediment-source rocks, sediment types, watershed evolution, and geologic structure of the river basins. Many factors can be attributed to the shape of the longitudinal factors such as structural and geological processes.

7.3.1 Methodology

The longitudinal profile has been prepared for the main stem of the Brahmaputra River. It was prepared from Google Earth by considering the elevations at a distance of 10 km from upstream of Pe till Dhubri. The profile shows that the river has a steep slope in its mountainous stage. The slope gradually decreases when it reaches plains of Assam.

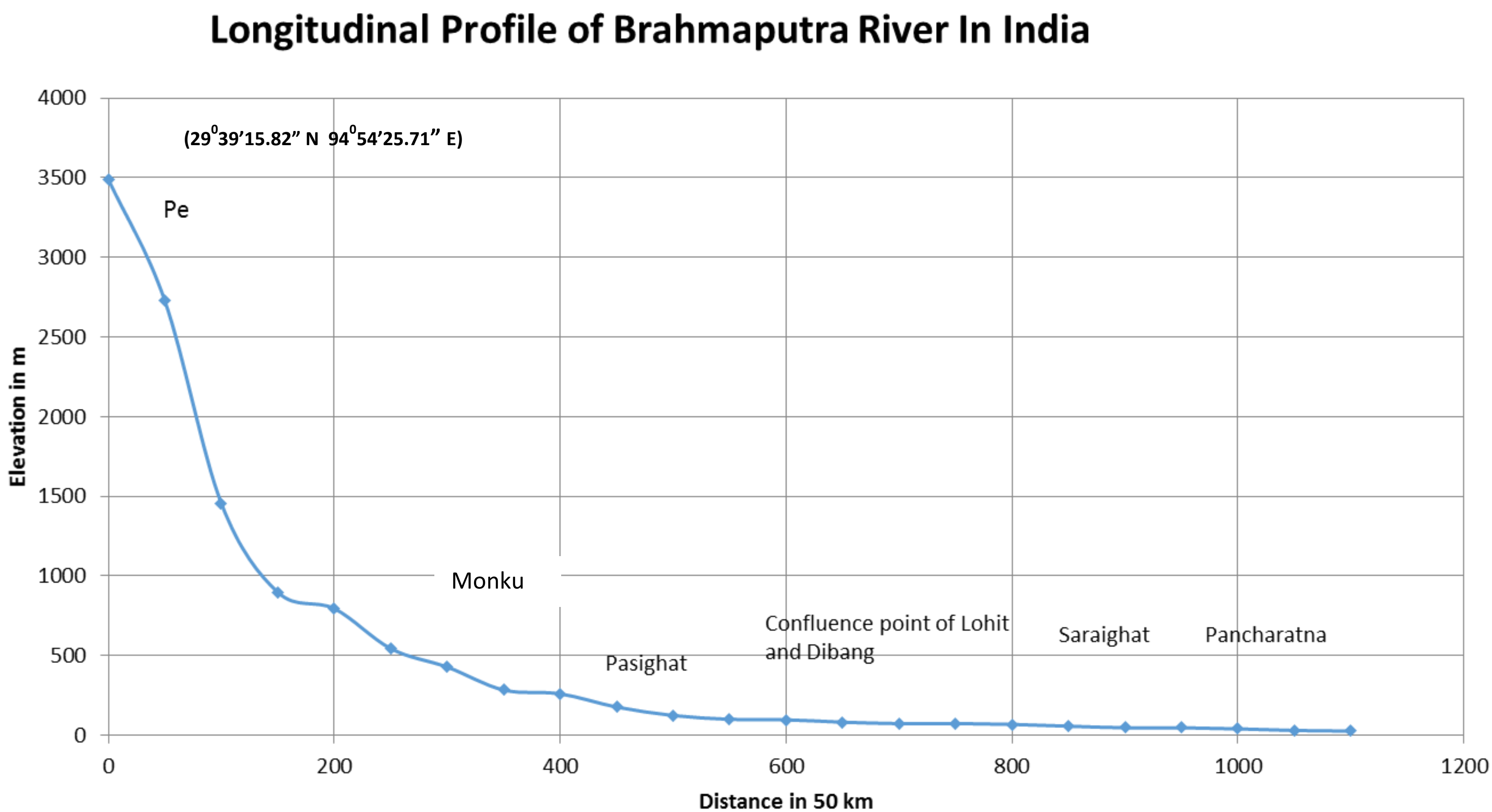

Figure 30: Longitudinal profile of Brahmaputra within India

7.3.2 Observations

The longitudinal profile of the Brahmaputra River is prepared from upstream of Pe to Dhubri. At Pe, the river is around 600m wide. It turns abruptly to the northeast and flows narrow steep gorges between the mountains. The Tsangpo enters India at an elevation of about 660 m near Monku. In Arunachal Pradesh, Tsangpo is better known as Siang. After traversing a distance of 200 Km Siang enters Assam at Pasighat which is Assam-Arunachal border at an elevation of around 50m. Siang meets Lohit and Dibang in Sadiya at an elevation of 50 m. At the confluence of Lohit, Dibang, and Siang, the Siang contributes about 31.63% of the total discharge of Brahmaputra (Sarma, 2004). The three rivers meet and flow as the Brahmaputra together in Assam. In Assam, Brahmaputra River is contributed by numerous tributaries both on the north bank and the south bank. The slope of the Brahmaputra River in Assam is relatively flatter (Figure 30). The river has a braided nature when it flows through the alluvium of Assam except at Pandu where the channel flows as a single channel of around 1.2 km.

Chapter 8
BANKLINE EROSION/DEPOSITION

The factors responsible for the changes in alluvial channels and rate of meander migration include water discharge, the character of the bank material, and height of the concave bank, presence or absence of vegetation and sediment supply (Hicking and Nanson, 1975). Floods of very high magnitude may be a contributing factor to channel widening and river bank erosion along with associated changes in the channel pattern (Schumm and Lichty, 1963; Schumm, 1968). The erosion process may be triggered by the channels during the high floods which result in the undercutting of the upper bank materials.

7.1 Decadal Analysis of Erosion Deposition

A comparative decadal analysis of banklines has been conducted from 1973-74 to 2008-11 for both the banks of the river Brahmaputra as well as across 50 km length reach-wise in Assam.

7.1.1 Methodology

A comparative study has been carried out using the datasets of 1973-74, 1976-80, 1993-95, 2003-04 and 2008-11. The overall erosion–deposition phenomenon considering the left bank and right bank were analyzed. The right and the left bank of the river Brahmaputra were digitized manually in ArcGIS. The bank lines of different time periods were then overlaid and polygon shapefiles are created wherever changes are observed showing erosion and deposition. The areas of the polygons are then calculated to quantify the amount of erosion and deposition along the banks. The whole river was divided into 13 reaches at 50 km interval and then reach-wise amount of erosion has been calculated for different decades on both the banks (Table 2 & 3). From these amount of erosion over different decades, the decadal change in the rate of erosion is then calculated for each reach in Microsoft Excel and plotted accordingly. The reach-wise decadal analysis of erosion-deposition has been carried out for the decades 1973-74 to 1976-80, 1976-80 to 1993-95, 1993-95 to 2003-04, 2003-04 to 2008-11 and 2008-11 to 2016-17.

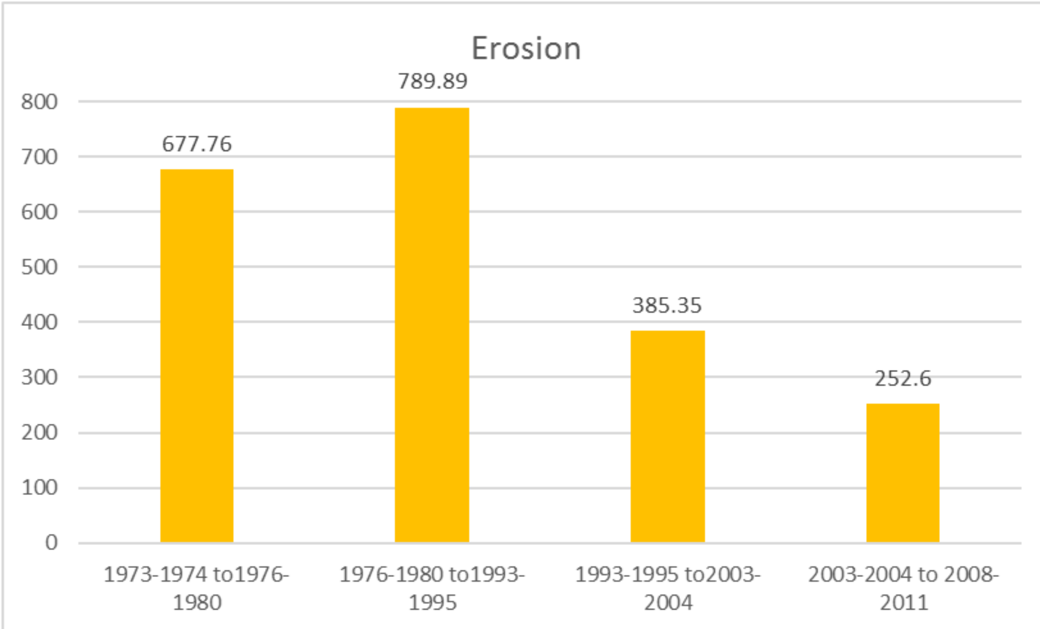

Figure 31: Total amount of Erosion in Brahmaputra over different decades

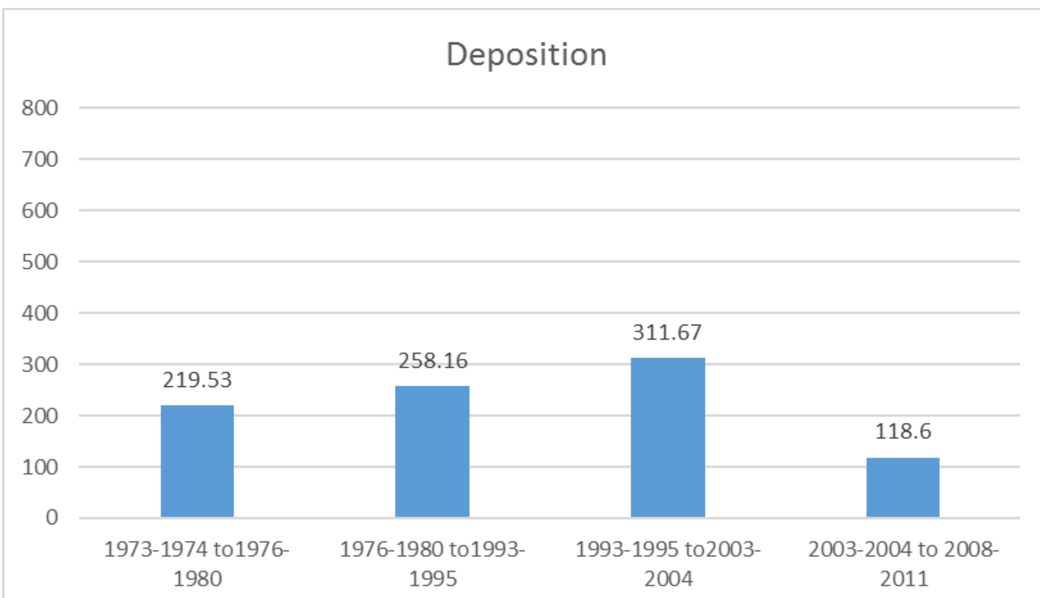

Figure 32: Total amount of Deposition in Brahmaputra over different decades

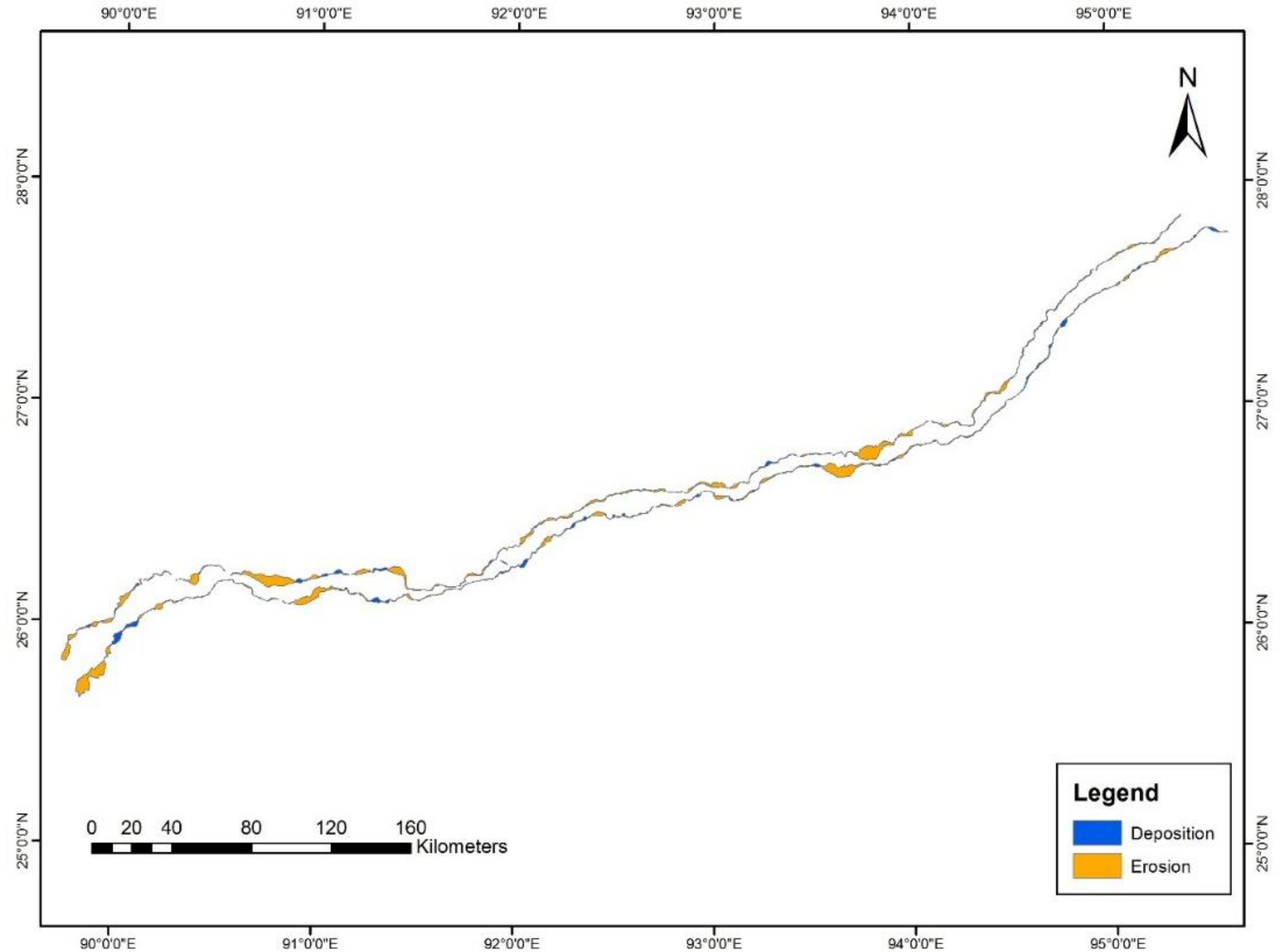

Figure 33: Map showing erosion-deposition along the Brahmaputra river over the period 1973-74 to 1976-1980

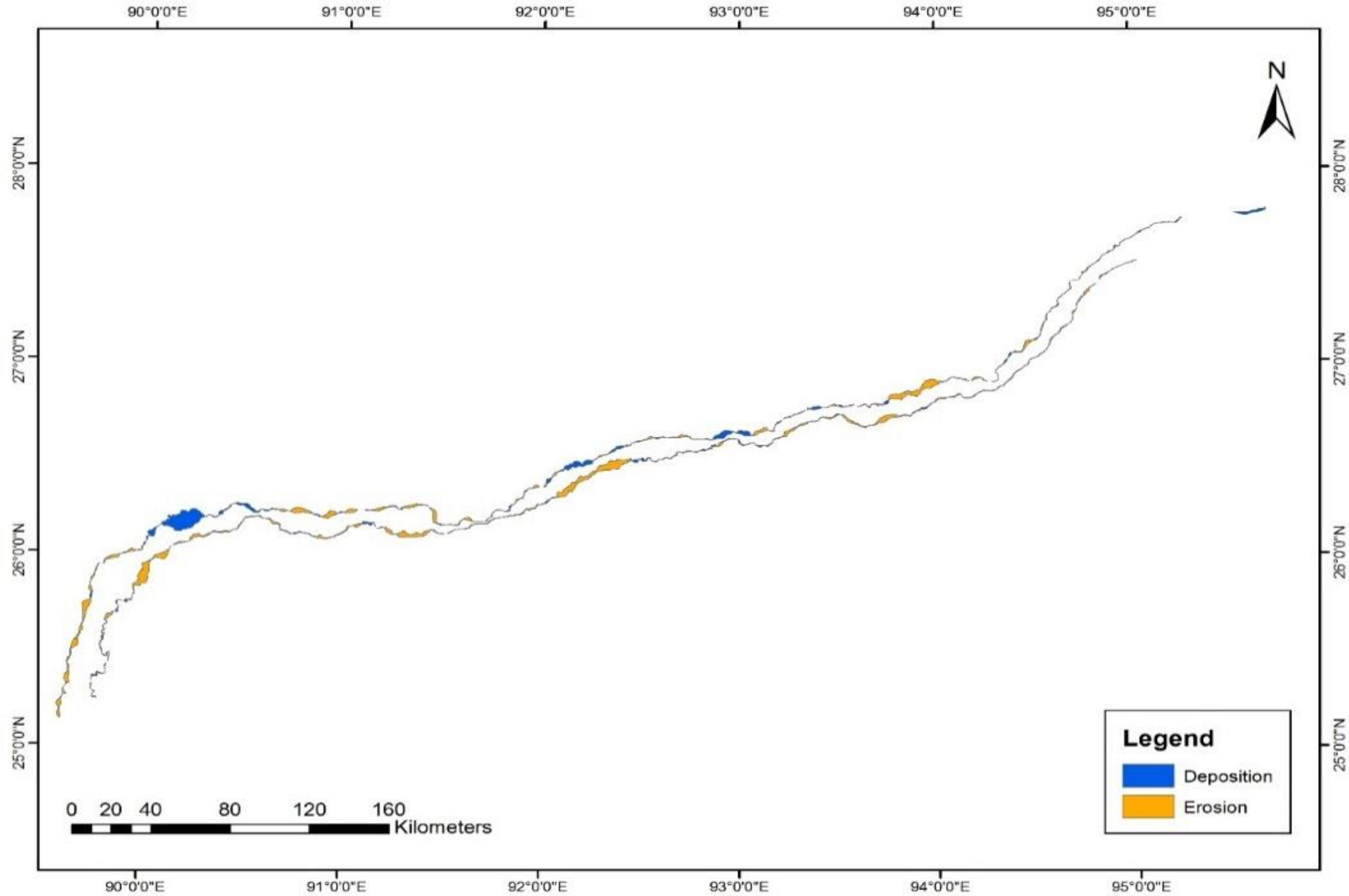

Figure 34: Map showing erosion-deposition along the Brahmaputra river over the period 1976-1980 to 1993-1995

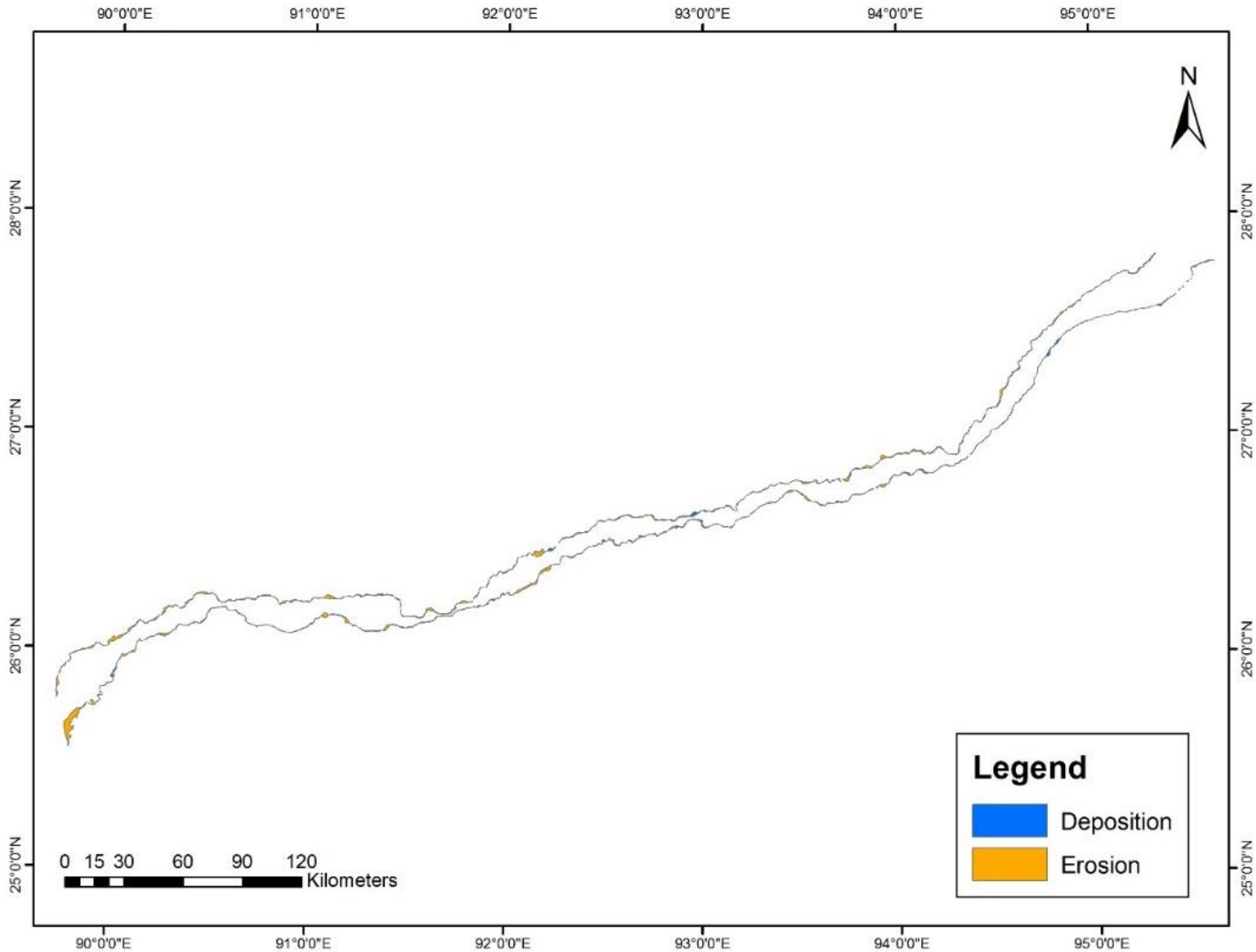

Figure 35: Map showing erosion-deposition along the Brahmaputra river over the period 1993-1995 to 2003-2005

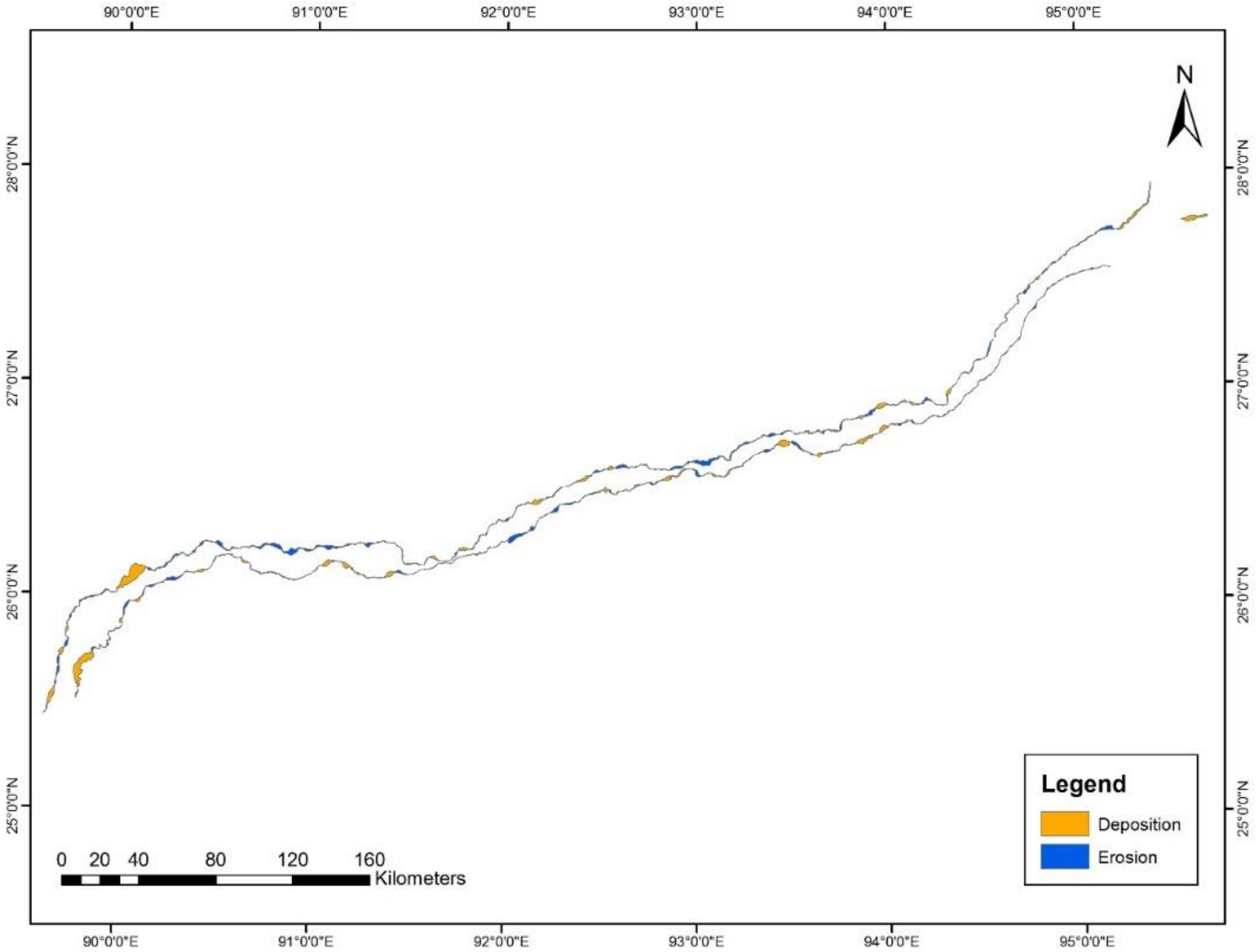

Figure 36: Map showing erosion-deposition along the Brahmaputra river over the period 2003-2005 to 2008-11

7.1.2 Reach-wise Decadal Estimation of Erosion/Deposition

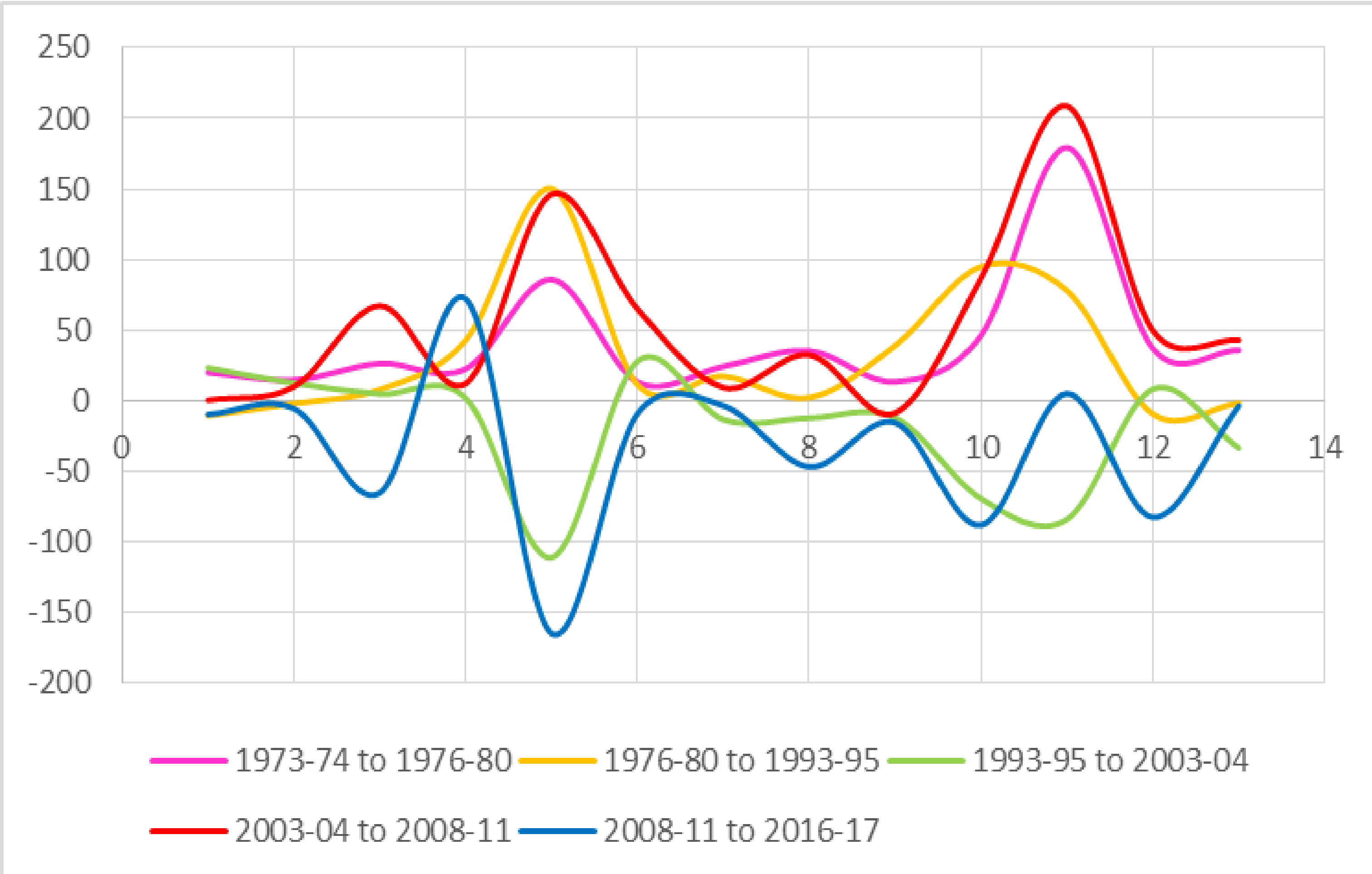

Figure 37: Reach-wise distribution of amount of erosion in different decades on the right bank of Brahmaputra

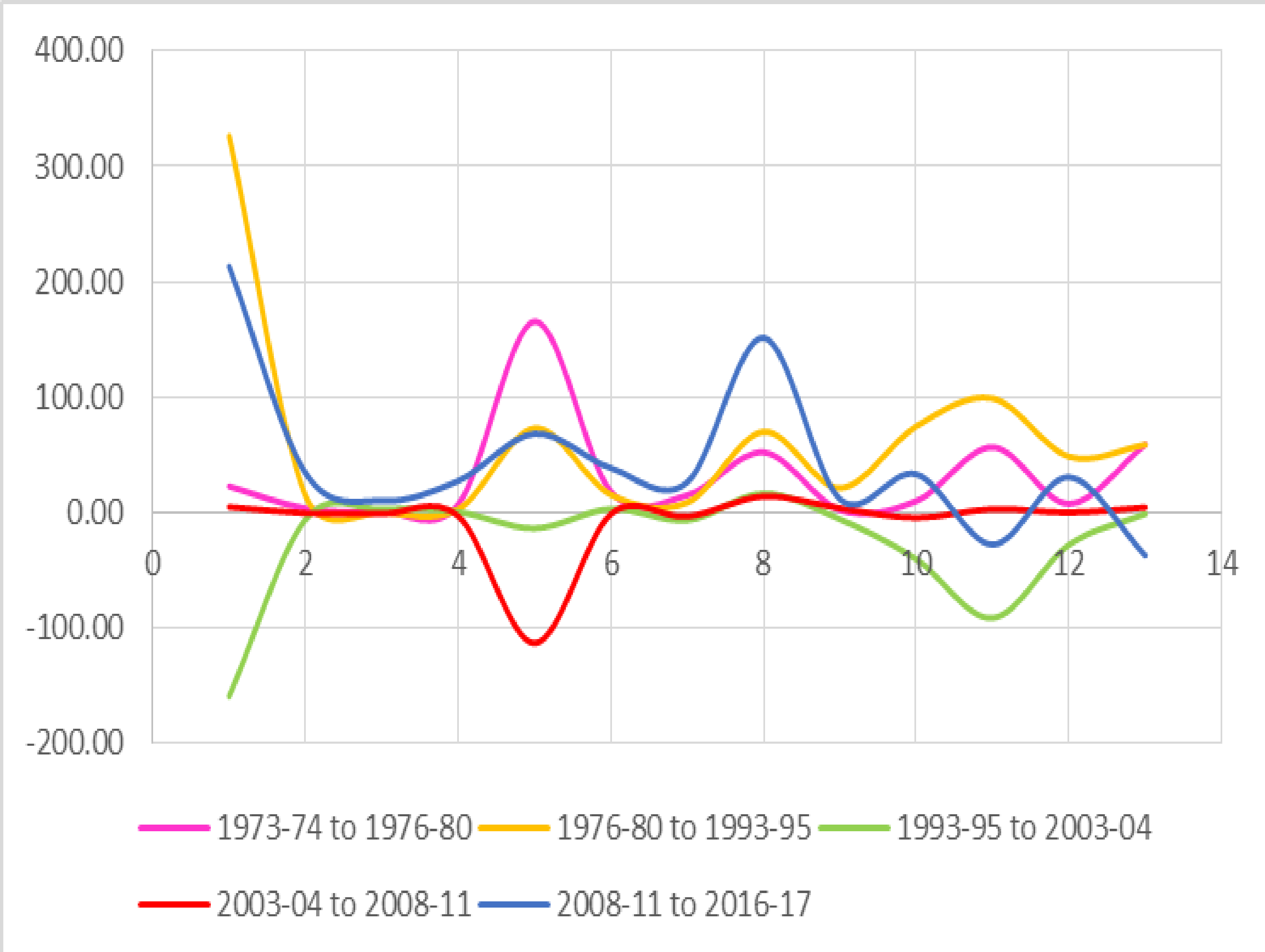

Figure 38: Reach-wise distribution of amount of erosion in different decades on the left bank of Brahmaputra

Table 2: Reach-wise amount of erosion in different decades on the right bank of Brahmaputra

Year/Amount of Erosion (sq.km.)	1	2	3	4	5	6	7	8	9	10	11	12	13
1973-74 to 1976-80	19.82	14.49	26.23	22.42	85.87	13.11	24.14	35.26	13.27	46.02	179.29	36.82	35.61
1976-80 to 1993-95	-10.83	-2.23	7.75	42.56	150.15	11.31	17.20	1.93	38.92	94.83	77.87	-9.57	-1.85
1993-95 to 2003-04	23.21	12.24	4.66	1.65	-111.30	27.83	-13.60	-12.46	-12.19	-69.58	-84.29	8.05	-33.76
2003-04 to 2008-11	0.17	9.72	67.15	11.94	146.23	64.98	9.10	32.24	-8.88	86.67	208.75	49.51	42.79
2008-11 to 2016-17	-9.95	-5.71	-65.55	72.16	-165.27	-9.43	-3.74	47.170	-15.78	-88.50	4.93	-82.89	-3.99

Table 3: Reach-wise distribution of amount of erosion in different decades on the left bank of Brahmaputra

Year/Amount of Erosion (sq.km.)	1	2	3	4	5	6	7	8	9	10	11	12	13
1973-74 to 1976-80	22.42	3.24	0.33	6.97	165.41	17.86	14.68	51.93	2.02	9.67	56.43	7.33	58.67
1976-80 to 1993-95	326.37	13.90	0.31	2.59	72.81	15.18	8.37	69.78	20.99	74.62	98.89	48.19	58.48
1993-95 to 2003-04	-159.68	-6.17	2.46	0.17	-13.94	2.94	-6.97	16.24	-6.11	-40.82	-91.86	-28.23	-1.46
2003-04 to 2008-11	4.55	-0.75	-1.262	-3.44	-113.60	-1.483	-3.67	13.76	3.48	-4.77	2.81	-0.26	4.15
2008-11 to 2016-17	213.30	33.85	9.77	27.17	68.07	38.29	25.98	151.46	11.24	33.00	-28.08	30.41	-37.56

7.1.3 Reach-wise rate of erosion

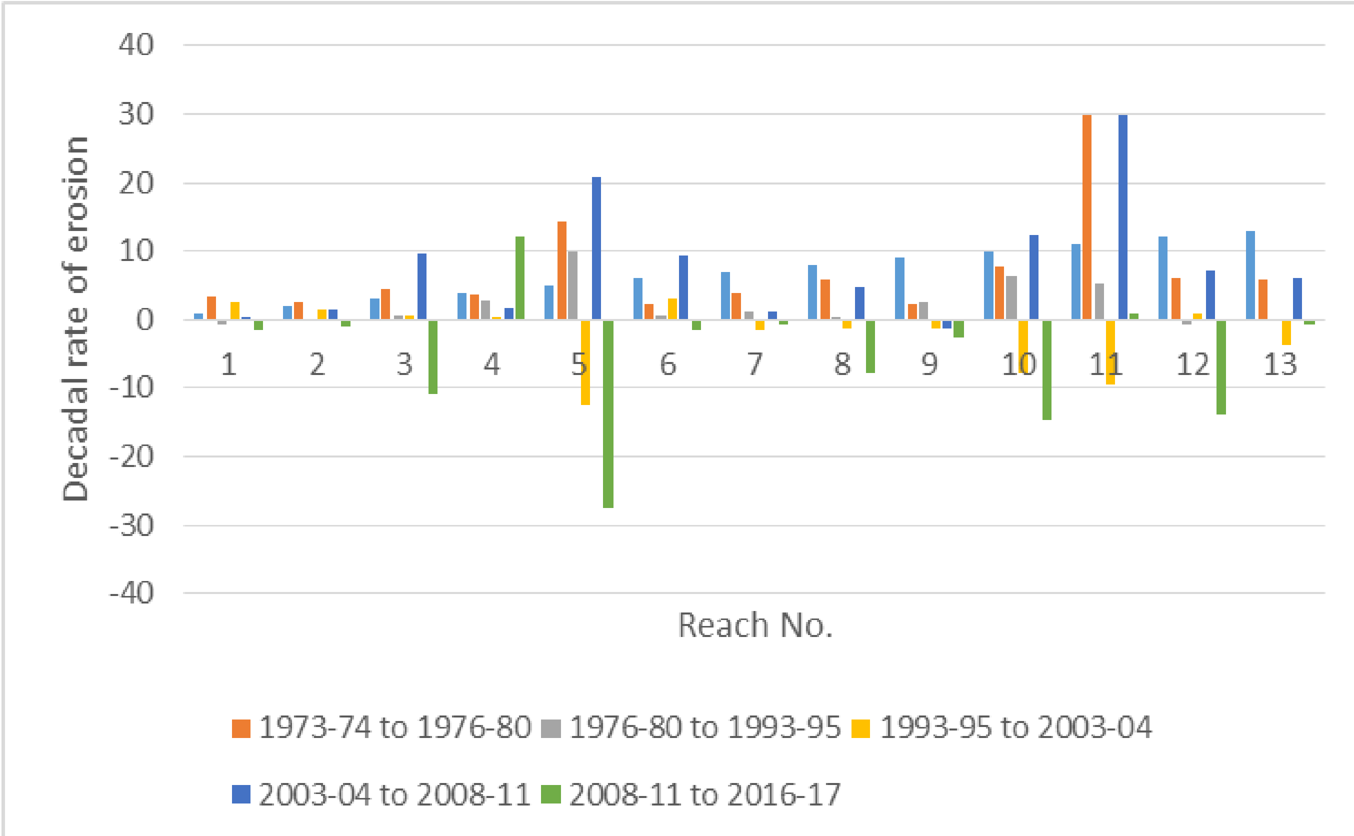

Figure 39: Reach-wise rate of erosion in different decades on right bank

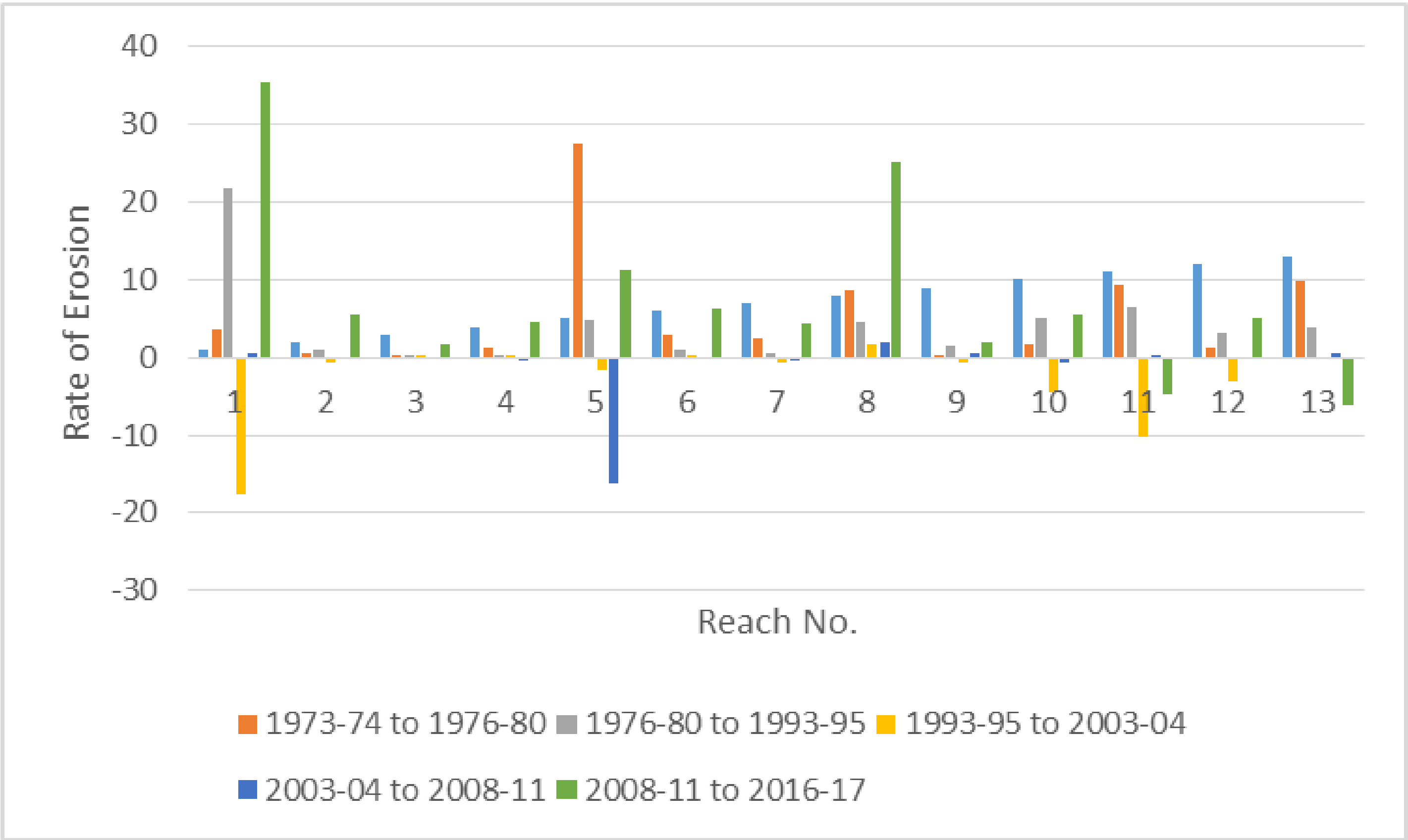

Figure 40: Reach-wise rate of erosion in different decades on left bank

7.1.4 Observations

From the study, it has been estimated that in the Brahmaputra river a total erosion of 677.76 sq.km and deposition of 219.53 sq.km occurred over the time period 1973-74 to 1976-80, erosion of 789.32sq.km and deposition of 258.54sq.km occurred during the span of 1976-80 and 1993-1995, erosion of 385.35 sq.km and deposition of 311.67 sq.km occurred during 1993-95 and 2003-05, and erosion of 252.6sq.km and deposition of 118.6 sq.km occurred during 2003-05 and 2008-11. Figure 31 & 32 shows the total amount of erosion and deposition occurred over different time periods respectively. A decreasing trend in overall erosion pattern has been observed in this study. From the decadal analysis of reach-wise erosion estimation, it can be inferred that in the river Brahmaputra, the processes of erosion/deposition occurs alternatively in different decades. From the study it has been observed that on the right bank, deposition is happening in the recent decade almost in all the reaches except for the reach 4 (Figure 37 & 39). The reach 4 on right bank is facing erosion where the Majuli island resides. However, on the left bank the severity of the erosion problem is more at present time. The highest amount of erosion on the left bank has been observed in reach 1 where the Dibru-Saikhowa National Park and Dibrugarh city lies and in reach no. 8 where lies the Lahorighat, Morigaon area (Figure 38 & 40).

7.2 District-wise Erosion Deposition Analysis

District wise erosion deposition analysis has been conducted to assess the more erosion prone districts. All total of 24 districts are taken into consideration along both the banks.

7.2.1 Methodology

The banklines of toposheet of the year 1973-94 has been used as a base year bank line. The right bank and the left banks are compared with the base year bankline considering all the districts of Assam. The erosion area and erosion lengths are calculated using polygon and polyline shapefiles for all the districts.

7.2.2 Observations

From the district-wise erosion-deposition analysis it has been found that on the right bank, Barpeta district is facing more erosion while on the left bank Morigaon district is facing acute erosion problem. In 2016-17 the erosion area in Barpeta district is found to be around 1527.74 sq.km from the base year i.e. from 1973-74 and the amount of erosion in Morigaon district is found to be 628.07 sq.km from the base year to 2016-17 (Figure 41 & 42). The maximum length of erosion from the base year to the recent year has been observed in Dhemaji district (Figure 43 & 44).

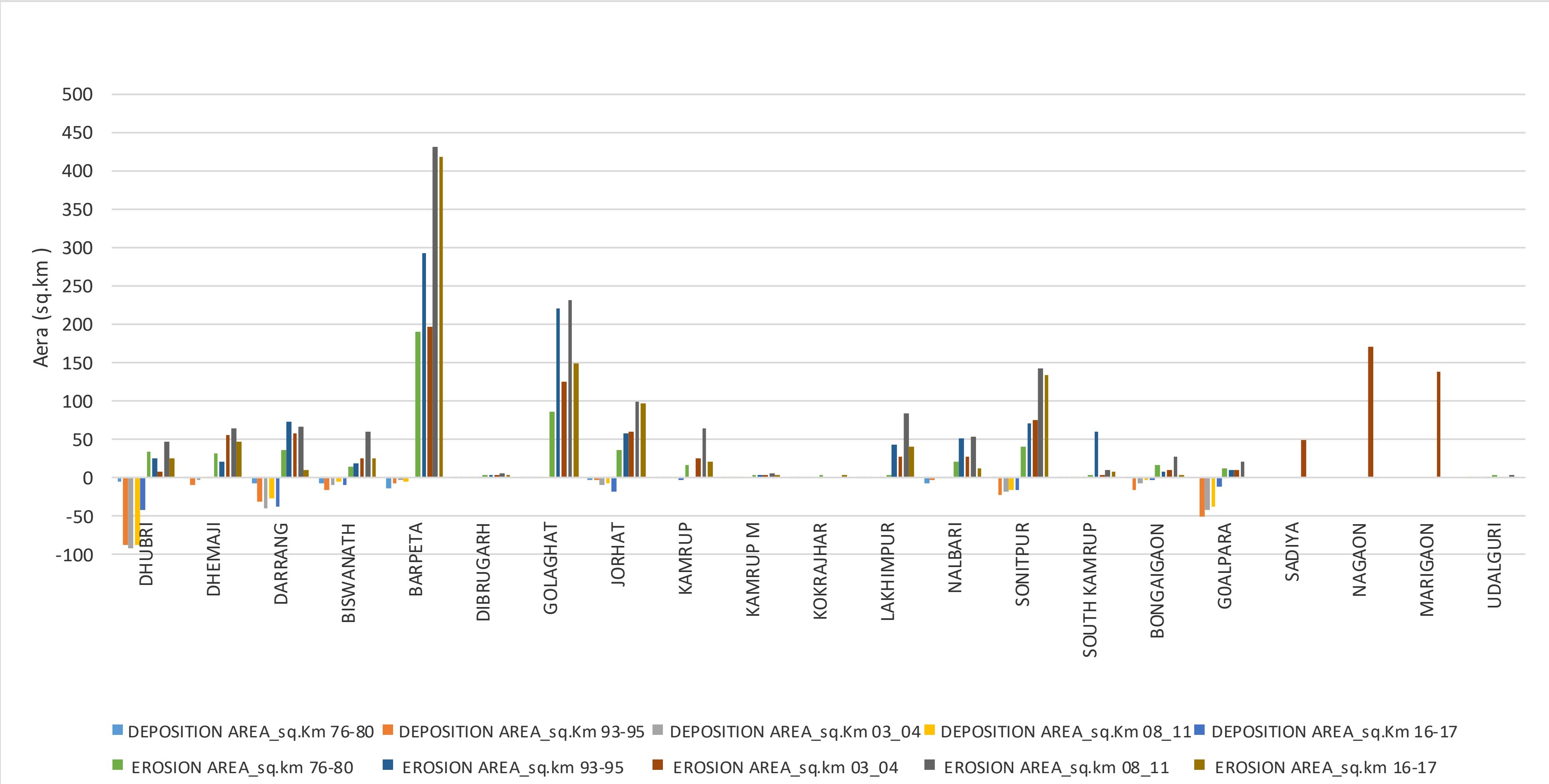

Figure 41: District-wise estimation of Erosion/Deposition Area with reference to the base year (1973-74) on the right bank of Brahmaputra

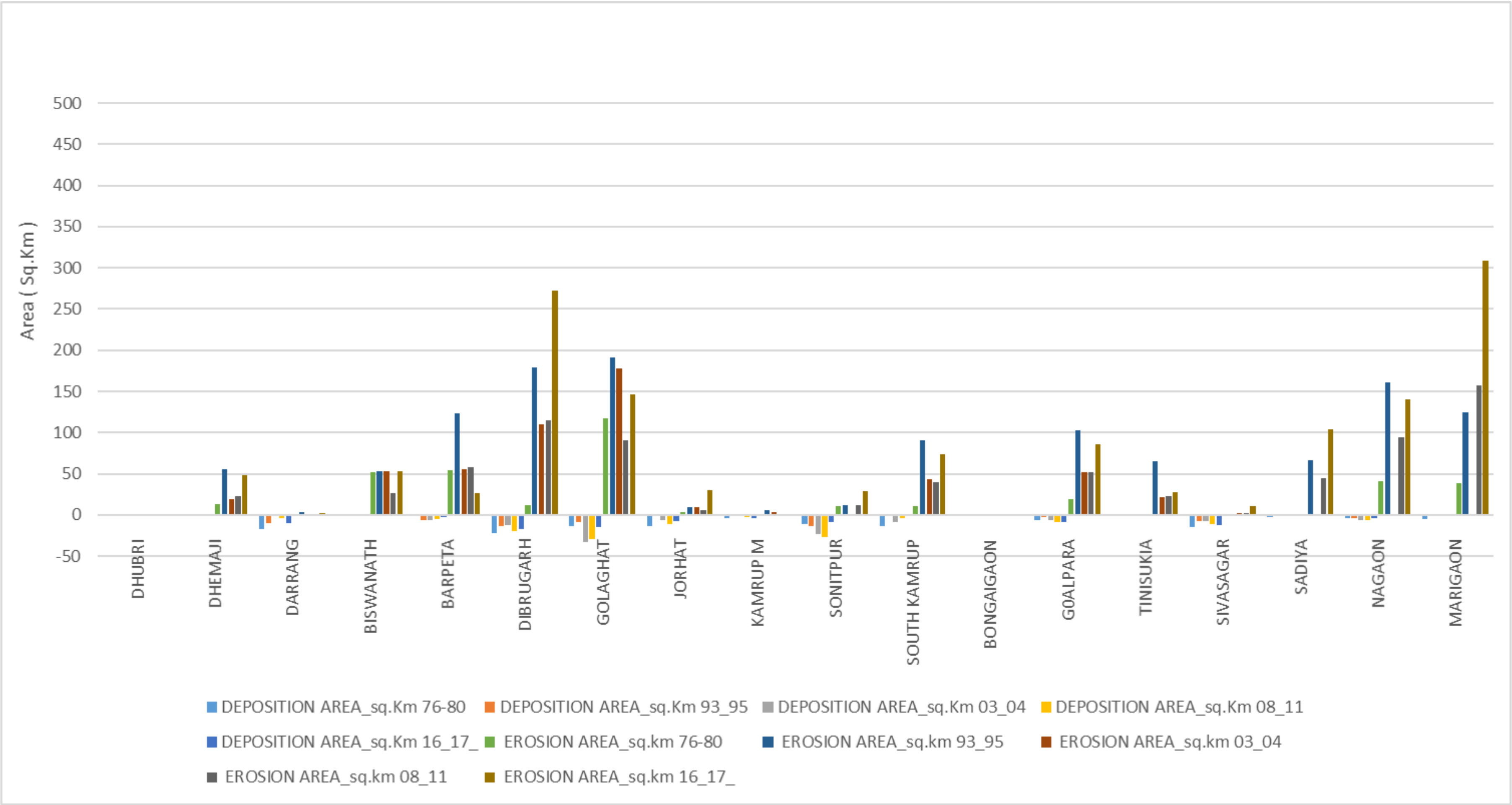

Figure 42: District-wise estimation of Erosion/Deposition Area with reference to the base year (1973-74) on the left bank of Brahmaputra

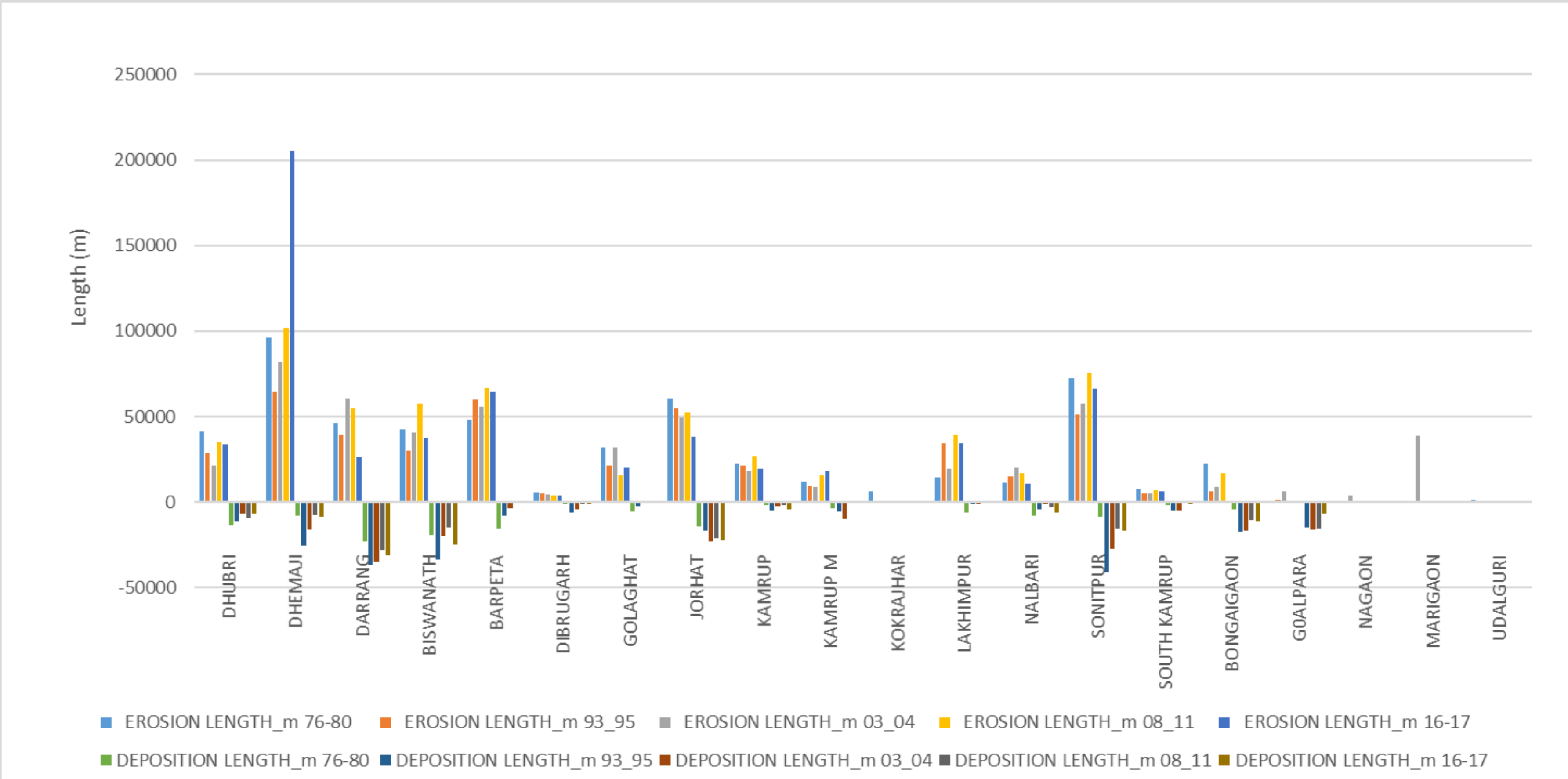

Figure 43: District-wise estimation of Erosion/Deposition Length with reference to the base year (1973-74) on the right bank of Brahmaputra

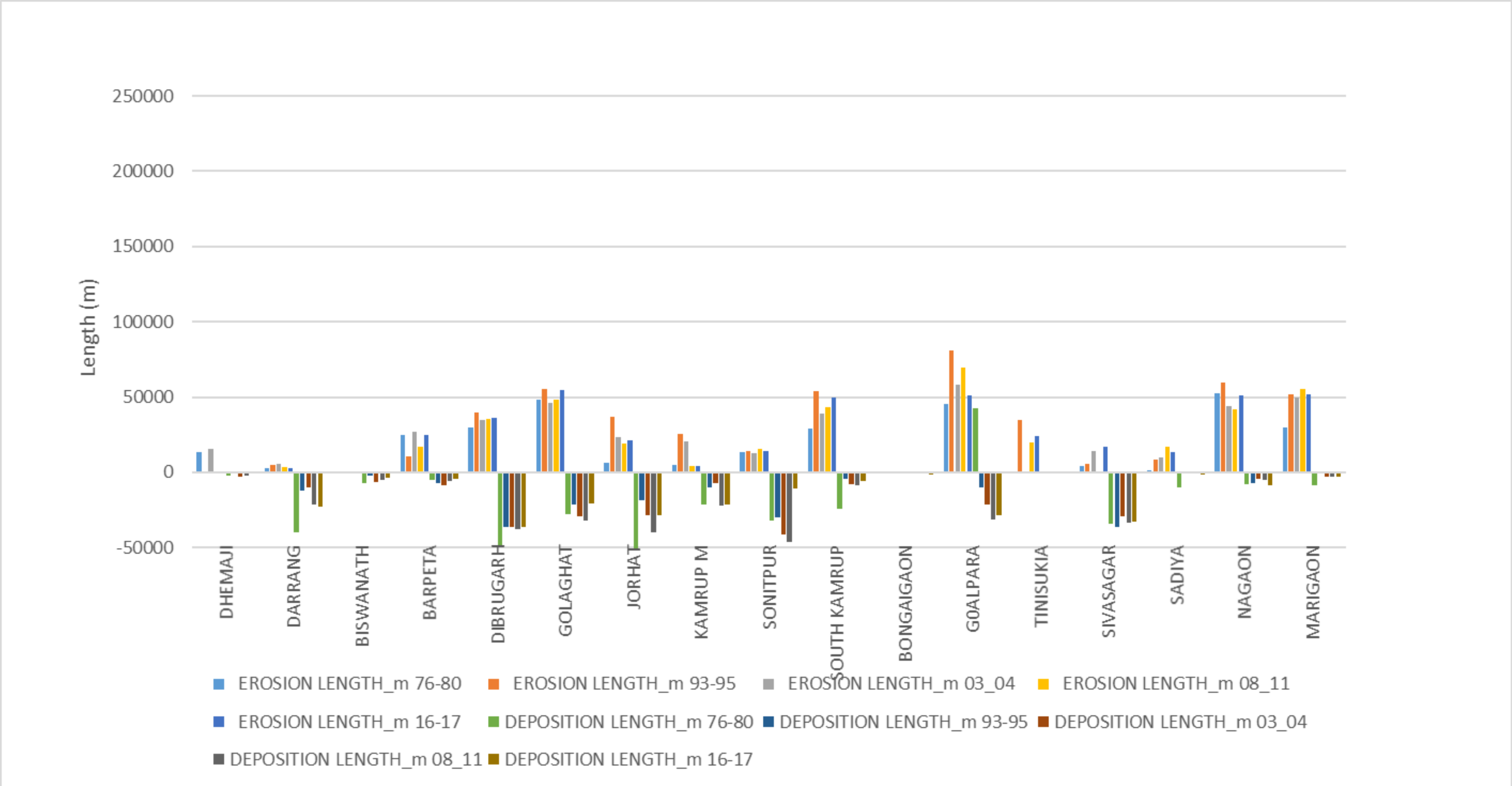

Figure 44: District-wise estimation of Erosion/Deposition Length with reference to the base year (1973-74) on the left bank of Brahmaputra

Chapter 9
MORPHOLOGICAL PARAMETER ANALYSIS

Horton (1932) in his studies reveals about the drainage basin characteristics and its need for assessing the groundwater recharge zone studies. Chow (1964) stated influence of the geological parameters on construction the recharge structures. Morphometric analysis of stream networks have been used to quantitatively describe stream basins with the goal of understanding their processes and evolution (Horton, 1945; Strahler, 1952, 1957 & 1964).This quantitative Morphometric analysis of watersheds was continued by a series of methodological and theoretical papers spanning more than a quarter century Schumm 1956).Jamieson et al (2004) showed that tectonic zones in the Indus Valley of Ladakh, in north India, can be differentiated using morphometric analyses of longitudinal valleys. Watersheds draining one of the tectonic zones were shorter, narrower, and had lower hypsometric integrals than the other two. These watersheds have been influenced by thrust propagation that has led to erosion and increased sediment delivery to the main stream of the river and elevated local base levels. Morphometric analysis through remote sensing and GIS techniques have been attempted by a number of researchers [Nautiyal, 1994; Srivastava, 1997; Nag, 1998; Agarwal, 1998; Biswas,et al., 1999; Singh et, al., 1997; Vittala et al 2004] and all have arrived to the conclusion that remote sensing and GIS are the powerful tools for studying basin morphometry and continuous monitoring. Zende and Nagrajan (2011) have studied Krishna basin for the quantitative analysis of morphometric parameter, using GIS software and utilized for watershed prioritization for soil and water conservation, flood prediction and natural resources management. The landforms are important from the hydrological point of view and include the linear, aerial and relief aspects of the drainage basin.

9.1 Plan form Index (PFI)

Shape of river in plan is an important parameter in context of hydraulic design such as bridges, spur etc. In general, the plan forms of alluvial rivers can be classified as (i) Braided, (ii) Straight and (iii) Meandering. To identify the degree of braiding in highly braided river, Sharma (1995) proposed Plan Form Index (PFI). PFI reflects the fluvial landform disposition

with respect to a given water level and its lower value is indicative of higher degree of braiding.

Plan Form Index represents the percentage of actual flow width per braided channel. It can be computed as,

$$\text{Plan Form Index} = \frac{T \times 100}{B \times N}$$

where , T = flow top width; B= overall width of the channel ; N = number of braided channels.

For providing a broad range of classification of the braiding phenomenon, the following are the threshold values for PFI-

Highly Braided: PFI < 4
Moderately Braided: 19 > PFI > 4
Low Braided: PFI > 19

9.1.1 Methodology

In this study, the Plan Form Indices were computed for every 10 km reach starting from upstream of Brahmaputra near Sadiya to the downstream at Dhubri, Assam (Figure 47). A sample calculation of PFI is shown in Figure 48. The cross section indicating highest braiding within each of the reaches was selected on the basis of visual analysis and corresponding PFI were computed. These exercises had been performed for all the datasets and were tabulated as Annexure III. The plot of the PFI for different years are presented from Figure 49 to 53.

9.1.2 Observations

From the Planform Index (PFI) analysis, it has been found in the extreme upstream and extreme downstream portion within India, the river is highly braided in nature while the middle portion of the river is moderately braided. However, from 2003-04 onwards braiding in the middle portion of the river has also increased.

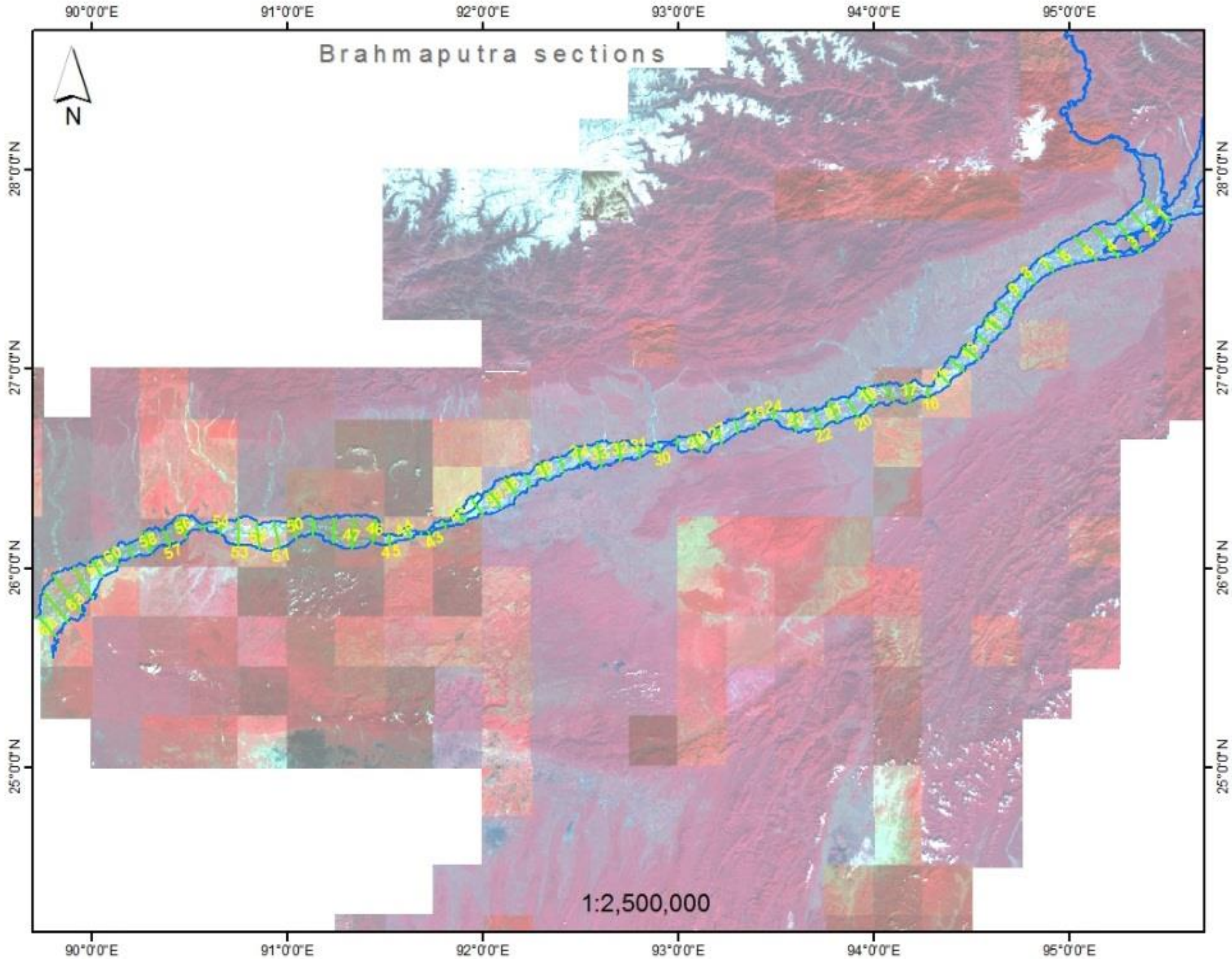

Figure 45: Sections of Brahmaputra identified for PFI calculations

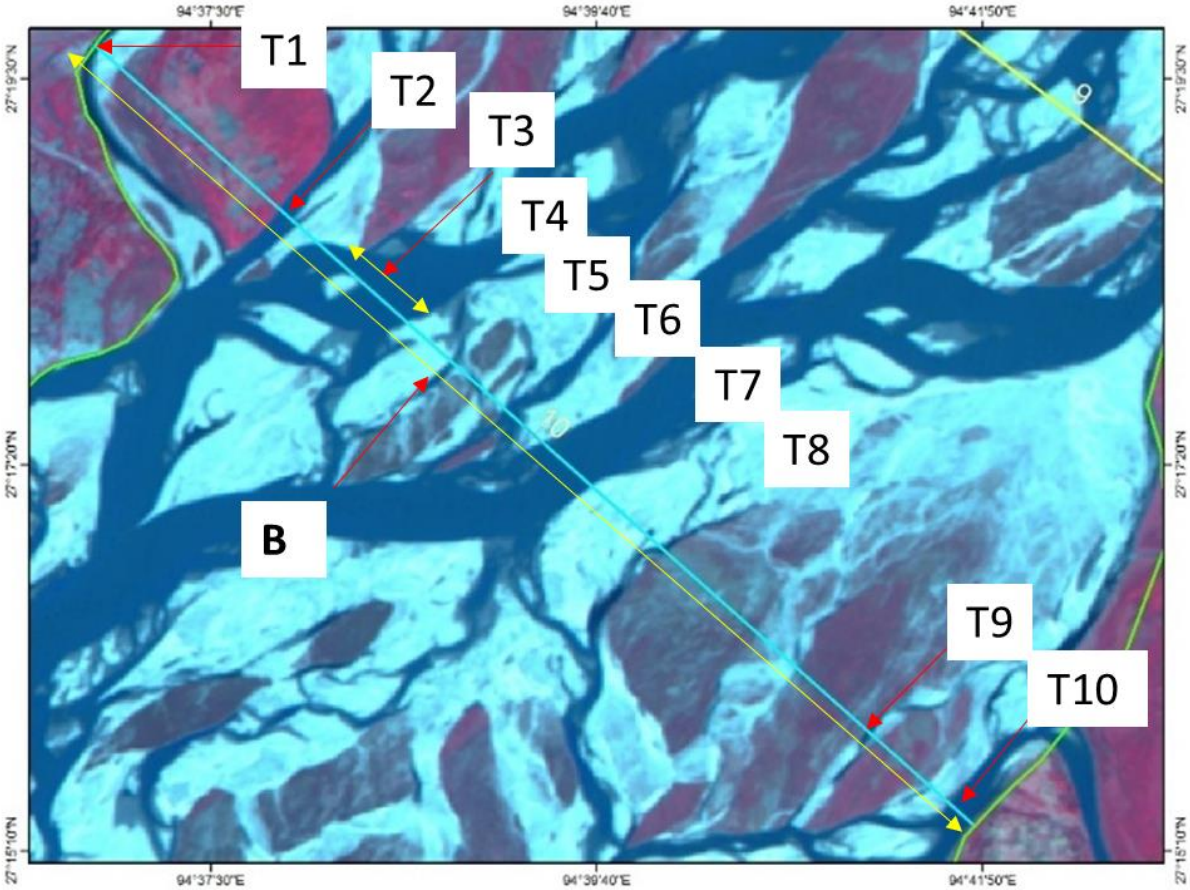

Figure 46: PFI calculation at Reach No. 10 of Brahmaputra River (2008-2011)

From Figure 48,

$$T = T1+T2+T3+T4+T5+T6+T7+T8+T9+T10$$

$$= 4.2 \text{ km}$$

$$B = 11.3 \text{ km}$$

$$N = 10$$

$$PFI = \frac{4.2 \times 11.3 \times 100}{10}$$

$$=3.72\ (< 4), \text{ Highly Braided}$$

The computed PFI values were plotted against the reach number and is shown in Figure 49 to 53.

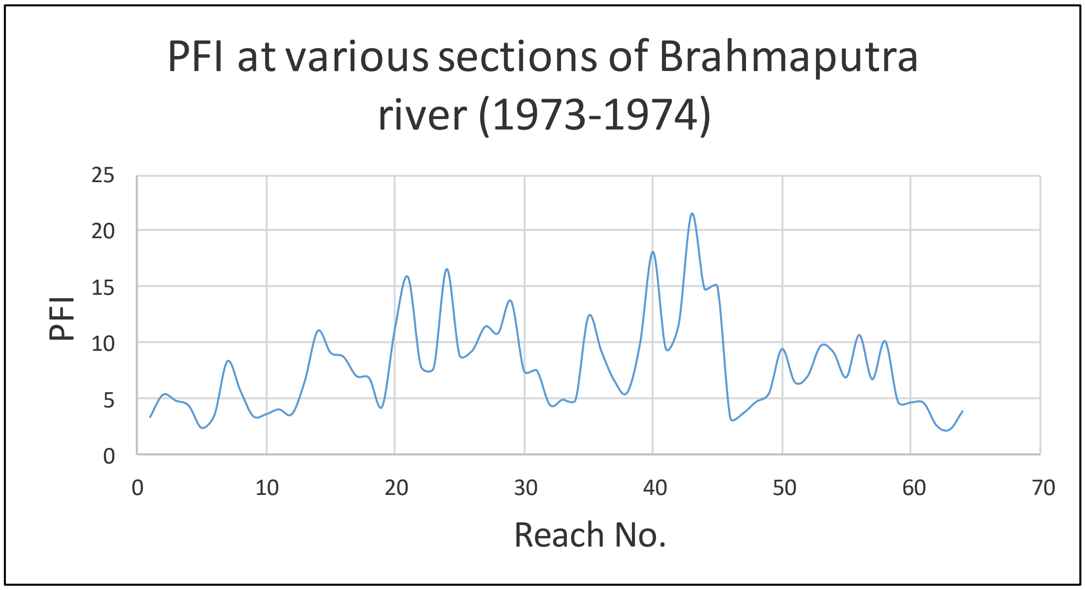

Figure 47: PFI of Brahmaputra for the year 1973-74

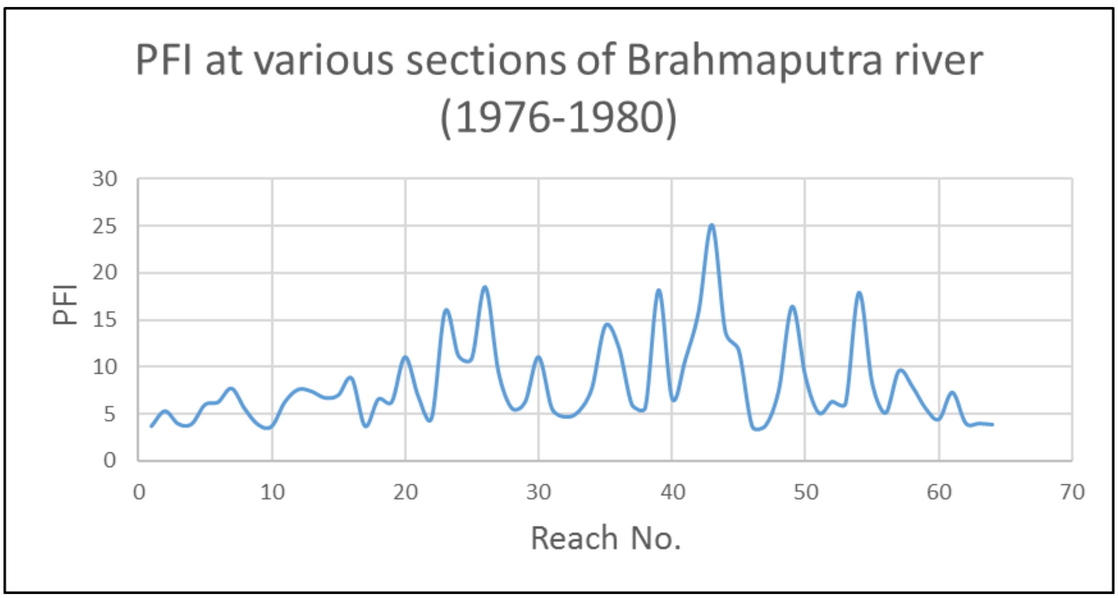

Figure 48: PFI of Brahmaputra for the year 1976-80

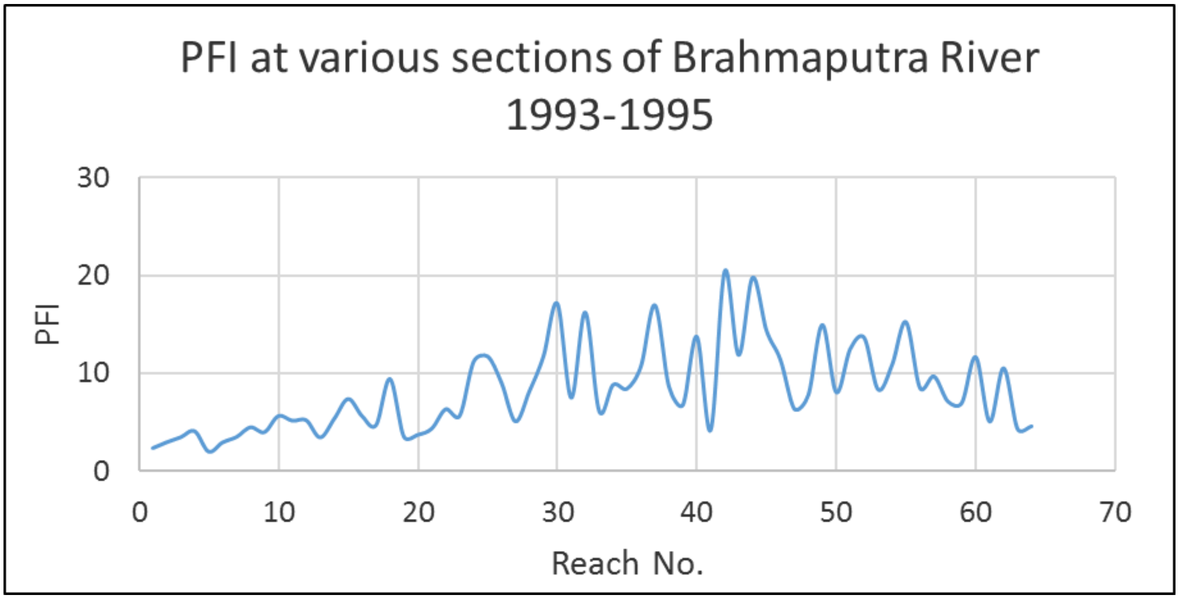

Figure 49: PFI of Brahmaputra for the year 1993-95

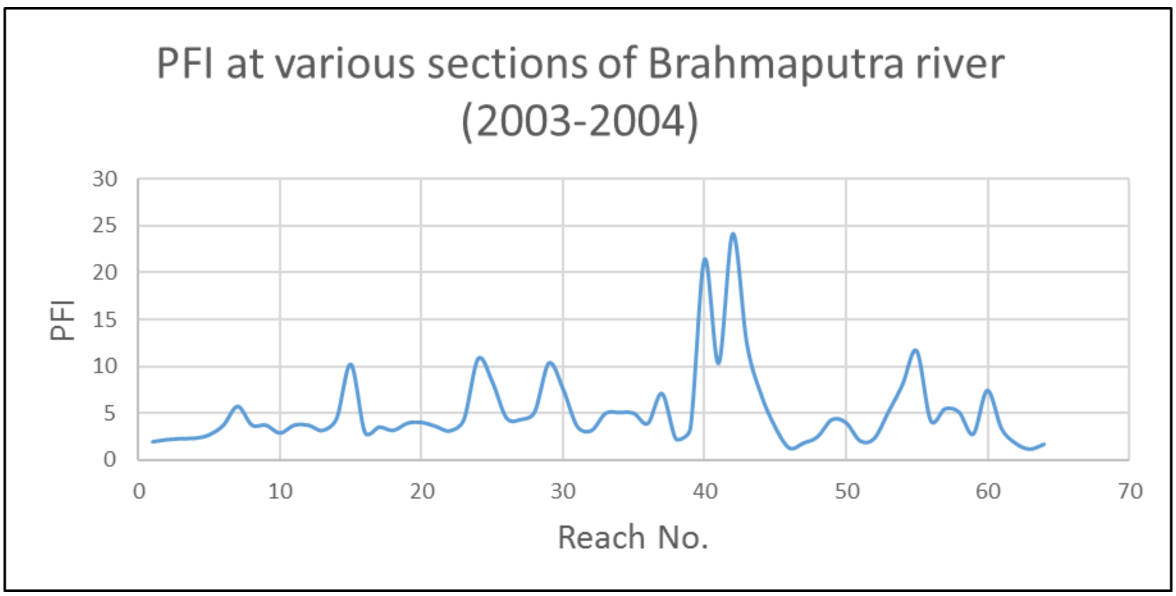

Figure 50: PFI of Brahmaputra for the year 2003-04

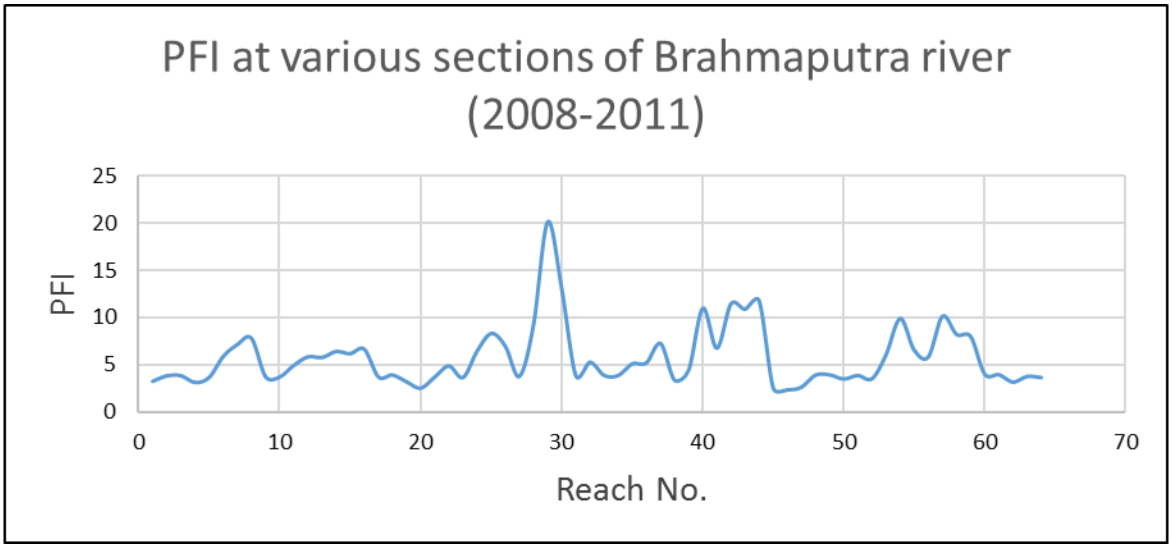

Figure 51: PFI of Brahmaputra for the year 2008-11

9.2 Watershed Delineation

A watershed is the area of land draining into a stream at a given location [Chow, 1964]. The watershed analysis is very essential for the management and planning of natural resources. For this, a proper boundary of a channel and the area of influence is of utmost importance. To study the basin characteristics morphometric analysis is the most indispensable part of geomorphology. The first step is to delineate the watershed from DEM. Watershed analysis based on morphometric analysis is very important for watershed planning and management.

9.2.1 Methodology

The watershed delineation in Arc GIS can be done by using the hydrology sub tool of Spatial Analyst tool. Flow across a surface will always be in the steepest downslope direction. A stream network is also required. To create the stream network it is necessary to calculate the flow accumulation each cell location. For delineation of the watershed it is essential to define a pour point. These points are generally taken as the locations at the mouth of the river or at the gauging stations. The flow chart in Figure 54 shows the procedure of watershed delineation from DEM using hydrology tool of ArcGIS.

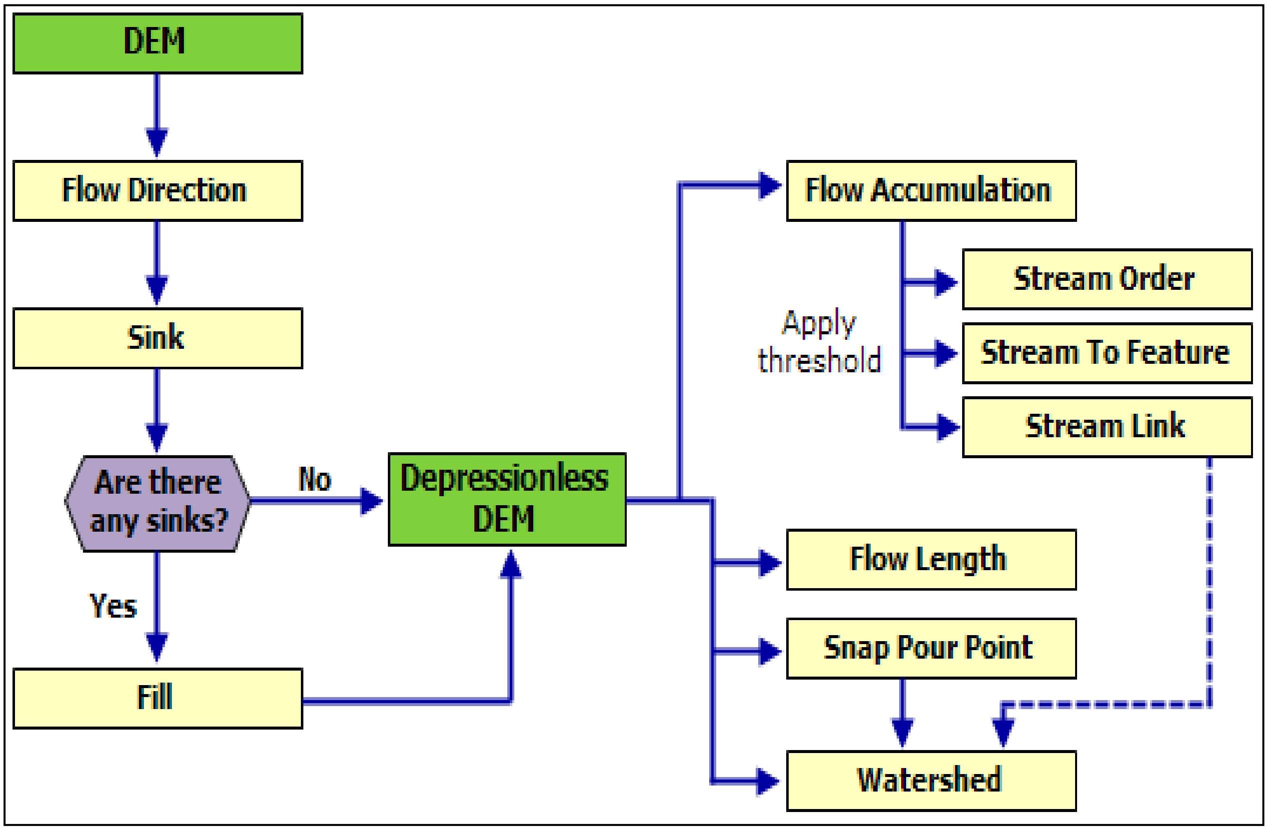

Figure 52: Flowchart showing delineation of watershed

Source: ESRI ArcMap (http://desktop.arcgis.com/en/arcmap/10.3/tools /spatial-analyst-toolbox/deriving-runoff-characteristics.html)

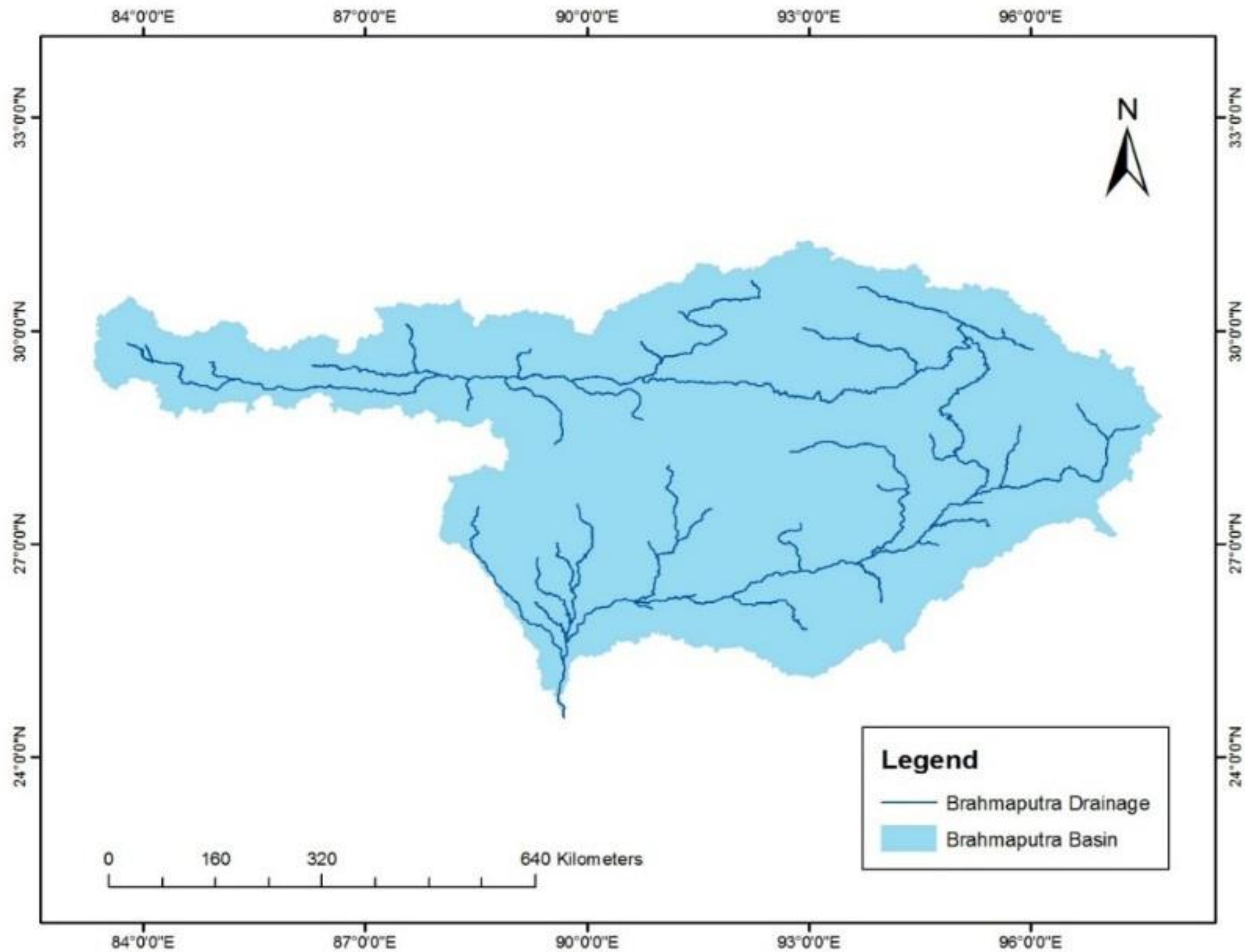

Figure 53: Delineated watershed of Brahmaputra

9.2.2 Observations

The watershed of the Brahmaputra is delineated using SRTM DEM of 90 m resolution and the flow accumulation and flow direction maps were generated. The location of the pour point was taken at 89°40'23.35"E and 24°32'41.191"N. A conditional flow accumulation raster (stream raster) was generated using a threshold value of 3000 which was decided by trial and error method. The area and the perimeter of the Brahmaputra watershed are found to be 502304.37 km^2 and 6383.86 km respectively. The delineated watershed of Brahmaputra is shown in Figure 55.

9.3 Mophometric parameter analysis

Morphometric analyses of Brahmaputra Basin were carried out using the delineated watershed. The generated streams were compared with toposheets to finalize the threshold value. The stream order was then generated using Strahler's method in ArcGIS where conditional flow accumulation and flow direction were given as input. The parameters were then calculated from the attributes generated in the attribute table.

9.3.1 Bifurcation Ratio (R_b)

According to Strahler, the bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1). If the bifurcation ratio of a river network is low, there is a higher chance of flooding. The bifurcation ratio can also show which parts of a drainage basin is more likely to flood, comparatively, by looking at the separate ratios. The bifurcation ratio is dimensionless property and generally ranges from 3.0 to 5.0. The estimated bifurcation ratios for different stream orders of Brahmaputra are presented in Table 4.

Table 4: Number of segments and total lengths of all the segments of various order

Sl. No	Stream Order	Number of Segments (N_μ)	Length (L_u)
1	1	6147	41385.33 km
2	2	2791	19687.56 km
3	3	1603	10344.26 km
4	4	767	5104.03 km
5	5	518	3080.77 km
6	6	169	901.91 km
7	7	279	1913.65 km

$$R_b = \frac{N_\mu}{N_{\mu+1}}$$

R_{b1} = 6147/2791 = 2.20

R_{b2} = 2791/1603 = 1.74

R_{b3} = 1603/767 = 2.09

R_{b4} = 767/518 = 1.48

R_{b5} = 518/169 = 3.06

R_{b6} = 169/279 = 0.61

From the analysis it has been found that the bifurcation ratios of different stream orders are less than 3 except for R_{b5}. It can also be attributed that bifurcation ratio of higher stream orders have a greater risk of flooding.

9.3.2 Drainage Density (D_d)

The drainage density, which is expressed as km/ km^2, indicates a quantitative measure of the average length of stream channel area of the watershed. In Brahmaputra basin drainage density was found to be 0.164 km/km^2 which is low. In general when the D_d is very low, intense rainfall events are more likely to result in high discharge to a few streams and therefore a greater likelihood of flashy discharge and flooding. However, more analysis on sub-basin level can be carried out to see which basins are actually prone to flash flooding.

Area of the basin, A = 502304.37 km^2

$D_d = \frac{\sum L_u}{A}$ (km/sq km)

D_d= (41385.33+19687.56+10344.26+5104.03+3080.77+901.91+1913.65)/502304.37

= 0.164 km/km^2

9.3.3 Stream Frequency (F_s)

The number of stream segments per unit area is termed as Stream Frequency or Channel Frequency or Drainage Frequency (Fs) Horton (1945). The basins of the structural hills have higher stream frequency, drainage density while the basins of alluvial has minimum.

$$F_s = \frac{\sum N_\mu}{A}$$

F_s = (6147+2791+1603+767+518+169+279)/502304.37 = 0.0244km$^-$

9.2.4 Form factor (F_f)

Form factor is the numerical index (Horton, 1932) commonly used to represent different basin shapes. The value of form factor is in between 0.1-0.8. Smaller the value of form factor, more elongated will be the basin. The basins with high form factors 0.8, have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration. The value of form factor would always be less than 0.754 (for a perfectly circular watershed)

Length of the basin, L_b = 2257.79 km

F_f = 502304.37/ (2257.79)^2 = 0.0985

9.3.5 Drainage Factor (D_f)

$$D_f = \frac{F_s}{D_d^2}$$

D_f = 0.0244/ (0.164)^2

= 0.907

9.2.6 Circulatory Ratio (R_c)

The circularity ratio is a similar measure as elongation ratio, originally defined by Miller (1953), as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The value of circularity ratio varies from 0 (in line) to 1 (in a circle).

Area of the basin, A = 502304.37 km^2

Perimeter,P = 6383.86 km

$$R_c = \frac{4\pi \times A}{P^2}$$

R_c = 12.566 x (502304.37/ $(6383.86)^2$)

= 12.566 x (502304.37/40753668.4996)

= 0.155

9.3.7 Basin shape factor (L_l)

L_{ca} = 1796.65 km = 1116.38 miles

L= 2257.79 km = 1402.02 miles

$L_l=(LL_{ca})^{0.3}$ = 72.172

9.3.8 Elongation ratio (R_e)

The shape of the basin is conveyed by the elongation ratio. Schumm (1956) elongation ratio is the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin .Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5).

$$R_e = \frac{2\times\sqrt{(\frac{A_b}{\pi})}}{L_b} \; ; \; R_e = \frac{2\times\sqrt{(\frac{502304.37}{\pi})}}{2257.79} = 0.3542$$

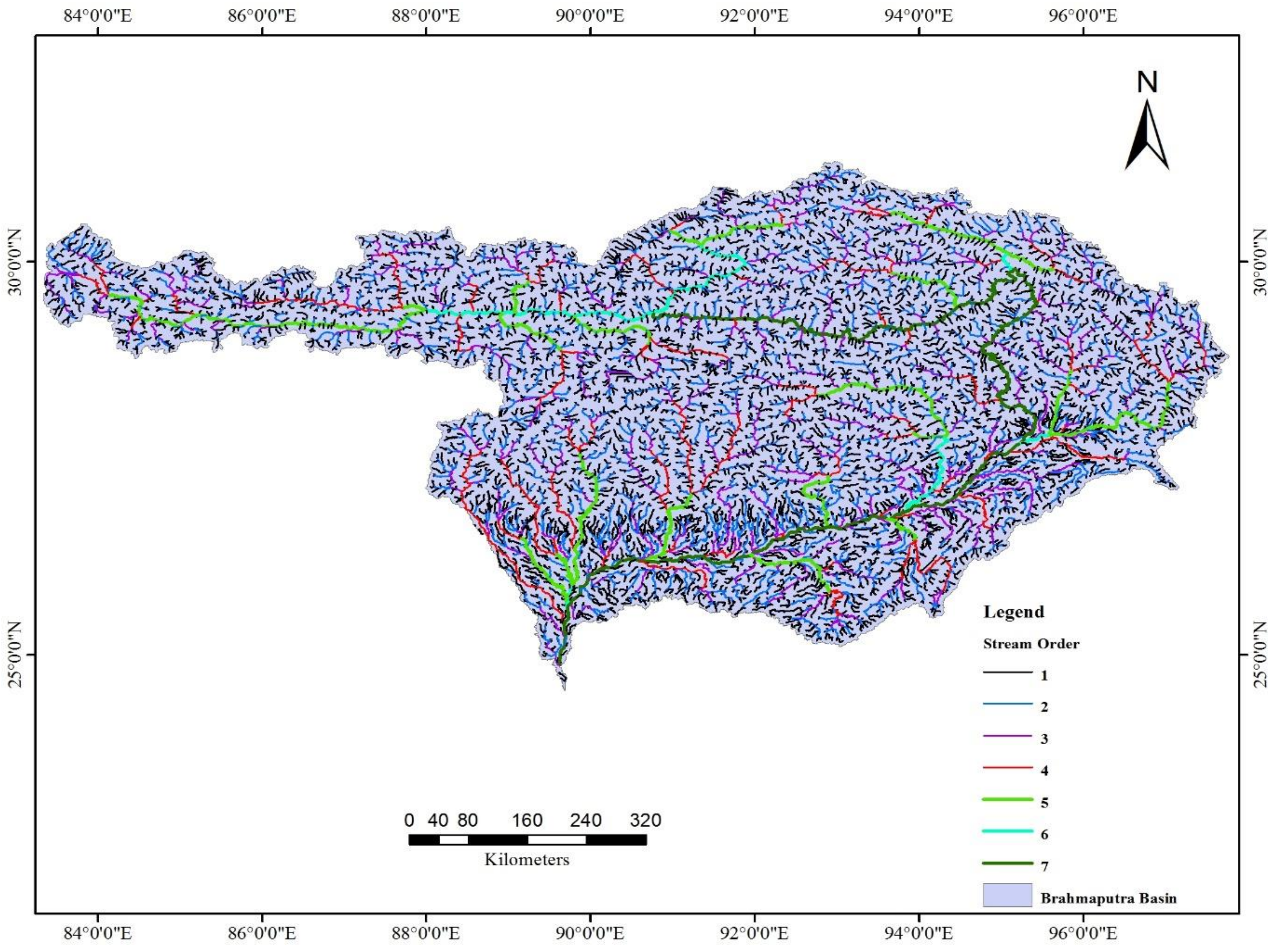

Figure 54: Stream Order of Brahmaputra Basin

9.3.9 Observations

From the analysis of morphometric parameters viz. circulatory ratio, elongation ratio, form factor of the Brahmaputra basin, it can be inferred that the shape of the basin is elongated; although the delineated basin area of Brahmaputra appears to be more of circular in nature. In fact, as the river first flow in the west to east in the Tibetan part and then flow from east to west in the Indian part, it is clear that it has a ridge line between Indian part and Tibetan part and consideration of that ridge line in the estimation of perimeter will show that the basin is truly elongated and not of circular nature. Also, the bifurcation ratio for the highest order stream is the lowest due to larger no. of segments in the higher order (as more no. of tributaries join the main channel in the downstream) which results in flooding in the downstream area.

Chapter 10
PROBABILITY EXCEEDENCE CURVE

10.1 Flow Duration Curve

The flow-duration curve (FDC) is a plot of cumulative discharge frequency that shows the percentage of time during which specified discharges were equaled or exceeded in a given period. It describes the relationship between the frequency and magnitude of stream flow and also depicts the characteristics of a stream throughout the discharge range (Searcy, 1959). FDCs are being widely used in hydrologic studies such as hydropower engineering, flood control, water quality management, river sedimentation, water-use engineering and irrigation planning and design since history (Vogel & Fennessey 1995; Chow 1964; Wamick 1984). Gordon et al. (1992) illustrated the use of FDCs for the assessment of river habitats in the estimation of stream flow requirements. Wilby et al. (1994) used FDCs to assess the effects of different climate scenarios on streamflow with particular reference to low-flows. Hughes and Smakhtin (1996) suggested a nonlinear spatial interpolation approach (based on FDCs) for patching and extension of observed daily flow time series, which has later been extended to generation of flow time series at ungauged sites. Hughes et al. (1997) developed an operating rule model which is based on FDCs and is designed to convert the original tabulated values of estimated ecological stream flow requirements for each calendar month into a time series of daily reservoir releases. Lanen et al. (1997) and Smakhtin et al. (1998) used FDCs as a tool for rainfall–runoff model calibration and/or for the comparison of flow-time series simulated for different scenarios of development. The flow duration curve is actually a river discharge frequency curve and longer the period of record, more accurate is the indication of the long term yield of a stream. A flat curve indicates a river with a few floods with large groundwater contribution whereas a steep curve indicates frequent floods with little ground water contribution. The flow duration curve has a wide application in sustainable water resource system. FDCs are used to study the characteristics of a river basin or to compare with another basin. The FDC of a flashy stream whose flow is contributed mostly from direct run-off generally has steep slope throughout the curve while a

FDC with flat slope reveals the presence of surface or ground-water storage, which tends to equalize the flow. A flat slope at the lower end of the FDC denotes a large amount of perennial storage whereas a steep slope at the end of the FDC indicates a negligible storage (Searcy, 1959).

10.1.2 Methodology

The flow duration curves for the river Brahmaputra were plotted for sites Pandu and Pancharatna (Figure 57 &58). As daily discharge data was not provided, the ten daily discharge data provided by Middle Brahmaputra Division, CWC, Guwahati was used to develop the flow duration curve. It is worth mentioning that the ten daily discharge data, which is basically the flow rate averaged over ten daily, will not provide actual scenario of probable maximum yearly discharge. However, in the review meeting it was decided that the daily discharge data will be provided and accordingly another request was sent on 19th September, 2017 to CWC, Shillong. As a reply to this request, it was informed by the CWC, Shillong that whatever data is available with the department had already been sent to IITG indicating ten daily discharge as the available data.

The discharge data were arranged in descending order of class value and the total no. of days in each class were marked. Also, the number of days the flow is equal to or greater than the class interval is calculated which gives the value of *m*. The percentage probability (Pp) i.e. the probability of flow in the class interval being equaled or exceeded is given by the equation:

$$Pp = \frac{\mathrm{m}}{\mathrm{N}+1} * 100$$

where, Pp = percentage probability of flow magnitude being equaled or exceeded

m = order number of the discharge

N = number of data points

The plot of discharge Q against Pp is the flow duration curve. The highest value of the discharge in each class interval is plotted against Pp in a logarithmic scale.

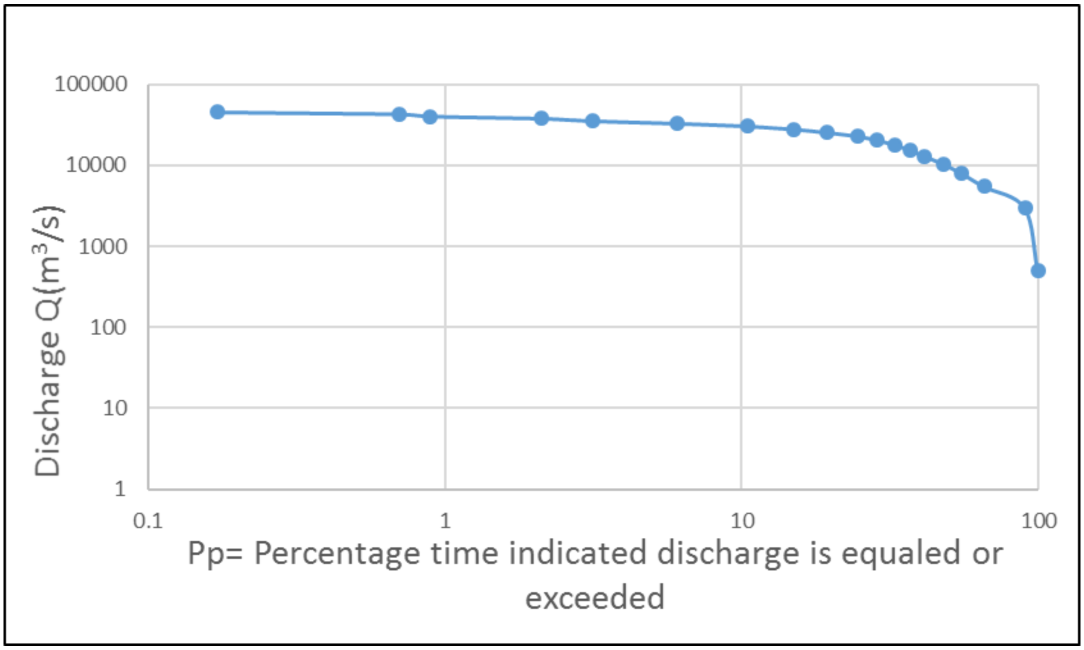

Figure 55: Flow Duration Curve (Pandu station)

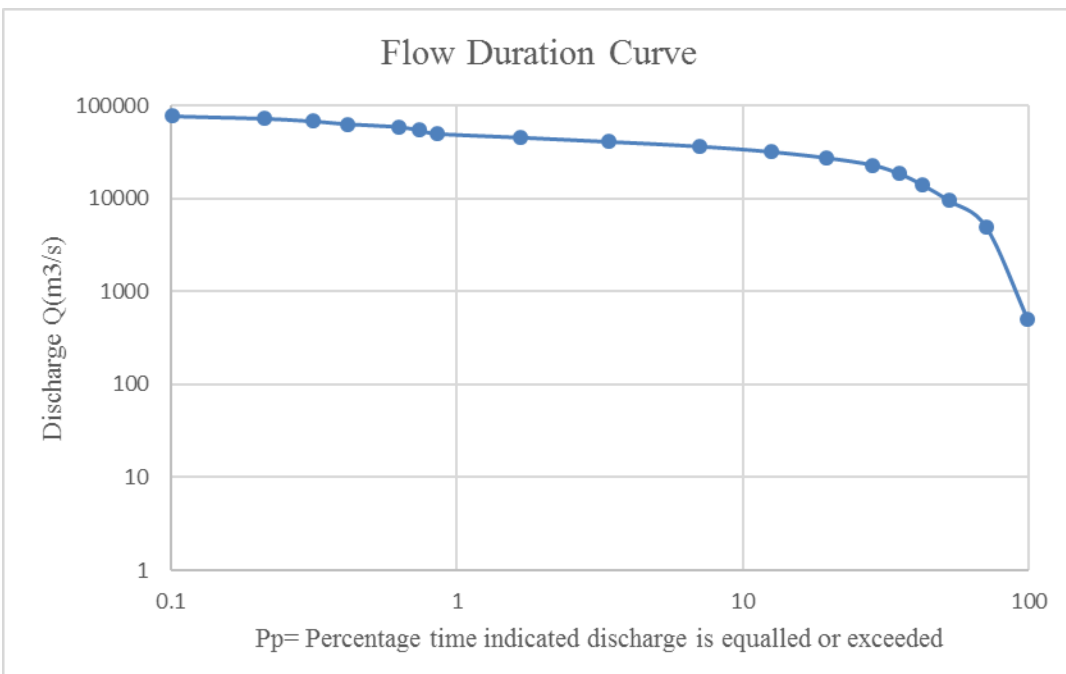

Figure 56: Flow Duration Curve (Pancharatna station)

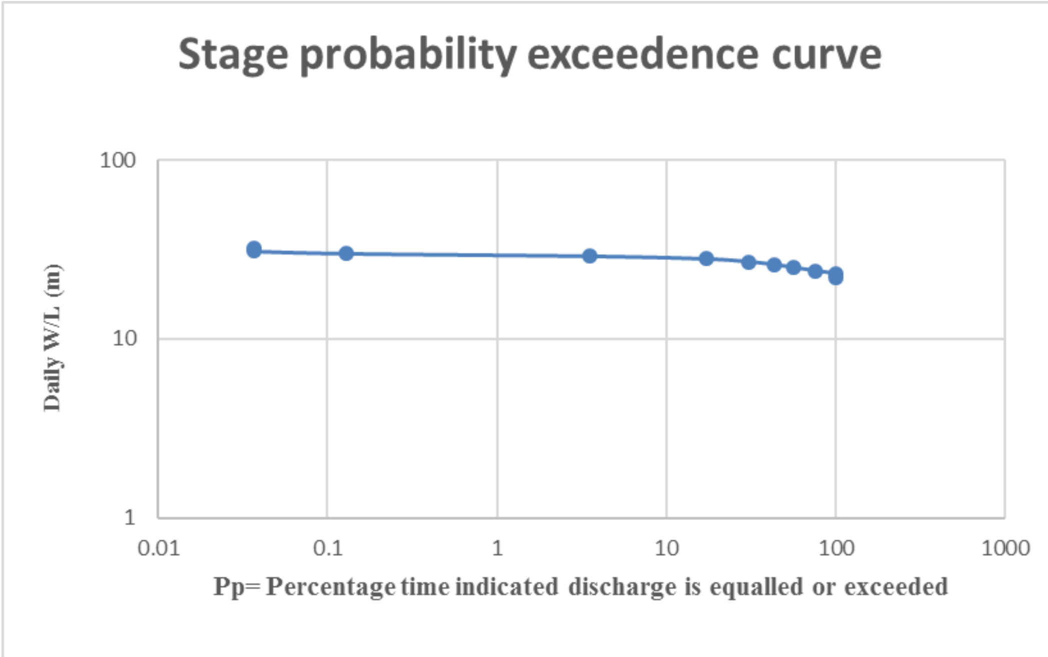

Figure 57: Stage probability exceedance curve of Dhubri

10.2 Flood Frequency Analysis

Hydrologic processes such as floods are quite complex in nature. A host of constituent parameters influence these events which results in adversity in processing the model analytically. Another problem in hydrology includes the interpretation of past records of hydrologic events to predict the future probabilities of occurrence. This problem arises in the estimates of frequencies of floods, droughts, storage, rainfalls, water qualities, waves etc. the procedure involved is called frequency analysis (Chow, 1964). Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs to government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains (Tumbare, 2000).

10.2.1 Gumbel's Method

Gumbel (1941) introduced the extreme value distribution and is commonly known as Gumbel's distribution. Gumbel defined a flood as largest of 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. According to this theory of extreme events, the probability of occurrence of an event equal to or larger than a value X_0 is

$P(x \geq x_0) = 1 - e^{-e^{-y}}$ in which y is a dimensionless variable given by (10.1)

$y = \alpha(x-a)$ where , $a = \bar{x} - 0.45005\sigma x$ and $\alpha = 1.2825/\sigma x$

Thus $y = \frac{1.2825(x-\bar{x})}{\sigma x} + 0.577$ (10.2)

where $\bar{x}$ = mean and

σx = standard deviation of variate x.

Eq.8.1 can be written as,

$yP = -\ln[-\ln(1-P)]$ (10.3)

Considering $T = \frac{1}{P}$ where T is the return period Eq. 8.3 can be written as,

$yT = -[\ln + \ln\frac{T}{T-1}]$ (10.4)

$yT = -[0.834 + 2.303\log\log\frac{T}{T-1}]$ (10.5)

Rearranging Eq.8.5, the value of variate of x with return period T

$xT = \bar{x} + K\sigma x$ where $K = \frac{(yT - 0.577)}{1.2825}$ (10.6)

For practical use Gumbel equation Eq. 8.6 gives the value of variate X with a recurrence interval T used as

$xT = \bar{x} + K\sigma n\text{-}1$ (10.7)

where $\sigma n\text{-}1$= standard deviation of the sample of size $N = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$

K= frequency factor, $\frac{(yT - \bar{y}n)}{Sn}$ (10.8)

Where, $\bar{y}n$ = reduced mean, a function of sample size N ; Sn = reduced standard deviation, a function of sample size N

10.2.2 Methodology

From the maximum discharge evaluated per year for Pandu and Pancharatna sites in Brahmaputra River, the discharge values corresponding to 1.5 years and 2 years return period was found out using Gumbel's equations as mentioned above. The percentage probability of flow magnitude being equaled or exceeded was thus calculated from the flow duration curve corresponding to the discharge values for 1.5 years and 2 years return period and is shown in table below:

Table 5: Percentage Probability discharge values for 1.5 year and 2 years

H.O. Sites	**Return Period Tp (Years)**	**Discharge(m3/s)/Stage (m)**	**Pp (%)**
Pandu	1.5	32784.66	3.28
	2	35290.3	2.32
	25	50697.68	0.282
	50	54524.49	0.167
	100	58323.05	0.099
Pancharatna	1.5	35697.9	5.61
	2	39559.62	3.89
	25	65998.28	0.282
	50	72488.35	0.167
	100	78930.51	0.099
Dhubri (Stage)	1.5	29.13	0.65
	2	29.53	0.43

Chapter 11
LANDUSE/LANDCOVER CHANGE

River systems are of immense importance to sustain human life on the Earth. However, human activities, especially change in land use has impacted the river systems to a great extent not only in terms of water quality and quantity such as surface runoff, groundwater, and non-point source (NPS) pollutions, but also in long-term changes in the channel morphology (Wu, et.al., 2018; Zhu & Li, 2014). Therefore, in order to study the morphological changes of river systems, it is important to study the changes in the land use/land cover (LULC) pattern of the watershed too. The study of the changes in LULC can attribute to different underlying causes of the observed morphological changes in the river systems. Keeping this in mind, LULC changes of Brahmaputra have been analyzed over the study period.

11.1 Methodology

Land Use/Land Cover mapping has been carried out within a 10 km buffer area from the 1973-74 centerline of Brahmaputra river for the years 1973-74, 1976-80 and 1993-95. For the years 2005-06 and 2011-12, the LULC data have been collected from North Eastern Space Applications Center (NESAC), DOS, Umiam, Meghalaya which were at 1:50000 scale. The LULC map for the year 1973-74 has been prepared from SOI toposheets using manual delineation technique with the help of ArcGIS 10.0 software at 1:50000 scale. For the year 1976-80 and 1993-95, supervised classification technique has been used in ERDAS Imagine software to carry out the LULC mapping from Landsat MSS and IRS 1B LISS 1 imageries respectively. Total seven classes viz. Agriculture, Built-up Area, Dense Forest, Open Forest, River/Water bodies, Sandbar/Dry riverbed and Wetland/Marshy land were assigned to the entire dataset. The classified LULC raster data were then converted into vector form using the raster to vector conversion tool in ArcGIS. The LULC data collected from NESAC for the years 2005-06 and 2011-12 covered the entire north-eastern states and therefore clipping was done for the buffer area. Area of the polygons of different classes are then calculated using calculate geometry function in ArcGIS for each year. The LULC maps of different years are shown in Figure 61 to 65. However, it has been found that the LULC map prepared for the year 1976-80 and 1993-95 are not comparable to the LULC maps of rest of the years due to coarse resolution of the input data for these two years and also there is a data gap in the upstream portion. Therefore, the LULC change analysis in the study has been limited to only for the years 1973-74, 2005-06 and 2011-12. The estimated LULC change are plotted in Figure 65.

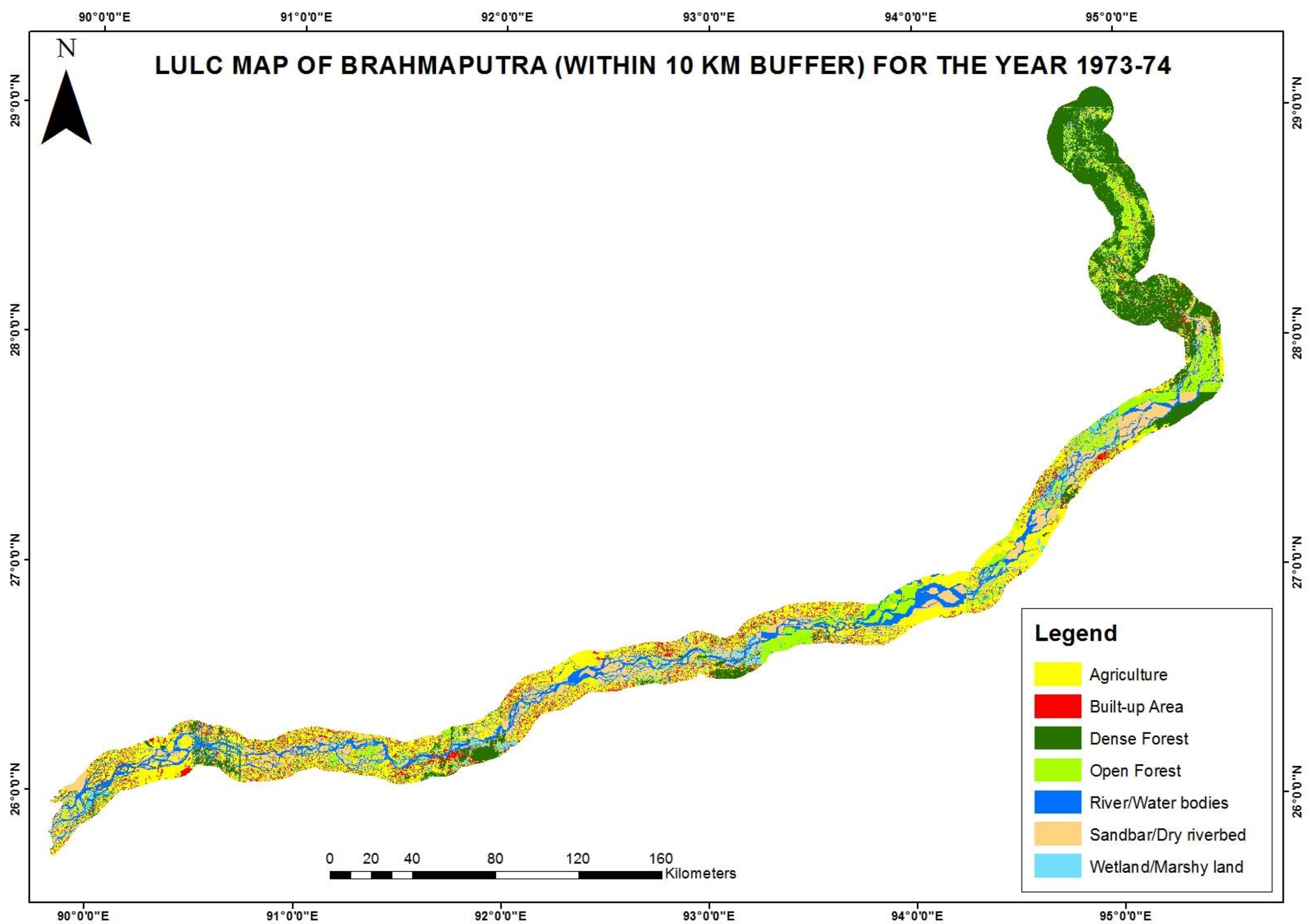

Figure 58: LULC map of Brahmaputra for the year 1973-74

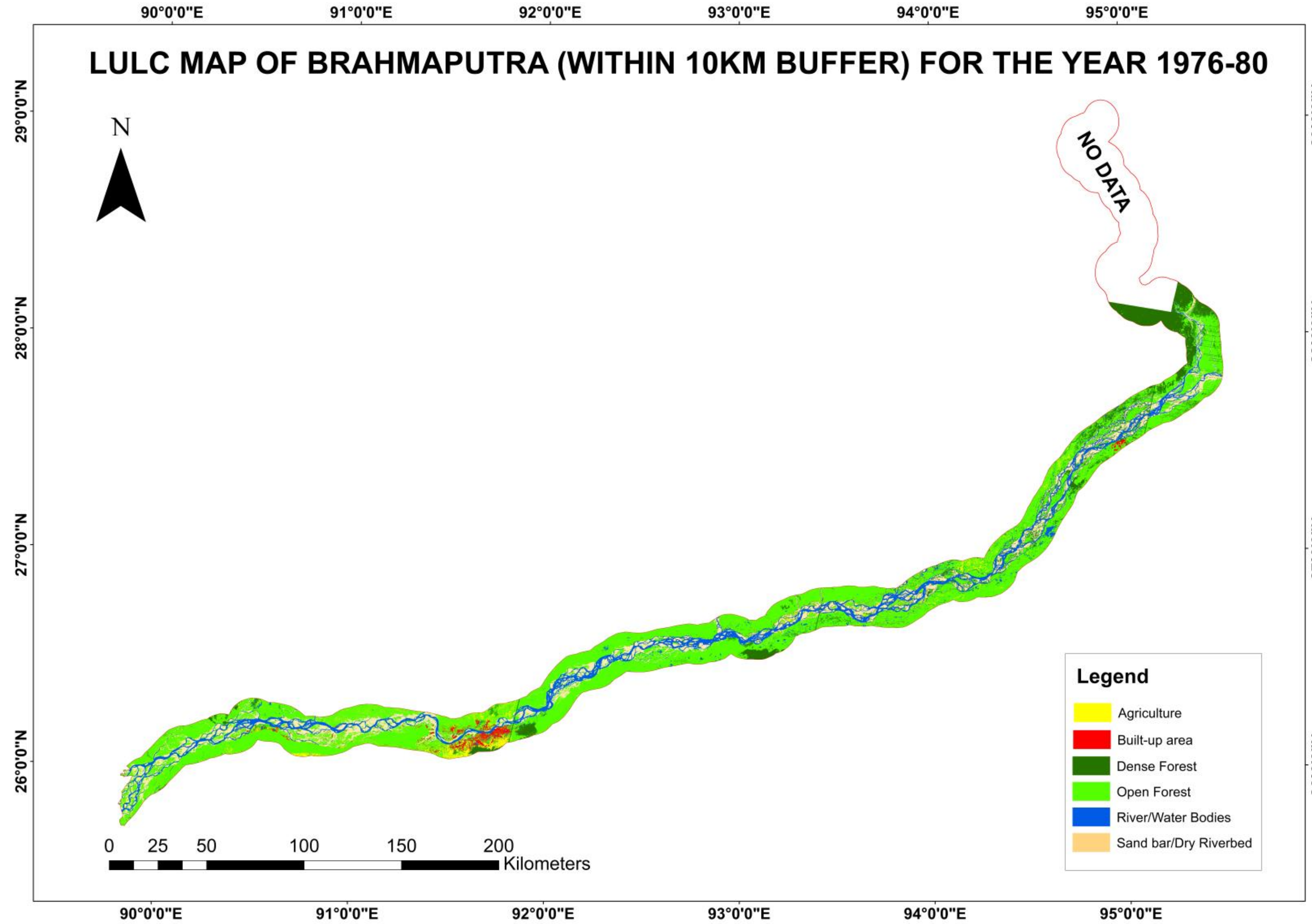

Figure 59: LULC map of Brahmaputra for the year 1976-80

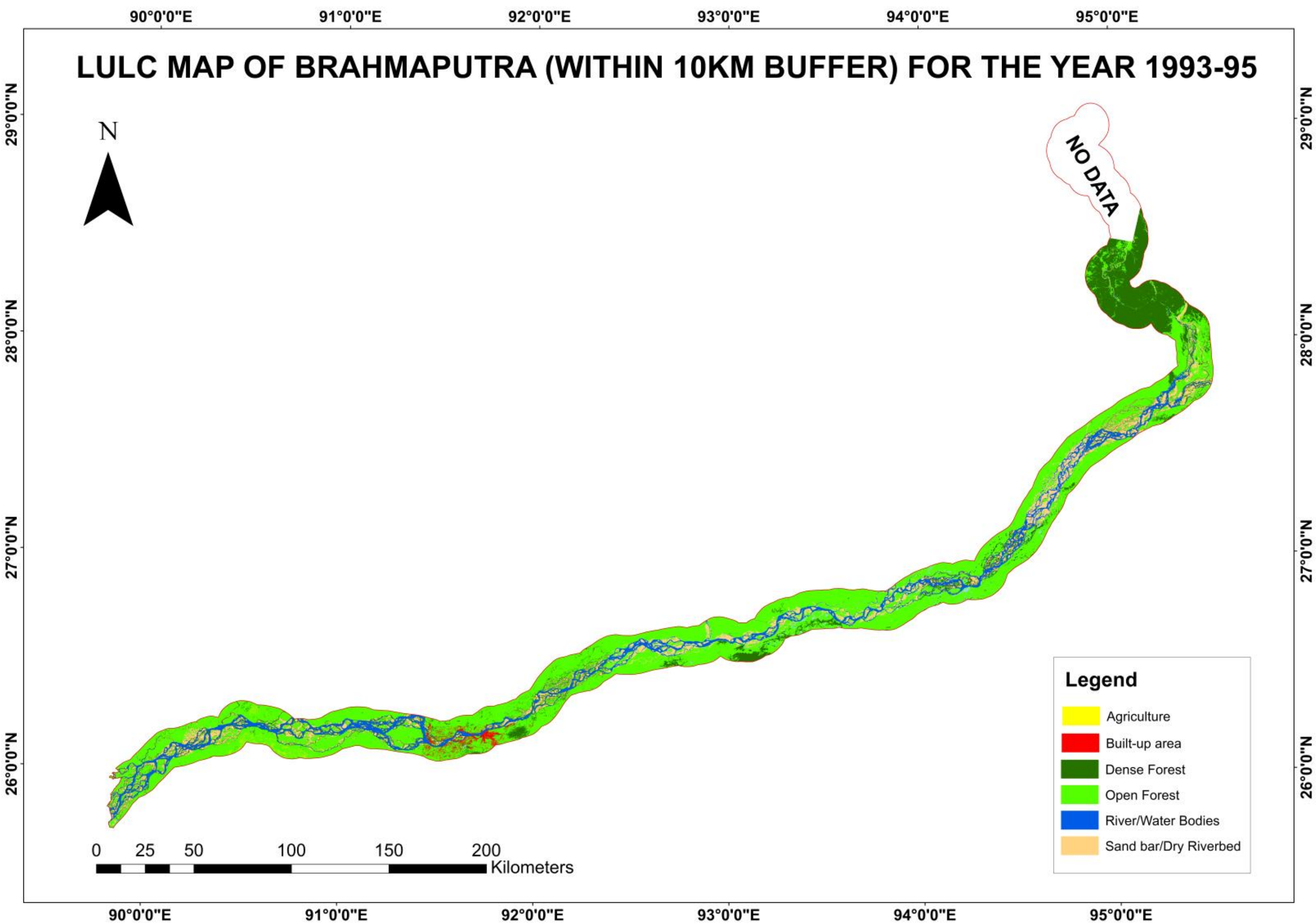

Figure 60: LULC map of Brahmaputra for the year 1993-95

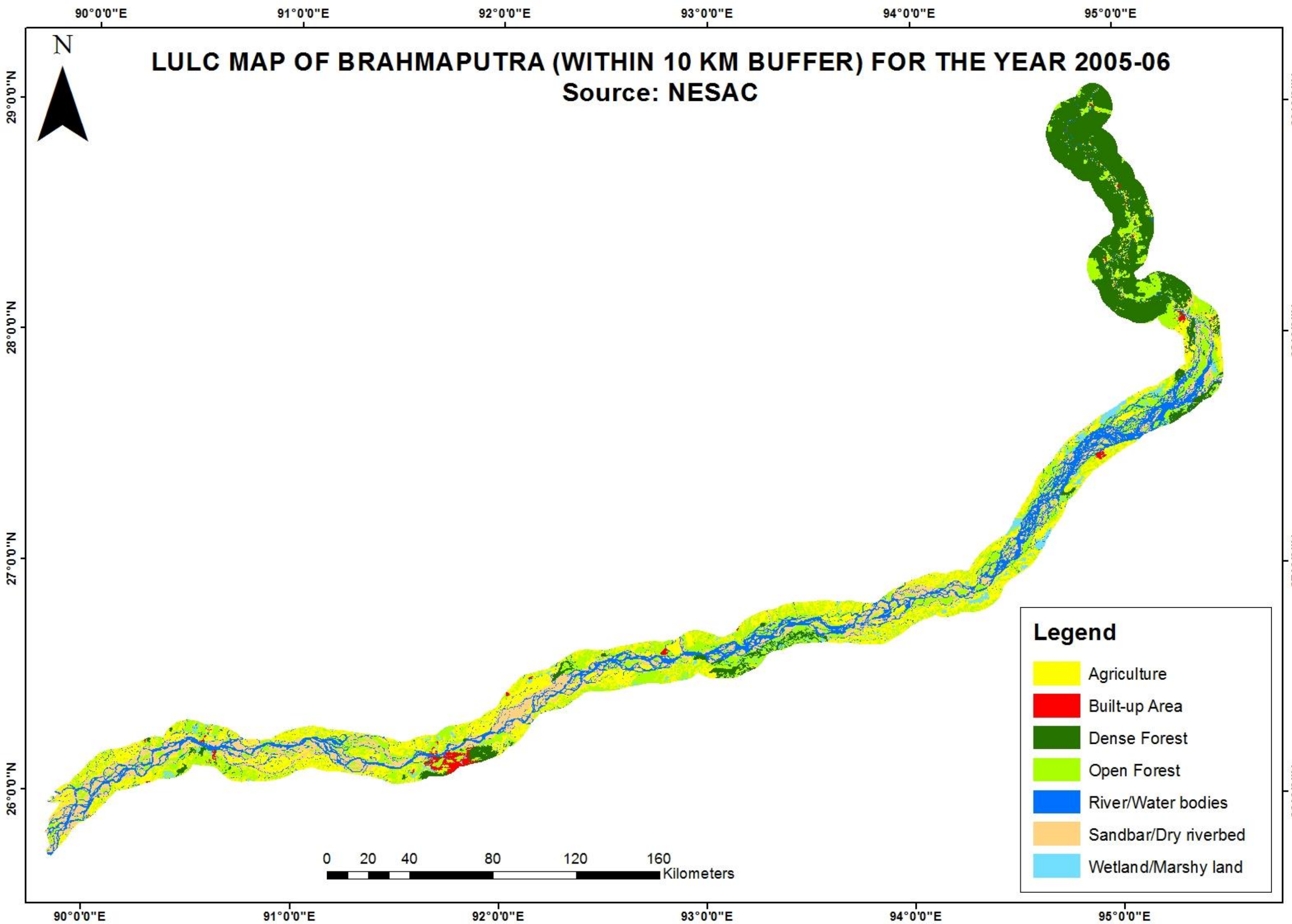

Figure 61: LULC map of Brahmaputra for the year 2005-06

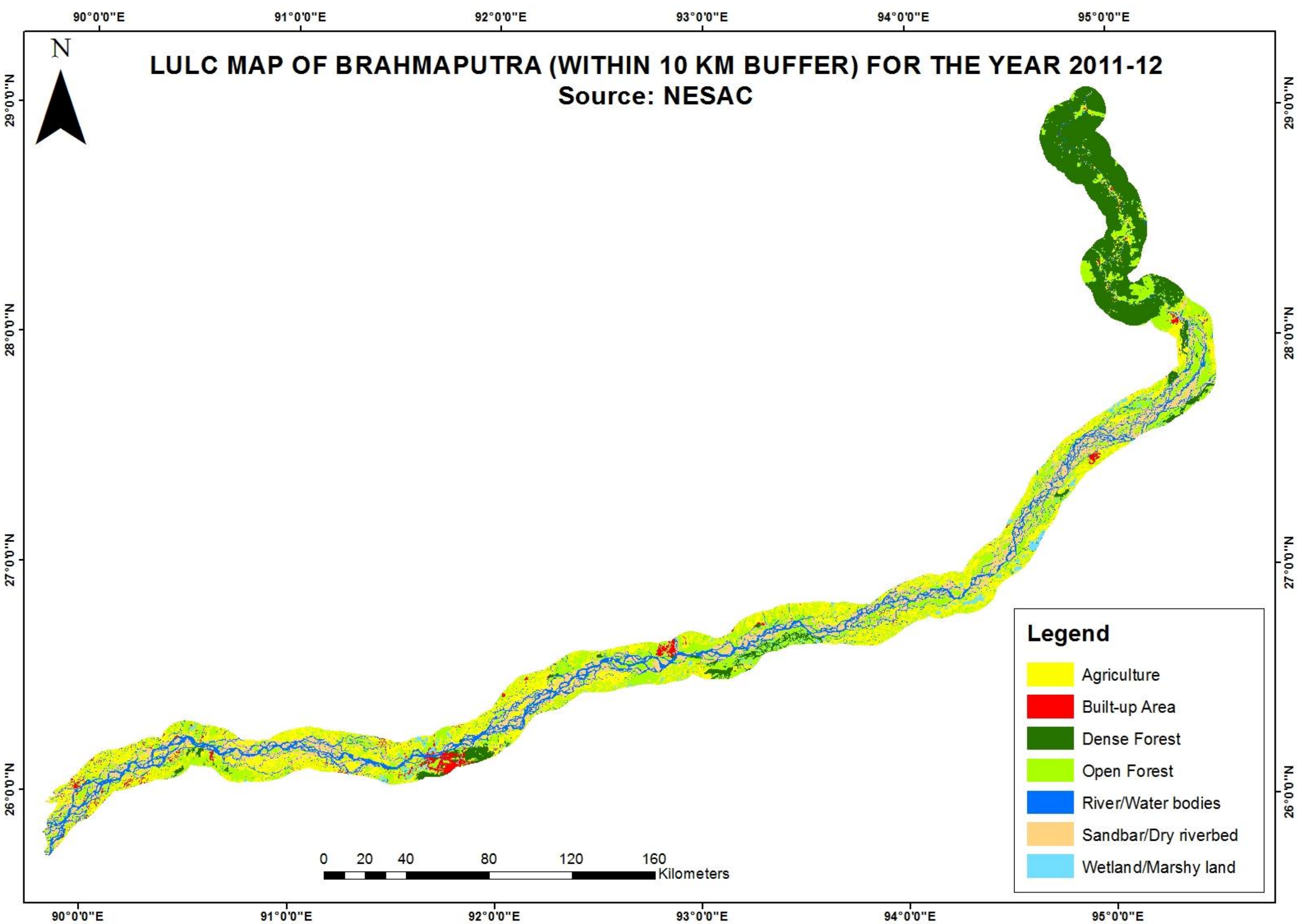

Figure 62: LULC map of Brahmaputra for the year 2011-12

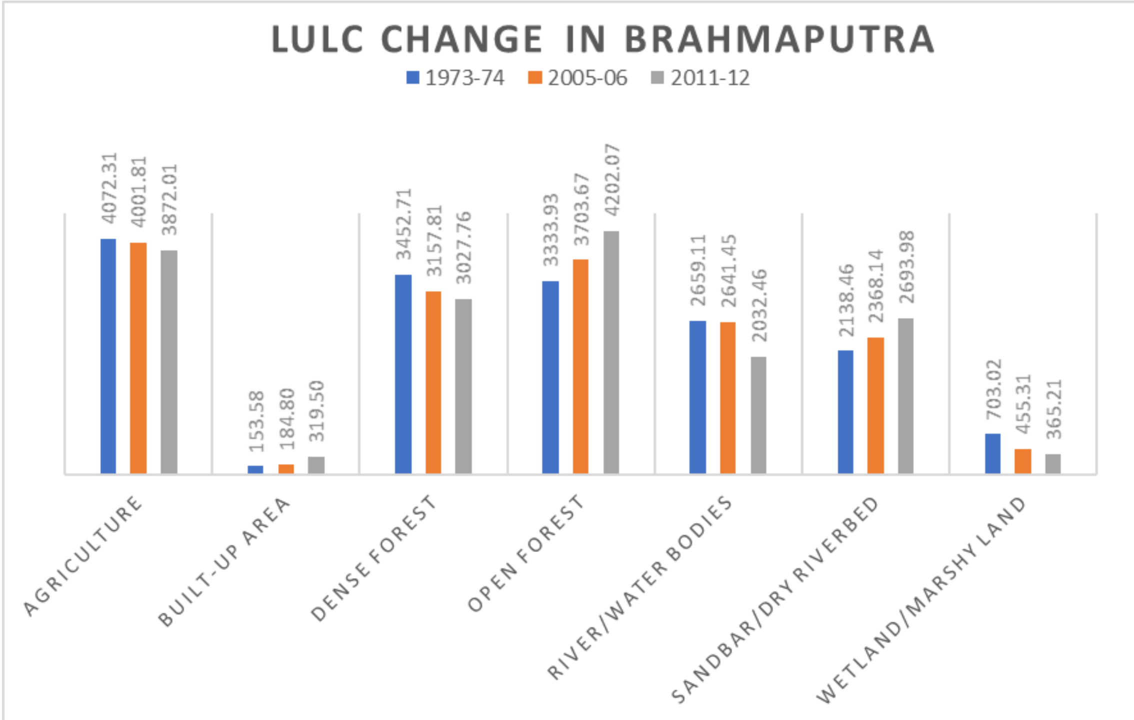

Figure 63: Change in LULC of Brahmaputra over 1973-74 to 2011-12

11.2 Observations

From the analysis of LULC for the years 1973-74, 2005-06 and 2011-12, it has been observed that area under Agriculture, Dense Forest, River/Water bodies and Wetland/Marshy land have been reduced over the years; however, area under Built-up area, Open Forest and Sandbar/Dry riverbed classes have increased over time. These changes imply that there is a conversion of land use from Agriculture, Dense Forest, and Wetland/Marshy land to Built-up area, Open Forest and Sandbar/Dry riverbed. This reduction in the Wetland/Marshy land and increase in the Sandbar/Dry riverbed area might have contributed to the increase in both riverine and flash flood in the region.

Chapter 12
FLOOD INUNDATION

12.1 Flood Inundation Mapping

Flood Inundation maps of Brahmaputra Basin in Assam has been downloaded from NRSC's BHUVAN website for the years 1999 to 2010 (Figure 66 to 77). The flood maps of NRSC are prepared from observed inundation data. It is a well-known fact that most of the rivers in North East India have flood protecting embankments. Flooding in these regions occurs primarily due to the breaching of embankments at different locations. Therefore, an area not getting flooded in these layers may also get affected by the severe flood if embankment protecting that area suffers failure. Similarly, an area experiencing flood may not experience it with the same intensity if relevant embankment is repaired or reconstructed to protect that area. These facts need to be considered while preparing policies for flood relief, insurance, etc. To have more clarity on flood risk, inundation map can be prepared by running a hydrodynamic model in the river without considering the existence of embankments. Areas coming under flood in such simulations may be designated as Potential Flood Prone Area (PFPA) and policy decision may be taken for relief, insurance, etc. by considering if the areas fall under PFPA.

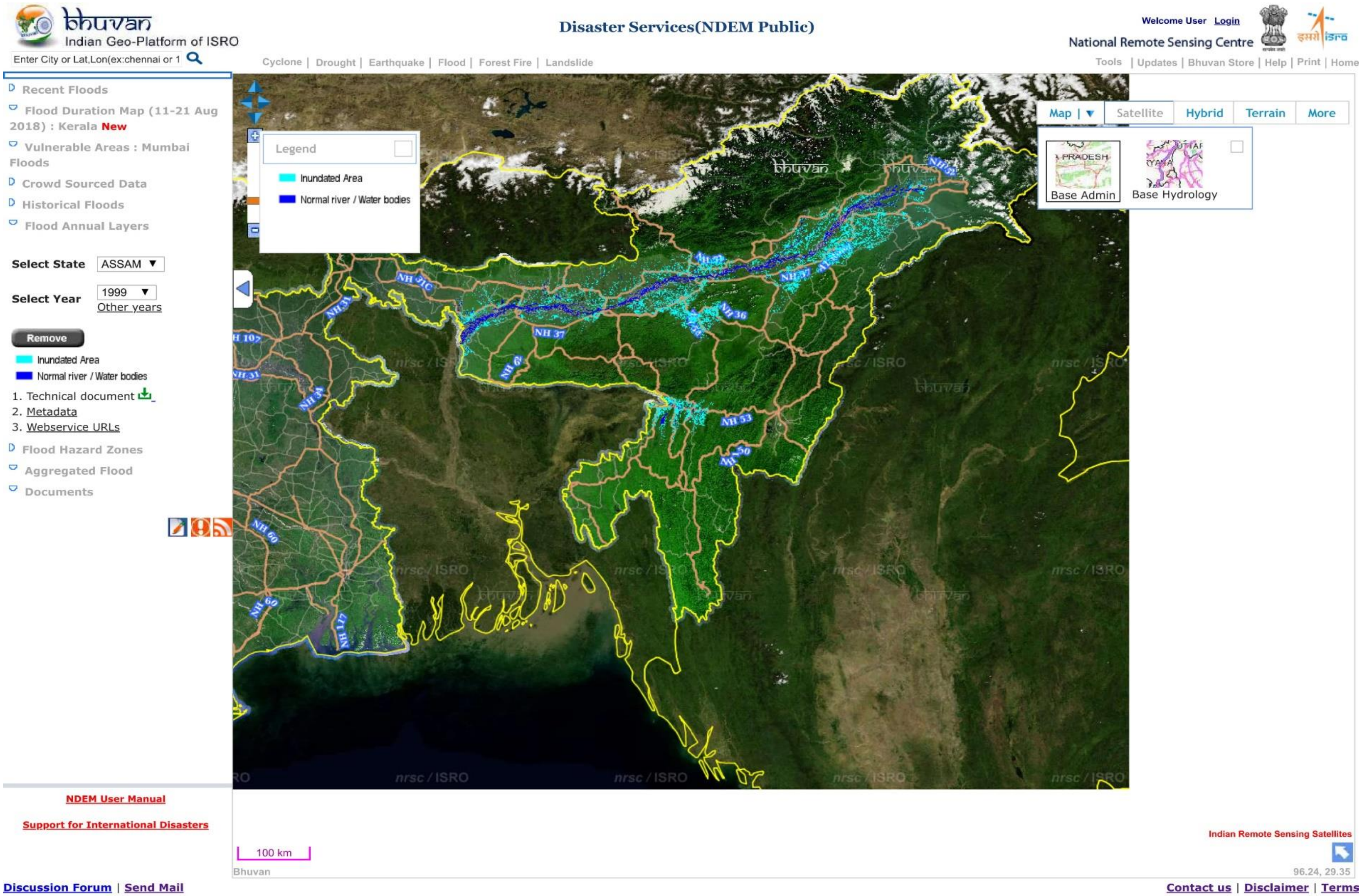

Figure 64: Flood inundation map of Brahmaputra for the year 1999

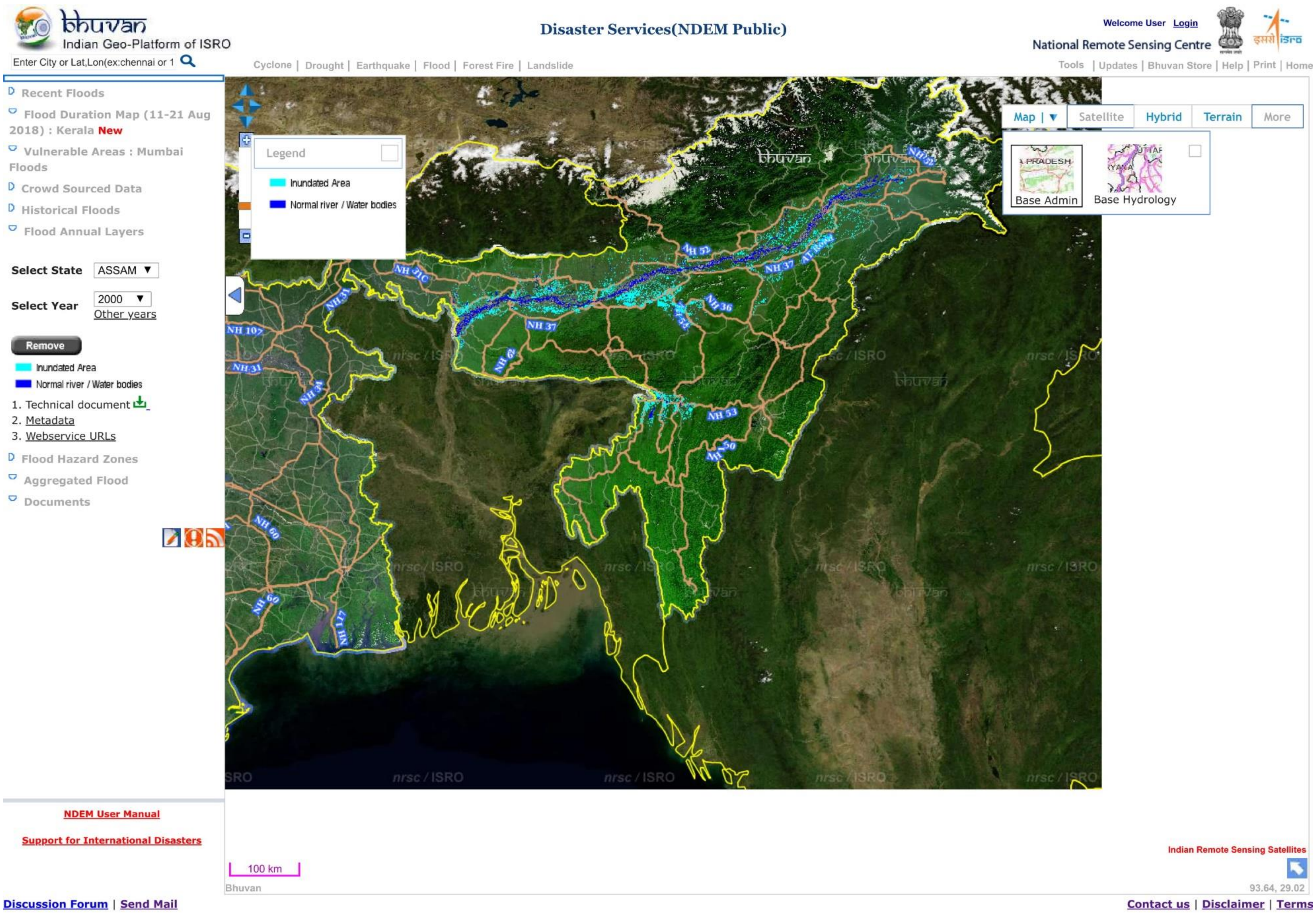

Figure 65: Flood inundation map of Brahmaputra for the year 2000

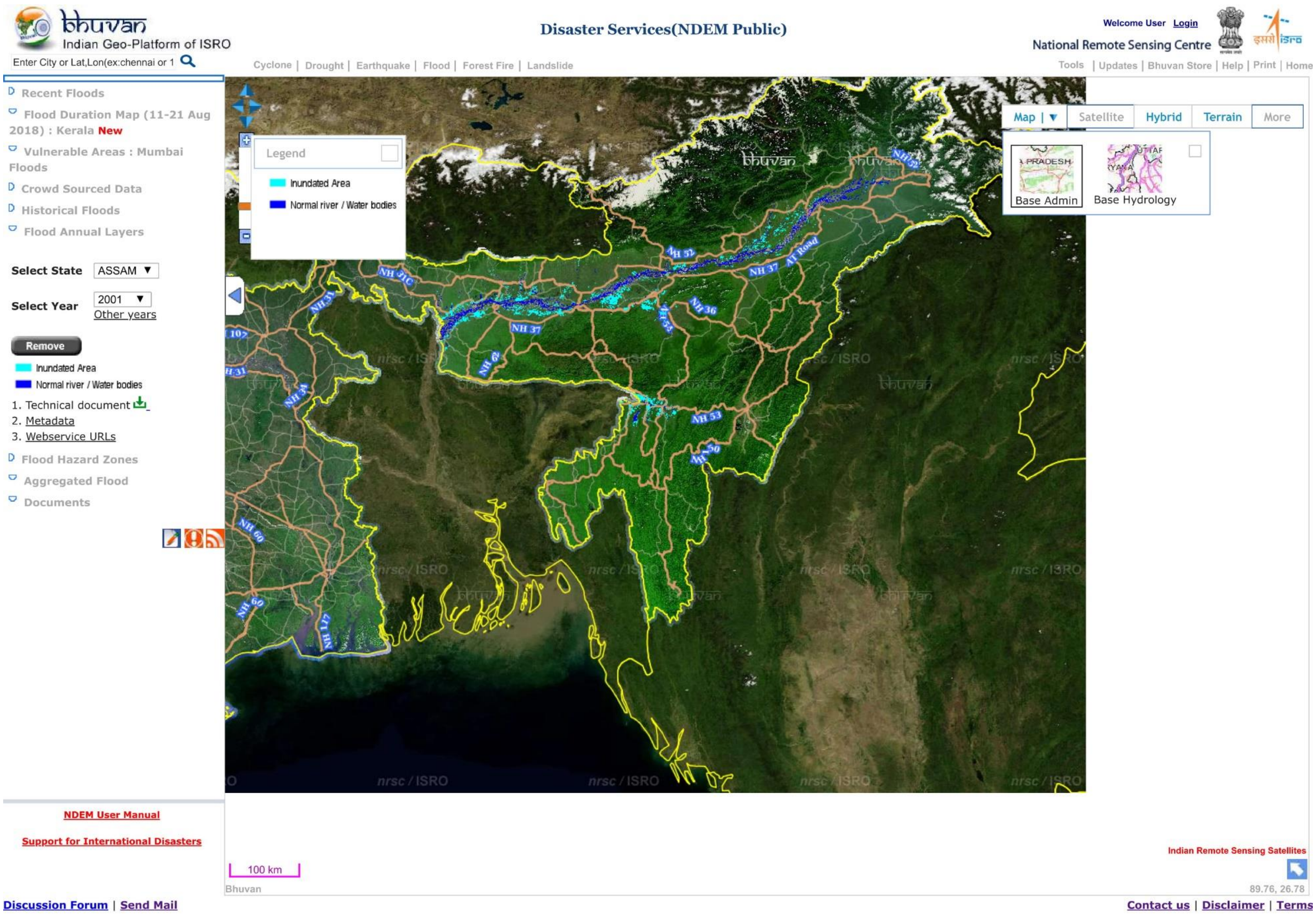

Figure 66: Flood inundation map of Brahmaputra for the year 2001

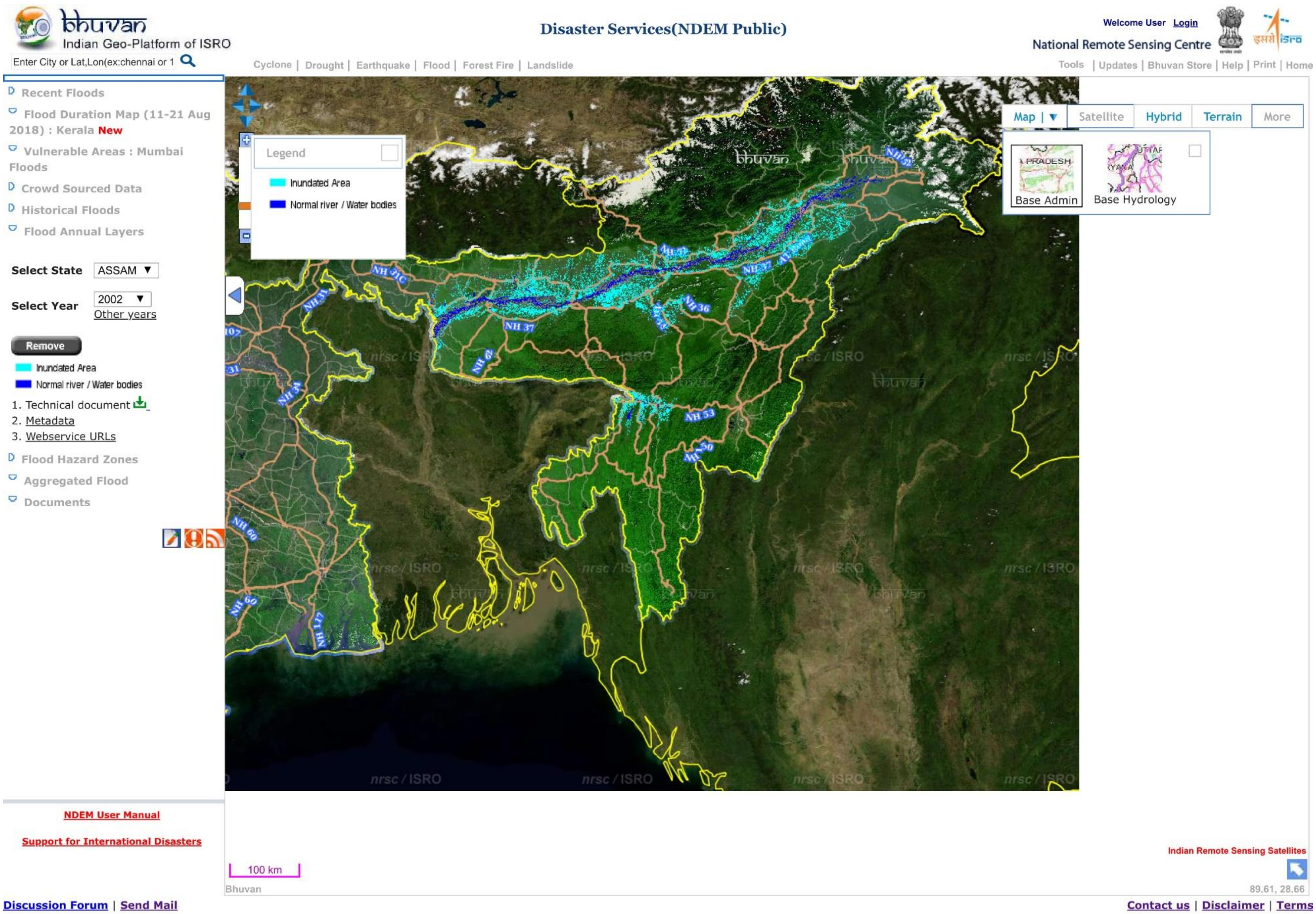

Figure 67: Flood inundation map of Brahmaputra for the year 2002

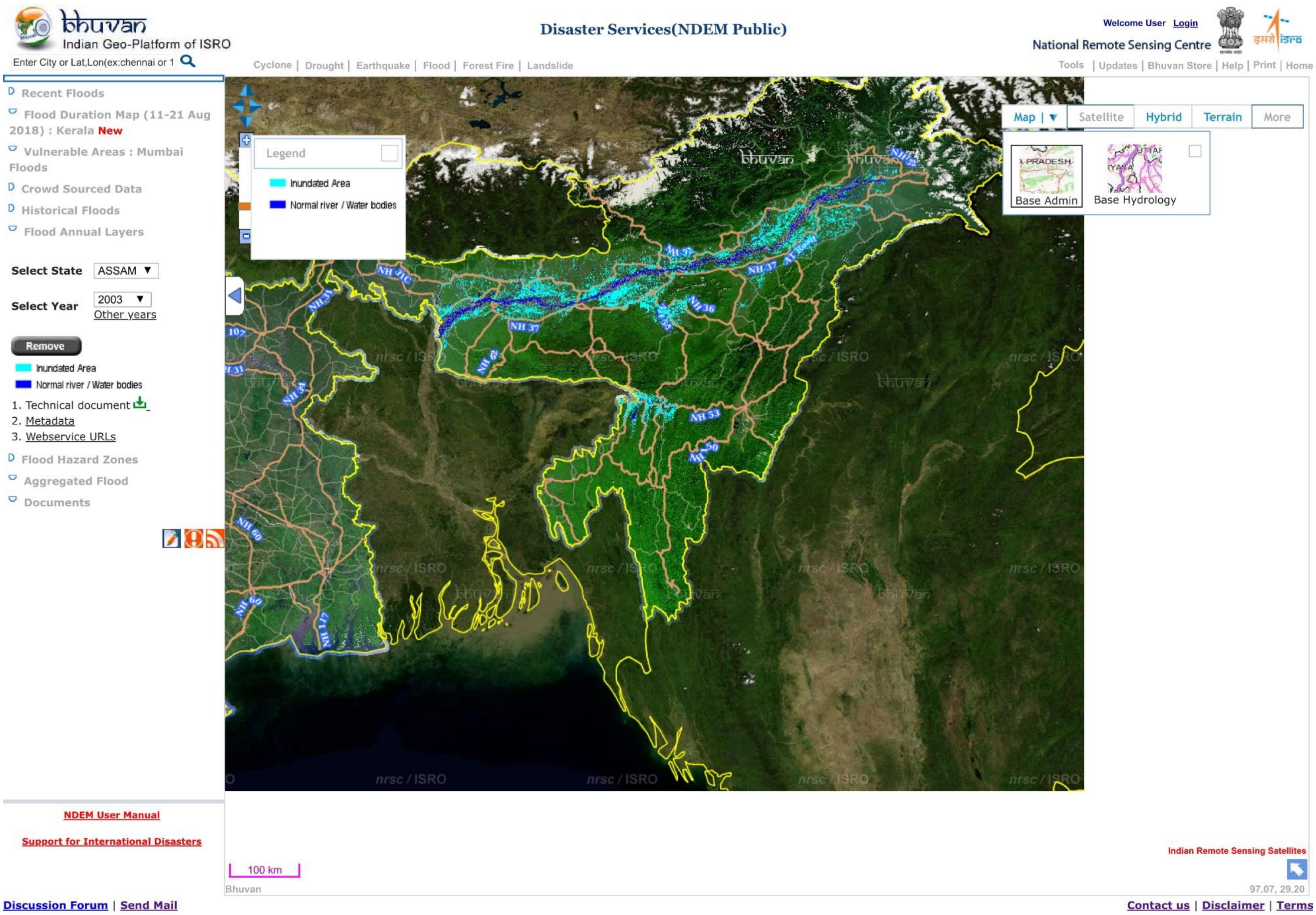

Figure 68: Flood inundation map of Brahmaputra for the year 2003

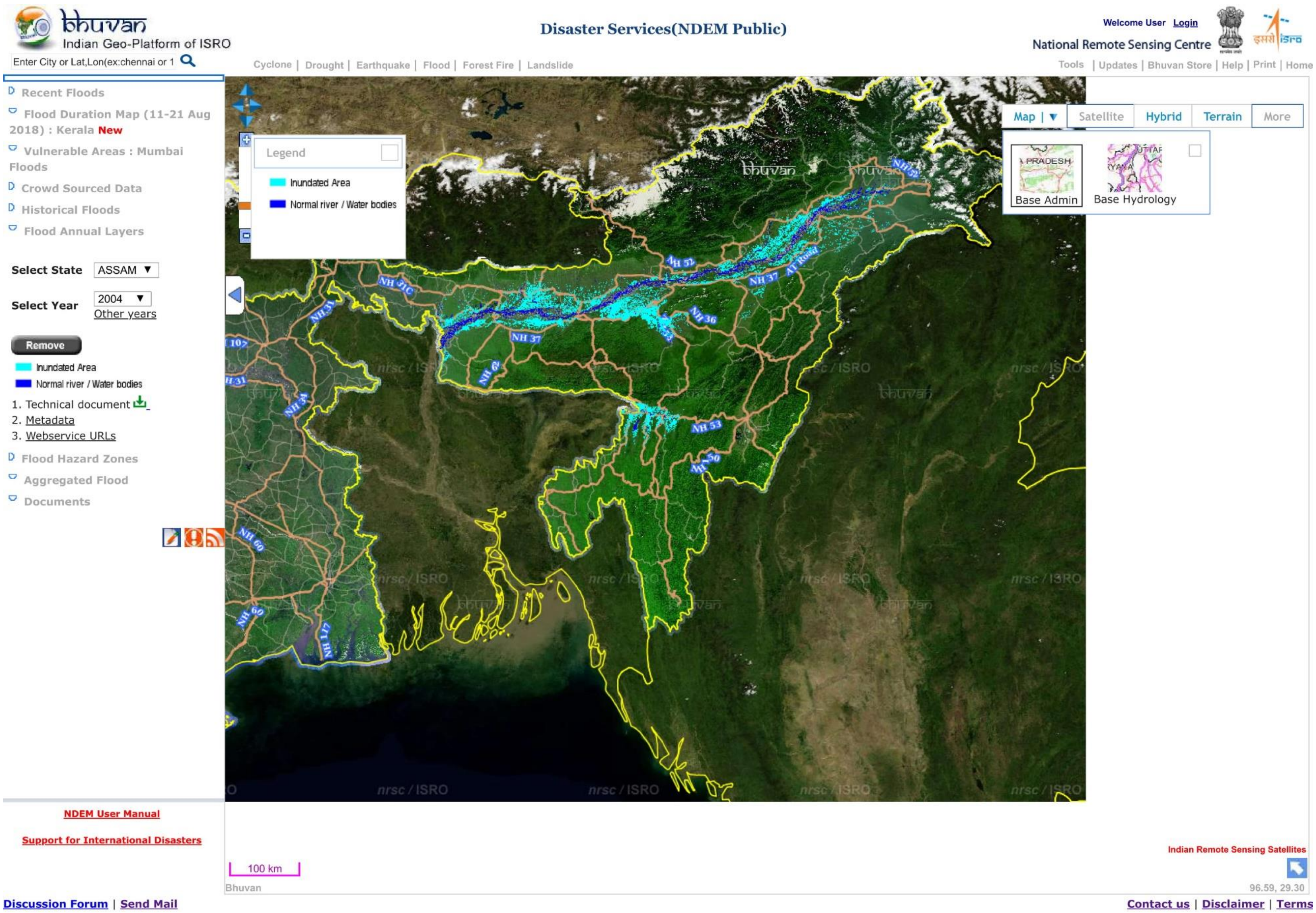

Figure 69: Flood inundation map of Brahmaputra for the year 2004

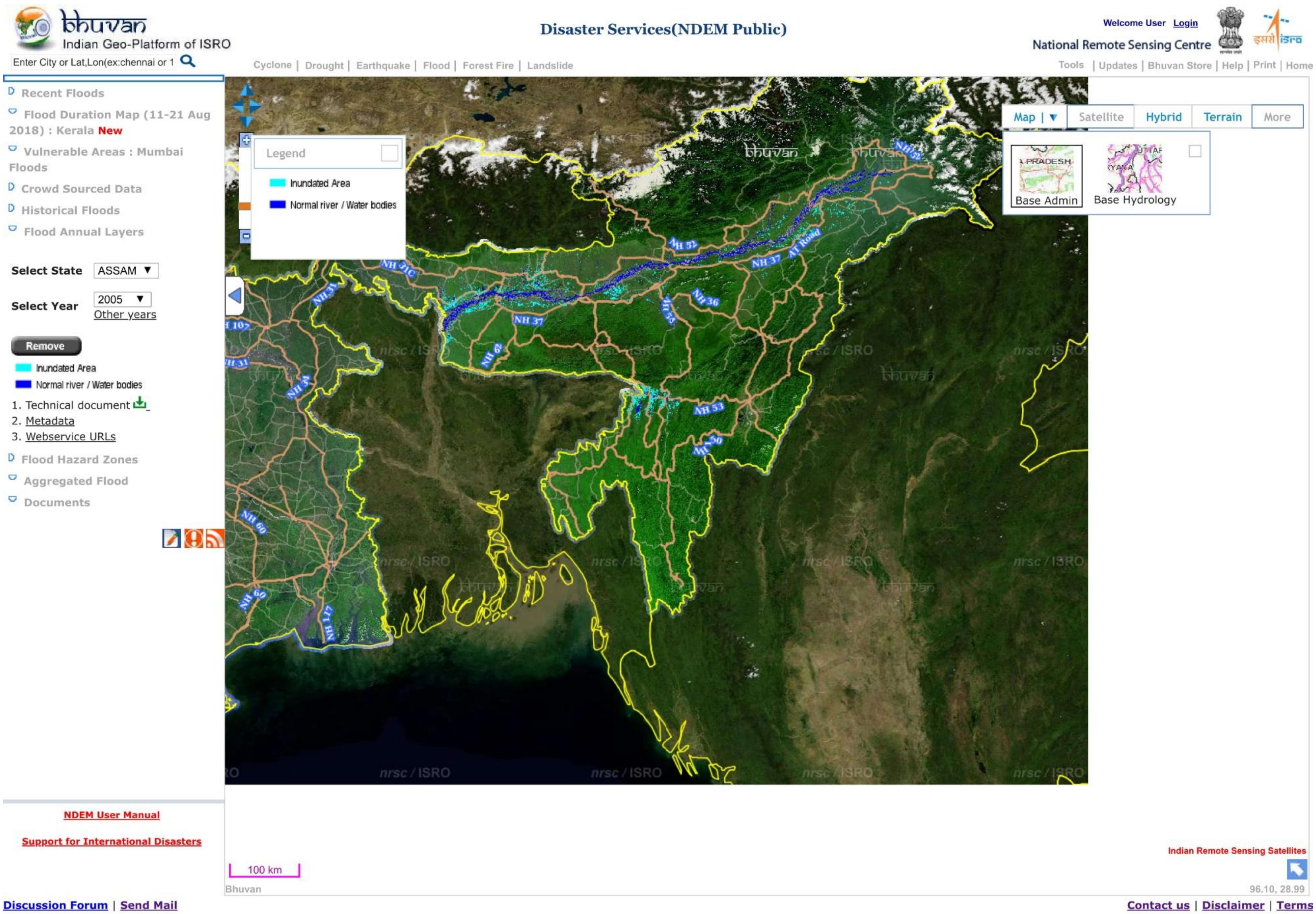

Figure 70: Flood inundation map of Brahmaputra for the year 2005

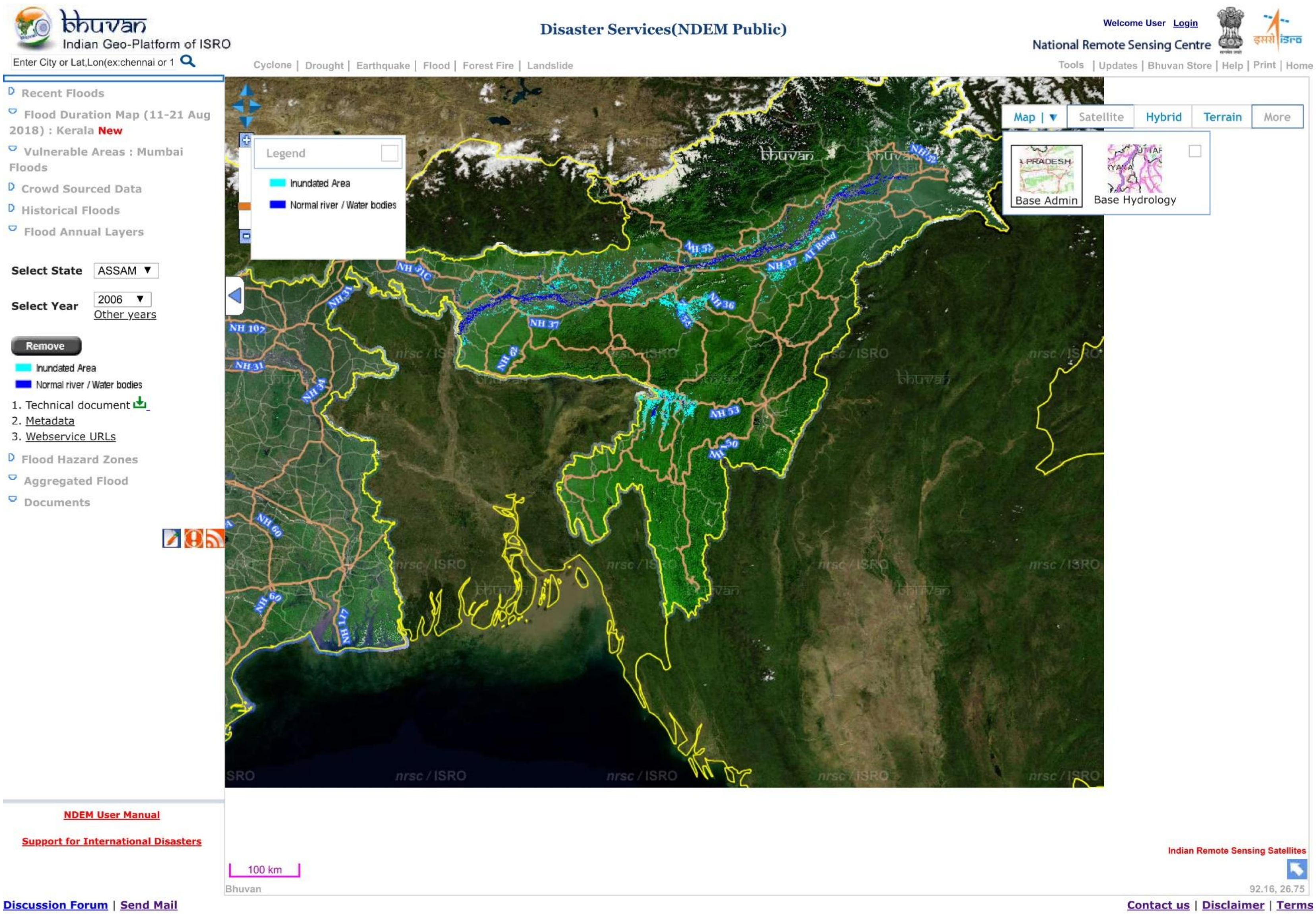

Figure 71: Flood inundation map of Brahmaputra for the year 2006

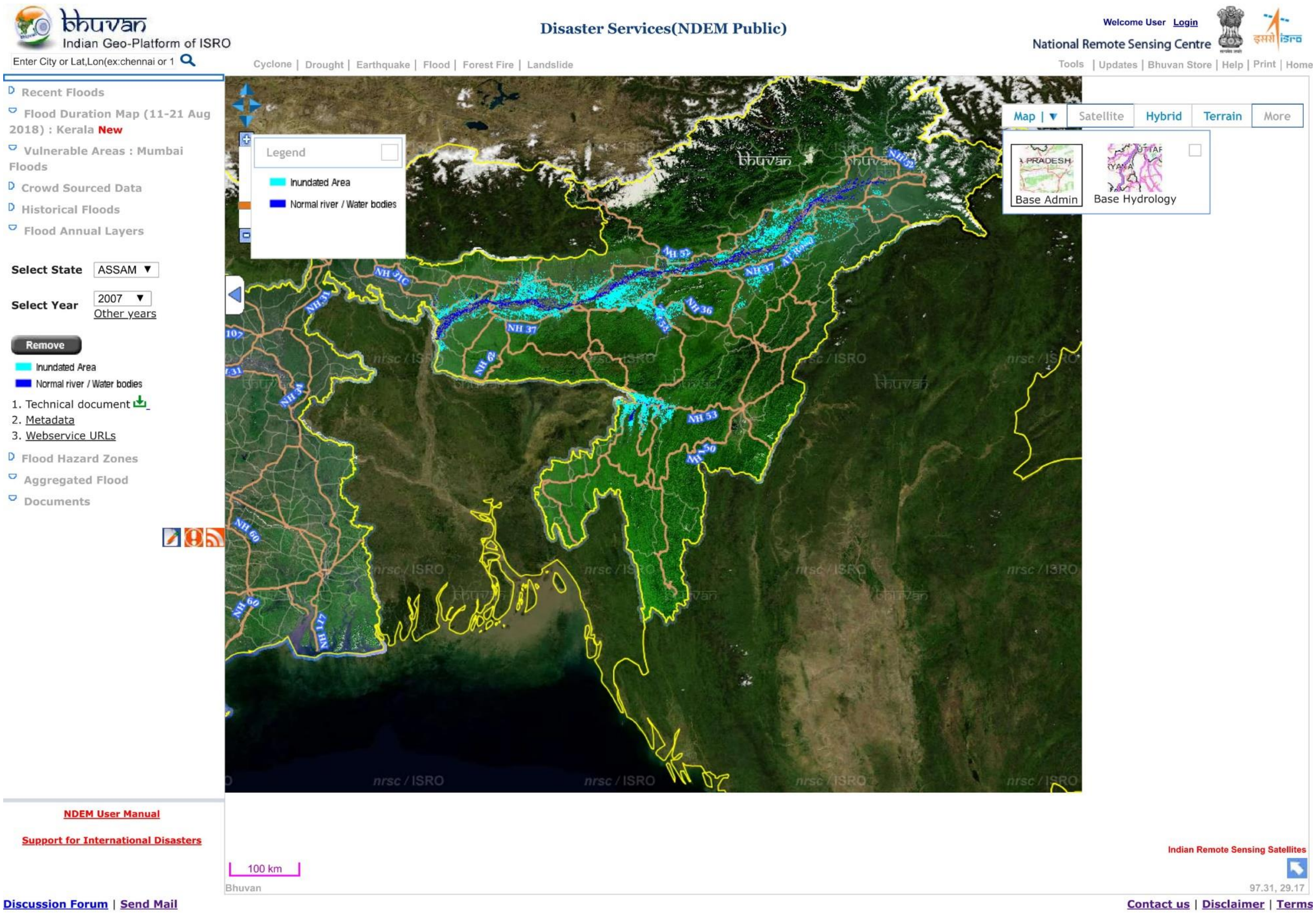

Figure 72: Flood inundation map of Brahmaputra for the year 2007

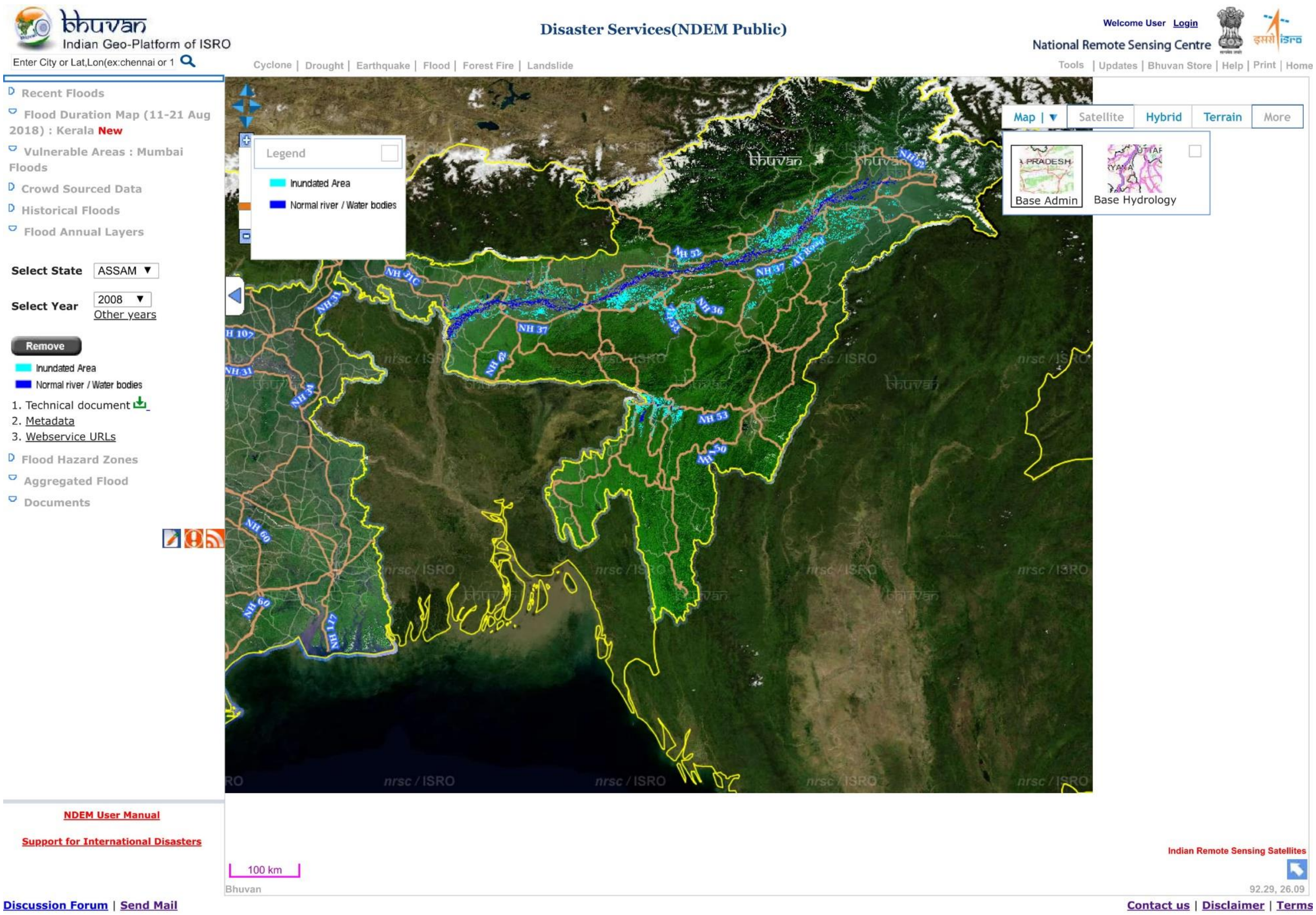

Figure 73: Flood inundation map of Brahmaputra for the year 2008

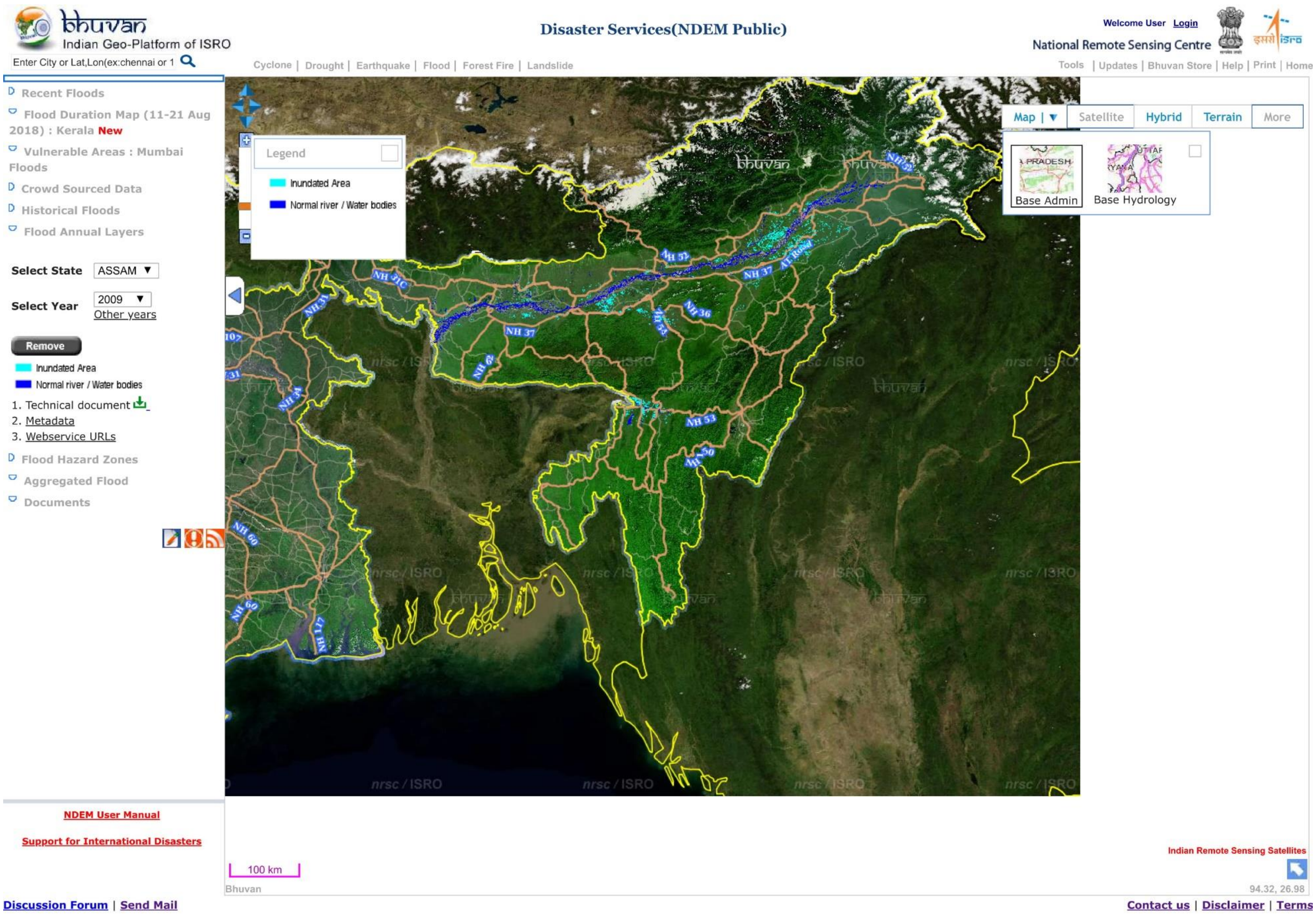

Figure 74: Flood inundation map of Brahmaputra for the year 2009

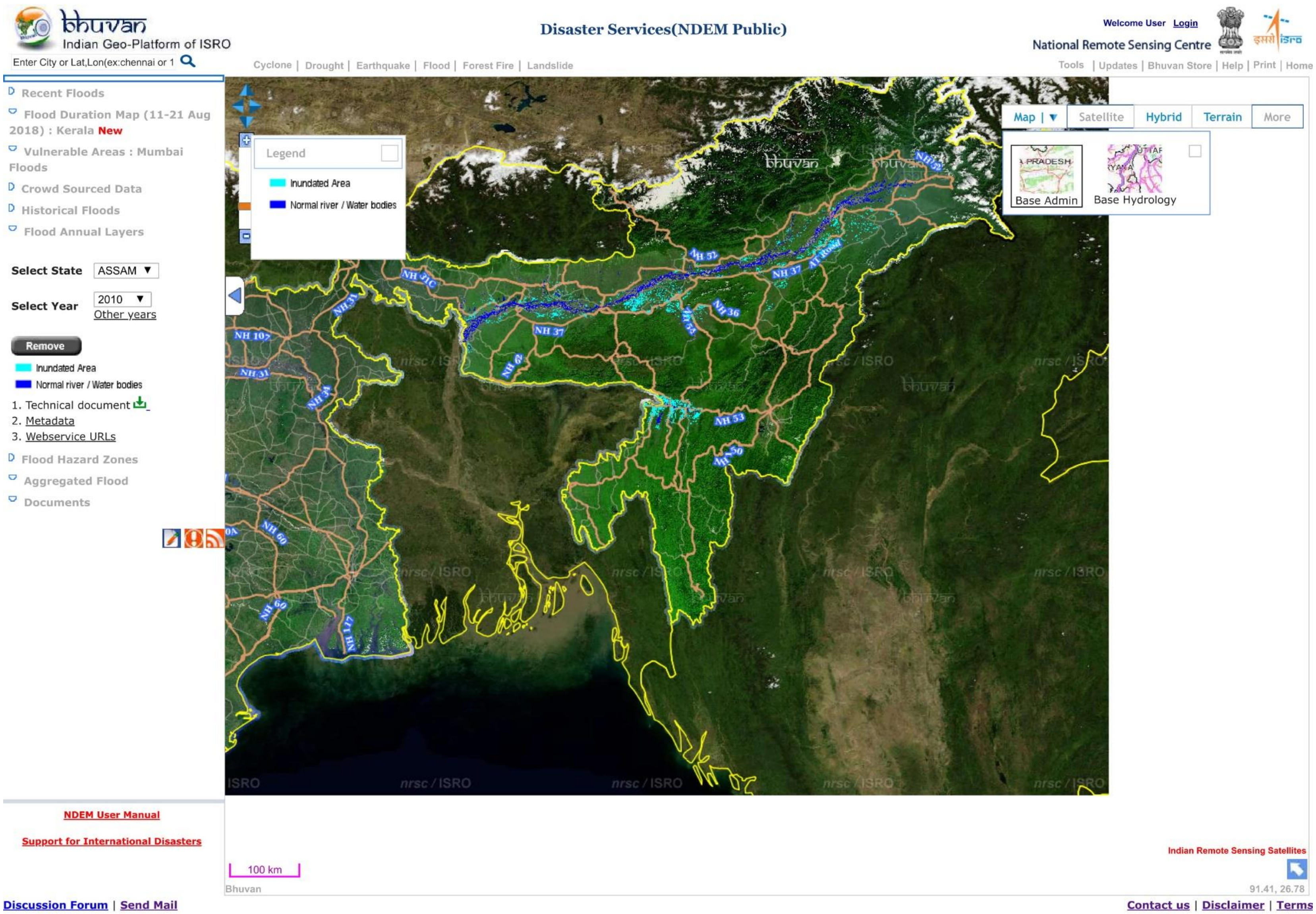

Figure 75: Flood inundation map of Brahmaputra for the year 2010

Chapter 13
RIVER CROSS-SECTION ANALYSIS

13.1 Cross Sectional Analysis of Pandu and Pancharatna

The study of the river channel evolution plays a vital role in the planning and managerial activities. The evolution process depends on the flow velocity, sediment characteristics and also on the cross sections of the channel. Therefore, it is of utmost importance to study the flow velocity along the cross sections in response to the changing seasonal discharges. Changes in river channels are also a result of altered sediment transport rate across the river cross sections (Baker, 1994; Goring and Walsh, 1997).

13.1.2 Methodology

The stations Pandu and Pancharatna are located at the downstream of Brahmaputra basin. From the available cross-sections, data of the above mentioned stations are plotted as below. The cross-sectional areas of Pandu and Pancharatna were calculated using the trapezoidal formula for area calculations using an assumed RL for each cross-section. The hydraulic depth is then calculated dividing the cross section area with top width. The hydraulic depths of Pandu and Pancharatna were calculated and are shown in the Table 6 and 7 respectively.

13.2.1 Spatial and temporal variation of hydraulic depths from sections 32 to 62

The hydraulic depth of the cross sections are analyzed in order to know the depth changes over the years. The cross sectional analysis of a river is also essential for hydrodynamic numerical modelling to understand the flow behavior, variation of velocity in a particular section.

13.2.1.1 Methodology

The cross-sections of each stations are plotted as shown above. A particular RL is assumed for each cross-section. The cross-sectional areas were then calculated using the trapezoidal formula. The hydraulic depths of each cross-section are then plotted for 2013-14, 2014-15 and 2015-16.

13.2.1.3 Observations

The hydraulic depths observed to be varying in different cross-sections. In cross-sections 35, 41, 48, 53 and 62, the hydraulic depths are decreasing. The average depth of the cross sections are given in Table 8.

Table 8: Average Hydraulic Depths in different years

	2013-14	**2014-15**	**2016-17**
Hydraulic Depths (km)	3.442	3.3733	3.3995

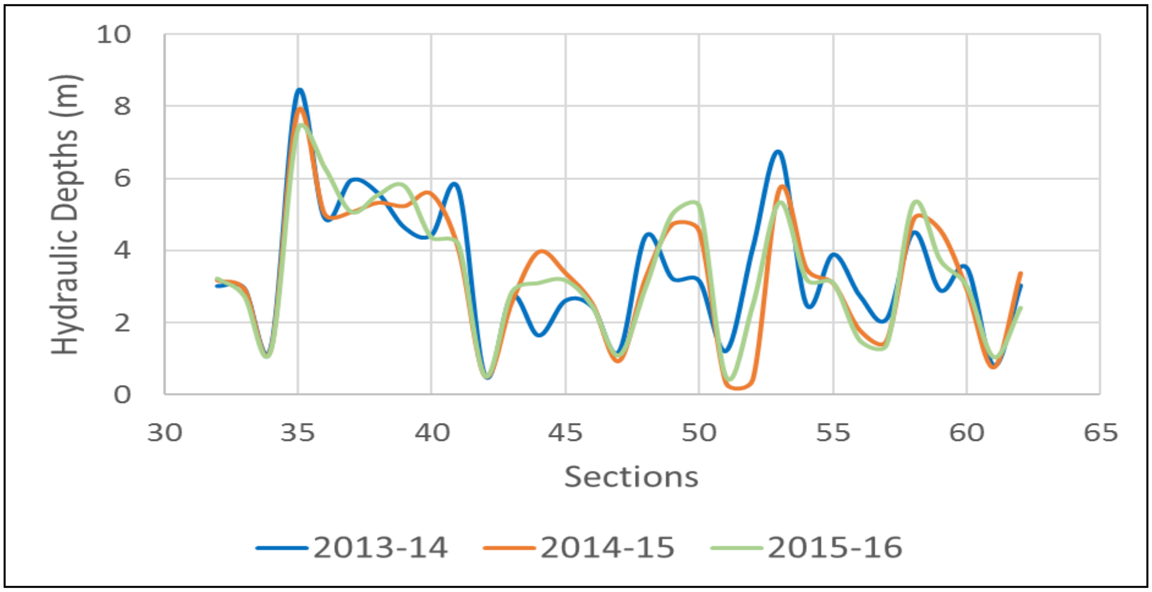

Figure 77: Change in Hydraulic Depth of Brahmaputra

13.3 Change in Average Width of Brahmaputra

The width of the Brahmaputra is changing as the river is extremely dynamic in nature. The river cross sections are subjected to continuous aggradation and degradation. Also the river banks undergo continuous erosion deposition processes. These factors are responsible for the change of width of Brahmaputra.

13.3.1 Methodology

The area of the entire Brahmaputra from Sadiya to Dhubri in Assam for each dataset has been calculated using polygon shapefiles in ArcGIS. A centerline is then created as a polyline shapefile. The average width is then calculated by dividing the total area of each polygon by the length of the centerline (Figure 80).

13.3.2 Observations

From the analysis of average width calculation it can be assessed that the width of the Brahmaputra is increasing over the time. In the year 1973-74 the average width is found to be 8.04 km. In 2008-11 the average width is found to be 9.97 km as shown in Figure 81.

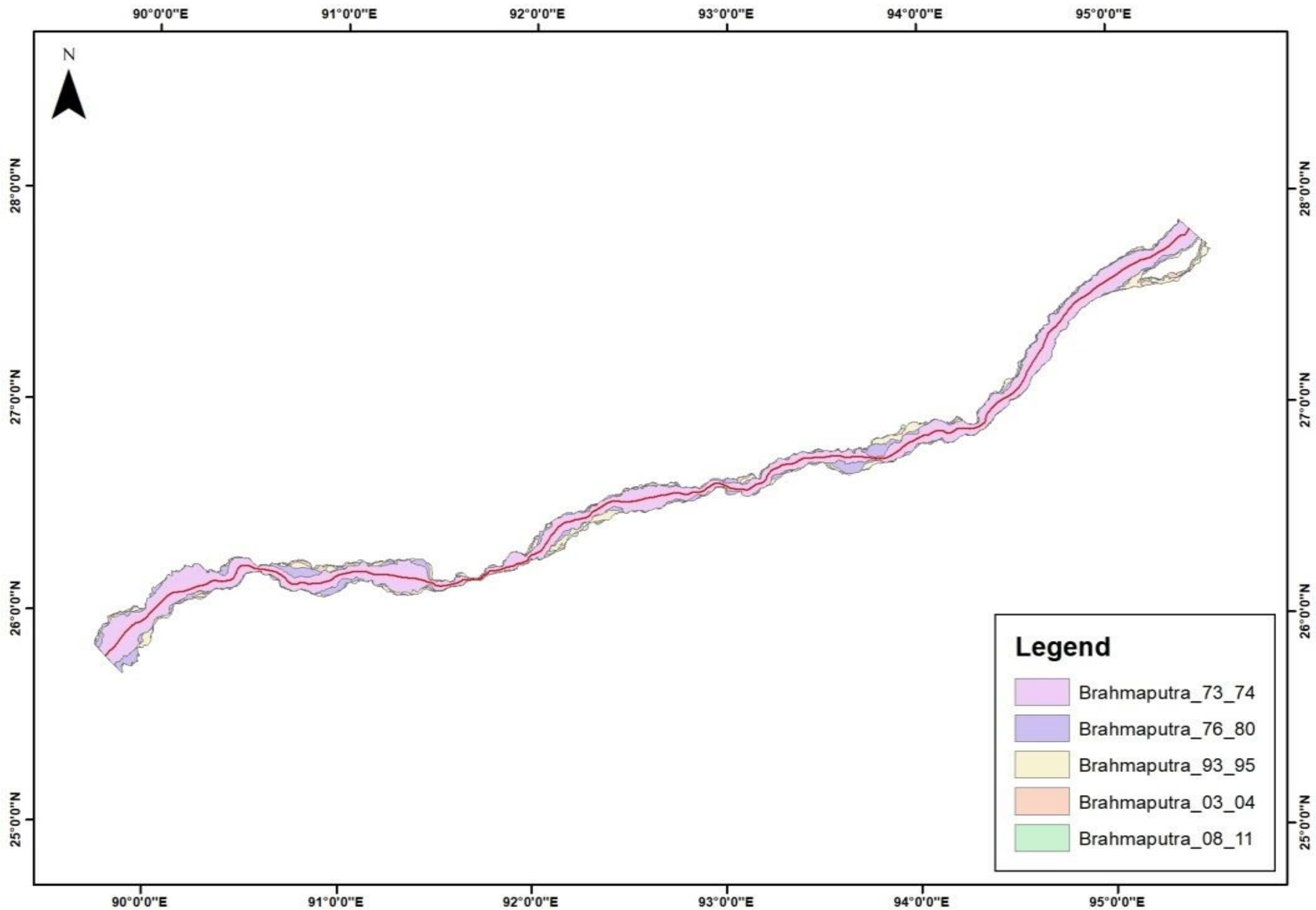

Figure 78: Map showing Change in Average Width of Brahmaputra over time

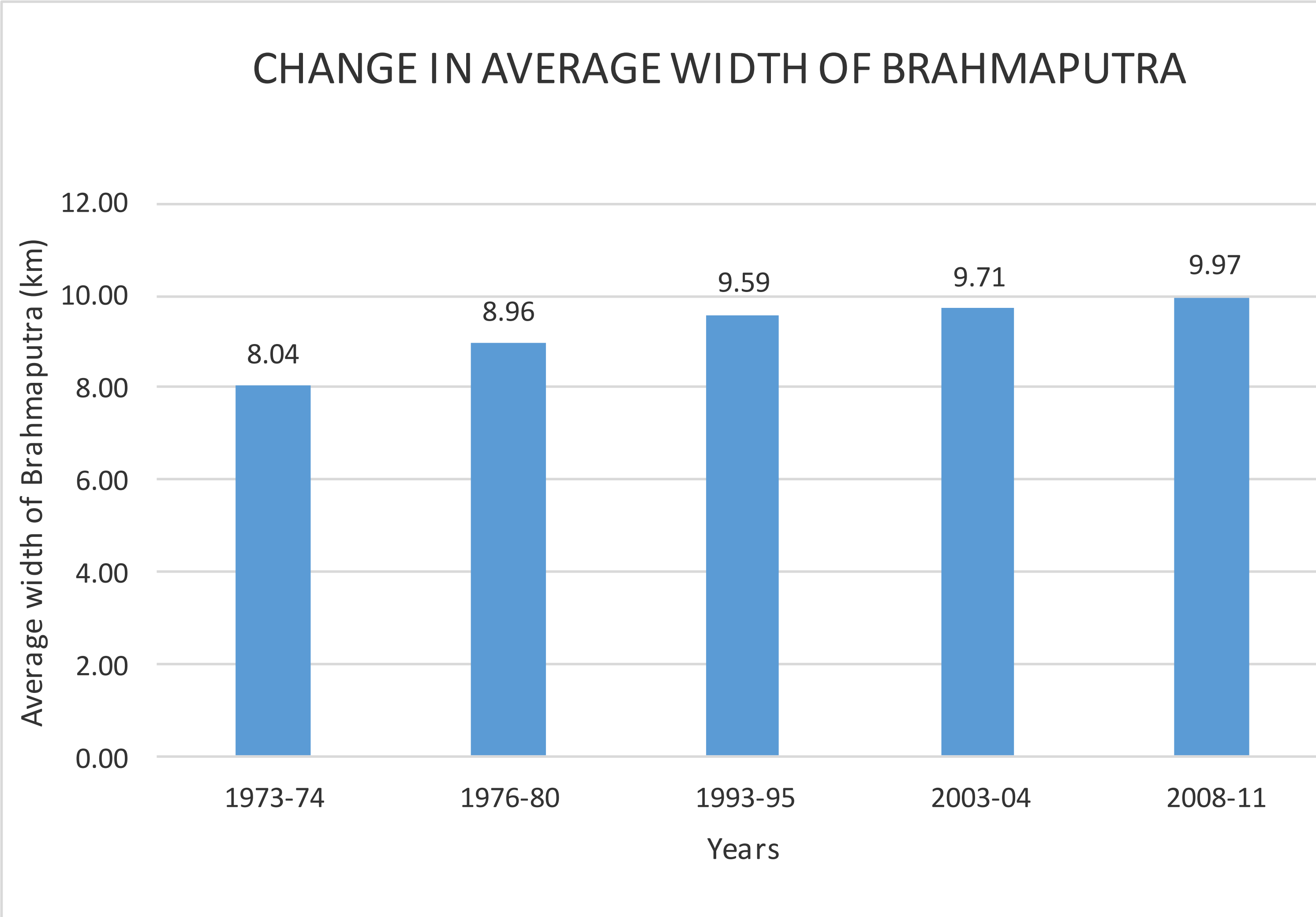

Figure 79: Change in Average Width of Brahmaputra over time

Chapter 14
MORPHOLOGICAL CHANGE IN MAJULI

There was a special request from Central Water Commission during the presentation of the Draft Report, to include a chapter on Majuli Island considering its importance as one of the World Heritage Sites. Therefore, this particular chapter contains the change in the morphology of the river island and the available literature on its origin and historical development of the Satras, culture, and livelihood are also referred.

14.1 Origin and formation of Majuli island:

Majuli is an important cultural heritage site of Assam and is home to the 'Vaisnavite' monasteries, popularly known as 'Satras'(Sarma & Phukan, 2004). Once the largest inhabited river island of the world, Majuli, was formed by the action of fluvial processes on the low-energy reach of the river Brahmaputra (Singh & Goswami, 2011). In a study mainly based on the historical reports and ancient literatures, Sarma & Phukan (2004) mentioned that in histories Majuli was referred as 'Majali', an assamese word, meaning a piece of land situated between two adjacent and parallel rivers. The study also reported that earlier, the river Brahmaputra, also known as Luhit or Luit, used to flow to the north of Majuli and the river Dihing, one of Brahmaputra's major tributaries, flowed south of Majuli. Flowing to the south of Majuli, the Dihing received many other tributaries such as Dikhow, Jhanji, Bhogdoi, Dhanisri etc. and then finally met the Brahmaputra at a place called Lakhu. Later on, the Brahmaputra shifted its course towards south and joined the Dihing river at its present confluence point at Dihingmukh located about 190 km east of Lakhu. This shift in the river course resulted into the creation of the Majuli island. After the creation of the island, the flow of the Brahmaputra got divided into two anabranches – one flowing along the Brahmaputra or Luhit to the north of Majuli, which is now known as the Kherkatia Suti and the other directed to the south of Majuli through the Dihing channel. In due course of time, the flow in the Kherkatia suti gradually decreased and a major part of the discharge of Brahmaputra was diverted to flow through the Dihing river. Due to this natural diversion of the river flow, channel widening in the present course of Brahmaputra started causing unrelenting erosion in both the banks of the river (Sarma & Phukan, 2004, Sarma, 2013).

14.2 Environmental Setting

Majuli, the nerve-centre of the Neo-Vaishnavite culture is situated between 26º45´ N - 27º12´ N latitude and 93º39´ E - 94º35´ E longitude. The area is bounded by the Brahmaputra river in the south, river Subansiri in the north-west and the Kherkatia Suti (an anabranch of the river Brahmaputra) in the north-east. In 1964, the mouth of the Kherkatia Suti was closed with the construction of a check dam across this spill channel (Hussain et al., 1993). The mean height of the area is around 77.5 m above mean sea level (m.s.l.). Geologically, Majuli is a part of the great alluvial tract of the Brahmaputra river and geomorphologically, it forms a part of the Brahmaputra floodplains. Being an active floodplain, the area is characterized by the presence of numerous alluvial features including natural levees, crevasses, splay deposits, point bars, channel bars etc. (Singh & Goswami, 2011). Majuli is marked by the presence of around seventy beels (local name for small ponds, ox-bow lakes and swamps) that cover 14% of its total area (Bhaskar et al., 2010). The climate of the area lies within the monsoon rainfall regime and receives an annual rainfall of about 2,150 mm. The temperature of Majuli, varies from 28º C to 33º C and relative humidity varies from 54% to 86% (Singh & Goswami, 2011). According to the 2011 census, the population of Majuli is 1.68 lakhs of which 70% belongs to the tribal communities (Board, 2012).

14.3 Soil

Bank materials of the river Brahmaputra are mostly composed of varying proportions of fine sand and silt, with only occasional presence of minor amounts of clay (generally less than 5%) (Goswami, 1985). According to the sub-soil investigations carried out by the River Research Station at different locations of Majuli extending up to a depth of 30 m indicate that the area is mostly underlain by grey coloured, fine to medium sized, poorly graded sand covered by light grey coloured silt mixed with clay and/or fine sand of varying thickness ranging from 1.5 to about 12 m. However, there are few pockets like Salmora, Dakhinpat and Bessamora, located on the south-western part of Majuli bordering Brahmaputra river, where the soil is rich in inorganic clay content and the depth of clay rich horizon extends even beyond 15 m from the ground (Goswami, 2001; Singh & Goswami, 2011).

14.4 Livelihood and Culture

Being endowed with naturally fertile soil and plenty of water, agriculture plays the dominating role in the livelihood of the people of Majuli. Farmers grow more than hundred varieties of rice and many other crops like maize, black gram and various types of cereals, vegetables, fruits, sugarcane, cotton, jute, castor etc. The extraordinary pottery craft of Majuli is not only an age-old profession of the people but also an invaluable ingredient of its cultural life having immense archaeological significance. The facts that this craft has flourished through ages without using the potter's wheel and is traded through a traditional barter system make it a heritage of mankind that needs to be studied and preserved. Archaeologists have found in this form of pottery of Majuli a missing link between the Mohenjo-Daro and Harappa civilizations. Other occupations of the people include pisciculture, sericulture, horticulture, cattle farming, dairy, handloom, handicrafts (eg. - cane works, bamboo crafts) and boat making (Sarma, 2013).

Majuli, characterized by the meeting and branching of numerous channels around alluvial sandbars, is a meeting ground of diverse cultural streams with an assortment of ethnic communities such as Mishings, Deoris, Kacharis, Koch Rajbangshis and sundry castes and creeds living peacefully and cohesively for hundreds of years. In the community lives of the people of Majuli, one can see a distinct mark of assimilation and synthesis of varied ethnic and cultural traditions fused with the dominant Satra culture. The famous 'Ras' festival of Majuli that is celebrated in the month of November attracts thousands of people and tourists every year (Goswami, 2001).

14.5 The Satras

One of the unique and important features of this riverine landmass is the presence of the 'Vaishnavite' monasteries, popularly known as the Satras. The Satras were founded by the great saint, poet litterateur and religious reformer Srimanta Sankardeva in the fifteenth century A.D. In Assam, around the unique system of these 'Vaishnavite' monasteries, the Neo-Vaishnavite culture has evolved over the last five hundred years. Earlier, as many as sixty five such Satras flourished with lakhs of 'Bhakats' (disciples) in Majuli and thousands of followers all over the state. These Satras not only have an impact on the religious and spiritual lives of the people but also have nurtured and preserved a rich tradition of art and craft like the Satriya dance – a classical dance form known worldwide, mask and boat making, pottery etc. Besides, many antiquities, manuscripts, coins etc. of great archaeological value are still preserved in the Satras (Goswami, 2001). Due to the engulfing of the river Brahmaputra and Subansiri, out of these sixty five Satras only twenty two are left at present. Among these twenty two, Auniati, Dakhinpat, Garmur, Uttar Kamalabari, Natun Kamalabari, Chamaguri and Bengenati Satra have still retained much of their past pride, position, tradition and glory and thereby become the nucleus of the Vaishnav religion and culture (Sarma, 2013).

14.6 Literature review

The problem of severe bank erosion in Majuli is well known and many researchers have investigated this problem at different times. Mani et al. (2003) observed the trends of riverbank erosion in a small part of Majuli, the area near Kaniajan village located in south Majuli. This study was carried out for a stretch of about 11 km and the erosion-deposition maps were prepared for the area using satellite data of 1991, 1997 and 1998. Erosion of the area was measured at various sections at 1 km interval and loss of 1900 ha of land was observed during 1991-1997 and 845 ha of land during 1997-1998 (Mani et al., 2003).

Kotoky et al. (2003) studied the erosion problem of Majuli with the help of IRS imagery of 1998 and found a drastic decrease in the area of the island from 1245 km2, as per the available historical records, to 577.65 km2 in 1998. The study found that the rate of erosion in Majuli was 1.9 km2/yr. during 1920-98 (Kotoky et al., 2003).

Another study carried out by Sarma & Phukan (2004) assessed the changes in the Majuli island during 20th century by superimposing the bank lines of 1917, 1966-72, 1996 and 2001 and subdividing the island into an array of twenty-six 5´latitude x 5´longitude blocks. The study found that the rate of bank line shift was not uniform throughout the island in time and space. Shifting of the bank line leading to erosion along the Brahmaputra was found to be dominant at the south bank with the maximum rate of retreat being 0.480 km./yr. and that leading to siltation was found to be confined mostly to the north bank due to the Subansiri river with the maximum rate of advance being 0.146 km./yr. According to the study, there is a continuous decrease in the area of Majuli from 751.31 km2 in 1917 to 564.01 km2 in 1966-1972, 453.76 km2 in 1996 and 421.65 km2 in 2001. The average annual rate of erosion was found as 1.77 km2/yr. from 1917 to

1972, 1.84 km2/yr. from 1972 to 1996 and 6.42 km2/yr. from 1996 to 2001 (Sarma & Phukan, 2004).

In a research work done by Sankhua et al. (2005), the authors deployed the use of remote sensing and artificial neural network (ANN) technique to study the erosion problem of the decaying island Majuli and suggested that the ANN model had a very good forecasting capability of the area loss due to the complex process of stream bank erosion. The study reported that the erosion problem of Majuli became significant only after 1950 earthquake and took a serious turn especially from 1954 onwards. This was due to the construction of erosion protection measures in 1950 on the south bank of the river Brahmaputra in the Kokilamukh area, leaving the north bank unprotected. The authors also remarked that nothing substantial had been done to control the erosion problem of Majuli, except the construction of the embankments, a structural measure useful for temporary flood protection purpose only (Sankhua et al., 2005).

14.7 Morphological changes in Majuli

Majuli is situated at the bosom of the three river systems viz. the Subansiri, the Kherkatia suti and the main Brahmaputra river. Geomorphologically, Majuli forms a part of the floodplains of Brahmaputra river and thereby continuously facing serious problems of flood hazard (due to the influence of SW monsoon) and riverbank erosion which has posed a threat to its rich cultural heritage and its existence as well (Kotoky et al. 2003). Therefore, in this study, the decadal changes in the total area of Majuli has been evaluated with the help of satellite imageries.

14.7.1 Methodology

This study has been carried out using the SOI toposheet of 1973-74 and georeferenced satellite imageries viz. LANDSAT MSS of 1976-80, IRS 1B, LISS 1of 1993-95, IRS P6, LISS 3 of 2003-04, Resourcesat-1 LISS 3 of 2008-11 and Resourcesat-2 LISS 4 of 2016-17. First of all, the SOI toposheets were georeferenced and then mosaicking of the georeferenced toposheets were done. Also, mosaicking of all the different satellite datasets were done separately for each year. From these datasets, banklines of the three river systems surrounding the Majuli island were delineated for each decade as polylines in ArcGIS (Figure 83). Also to evaluate the change in the area of Majuli, polygon shapefiles were delineated for each decade and then for each year, area of the polygon was calculated in square kilometre using calculate geometry tool in ArcGIS (Figure 84).

14.8 Observations

From the morphological analysis of Majuli, it has been observed that there is a northward shift in the Brahmaputra right bank towards Tekeliphuta embankment which is on the easternmost boundary of Majuli. It is also evident that presently, the Kherkatia Suti i.e. the channel flowing on the northern boundary of the Majuli island, which was originated from this point of Brahmaputra river, is not as active as it was before 1960s. This is because of construction of the closing dyke i.e. the Tekeliphuta embankment on the channel to mitigate the flood hazard in the northern part of Majuli. Also, an enormous shift (around 15 km) has been observed at the Brahmaputra-Subansiri confluence point. These shifting in the river banklines over time has resulted in massive erosion in the western and eastern boundary of Majuli island. Also, in the southern part of Majuli continuous process of erosion has been observed near Sumoimari village. However, some amount of deposition has also been observed near Sukan Suti Miri village. The decadal change in total area of Majuli is estimated as 561.19 km2 in 1973-74, 484.32 km2 in 1976-80, 423.65 km2 in 1993-95, 425.99 km2 in 2003-04, 422.37 in 2008-11 and 422.56 in 2016-17 (Figure 83).

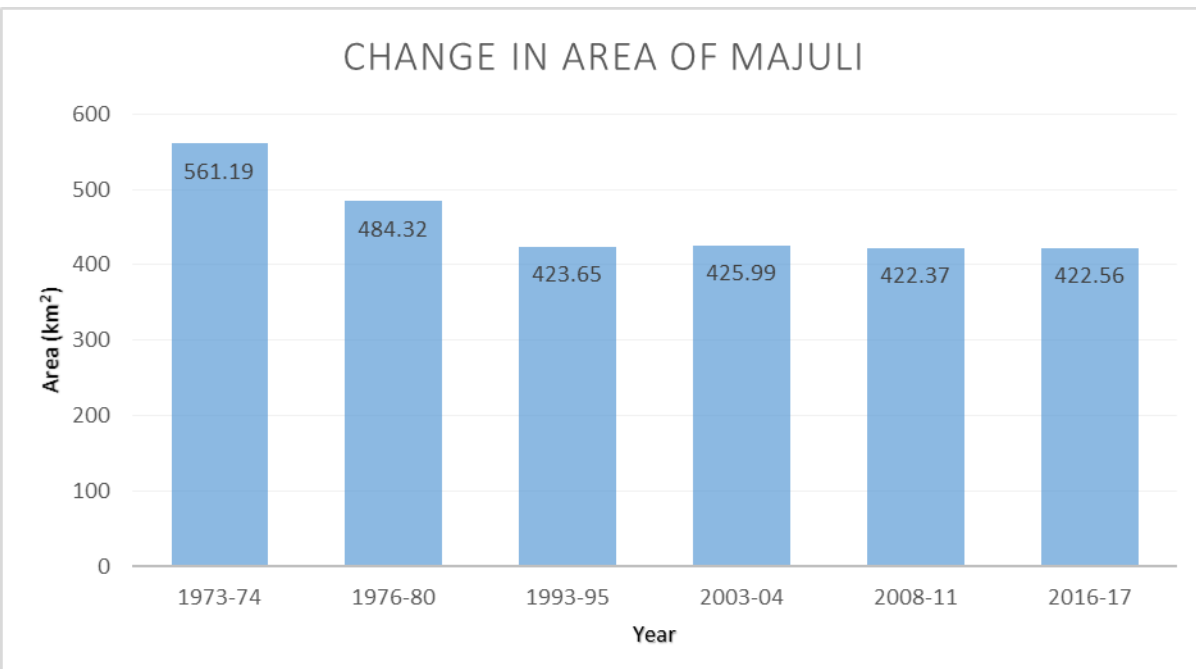

Figure 80: Change in Area of Majuli

From the area estimation it is found that although there is a decrease in the total area of Majuli from the base year i.e. 1973-74, in the recent decades the total area of the Majuli almost remains same. However, this does not indicate that no erosion has occurred in the recent times and this might be owed to the fact that there exists a continuous process of erosion-deposition around the landmass.

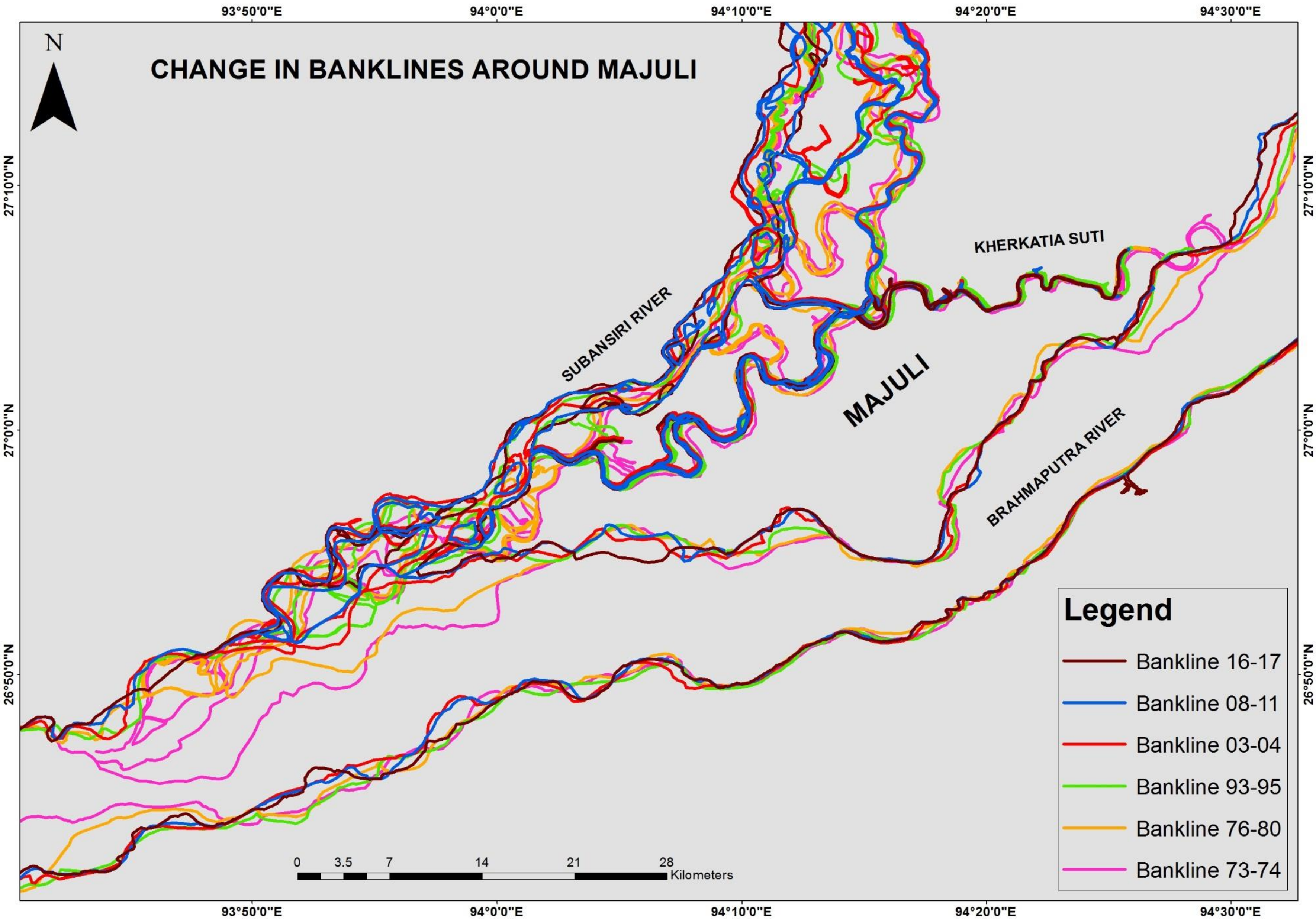

Figure 81: Change in Banklines around Majuli

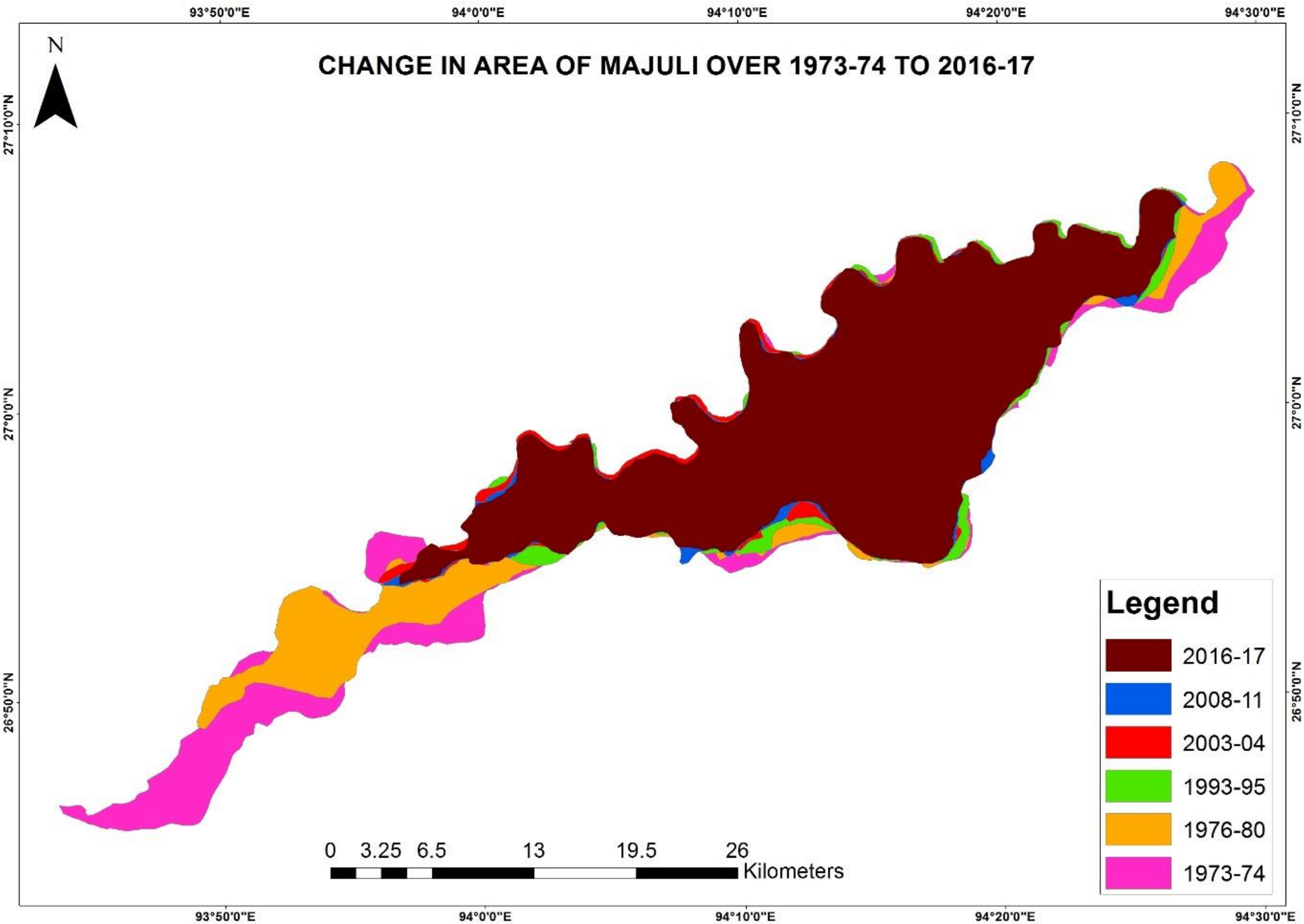

Figure 82: Change in area of Majuli over 1973-74 to 2016-17

Chapter 15
IDENTIFICATION OF VULNERABLE REACHES

Based on the shift in river course/bank-line and its proximity to flood/erosion protection structures as envisaged from the satellite imageries, vulnerable reaches of the river Brahmaputra were identified. Field verification of the identified sites are also underway to have a clear idea of the actual ground situation. The identified vulnerable reaches are as follows:

15.1 Vulnerable Reaches

15.1.1 Confluence of the Simen river with Brahmaputra, Dhemaji

Overlaying the banklines of different time periods i.e. from 1973-74 to 2016-17 as shown in Figure 85, it has been observed that near the confluence of Simen river with Brahmaputra, there is a gradual shift in the right bank of the river Brahmaputra towards north (near Kulajan Pam). Also, a change in the course of Simen river at the confluence has been observed in the recent imagery. As apparent from Figure 86 & 87, earlier, the confluence of Simen river was at downstream of the present day confluence.

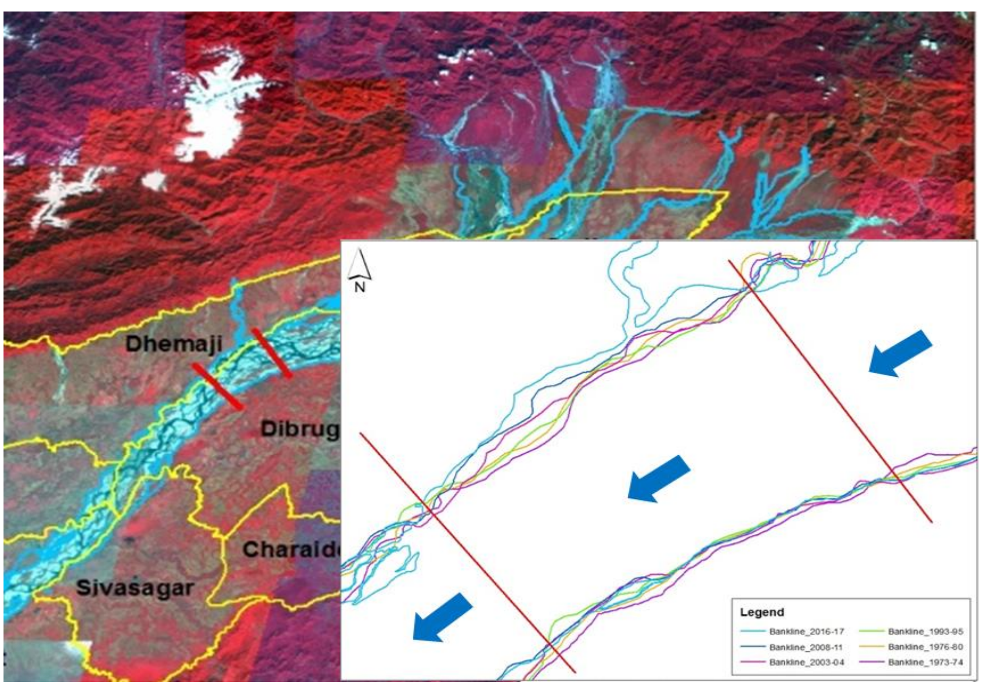

Figure 83: Shifting of Brahmaputra banklines near the confluence of Simen river Dhemaji

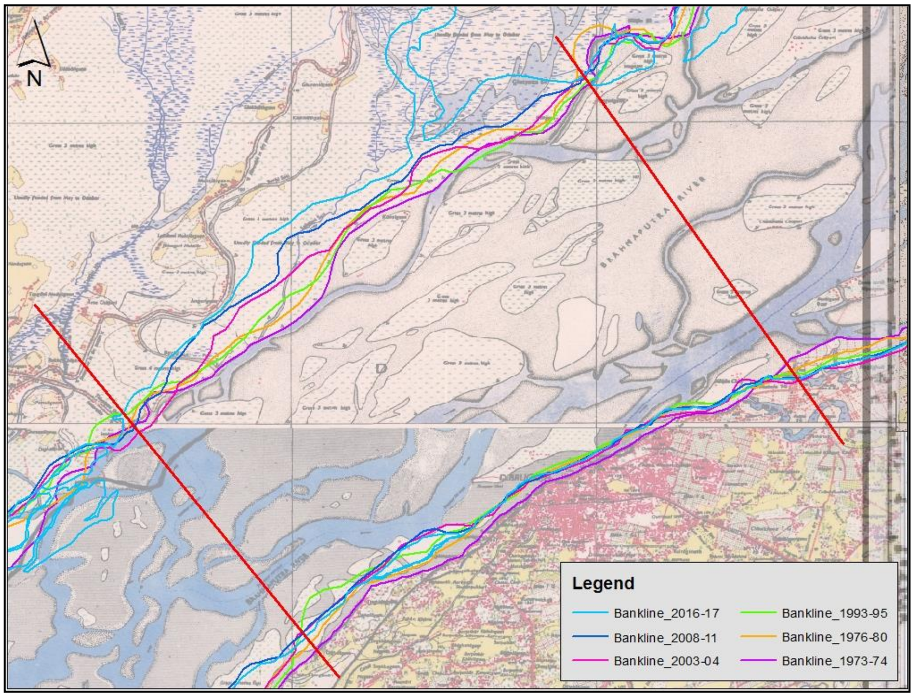

Figure 84: Earlier and present day confluence of Simen river, Dhemaji

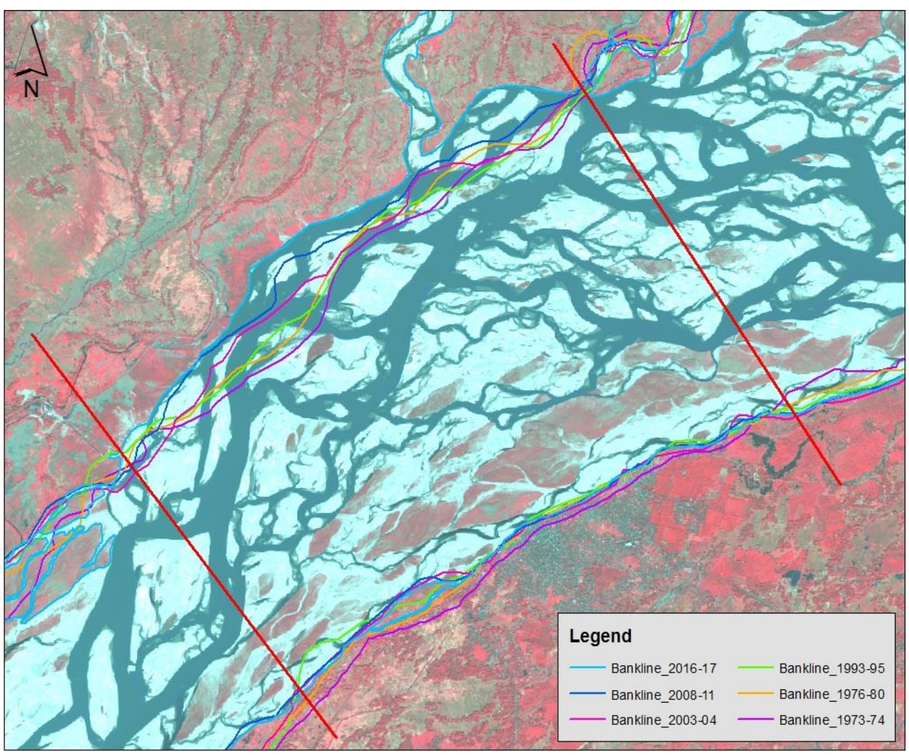

Figure 85: Confluence of Simen river in 2016-17

15.1.2 Tekeliphuta embankment, Majuli

As shown in Figure 88, a northward shift in the Brahmaputra right bank towards Tekeliphuta embankment was obeserved. The reach is adjacent to the easternmost boundary of Majuli (once largest inhabited river island of the world). It is worth mentioning that the channel flowing on the northern boundary of the Majuli island, which was originated from this point of Brahmaputra river, is not as active as it was before 1960s. This is because of construction of a closing dyke i.e. the Tekeliphuta embankment on the channel to mitigate the flood hazard in the northern part of Majuli (Figure 89 & 90). Therefore, care should be taken to prevent further migration of the right bank towards this, as breaching of this closing dike may cause disastrous flood in the Majuli island.

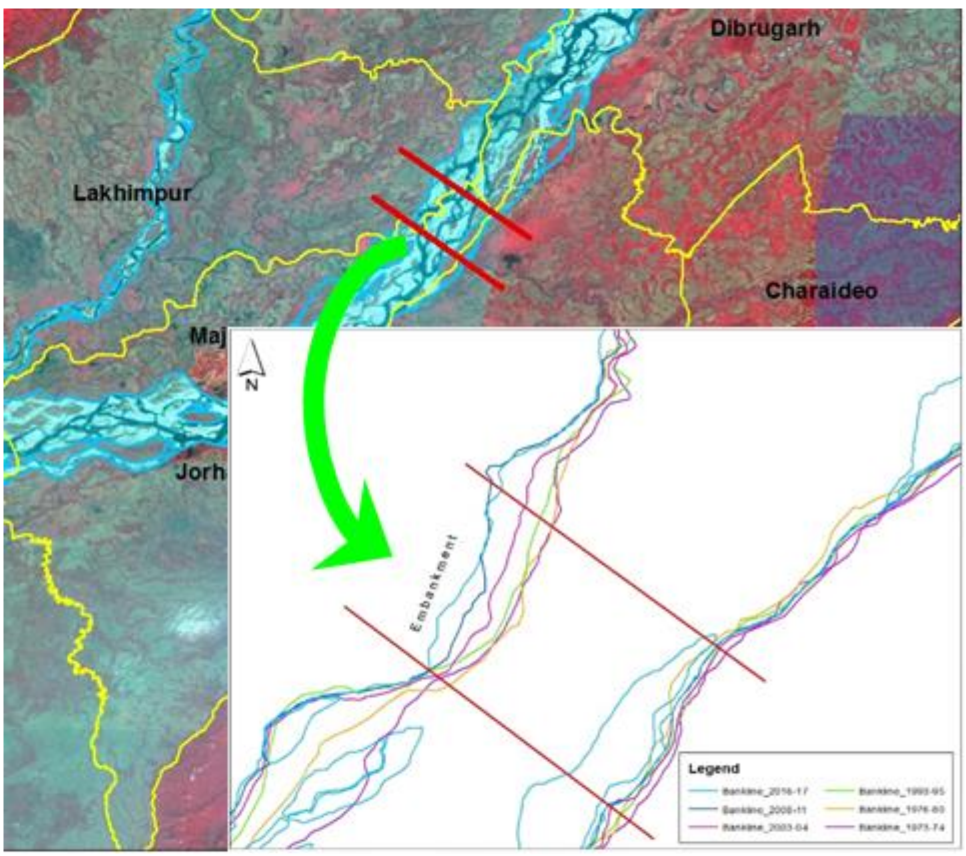

Figure 86: Shifting of Brahmaputra right bank towards Tekeliphuta embankment near Majuli

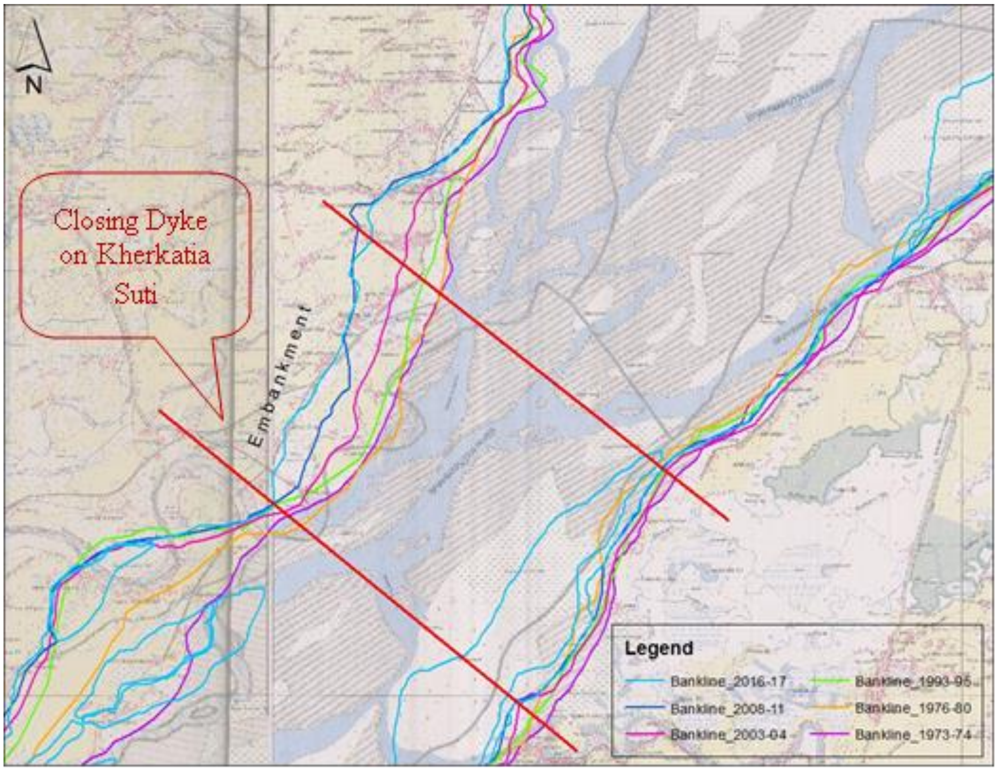

Figure 87: Closing dyke on the Kherkatia suri as seen in the toposheet of 1973-74 near Majuli

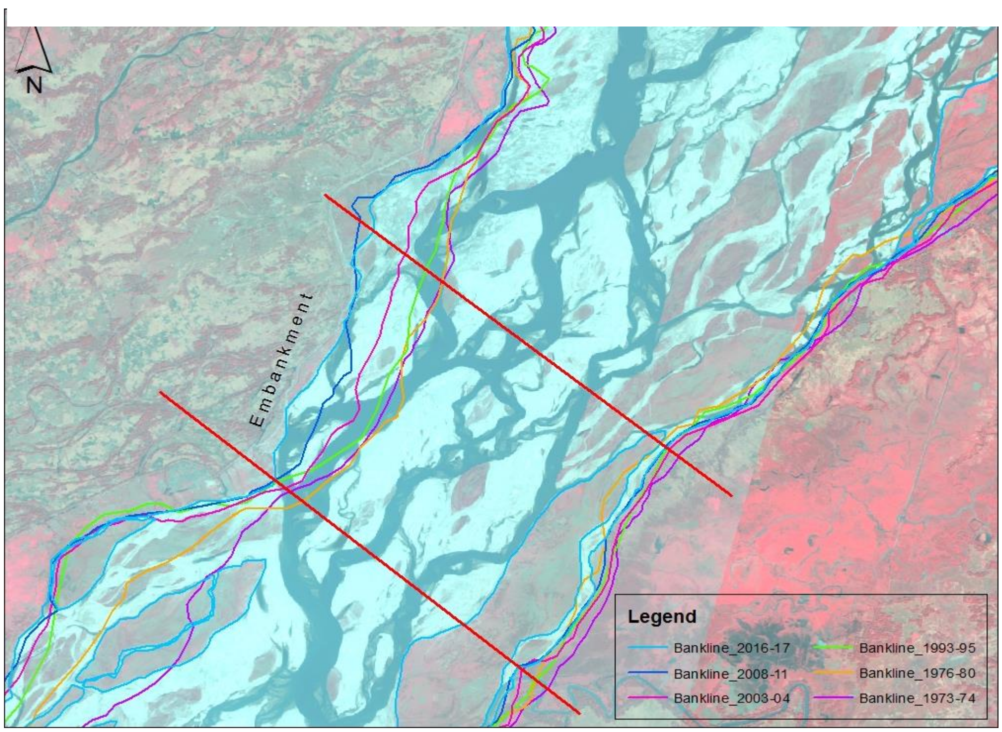

Figure 88: Tekeliphuta embankment as seen in satellite imagery of 2016-17

15.1.3 Biswanath Chariali

Another reach has been identified near Biswanath, where severe erosion is observed on the right bank of the river at the immediate downstream section of a stable landmass protruding towards the river as shown in Figure 91. Although not hilly, elevation of this land mass is observed to be higher than the surrounding. However, a thorough field survey is needed at this point.

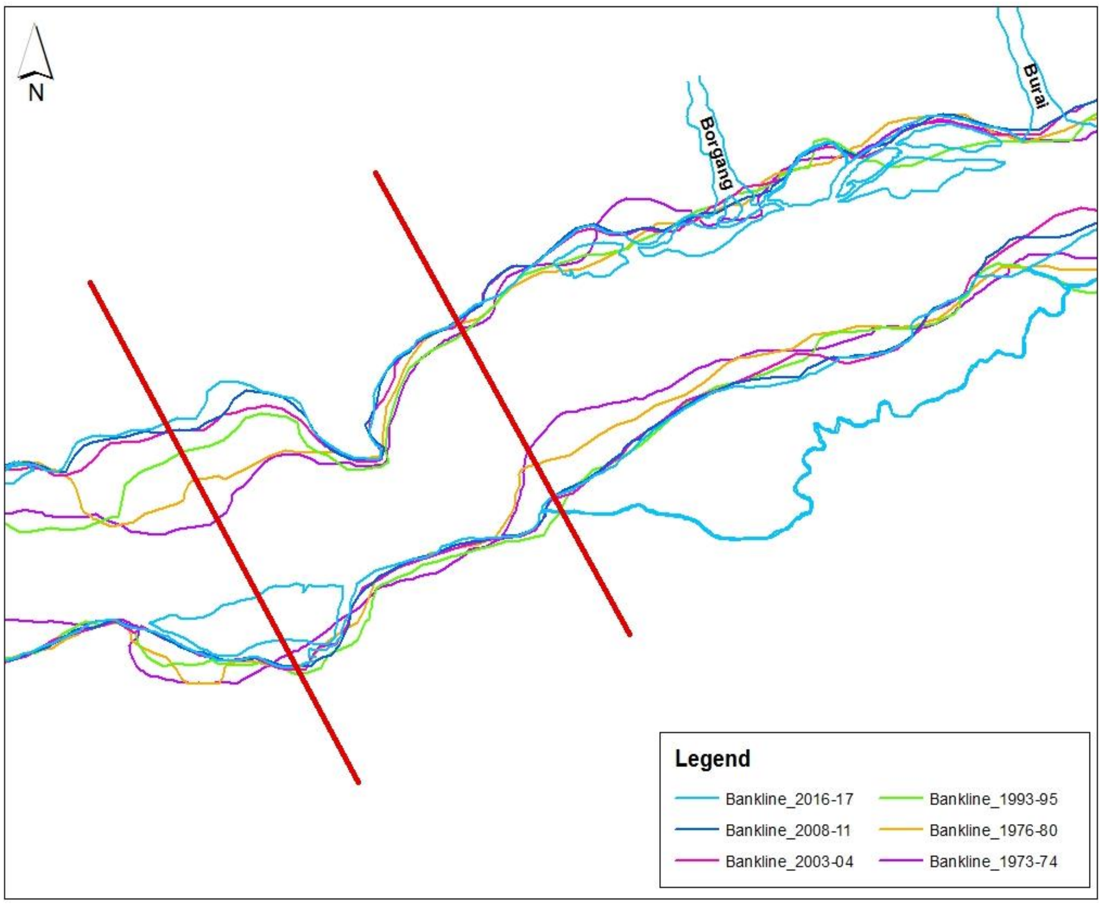

Figure 89: Vulnerable reach near Biswanath

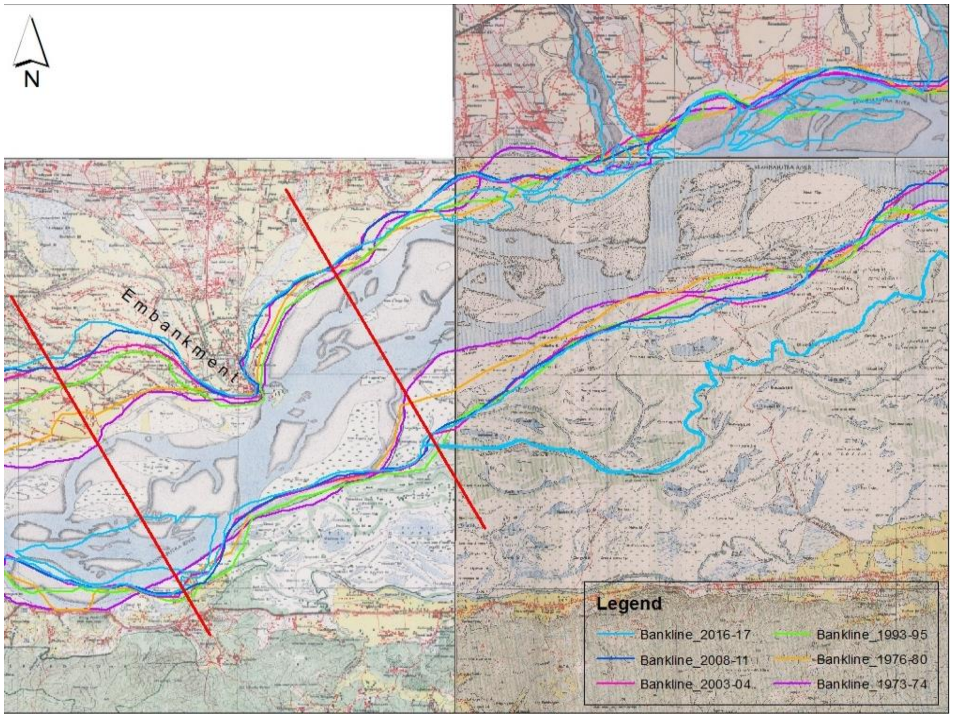

Figure 90: Vulnerable reach near Biswanath as seen in toposheet of 1973-74

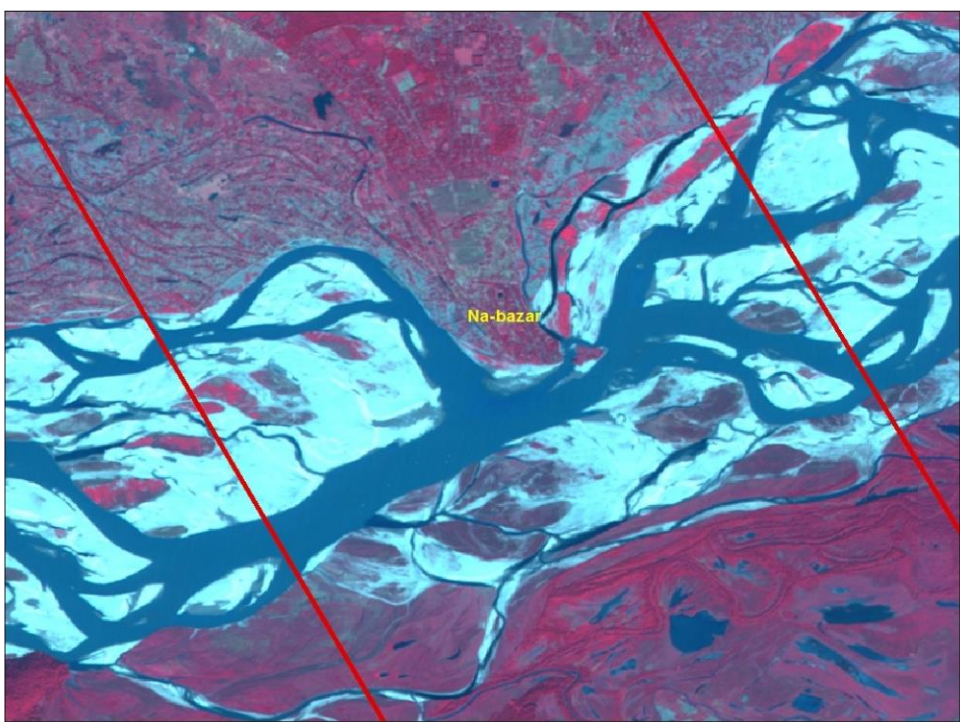

Figure 91: Vulnerable reach near Biswanath as seen in satellite imagery of 2008-11

15.1.4 Darrang (Right bank)-Morigaon (Left bank)

A reach covering parts of Darrang and Morigaon districts on both the right and left bank respectively, has been identified as vulnerable reach as unrelenting erosion is observed on both banks of the river over the years (Figure 94). To verify the satellite based observations, a field survey was also carried out on 12th of December, 2017 at Lahorighat, Morigaon. During field survey, severe erosion was witnessed in the reach including erosion of a land spur at Lahorighat (Figure 95 to 98).

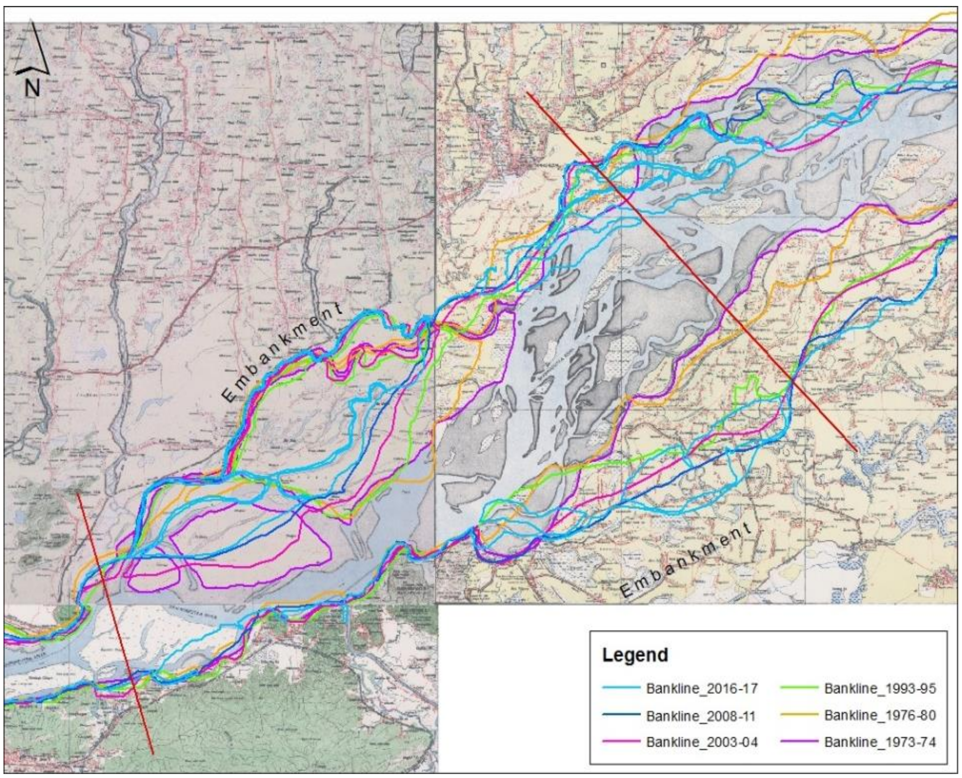

Figure 92: Vulnerable reach of Brahmaputra covering parts of Darrang and Morigaon

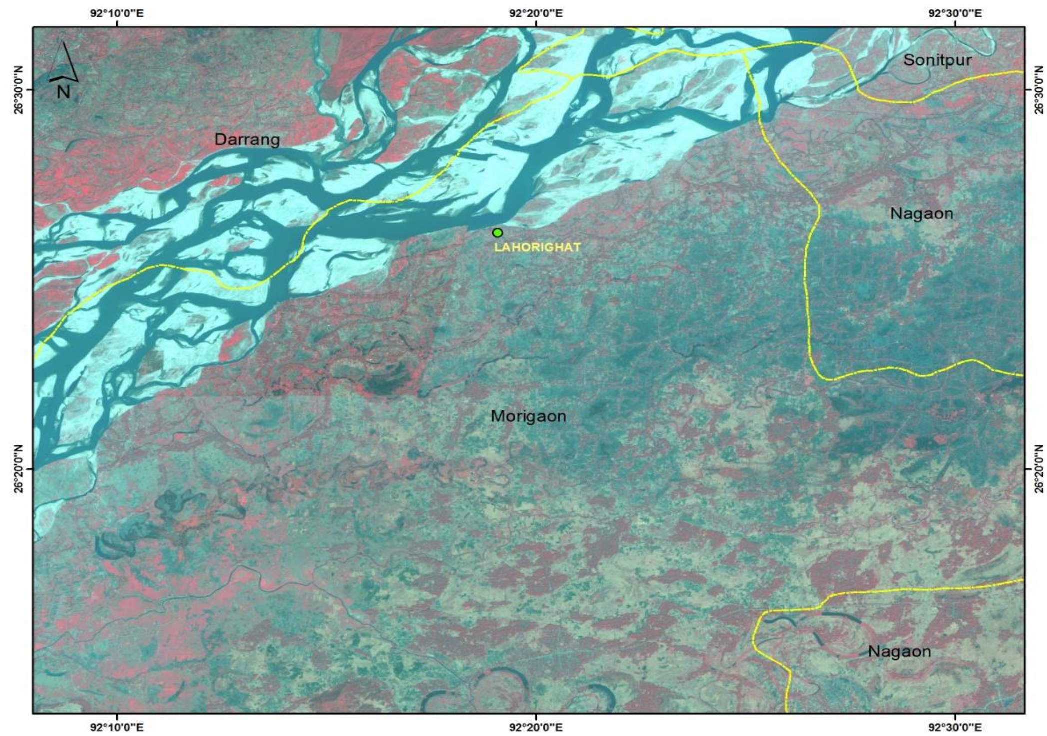

Figure 93: Location of the site visited near Lahorighat, Morigaon

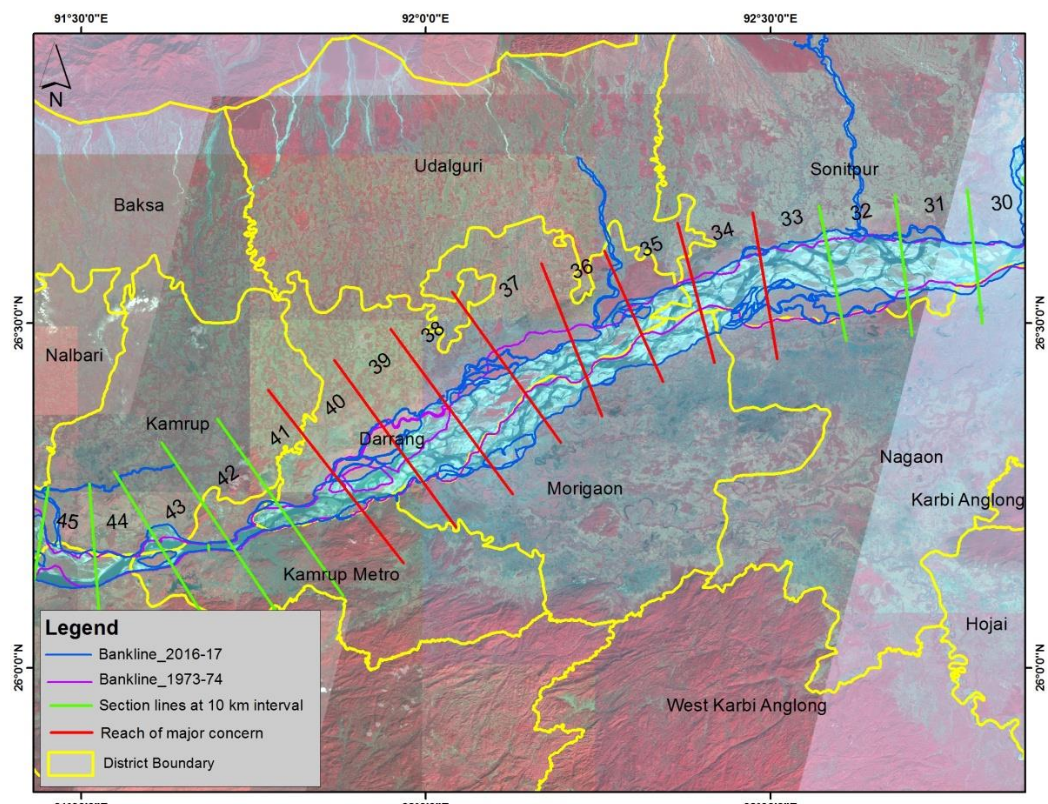

Figure 94: Close view of the vulnerable reach visited during the field survey at Morigaon

Figure 95: Eroded part of the Land spur at Lahorighat, Morigaon

Figure 96: Active bank erosion on the southern bank of Brahmaputra at Morigaon

In the Darrang side i.e. on the right bank of Brahmaputra, a shift in the confluence of an anabranch of the river (near Niz-rangamati village) towards the embankment has been observed from satellite imageries (Figure 99).

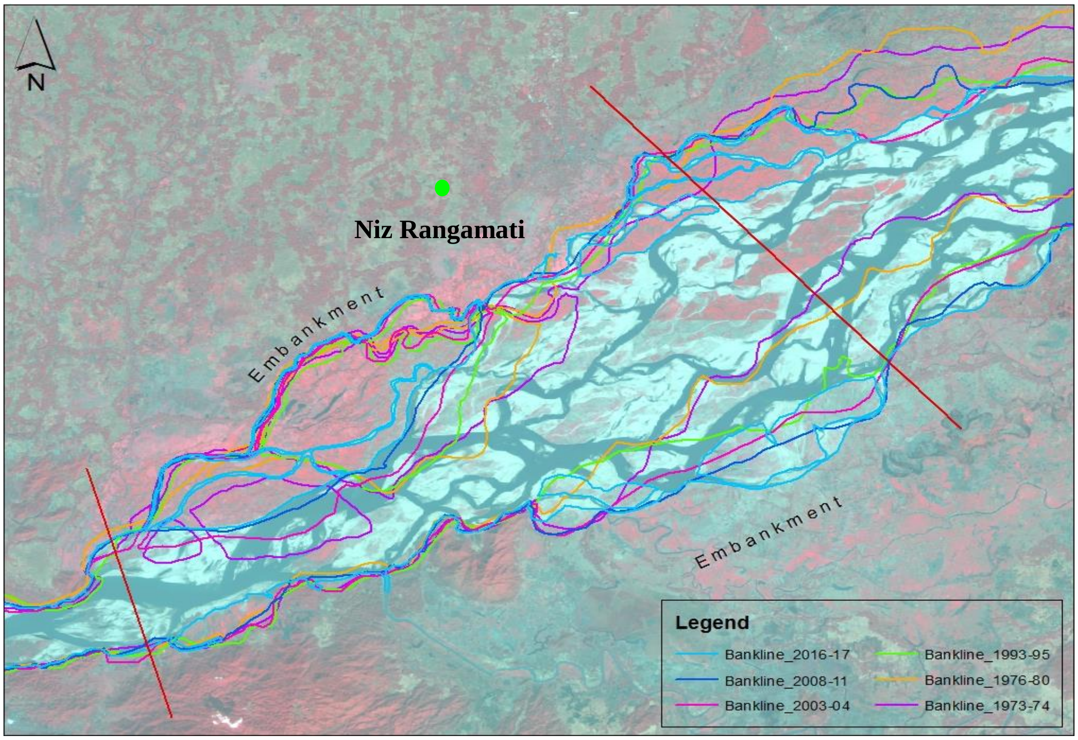

Figure 97: Shifting of the Brahmaputra right bank and confluence of an anabranch of the river towards north near Niz Rangamati village

15.1.5 Barpeta

The vulnerable reach identified in Barpeta district near Balidhari (right bank) and Kadulimari (left bank) is facing continuous erosion over the years on both banks of the river as envisaged from the satellite imageries. As shown in Figure 101, overlaying the banklines of different time period on the toposheet, it has been observed that a part of the embankment on the northern side of the river had already been breached by the right bank of the river and the bankline is still shifting towards north. On the southern side of the river i.e. on the left bank also a continuous shift of the river has been observed towards the embankment on the south. However, it is also observed that habitation has been taken place within the embankment on the southern side of the river, where the river was once flowing.

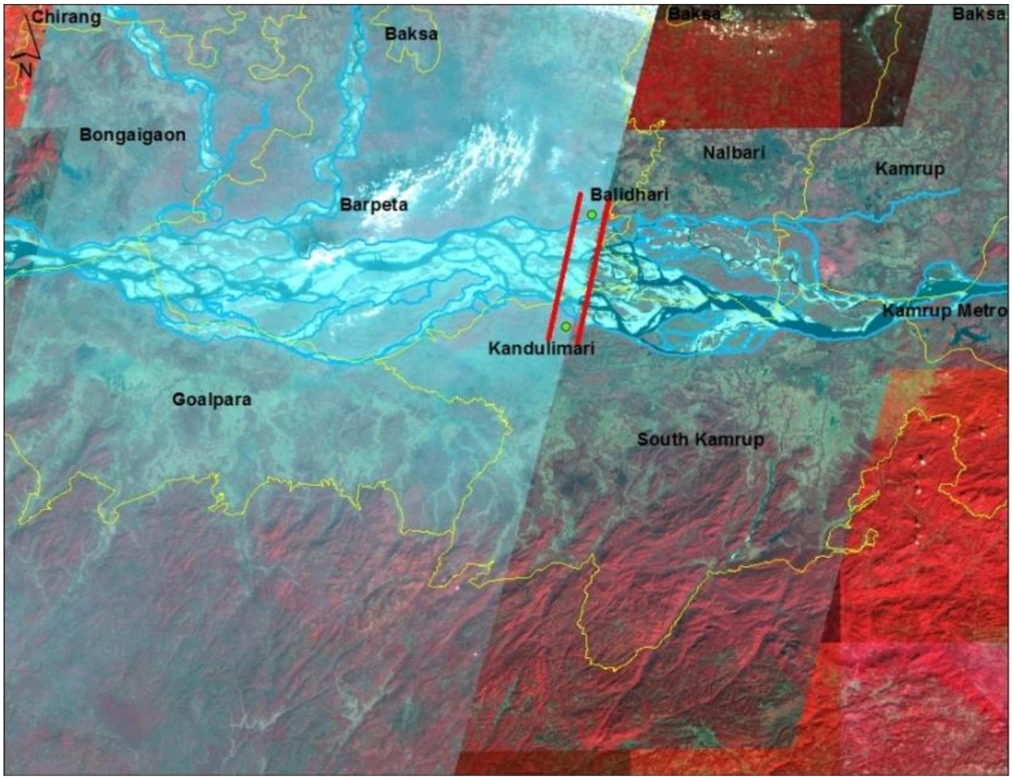

Figure 98: Vulnerable reach in Barpeta as seen in the satellite imagery of 2016-17

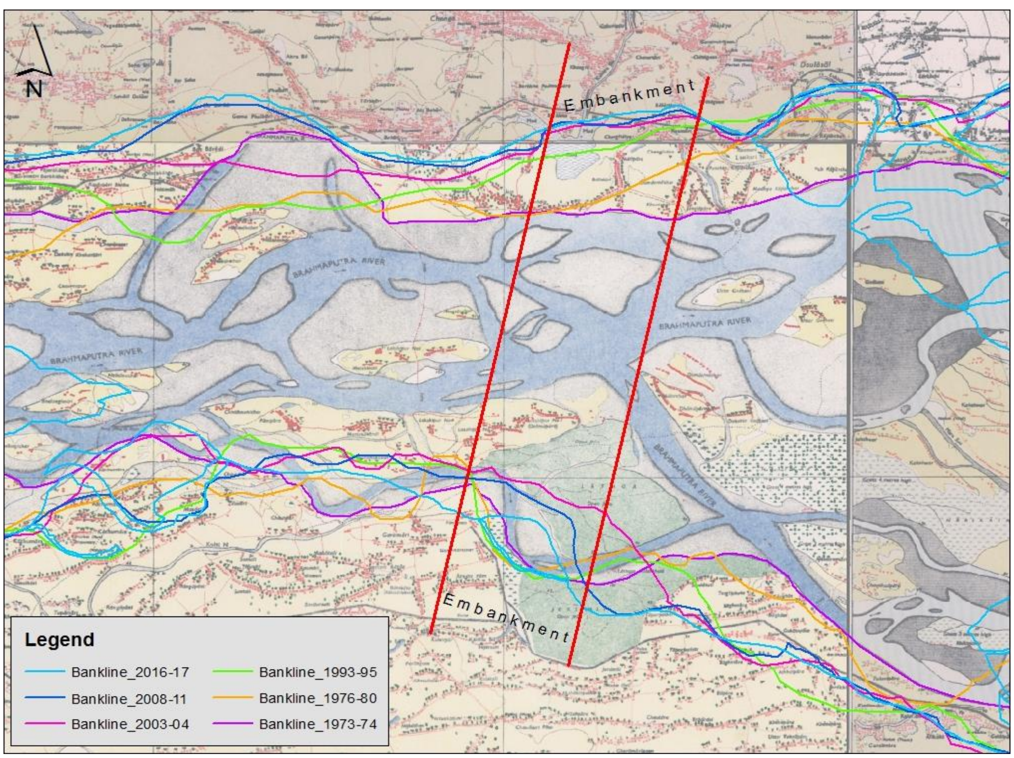

Figure 99: Vulnerable reach of Barpeta as seen in the toposheet of 1973-74

15.1.6 Possibility of Avulsion of Manas River by Brahmaputra

Another point at the border of the Barpeta and Bongaigaon districts is identified as vulnerable reach, as the right bank of the river Brahmaputra is shifting towards north at that point causing severe bank erosion over there. Also the Manas river, a northern tributary of Brahmaputra, is meandering before its confluence with Brahmaputra and approaching towards the main channel. Therefore, at times the tributary may shift its confluence upstream of the present confluence (near Moinbari East bazar) causing havoc in that portion (Figure 102 to 104).

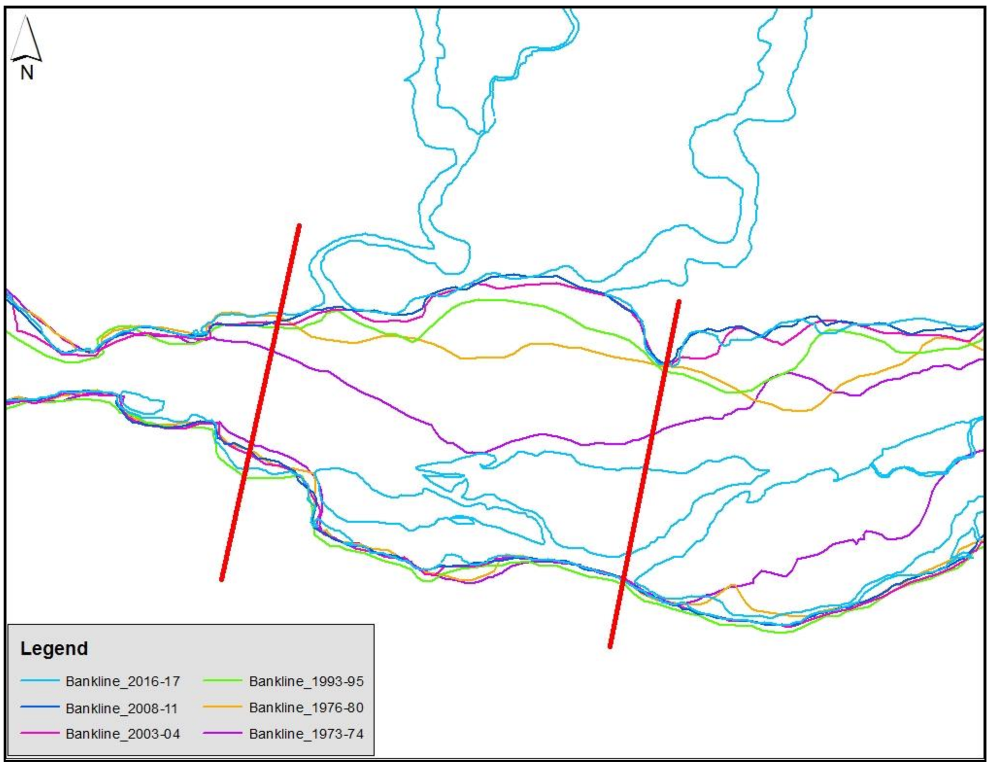

Figure 100: Meandering of the Manas river towards Brahmaputra

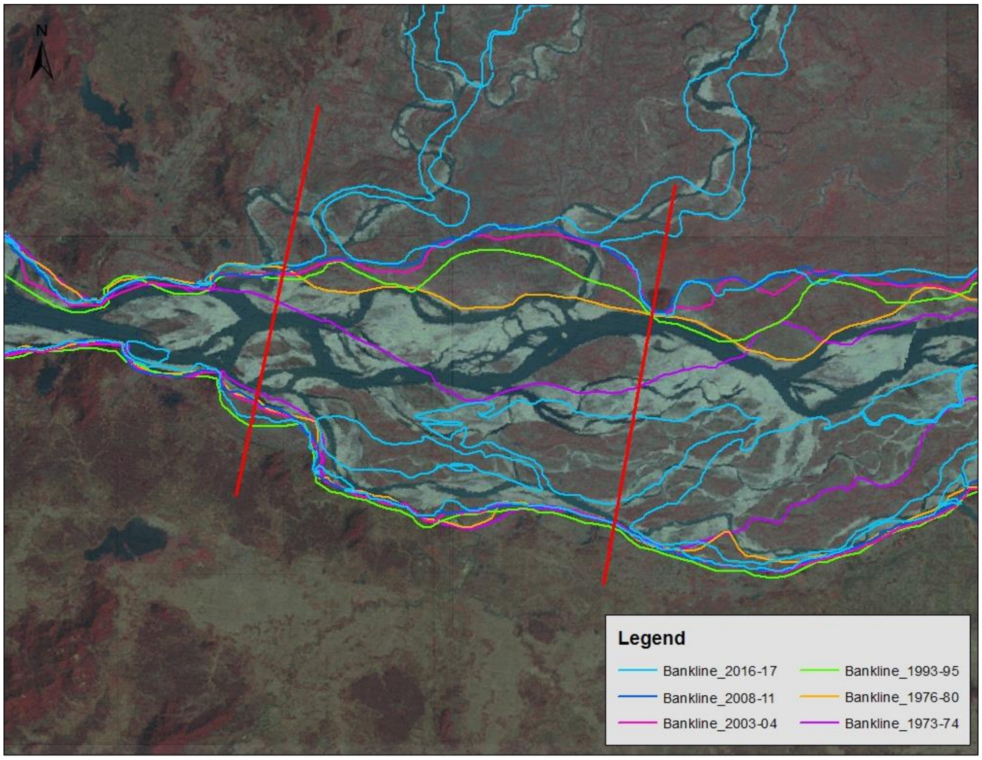

Figure 101: Earlier (Landsat MSS 1976-80) and present day (2016-17) course of the Manas river

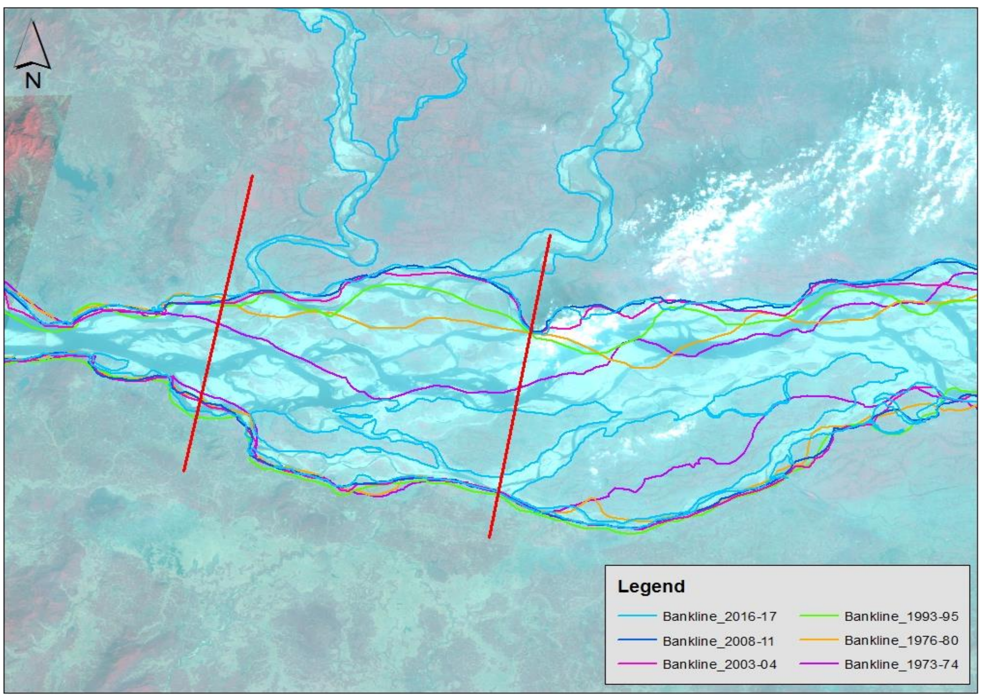

Figure 102: Vulnerable reach near the confluence of Manas and Brahmaputra river as seen in the recent satellite imagery of 2016-17 (LISS IV MSS)

15.2 Vulnerability Index

15.2.1 Methodology

To identify the vulnerable reaches in terms of proximity to important cities/villages, airports, roads, railways, national parks etc. a vulnerability index has been developed based on expert opinions. To develop the vulnerability index, first of all, a map has been prepared overlaying the 2016-17 river bank line over the layers of airports, dam locations, important cities/villages, refineries, national parks/wildlife sanctuaries, embankments, bridges, railways and highways (Figure 106). The whole river from Sadiya to Dhubri has been divided into 13 reaches at 50 km interval. Then a 2 km buffer area from the river centerline has also been demarcated in both the banks of the river. Presence/absence of the protective structures such as spurs in each reach of the river has been identified visually from high resolution LISS 4 imagery and also the presence/absence of cities/towns/airport/railways/highways/refineries within 2 km from the river has been marked. From the reach-wise decadal rate of erosion estimation (Figure 39 & 40), trend in the rate of erosion in recent years has been marked and considered for Vulnerability Index calculation. Eight factors have been identified as responsible for vulnerability of a reach to erosion hazard and binary values were assigned to each factor depending on its presence or absence in the reach. The identified factors of vulnerability are:

I. Increasing Rate of Erosion
II. Presence of important City/Town within 2 km from the Bank
III. Presence of Airport within 2 km from the bank
IV. Presence of National Park/Wildlife Sanctuary
V. Presence of National Highway within 2 km from bank
VI. Presence of Railway Line within 2 km from bank
VII. Presence of Protective Structure
VIII. Presence of Refinery within 2 km from the bank

These factors of vulnerability are then distributed among different stakeholders from various departments to assign weightage to the factors in Likert Scale (enclosed as Annexure VI). Few suggestions on various other factors of vulnerability has also been received from different stakeholders which can be incorporated in future studies to identify vulnerable reaches of the river.

The averages of the weights are then calculated for each factor and these weights are then multiplied with the binary values assigned against the factor. Finally, Vulnerability Index (VI) has been calculated as the sum total of the products of average weight and binary value assigned against the factor. This exercise has been performed for each bank separately. The calculation of Vulnerability Index for both the banks are shown in Table 9 & 10.

15.2.2 Observations:

From the Vulnerability Index calculation, it has been observed that except for reach no. 4, 7, 11 and 13 in all other reaches of Brahmaputra, the vulnerability to erosion in the Left Bank is more than the right bank at the present stage. The highest vulnerability in the left bank is found to be in Reach 9 where the city of Guwahati and LGBI Airport exist. The highest vulnerability for the right bank is found to be in Reach 4 where the Majuli island resides (Figure 105). Also it has been observed that at many locations of the river protective structures have been developed which have reduced the problem of erosion locally; however these structures have also contributed to the alterations in the channel’s natural morphology.

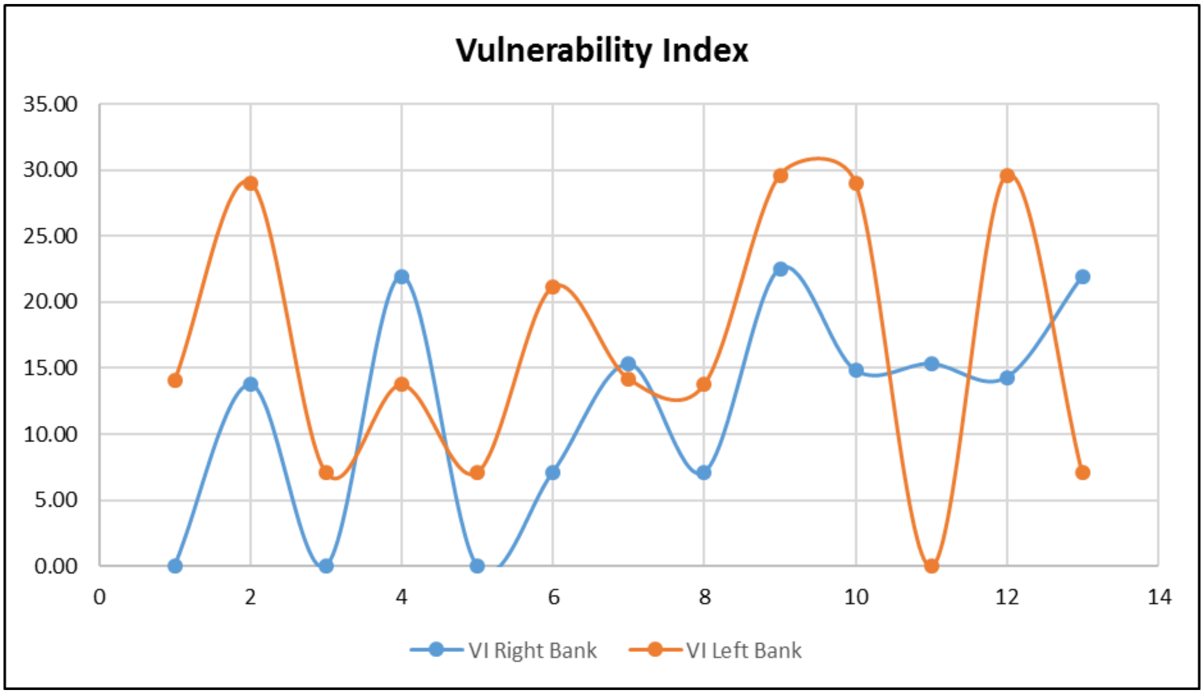

Figure 103: Vulnerability index for both the banks of Brahmaputra

Table 9: Vulnerability index calculation for the right bank of Brahmaputra

Vulnerability factor	Average Vulnerability Weightage based on Expert Opinion	Reach No.												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Increasing Rate of Erosion	7.11	0	0	0	1	0	0	0	0	0	0	1	0	0
Presence of Imp City/Town within 2km from the Bank	8.21	0	0	0	1	0	0	1	0	1	1	1	0	1
Presence of Airport within 2km from the bank	7.62	0	0	0	0	0	0	0	0	0	0	0	0	0
Presence of National Park/Wildlife Sanctuary	6.92	0	0	0	0	0	0	0	0	0	0	0	0	0
Presence of National Highway within 2km from bank	7.10	0	1	0	0	0	1	1	1	1	0	0	1	1
Presence of Railway Line within 2km from bank	7.18	0	0	0	0	0	0	0	0	1	0	0	1	0
Presence of Protective Structure	6.63	0	1	0	1	0	0	0	0	0	1	0	0	1
Presence of Refinery within 2km from the bank	6.92	0	0	0	0	0	0	0	0	0	0	0	0	0
Vulnerability Index		**0.00**	**13.73**	**0.00**	**21.95**	**0.00**	**7.10**	**15.31**	**7.10**	**22.49**	**14.84**	**15.32**	**14.29**	**21.94**

Table 10: Vulnerability index calculation for the Left Bank of Brahmaputra

Vulnerability factor	Average Vulnerability Weightage based on Expert Opinion	Reach No.												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Increasing Rate of Erosion	7.11	1	1	1	1	1	1	1	1	1	1	0	1	0
Presence of Imp City/Town within 2km from the Bank	8.21	0	1	0	0	0	0	0	0	1	1	0	1	0
Presence of Airport within 2km from the bank	7.62	0	0	0	0	0	0	0	0	0	0	0	0	0
Presence of National Park/Wildlife Sanctuary	6.92	1	0	0	0	0	1	0	0	0	0	0	0	0
Presence of National Highway within 2km from bank	7.10	0	1	0	0	0	1	1	0	1	1	0	1	1
Presence of Railway Line within 2km from bank	7.18	0	0	0	0	0	0	0	0	1	0	0	1	0
Presence of Protective Structure	6.63	0	1	0	1	0	0	0	1	0	1	0	0	0
Presence of Refinery within 2km from the bank	6.92	0	0	0	0	0	0	0	0	0	0	0	0	0
Vulnerability Index		**14.03**	**29.05**	**7.11**	**13.74**	**7.11**	**21.14**	**14.21**	**13.74**	**29.60**	**29.05**	**0.00**	**29.60**	**7.10**

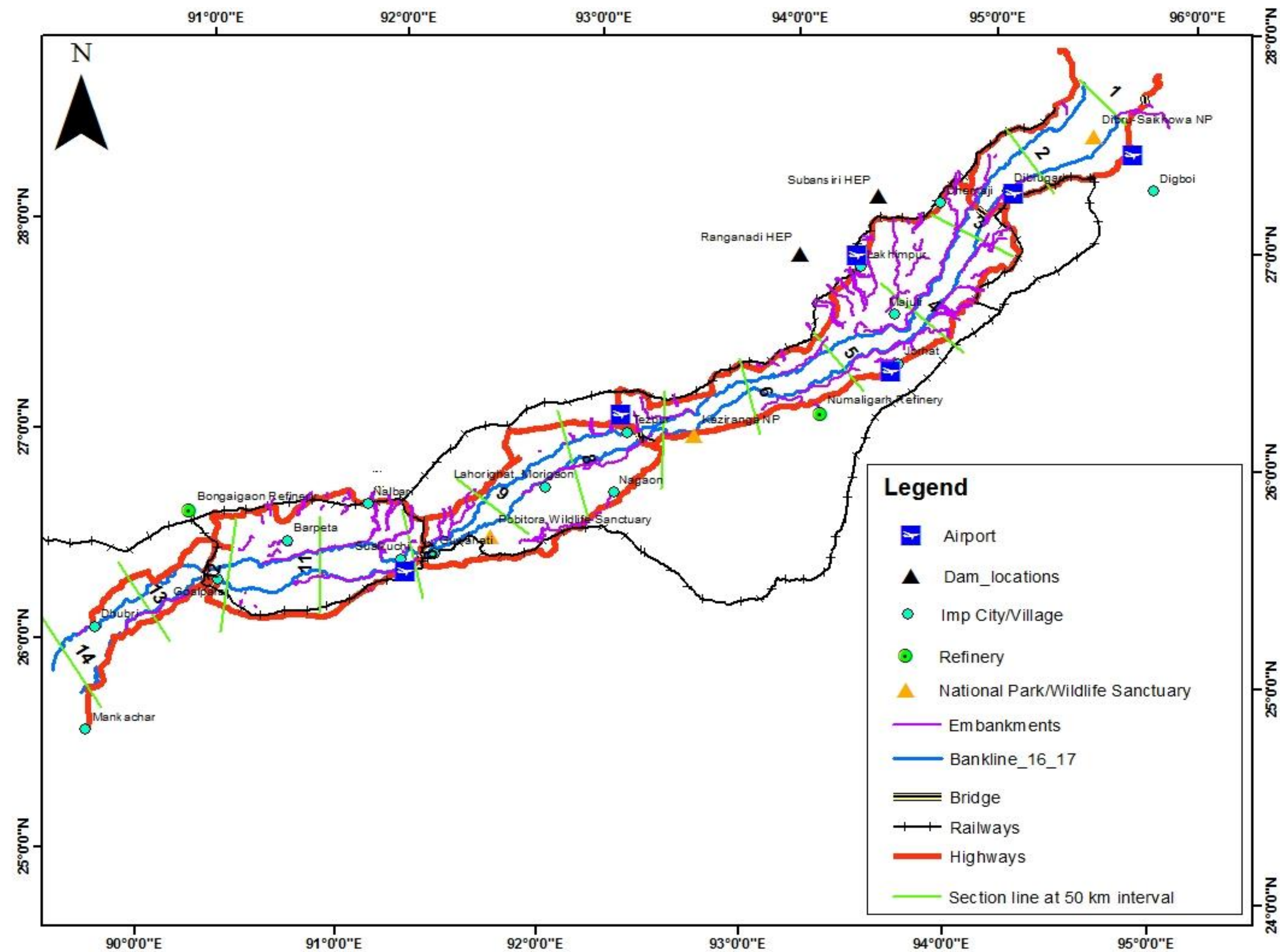

Figure 104: Map showing important features in proximity to the river Brahmaputra

Chapter 16
IMPACT OF HYDRAULIC STRUCTURES

Brahmaputra basin is one of the richest water resources potential in India. Around 30 % of India's water resources potential and 41% of our country's total hydropower potential are found in the basin (Singh et. Al., 2004). For temporary protection against flood, the length of the embankments is around 28% of those in the country (Sarma, 2004).

16.1 Types of Hydraulic Structures in the basin

The water resources potential in Brahmaputra basin is highest in the country. The construction of hydraulic structures over Brahmaputra basin and its tributaries goes back during Ahom period. The hydraulic structures constructed in the Brahmaputra basin includes-

1. Embankments constructed for flood protection
2. Hydraulic structures constructed under Irrigation Schemes
3. Bridges constructed over Brahmaputra Basin

16.1.1 Embankments in the basin

As per the accords of 1995, the total length of embankments are around 4721 km. These embankments are constructed to mitigate 1.745 Mha of flood prone areas [A.K.Sarma, 2004]. Most of the flood in Assam occur due to breaching of embankments. Failure of embankments may occur due to overtopping, seepage failure, structural failure and other factors like afflux of bridge etc.

16.1.2 Hydraulic Structures under Irrigation Schemes

To utilize the potential of water in agriculture the Irrigation Department has taken up several projects in the tributaries of Brahmaputra. Depending the Culturable Command Area (CCA) the schemes are differentiated as major, medium and minor.

16.1.3 Bridges constructed over Brahmaputra River

Bridges are the most important means of transportation of roadway, railway over a channel or other obstructions. For a proper planning and maintenance it is an utmost importance to understand the flow behavior around the bridge piers. Construction of bridges requires channelization of the river reaches which effect greatly in the downstream flow. There are a total of 6 major bridges constructed over Brahmaputra River in Assam (Figure 107). They are described below:

16.1.3.1 Dhola Sadiya Bridge

The Dhola-Sadiya Bridge is a beam bridge which is constructed across the river Lohit, a major tributary of Brahmaputra. The total length of the bridge is 9.15 km and width is 12.9 m. The bridge connect from the village Dhola which is in the Tinsukia district in the south to Sadiya in the north. The construction of the bridge started in November 2011 and was inaugurated in 26 May 2017.

16.1.3.2 Bogibeel Bridge

Bogibeel Bridge is a truss bridge constructed across Brahmaputra. Bogibeel Bridge spans across between Dhemaji district and Dibrugarh district. The total length of the bridge is 4.94 km and is the India’s longest rail-cum-road bridge. The construction of bridge took place in 21 April 2002 and was inaugurated in 25 December 2018.

16.1.3.3 Koliabhomora Setu

Koliabhomora Bridge is a pre-stressed concrete bridge constructed between Tezpur and Koliabor in Assam. The total length of the bridge is around 3 kms. The construction of Koliabor Setu was started in 1981 and was inaugurated in 1987.

16.1.3.4 Saraighat Bridge

The Saraighat Bridge is a rail-cum-road truss bridge constructed across Brahmaputra in Guwahati. The bridge connect North Guwahati and South Guwahati. The total length of the bridge is around 1.4km. The construction of the bridge took place in the year 1959 and completed in September 1962.

16.1.3.5 New Saraighat Bridge

The New Saraighat Bridge is constructed by the side of the Old Saraighat Bridge. The New Saraighat Bridge is a beam bridge with a length of 1.49km. The construction of the bridge started in 2007 and was inaugurated in 26 January 2017.

16.1.3.6 Naranarayan Setu

Naranarayan Setu is a truss bridge constructed to connect Jogighopa, a town in Bongaigaon district with Pancharatna, a town in Goalpara district. It is a double deck bridge with a length of 2.28 kms. The bridge was constructed in 1998.

16.2 Impact of Hydraulic Structures in the Brahmaputra Basin

The potential water resource of Brahmaputra basin is enormous but the basin is devoid of major hydraulic structures for harnessing water resources. The bridges, embankment, spurs etc. are the major hydraulic structure that exist on this river. Existing bridges has affected the river morphology to some extent. It has been observed from the delineated river banklines that at the immediate downstream of Saraighat and Pancharatna bridges, there is widening of the river Brahmaputra, which might be caused by the construction of the bridges on the river (Figure 108 & 112).

Saraighat bridges are located at the narrowest portion of the river where the width of the river is around 1.2 km. As the river constricted within the narrow portion, the fanning action was observed in the downstream otherwise also. Therefore, it may not be considered as an impact of bridge. The newly constructed Dhola-Sadiya Bridge which is of 9.5 km width crosses the Lohit River (Figure 111). As the span is sufficient, spatial impact may not be there. Similarly, the Koliabhomora Bridge at Koliabor (Figure 109) and Naranarayan Setu at Pancharatna have sufficient span across the river, major spatial impact may not be present. However, the Bogibeel Bridge at Dibrugarh whose span is narrow, if high discharge come there might be some effect downstream (Figure 110).

The closing dyke constructed dyke on Kherkatia Suti has forced the river to move towards southern part causing severe erosion in Nematighat and at the southern bank of Majuli.

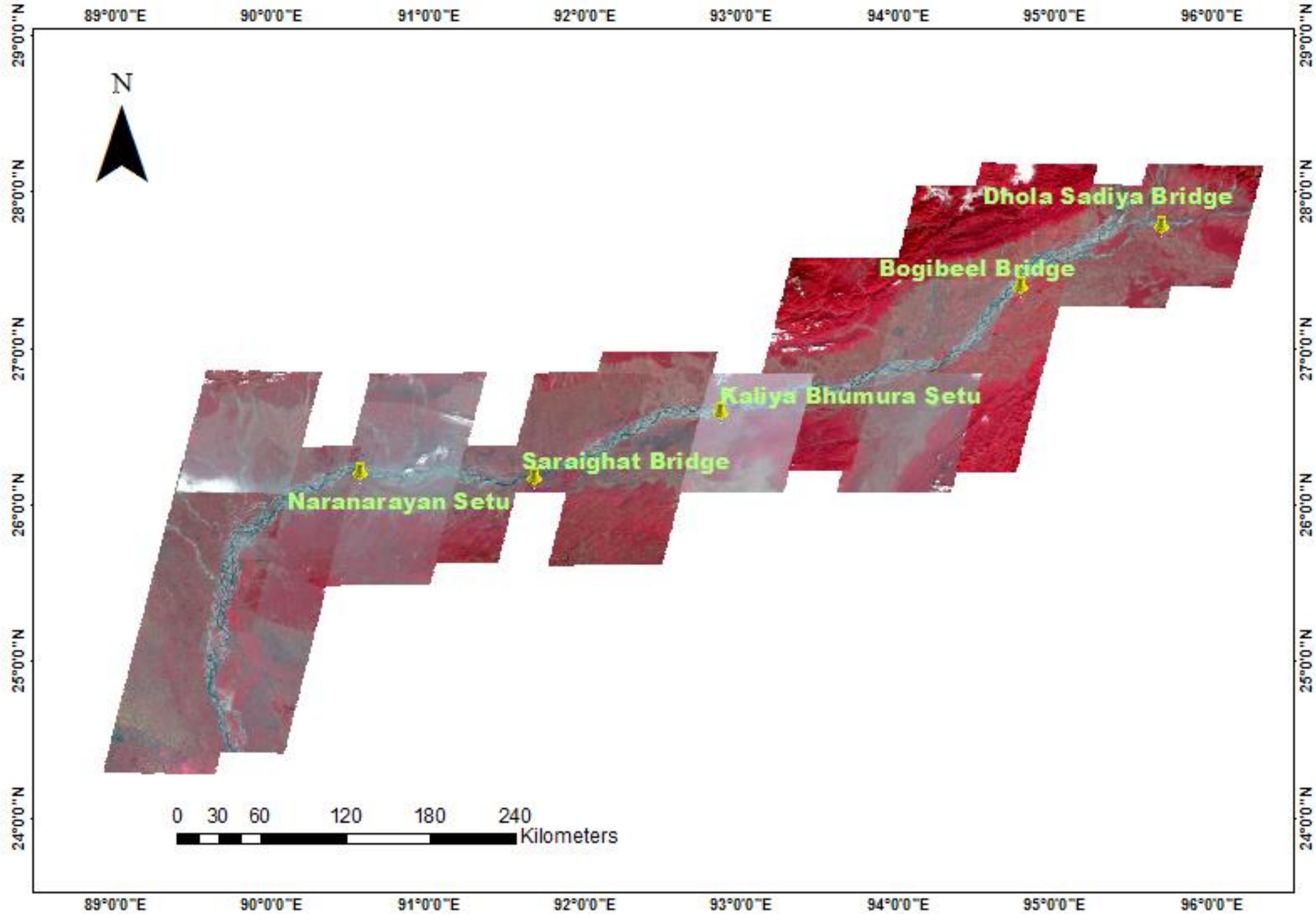

Figure 105: Location of the bridges on Brahmaputra

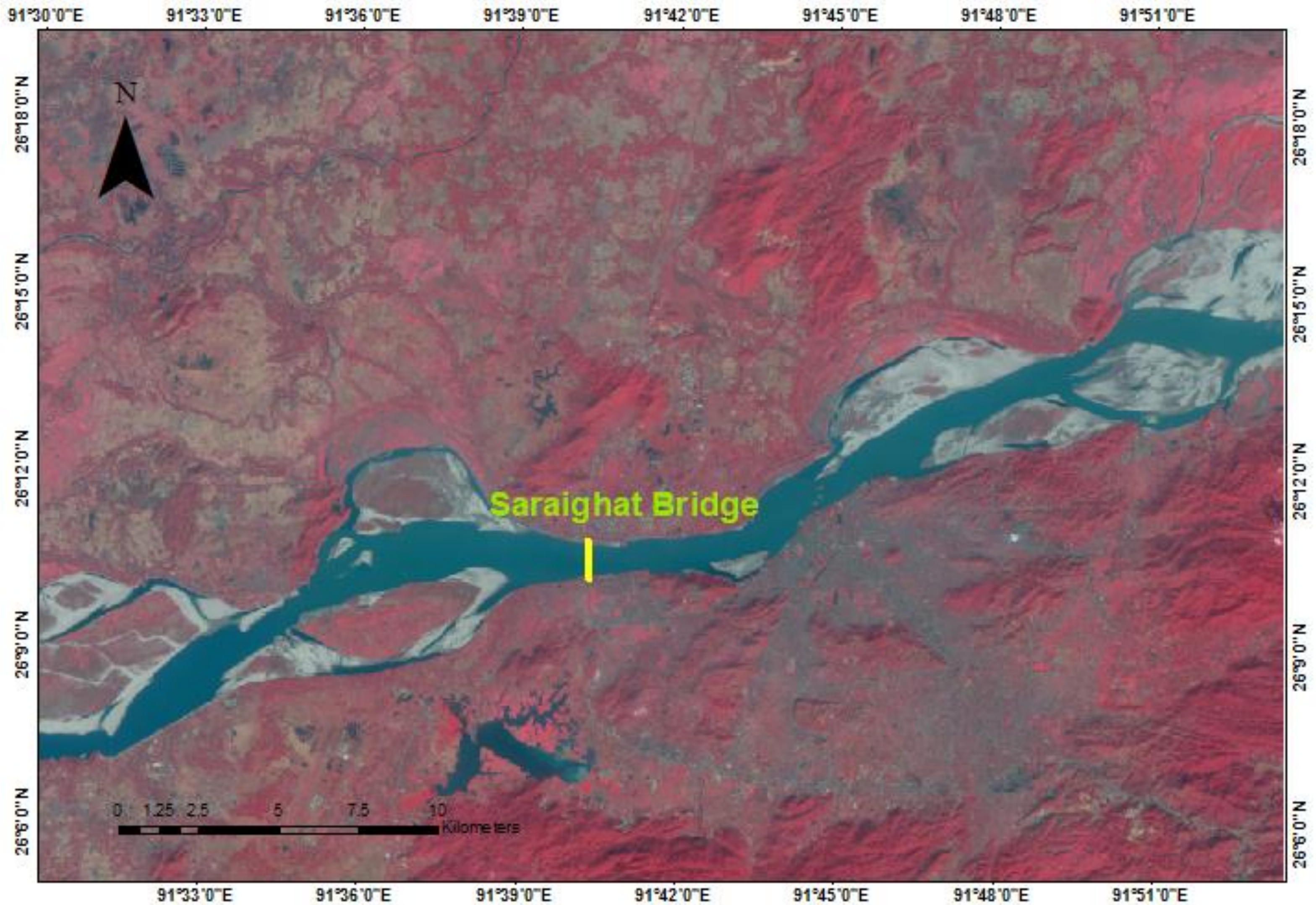

Figure 106: Saraighat Bridge, Guwahati

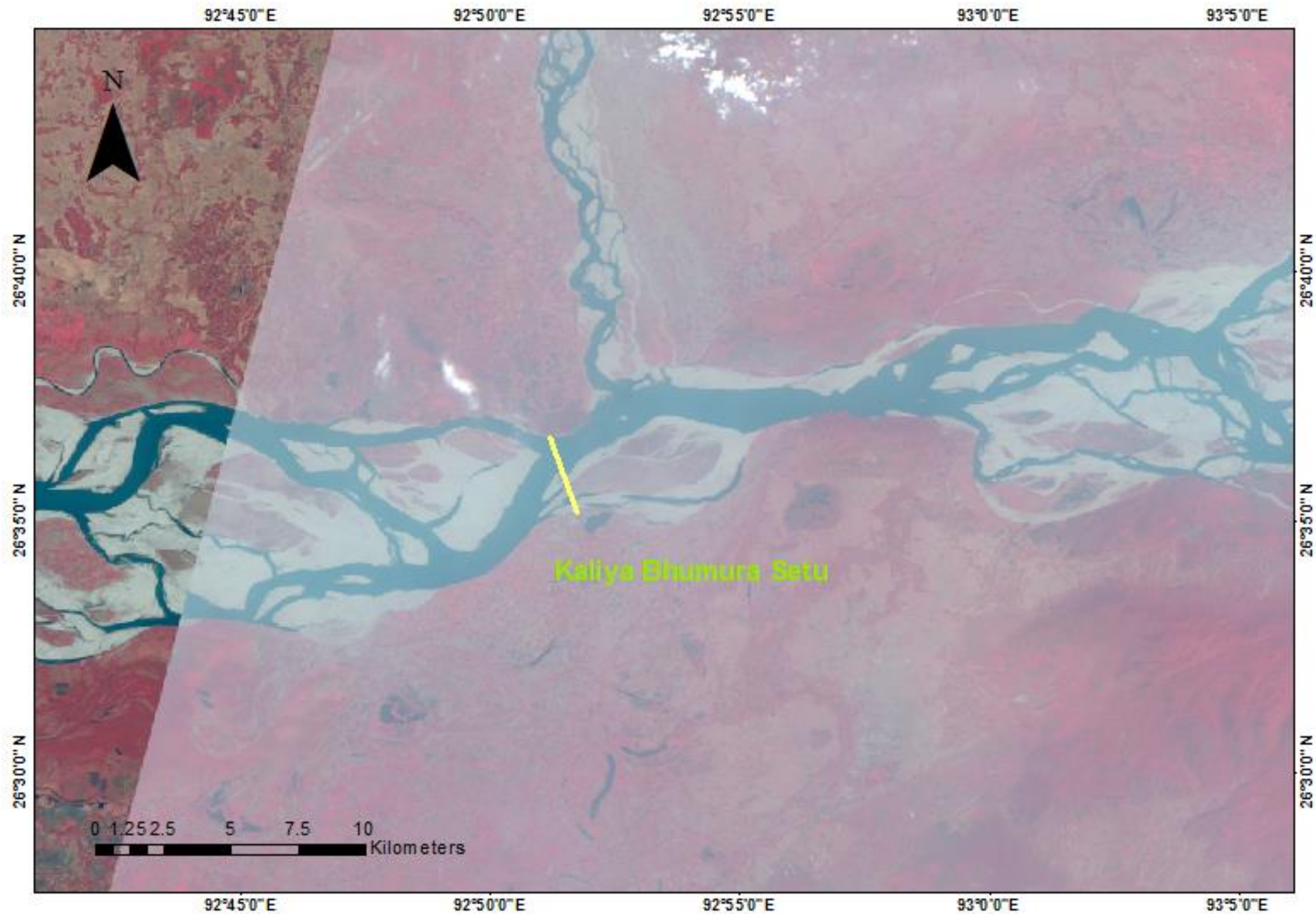

Figure 107: Koliabhomora Bridge, Sonitpur

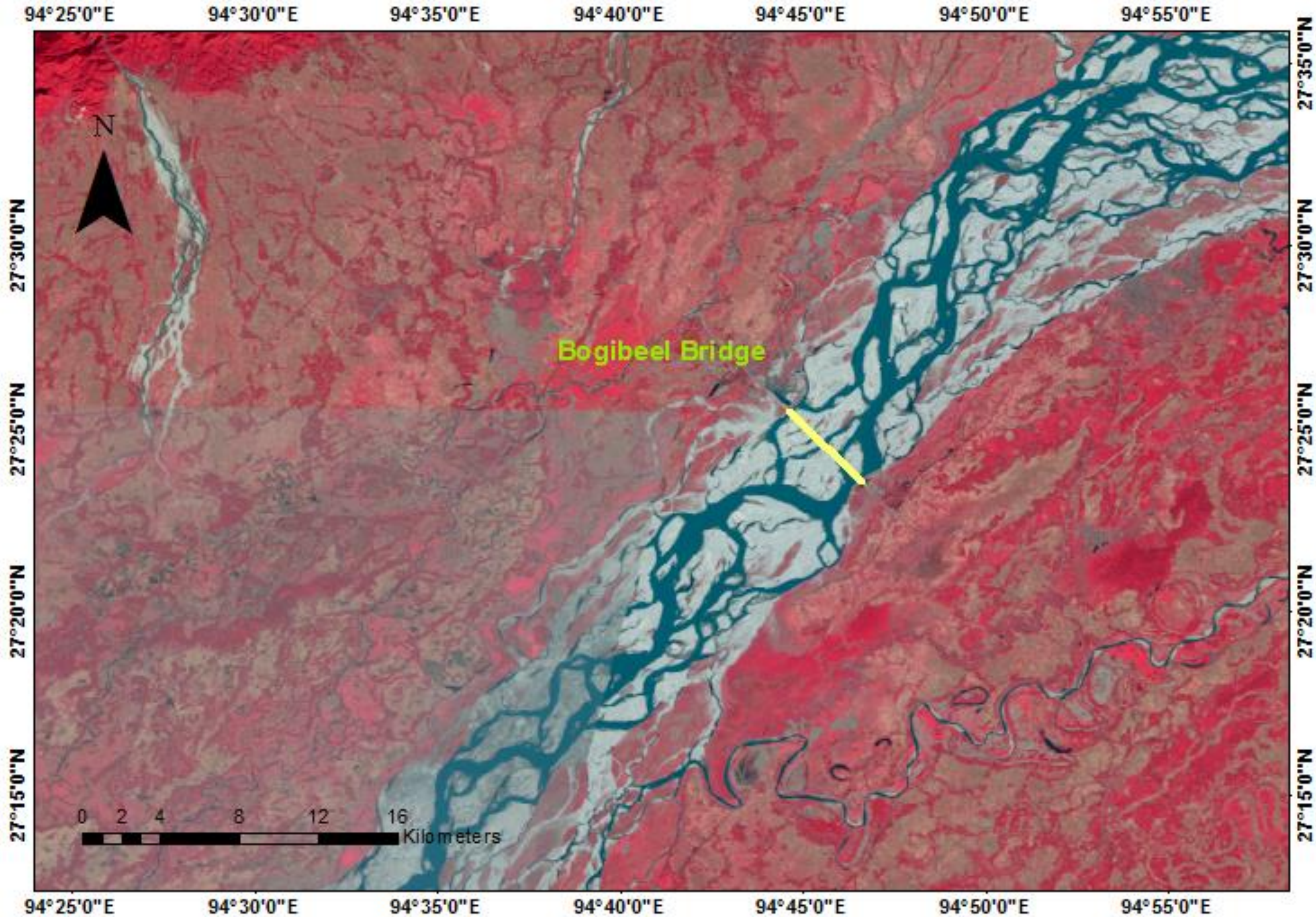

Figure 108: Bogibeel Bridge, Dibrugarh

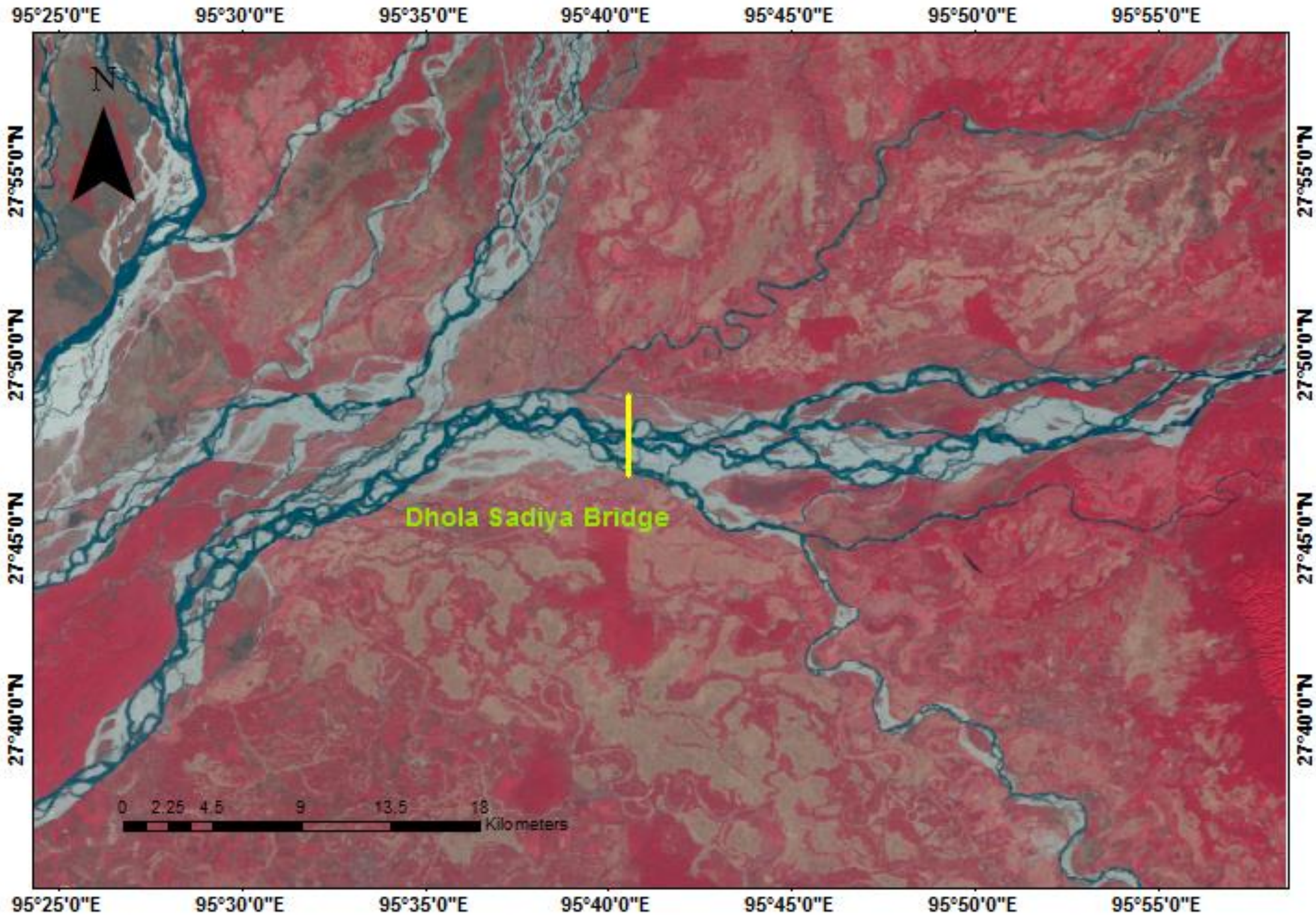

Figure 109: Dhola-Sadiya Bridge, Tinsukia

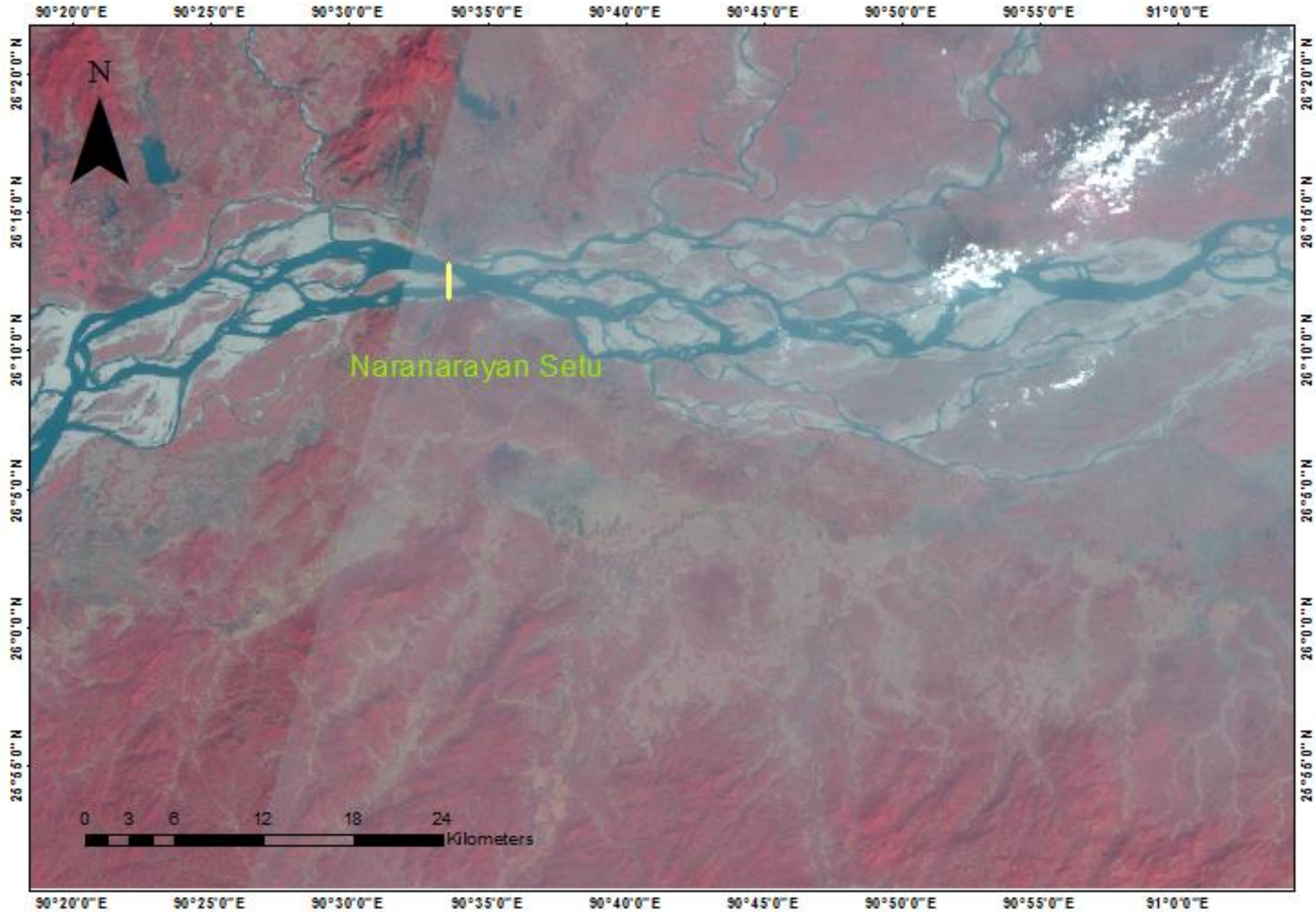

Figure 110: Naranarayan Setu, Pancharatn

Chapter 17
FIELD SURVEY

Field survey has been conducted at various vulnerable and erosion-prone sites within the study reach to understand the real scenario in those areas. Few photographs from the field survey are included in this report.

Figure 111: Active erosion in Lahorighat, Morigaon area

Figure 112: Landuse adjacent to riverbank, Morigaon area

Figure 113: Site visit and discussion with concerned officials

Figure 114: Erosion protection measures taken at Lahorighat

Figure 115: Site visit to Majuli with stakeholders

Figure 116: Erosion prone area in Majuli

Figure 117: Site visit of the vulnerable reach near Na-bazar, Biswanath

Figure 118: PI of the project showing the erosion prone area near Sualkuchi

Figure 119: Stable landmass near Sualkuchi that acts as a natural spur

Figure 120: Reverse flow of the river due to presence of natural spur

Figure 121: Deposition near Sualkuchi after development of submerged spur

Figure 122: Vegetated sandbar amidst Brahmaputra near Palashbari-Sualkuchi

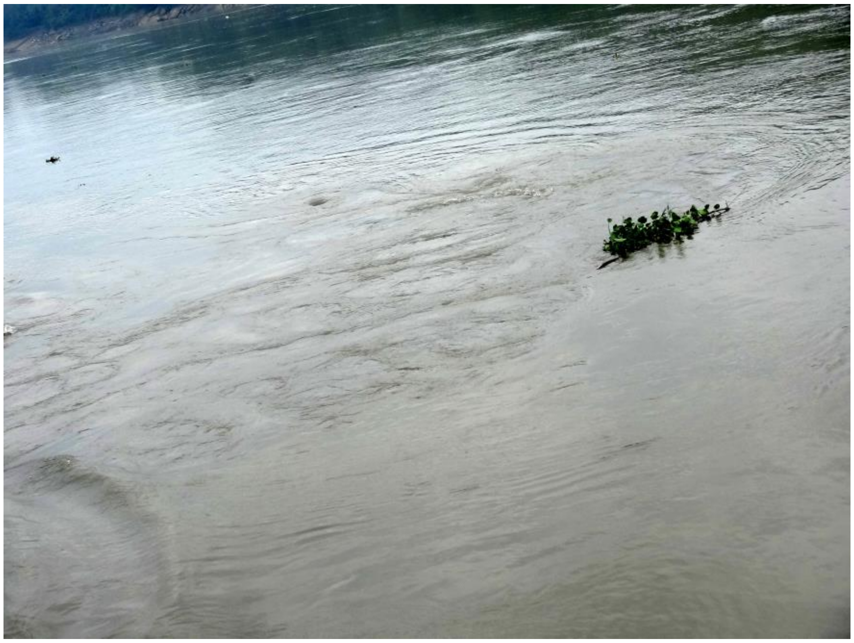

Figure 123: Whirlpool formation in the river Brahmaputra due to the interaction water column with the bedform

Figure 124: Saraighat Bridge

Chapter 18

DISSEMINATION WORKSHOP

A project ‘Morphological studies of rivers Brahmaputra, Subansiri and Pagladiya using Remote Sensing Technique’ sponsored by CWC, New Delhi was carried out by Department of Civil Engineering, IIT Guwahati during 2016 to 2019. To disseminate the findings of the project among different stakeholders, a Dissemination Workshop on ‘MORPHOLOGICAL STUDIES OF RIVERS BRAHMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE’ was organized at IIT Guwahati on 3rd May, 2019. Many dignitaries graced the workshop with their presence. The workshop was attended by several participants (registration sheet enclosed as annexure) from CWC Headquarter and Regional offices, Officials from various State departments viz. Water Resources Department, Assam, Assam Water Research and Management Institute (AWRMI), Assam State Disaster Management Authority (ASDMA), Brahmaputra Board, Soil Conservation Department, Assam Science Technology and Environment Council (ASTEC), Irrigation Department and North Eastern Space Applications Centre (NESAC), and many notable academic institutes viz. Assam Engineering College (AEC), Jorhat Engineering College (JEC), Dibrugarh University, Gauhati University and Professors and research fellows from IIT Guwahati.

The workshop was structured in two technical sessions – The first session was at IIT Guwahati Guest House Conference room and the second session was arranged as onboard workshop on Brahmaputra and group discussion was conducted on a specified questionnaire among different participants. A field visit was also conducted to the erosion prone area near Sualkuchi and Palashbari. The details of the technical sessions are described below:

18.1 Session 1

Prof. Arup Kr Sarma, Principal Investigator of the project welcomed all the participants and the dignitaries. Prof. Gautam Biswas, Director, IIT Guwahati then inaugurated the workshop with an inaugural speech. Following the inaugural speech, the lighting of lamp was done by Prof. Gautam Biswas (Director, IIT Guwahati), Mr Ravi Shankar (Chief Engineer, P&D, CWC, New

Delhi), Mr Ajay Kr Sinha (Director, M&CC, CWC, New Delhi), Mr Ravi Ranjan (SE, HDC, Guwahati) and Prof Arup Kr Sarma (Project PI).

The first presentation was delivered by Mr Ravi Shankar, Chief Engineer, P&D, CWC, New Delhi. The presentation started with the importance of river morphology and explained the background of initiation of the project. He also presented the work done by IIT Roorkee on change in the course of Ganga river, its erosion-deposition and the suggested river training works in Ganga. The presentation was concluded with the future scopes of work in flood management, sustainable sediment management, effect of climate change, rejuvenation of springs and water conservation.

Following Mr Ravi Shankar's presentation, Prof Arup Kr Sarma presented the findings of the project. The presentation included the objectives of the study followed by the methodology that was implemented to achieve the objectives and the outcome of the study. Some of the major findings highlighted in the presentation are as follows:

Avulsion of the Lohit channel is a major morphological change that has been observed in the study. Earlier, the Lohit channel used to meet the main Brahmaputra channel ahead of the Dibru-Saikhowa National Park flowing through the northern boundary of the Park. However, in the 1993-95 imagery, an avulsion was observed in the channel and the channel started flowing to the south of Dibru-Saikhowa, meeting the main Brahmaputra again near Rahmoria. This major change in the river morphology took place between 1976-80 and 1993-95. Present Lohit channel was marked as 'Ananta Nala' in the toposheet of 1973-74. It has been reported by local people that this small channel was cut by a man named Ananta to connect that area with main Brahmaputra for communication purpose and the channel was named after him as 'Ananta Nala'. But with time, the major flow has shifted to the 'Ananta Nala' converting it to the present day Lohit channel

Also a 15 km shift has been observed in Subansiri-Brahmaputra confluence point from the base year to the recent study period. Referring to various other studies and also referring to the fact that the first *Satra* known as Auniati satra was established on the Northern side of Majuli, Prof. Sarma pointed out that earlier, the main channel of Brahmaputra was probably flowing to the north of Majuli. To check the flood and erosion problems, in 1964 a closing dyke was constructed at the meeting point of present Brahmaputra River and the northern channel (Kherkatia Suti) by the Water Resources Department of Assam. Due to this construction, the flow from Brahmaputra to Kherkatia suti got completely obstructed leading to increase in flow in the southern channel causing severe erosion in the southern part of Majuli.

Another shift of about 4.6 km in the Pagladiya-Brahmaputra confluence point due to erosion work of Brahmaputra.

It is a well-known fact most of the rivers in North East India have flood protecting embankments. Flooding in these regions occurs primarily due to the breaching of embankments at different locations. Therefore, an area not getting flooded in these layers may also get affected by the severe flood if embankment protecting that area suffers failure. Similarly, an area experiencing flood may not experience it with the same intensity if relevant embankment is repaired or reconstructed to protect that area. These facts need to be considered while preparing policies for flood relief, insurance, etc. To have more clarity a flood inundation map can be prepared by running a hydrodynamic model in the river without considering the existence of embankments. Areas coming under flood in such simulations may be designated as Potential Flood Prone Area (PFPA) and policy decision may be taken for relief, insurance, etc by considering if the areas fall under PFPA

Prof. Sarma also mentioned that in Nagaon, the Kolong river was blocked and after that human settlements started sprawling in and around the area. However, around 50 years later, the barrier was eroded by the Brahmaputra river and water entered into the Kolong river causing flood havoc in the area.

Another issue was also pointed out by Prof. Sarma that two major causes of erosion in most of the affected areas in Brahmaputra are due to the seepage of water and direct current of the river.

The presentation was followed by an in-house discussion on the findings and suggestions from the stakeholders.

Figure 125: Prof. Arup Kr. Sarma welcomes the dignitaries and the participants

Figure 126: Felicitation of the dignitaries

Figure 127: Inaugural Address by Prof. Gautam Biswas, Director, IIT Guwahati

Figure 128: Lighting of the lamp

Figure 129: Presentation By Mr Ravi Shankar, CWC

Figure 130: Presentation by Prof. Arup Kr Sarma, PI

18.2 Session 2

A site-visit by boat to the erosion prone area of Palashbari and Sualkuchi was arranged in the second half of the workshop. During the journey an onboard session of the workshop was organized. The focus of this session was to have group discussion among participants of different organizations. The participants were randomly divided into 9 groups. The purpose of the discussion was to obtain feedback through questionnaire set to have constructive suggestion as well as to know whether the representatives of different organizations are aware of similar studies and their utilities/applicability in their respective organizations. Prof Arup Kr Sarma and Prof. Rajib Kumar Bhattacharjya were the facilitators of the discussion. The questions included in the questionnaire and response received from different groups are presented below:

Q1. Are you aware of such study done elsewhere for these rivers: If any, please provide information?

Response to Q1: From the discussion, it was found that there are several studies that have been conducted from time to time in different rivers in a piecemeal manner and with different objectives. However, this study is comprehensive morphological studies carryout for the first time in these rivers. Some of the other studies reported by the participants are:

1. Bathymetric survey was conducted by IIT Guwahati from Tezpur to Guwahati.

2. Flood estimation report of Brahmaputra was prepared by CWC.

3. Morphological study and cross-section of Barak river was carried out.

4. Studies for rivers like Ghagra and Gandak were done previously.

5. CWC carries out cross sectional survey on Brahmaputra at 64 cross sections at an interval of 10 km from Tinsukia to Dhubri each year. Cross sectional survey is also carried out in Subansiri and Pagladia each year.

6. NESAC has operational flood early warning system for some rivers of Assam.

7. Some pilot studies are going on at university levels.

8. Various organizations such as ISRO/DOS, Gauhati University, IIT Roorkee, Dibrugarh University, Brahmaputra Board are doing some Remote Sensing based studies in some reaches of these rivers.

9. At Rohmoria reach of Brahmaputra River (u/s), change in morphology was studied little bit and also the effect of porcupine screen on river cross section was studied.

10. IIT Guwahati and Brahmaputra Board are involved in the development of a hydrodynamic and morphological numerical model.

11. As a part of a mathematical model study of Brahmaputra, IIT Guwahati in collaboration with Brahmaputra Board has taken up a model study near Majuli.

12. Study of Kaziranga reach was jointly carried out by Brahmaputra Board, SAC Ahmedabad and NRSA.

13. Researchers from Gauhati University and Dibrugarh University are carrying out some academic research on Brahmaputra.

14. A PhD thesis on ‘Bed form morphology, spatio-temporal variability and erosional vulnerability of Brahmaputra river within Assam’ was carried out at Gauhati University.

Q2. How result of this study can help different organizations?

Response to Q2: The response given by the different groups revealed that this study can be of great help for various organizations. These can be summarized as:

1. Site selection for various hydraulic structures and river training works.
2. Formulating guidelines for Hydrological Observation sites.
3. Policy making for mitigating erosion in erosion prone areas.
4. Identification and prioritization of areas for protecting important structures.
5. The various data collected through morphological survey can be useful to the Railway Dept., PWD Dept., Irrigation Dept., in study and implementation of micro as well as macro projects.
6. Proper planning and design of water resources structures.
7. This will be a base for future studies in river restoration works.
8. Flood plain zoning and flood management
9. Navigation Development.
10. Water assessment of the river.
11. Help in understanding the river meandering process.
12. Help the disaster management departments to create awareness for people in flood area.
13. Help in selection of appropriate method/technology for river management.
14. Master plan preparation on the river basin.
15. GIS techniques are useful to analyze quantitatively in some remote areas where it is not physically accessible.

16. Identifying and prioritizing vulnerable location and calculation of vulnerability index for erosion prone area. The vulnerability index calculated can be useful for protection of vulnerable reaches.
17. Land use planning/Infrastructure development.
18. Identification of ‘Ghats.’
19. It can serve as geospatial database for related studies.
20. Based on river morphology, anti-erosion schemes are evaluated, whether those schemes were properly designed/executed, the percentage of success/achievements of the schemes can be found.
21. Prioritizing embankment strengthen.

Q3: Do you recommend similar study on some other rivers?

Response to Q3: Beki, Barak, Godavari, Kolong, Kapili, Jia Bharali, Jiadhol, Gandak, Ghagra, Jhelum, Lohit, Dibang, Dihang, Aie, Burhidihing, Dikhow, Dhansiri, Dibru, Manas are some of the rivers in which similar studies were recommended.

Q4: Suggestions, if any

Response to Q4:

1. The suggestions provided are as follows:
2. More recent data can be used for predicting the future scenario.
3. More morphological case studies of the rivers mentioned above can be taken up for prediction of erosion and morphological action of river.
4. Incorporation of sand bar and sediment load study.
5. Community awareness programme in educational institutes and departments can be held.
6. For better understanding of the river course/shifting, morpho-tectonic/ tectonic studies can be incorporated as a part of the study.

7. Space technology/high resolution satellite data may be utilized for site specific study.
8. Identification of hotspots for scientific sediment mining.
9. A study on effect of climate change on river morphology can be made.
10. Utilizing flood discharge in hydro power generation.
11. Sediment transport model can be made.
12. Prediction of future cutoffs, ox-bow lakes.
13. Collaboration between different organizations.
14. SOI topo sheet can be used for data before 1950, 1:1 mile scale data is available.
15. The data can be provided in public domain for further research studies.
16. Morphological studies can be conducted using latest technology, eg. Drones.
17. Ground control point maybe established to observe neotectonic activity.
18. Morphological survey is very important by manual method.
19. Presently Mikir Gaon area in Morigaon district is one of the most erosion prone areas along Brahmaputra. Special emphasis in this reach for delineation of bankline, its causes and appropriate approach to be given in the study.
20. Construction of solid spurs in erosion prone reaches often become counterproductive. This is because of river changing its flow direction after erosion and making the spurs attractive which were otherwise constructed as deflecting.
21. Awareness programs can be planned for various departments and technocrats for hydrological study like Arc GIS/working on toposheet.
22. Study of bank materials as well as bed materials and find the relative silting and scouring.
23. To determine the actual course of erosion, specific site wise.
24. Model study before implementation/execution.

25. Use of aerial photography, ultrasonic sound velocity method to find the change in depth of flow after execution of anti-erosion measures.

26. To study the change in morphology, w.r.t. the bed level before 1950 earthquake.

27. Field verification is essential along with remote sensing techniques to validate the findings.

28. River modelling can be done to find out the vulnerable reach along with remote sensing techniques.

29. For modelling purpose, high resolution DEM data can be used to get better results.

Based on the response from different groups, it is clear that morphological studies of rivers are important for flood management, navigation development and selecting sites for river training works. Similar studies can be carried out in future for other major rivers of India. Further studies can be made by incorporating tectonic studies, using higher resolution satellite data and latest technology like drones, etc. and providing the data in public domain so that it can be used by researchers.

After the group discussion, certificates were distributed to all the participants and the technical session of the workshop concluded with the valedictory function followed by a workshop dinner.

The facilitators of the group discussion

Group 1

Group 2

Group 3

Group 4

Group 5

Group 6

Group 7

Group 8

Group 9

Concluding the GD

Certificate distribution

Chapter 17
CONCLUSIONS AND RECOMMENDATIONS

17.1 Conclusion:

In this study detail morphological analysis has been carried out primarily based on remote sensing technique supported by secondary data and field survey. Following conclusions are drawn from this study:

- Between 1976-80 and 1993-95, a significant morphological change took place in the Lohit channel after its confluence with the Brahmaputra near Dibru-Saikhowa National Park. At this point, before 1993-95 the Lohit channel used to meet the main Brahmaputra channel ahead of the Dibru-Saikhowa National Park flowing through the northern boundary of the Park. However, in the 1993-95 imagery, an avulsion was observed in the channel and the channel started flowing to the south of Dibru-Saikhowa and meeting the main Brahmaputra again near Rahmoria.

- Major planform changes were observed near Majuli, once the largest inhabited river island of the world, where the right bank of the river Brahmaputra was migrating northward owing to the continuous process of erosion over the years. The northward erosion is happening in different locations with different degrees of severity. Details of these are given in the chapter 14 on Majuli Island.

- The slope of the Brahmaputra River in Assam is relatively flat. The river has a braided nature when it flows through the alluvium of Assam except at Pandu where the channel flows as a single channel of around 1.2 km.

- From the erosion-deposition analysis it has been found that on the right bank, Barpeta district is more prone to erosion while on the left bank Morigaon district is more erosion prone. In 2016-17 the erosion area in Barpeta district is found to be around 1527.74 sq.km from the base year i.e. 1973-74 and the amount of erosion in Morigaon district is found to be 628.07 sq.km from the base year to 2016-17. The maximum length of erosion from the base year to the recent year has been observed in Dhemaji district.

- It has also been observed that on the left bank, the decadal rate of erosion is increasing in most of the reaches causing severe erosion at present times whereas on the right bank except at reach no. 4 (Majuli area), in all other reaches the decadal rate of erosion is decreasing resulting in deposition in those reaches.

- From the Planform Index (PFI) analysis, it has been found in the extreme upstream and extreme downstream portion within India, the river is highly braided in nature while the middle portion of the river is moderately braided. However, from 2003-04 onwards braiding in the middle portion of the river has also increased.

- Morphometric parameter analysis indicates that the shape of the basin is elongated; although the delineated basin area of Brahmaputra appears to be more of circular in nature. It is because, there exists a ridge line separating the whole basin into the Tibetan part and the Indian part. Also, the bifurcation ratio for the highest order stream is the lowest due to larger no. of segments in the higher order (as several 1st order tributaries join the main channel directly in the downstream) which results in flooding in the downstream area.

- From the analysis of LULC change for the years 1973-74, 2005-06 and 2011-12, it has been observed that there is a conversion of landuse from Agriculture, Dense Forest, and Wetland/Marshy land to Built-up area, Open Forest and Sandbar/Dry riverbed. This reduction in the Wetland/Marshy land and increase in the Sandbar/Dry riverbed area might have contributed to the increase in both riverine and flash flood in the region.

- Flooding in the Brahmaputra basin occurs primarily due to breaching of the embankments at different locations. Therefore, an area not getting flooded in the flood inundation maps prepared by NRSC (based on observed inundation data) may also get affected by severe flood if embankment protecting that area suffers failure. Similarly, an area experiencing flood may not experience it with the same intensity if relevant embankment is repaired or reconstructed to protect that area. These facts need to be considered while preparing policies for flood relief, insurance, etc.

- From the cross-section analysis of Brahmaputra it has been found that there exists a cycle of 7-10 years after which the river undergoing changes reaches the same form at a particular section. A detail study in this direction will be helpful for deciding river management strategy.

- It has been found that the average width of the river Brahmaputra is increasing over the time while the average hydraulic depth of the river is found to be varying in different years. In the year 1973-74 the average width of the river is estimated to be 8.04 km. while in 2008-11 the average width is found to be 9.97 km.

- From the morphological analysis of Majuli, it has been observed that there is a northward shift in the Brahmaputra right bank towards Tekeliphuta embankment. It is also evident that presently, the Kherkatia Suti i.e. the channel flowing on the northern boundary of the Majuli island, is not as active as it was before 1960s. This is because of construction of the closing dyke i.e. the Tekeliphuta embankment on the channel to mitigate the flood hazard in the northern part of Majuli.

- Also, an enormous shift (around 15 km) has been observed at the Brahmaputra-Subansiri confluence point. These shifting in the river banklines over time has resulted in massive erosion in the western and eastern boundary of Majuli island. Also, in the southern part of Majuli, continuous process of erosion has been observed near Sumoimari village. However, some amount of deposition has also been observed at upstream of Salmara, i.e., near Sukan Suti Miri village.

- From the decadal analysis of change in total area of Majuli, it is found that although there is a decrease in the total area of Majuli from the base year i.e. 1973-74 to 2016-17 while in the recent decades the total area almost remains same. However, this does not indicate that no erosion has occurred in the recent times rather this might be owed to the fact that there exists a continuous process of erosion-deposition around the landmass.

- In this study six critical/vulnerable reaches were identified based on the shift in river course/bankline and its proximity to flood/erosion protection structures as envisaged from the satellite imageries. These reaches include confluence of the Simen river with Brahmaputra in Dhemaji, Tekeliphuta embankment in Majuli, reach near Na-bazar, Biswanath, reach near Niz Rangamati, Darrang and Lahorighat, Morigaon, reach near

Balidhari (right bank) and Kadulimari (left bank) in Barpeta and possible avulsion of Manas river at the border of the Barpeta and Bongaigaon districts

- From the Vulnerability Index calculation, it has been observed that except for reach no. 4, 7, 11 and 13 in all other reaches of Brahmaputra, the vulnerability to erosion in the Left Bank is more than the right bank at the present stage. The highest vulnerability in the left bank is found to be in Reach 9 where the city of Guwahati and LGBI Airport exist. The highest vulnerability for the right bank is found to be in Reach 4 where the Majuli island resides.

- It has also been observed that at many locations of the river protective structures were constructed which have reduced the problem of erosion locally; however, these structures have also contributed to the alterations in the channel's natural morphology.

- The potential water resource of Brahmaputra basin is enormous but the basin is devoid of major hydraulic structures for harnessing water resources. The bridges, embankment, spurs etc. are the major hydraulic structure that exist on this river. Existing bridges has affected the river morphology to some extent. It has been observed from the delineated river banklines that at the immediate downstream of Saraighat and Pancharatna bridges, there is widening of the river Brahmaputra, which might be caused by the construction of the bridges on the river.

- From this study it can be ascertained that the construction of the closing dyke on Kherkatia Suti has forced the river to move towards southern part causing severe erosion in Nematighat and at the southern bank of Majuli.

17.2 Recommendations:

- From this study and the responses of the various stakeholders during the Dissemination Workshop, it is clear that morphological studies of rivers are important for flood management, navigation development and selecting sites for river training works. However, further studies can be made by incorporating tectonic studies, using higher resolution satellite data and latest technology like drones, etc. Further, information generated should be made available in public domain so that it can be used by researchers.

- To have more clarity on flood risk, inundation map can be prepared by running a hydrodynamic model in the river without considering the existence of embankments. Areas coming under flood in such simulations may be designated as the Potential Flood Prone Area (PFPA) and policy decision may be taken for relief, insurance, etc. by considering if the areas fall under PFPA.

- As river cross-sections influence the flow of the river and its hydrodynamics significantly, therefore a more reliable statistical model, if can be developed, to derive river cross section in future time will be quite helpful in river management. Therefore, a project in this direction can be taken up for all available cross sections of Brahmaputra River.

- Management of the catchment through Ecological Management Practices (EMP) including afforestation, small cascade reservoir etc. can be taken up with detail study. Visible impact of such approach of course may take some time. Such EMP project will also yield revenue to pay back the invested amount though 5 to 10 years may be necessary to reach the breakeven point.

- Removal of bed sediments through dredging may be applied to divert the main flow from hitting the river bank at few locations. A model study carried out at Department of Civil Engineering, IIT Guwahati in 2011, indicated that the dredging of a sand bar in Morigaon reach along with construction of spurs to push the river away from the bank could mitigate the severe erosion problem of Morigaon as per simulation result. Such projects can be taken out to identify strategic solution for the vulnerable reaches.

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ANNEXURE I

Table 3: List of satellite data used in the project

Sl. No.	Satellite	Sensor	Path	Row	Date of acquisition
1	Landsat 2	MSS	144	041	1976-12-13
2			144	042	1977-01-18
3			144	042	1977-05-24
4			145	041	1977-01-01
5	Landsat 3	MSS	143	040	1981-10-20
6			143	041	1979-12-24
7			143	041	1981-10-20
8			145	042	1980-01-31
9			146	042	1979-03-14
10			146	042	1980-02-01
11			149	042	1980-01-17
12	Landsat 1	MSS	145	041	1973-11-15
13			146	041	1973-11-16
14	Landsat 2	MSS	147	041	1977-02-08
15			147	042	1977-02-08
16			148	041	1978-12-07
17			148	042	1978-02-22
18			149	041	1977-01-23

19	IRS 1B	LISS 1	14	46	1994-05-04
20			14	50	1994-10-27
21			14	51	1993-04-03
22			18	49	1994-11-22
23			18	50	1994-11-22
24			12	49	1993-3-10
25			12	50	1993-3-10
26			16	48	1994-11-20
27			16	49	1994-11-20
28			16	50	1994-11-20
29			16	51	1994-02-07
30			17	48	1994-01-17
31			17	50	1994-03-02
32			18	48	1994-11-22
33			13	51	1993-04-02
34			15	49	1993-04-04
35			15	50	1993-04-04
36			15	51	1993-04-04
37			17	49	1993-04-06
38			12	47	1994-11-22
39			13	47	1994-12-30

40			13	48	1994-12-09
41			13	49	1994-12-09
42	IRS 1B	LISS 1	13	46	1994-12-09
43			12	48	1993-03-10
44			13	50	1993-04-02
45			107	52	2004-03-25
46			114	52	2004-02-17
47			114	51	2003-12-31
48			109	52	2004-02-16
49			109	53	2004-02-16
50			110	52	2004-05-03
51			110	53	2004-05-03
52	IRS P6	LISS 3	110	54	2004-01-28
53			111	51	2004-01-09
54			108	53	2004-02-11
55			108	54	2004-02-11
56			111	52	2004-02-26
57			114	53	2004-02-17
58			111	53	2004-02-02
59			114	54	2004-02-17
60			111	54	2004-02-02

61			112	50	2004-03-02
62			112	51	2004-02-07

63	IRS P6	LISS 3	112	52	2004-02-07
64			112	53	2004-03-02
65			112	55	2004-03-02
66			111	55	2004-02-26
67			113	51	2004-02-12
68			113	54	2004-02-12
69			113	50	2003-12-26
70			113	52	2003-12-26
71			113	53	2003-12-26
72			113	55	2003-12-26
73			114	55	2003-12-31
74			107	53	2003-12-20
75			109	54	2003-12-30
76			112	54	2004-02-07
45			107	52	2004-03-25
46			114	52	2004-02-17
47			114	51	2003-12-31
48			109	52	2004-02-16
49			109	53	2004-02-16

50			110	52	2004-05-03
51			110	53	2004-05-03
52			110	54	2004-01-28

53			111	51	2004-01-09
54			108	53	2004-02-11
55			108	54	2004-02-11
56			111	52	2004-02-26
57			114	53	2004-02-17
58			111	53	2004-02-02
59			114	54	2004-02-17
60			111	54	2004-02-02
61	IRS P6	LISS 3	112	50	2004-03-02
62			112	51	2004-02-07
63			112	52	2004-02-07
64			112	53	2004-03-02
65			112	55	2004-03-02
66			111	55	2004-02-26
67			113	51	2004-2-12
68			113	54	2004-2-12
69			113	50	2003-12-26
70			113	52	2003-12-26

71			113	53	2003-12-26
72			113	55	2003-12-26
73			114	55	2003-12-31
74			107	53	2003-12-20

75	IRS P6	LISS 3	109	54	2003-12-30
76			112	54	2004-02-07

Table 11: List of Resourcesat -1 LISS 3 data

Sl. No.	Satellite	Sensor	Path	Row	Tile No.	Date of acquisition
1	Resourcesat 1	LISS 3	109	54	G46M11	2008-10-16
2			109	53	G46M09	2011-11-30
3			109	54	G46M12	2008-10-16
4			109	53	G46G10	2008-10-16
5			109	53	G46G11	2008-10-16
6			109	53	G46G09	2008-10-16
7			109	54	G46M06	2008-10-16
8			109	54	G46M07	2008-10-16
9			109	53	G46M05	2011-11-30
10			109	53	G46M08	2008-10-16
11			109	53	G46G06	2008-10-16
12			109	53	G46G07	2008-10-16

13	Resourcesat 1	LISS 3	109	53	G46G05	2008-10-16
14			109	53	G46G08	2008-10-16
15			110	53	G46M14	2011-11-11
16			110	54	G46M15	2009-11-09
17			109	53	G46M13	2011-11-30
18			110	54	G46M16	2011-11-11
19			109	53	G46M02	2008-10-16
20			109	54	G46M03	2008-10-16
21			109	53	G46M01	2011-11-30
22			109	54	G46M04	2008-10-16
23			109	53	G46G02	2008-10-16
24			109	53	G46G03	2008-10-16
25			109	53	G46G01	2008-10-16
26			109	53	G46G04	2008-10-16
27			111	55	G46T12	2008-11-19
28			110	54	G46N10	2009-11-09
29			110	54	G46N11	2009-11-09
30			110	53	G46N09	2011-11-11
31			110	54	G46N12	2009-11-09
32			110	53	G46H03	2009-11-09
33			110	53	G46H11	2009-11-09
34			110	52	G46H09	2008-12-08

35			110	53	G46H12	2011-11-11
36			110	52	G46B10	2008-12-08
37			110	52	G46B11	2008-12-08
38			110	52	G46B09	2008-12-08
39			110	55	G46T08	2008-10-21
40			110	54	G46N06	2009-11-09
41			110	54	G46N07	2009-11-09
42			110	53	G46N05	2009-11-09
43			110	54	G46N08	2009-11-09
44			109	53	G46G12	2011-11-30
45			109	53	G46G16	2011-11-30
46			109	53	G46G15	2008-10-16
47			110	53	G46H08	2009-11-09
48			111	55	G46T15	2008-11-19
49	Resourcesat 1	LISS 3	111	55	G46T16	2008-11-19
50			110	54	G46N14	2009-11-09
51			111	51	G46N15	2008-11-19
52			110	53	G46N13	2009-11-09
53			111	51	G46N16	2008-11-19
54			110	53	G46H14	2009-11-09
55			110	53	G46H15	2011-11-11
56			110	52	G46H13	2008-12-08

57	Resourcesat 1	LISS 3	110	53	G46H16	2011-11-11
58			110	52	G46B14	2008-12-08
59			110	52	G46B15	2008-12-08
60			110	52	G46B13	2008-12-08
61			110	54	G46N02	2009-11-09
62			110	54	G46N03	2009-11-09
63			110	53	G46N01	2009-11-09
64			110	54	G46N04	2009-11-09
65			110	53	G46H04	2009-11-09
66			111	51	G46U10	2008-11-19
67			111	55	G46U11	2008-11-19
68			111	51	G46U09	2008-11-19
69			112	55	G46U12	2008-11-24
70			111	51	G46O10	2008-11-19
71			111	51	G46O11	2008-11-19
72			111	53	G46O09	2008-11-19
73			111	51	G46O12	2008-11-19
74			111	53	G46I10	2008-11-19
75			111	53	G46I11	2008-11-19
76			111	52	G46I09	2008-11-19
77			111	53	G46I12	2008-11-19
78			111	52	G46C10	2008-11-19

79			111	52	G46C11	2008-11-19
80			111	52	G46C09	2011-10-23
81			111	52	G46C12	2008-11-19
82			111	51	H46U12	2008-11-19
83			111	51	G46U06	2008-11-19

84			111	55	G46U07	2008-11-19
85			111	51	G46U05	2008-11-19
86			111	55	G46U08	2008-11-19
87			111	51	G46O06	2008-11-19
88			111	51	G46O07	2008-11-19
89			111	53	G46O05	2008-11-19
90			111	51	G46O08	2008-11-19
91			111	53	G46I06	2008-11-19
92			111	53	G46I07	2008-11-19
93			111	52	G46I05	2008-11-19
94			111	53	G46I08	2008-11-19
95	Resourcesat 1	LISS 3	110	52	G46C06	2008-12-08
96			110	52	G46C07	2008-12-08
97			110	52	G46C05	2008-12-08
98			111	52	G46C08	2008-11-19
99			112	54	G46U14	2008-11-24

100	Resourcesat 1	LISS 3	112	55	G46U15	2008-11-24
101			112	54	G46U13	2008-11-24
102			112	55	G46U16	2008-11-24
103			111	51	G46O14	2008-11-19
104			111	51	G46O15	2008-11-19
105			111	53	G46O13	2008-11-19
106			112	54	G46O16	2011-11-21
107			111	53	G46I14	2008-11-19
108			111	53	G46I15	2008-11-19
109			111	52	G46I13	2008-11-19
110			111	53	G46I16	2008-11-19
111			111	52	G46C14	2008-11-19
112			111	52	G46C15	2008-11-19
113			111	52	G46C13	2008-11-19
114			111	52	G46C16	2008-11-19
115			111	51	H46U15	2008-11-19
116			111	51	H46U16	2008-11-19
117			111	51	G46U02	2008-11-19
118			111	55	G46U03	2008-11-19
119			111	51	G46U01	2008-11-19
120			111	55	G46U04	2008-11-19
121			111	51	G46O02	2008-11-19

122			111	51	G46O03	2008-11-19
123			111	53	G46O01	2008-11-19
124			111	51	G46O04	2008-11-19
125			110	53	G46I02	2011-11-11
126			111	53	G46I03	2008-11-19
127			110	53	G46I01	2011-11-11

128			111	53	G46I04	2008-11-19
129			110	52	G46C02	2008-12-08
130			110	52	G46C03	2008-12-08
131			110	52	G46C01	2008-12-08
132			110	52	G46C04	2008-12-08
133			112	54	G46V10	2008-11-24
134			112	55	G46V11	2008-11-24
135			112	54	G46V09	2008-11-24
136			112	55	G46V12	2008-11-24
137			112	53	G46P10	2011-11-21
138			112	54	G46P11	2008-11-24
139	Resourcesat 1	LISS 3	112	53	G46P09	2011-11-21
140			112	54	G46P12	2008-11-24
141			112	53	G46J10	2008-11-24
142			112	53	G46J11	2008-11-24

143	Resourcesat 1	LISS 3	112	52	G46J09	2008-12-18
144			112	53	G46J12	2011-11-21
145			112	52	G46D10	2008-12-18
146			112	52	G46D11	2008-12-18
147			112	52	G46D09	2011-11-21
148			112	52	G46D12	2008-12-18
149			111	51	G46V10	2008-11-19
150			109	53	G46G14	2008-10-16
151			109	53	G46H02	2008-10-16
152			109	53	G46G13	2008-10-16
153			109	53	G46H01	2008-10-16
154			112	51	H46V11	2008-11-24
155			112	51	H46V12	2008-11-24
156			112	54	G46V06	2008-11-24
157			112	55	G46V07	2008-11-24
158			112	54	G46V05	2008-11-24
159			112	55	G46V08	2008-11-24
160			112	53	G46P06	2011-11-21
161			112	54	G46P07	2011-11-21
162			112	53	G46P05	2011-11-21
163			112	54	G46P08	2008-11-24
164			112	53	G46J06	2008-11-24

165			112	53	G46J07	2008-11-24
166			112	52	G46J05	2008-12-18
167			112	53	G46J08	2011-11-21
168			111	52	G46D06	2008-11-19
169			111	52	G46D07	2008-11-19
170			111	52	G46D05	2008-11-19
171			111	52	G46D08	2008-11-19

172			111	51	H46V06	2008-11-19
173			111	51	H46V07	2008-11-19
174			111	51	H46V08	2008-11-19
175			113	54	G46V14	2008-11-29
176			113	55	G46V15	2011-11-26
177			113	54	G46V13	2008-11-29
178			113	55	G46V16	2011-11-26
179			112	54	G46P14	2008-11-24
180			112	54	G46P15	2008-11-24
181			112	53	G46P13	2011-11-21
182			112	54	G46P16	2008-11-24
183			112	53	G46J14	2008-11-24
184	Resourcesat 1	LISS 3	112	53	G46J15	2008-11-24
185			112	53	G46J16	2008-11-24

186			112	52	G46D13	2011-11-21
187			112	51	H46V14	2008-11-24
188			112	51	H46V15	2008-11-24
189			112	51	H46V13	2008-11-24
190			112	51	H46V16	2008-11-24
191			112	54	G46V02	2008-11-24
192			112	55	G46V03	2008-11-24
193			112	54	G46V01	2008-11-24
194			112	55	G46V04	2008-11-24
195			112	53	G46P02	2011-11-21
196			112	54	G46P03	2011-11-21
197			112	53	G46P01	2011-11-21
198			112	54	G46P04	2011-11-21
199			111	53	G46J02	2008-11-19
200			112	53	G46J03	2008-11-24
201			111	52	G46J01	2008-11-19
202			112	53	G46J04	2011-11-21
203			111	52	G46D02	2008-11-19
204			111	52	G46D03	2008-11-19
205			111	52	G46D01	2008-11-19
206			111	52	G46D04	2008-11-19
207			111	51	H46V03	2008-11-19

208	Resourcesat 1	LISS 3	111	51	H46V04	2008-11-19
209			113	54	G46W10	2008-11-29
210			113	54	G46W09	2008-11-29
211			113	53	G46Q10	2011-11-26
212			113	54	G46Q11	2008-11-29
213			113	53	G46Q09	2008-11-29
214			113	54	G46Q12	2008-11-29
215			113	53	G46K10	2008-11-29
216			113	53	G46K11	2008-11-29
217			113	52	G46K09	2008-11-29
218			113	53	NG46K12	2008-11-29
219			113	52	G46E10	2008-11-29
220			113	52	G46E11	2008-11-29
221			112	52	G46E09	2011-11-21
222			113	52	G46E12	2008-11-29
223			112	51	H46W10	2008-11-24
224			112	51	H46W11	2008-11-24
225			112	51	H46W09	2008-11-24
226			112	51	H46W12	2008-11-24
227			112	50	H46Q11	2008-12-18
228	Resourcesat 1	LISS 3	112	51	H46Q12	2008-11-24

229			113	54	G46W06	2008-11-29
230			113	55	G46W07	2011-11-26
231			113	54	G46W05	2008-11-29
232			113	55	G46W08	2011-11-26
233			113	53	G46Q06	2008-11-29
234			113	54	G46Q07	2008-11-29
235			113	53	G46Q05	2008-11-29
236			113	54	G46Q08	2008-11-29
237			113	53	G46K06	2008-11-29
238			113	53	G46K07	2008-11-29
239			112	52	G46K05	2011-11-21
240			113	53	G46K08	2008-11-29
241			112	52	G46E05	2011-11-21
242			112	51	H46W06	2008-11-24
243			112	51	H46W07	2008-11-24
244			112	51	H46W05	2008-11-24
245			112	51	H46W08	2008-11-24
246			112	51	H46Q08	2008-11-24
247			113	53	G46Q14	2008-11-29
248			113	54	G46Q15	2008-11-29
249			113	53	G46Q13	2008-11-29
250			113	53	G46K14	2008-11-29

251	Resourcesat 1	LISS 3	113	53	G46K15	2008-11-29
252			113	52	G46K13	2008-11-29
253			113	53	G46K16	2008-11-29
254			113	52	G46E14	2008-11-29
255			113	52	G46E15	2008-11-29
256			113	52	G46E13	2008-11-29
257			113	52	G46E16	2008-11-29
258			113	51	H46W14	2008-11-29
259			113	51	H46W15	2008-11-29
260			112	51	H46W13	2008-11-24
261			113	51	H46W16	2008-11-29
262			112	50	H46Q15	2008-12-18
263			112	51	H46Q16	2008-11-24
264			113	54	G46W02	2008-11-24
265			113	55	G46W03	2011-11-26
266			113	54	G46W01	2012-03-25
267			113	55	G46W04	2011-11-26
268			113	53	G46Q02	2008-11-29
269			113	54	G46Q03	2008-11-29
270			113	53	G46Q01	2008-11-29
271			113	54	G46Q04	2008-11-29

272	Resourcesat 1	LISS 3	112	53	G46K02	2008-11-24
273			112	53	G46K03	2008-11-24
274			112	53	G46K04	2008-11-24
275			112	52	G46E01	2011-12-21
276			112	51	H46W02	2008-11-24
277			112	51	H46W03	2008-11-24
278			112	51	H46W01	2008-11-24
279			112	51	H46W04	2008-11-24
280			112	51	H46Q04	2008-11-24
281			114	52	G46L09	2008-10-17
282			113	52	G46F10	2008-11-29
283			114	52	G46F11	2008-12-17
284			113	52	G46F09	2008-11-29
285			114	52	G46F12	2008-10-17
286			113	51	H46X10	2008-11-29
287			113	51	NH46X11	2008-11-29
288			113	51	H46X09	2008-11-29
289			113	51	H46X12	2008-11-29
290			113	50	H46R11	2008-11-29
291			113	51	H46R12	2008-11-29
292			113	52	G46L06	2008-11-29
293			113	52	G46L05	2008-11-29

294			113	52	G46F06	2008-11-29
295			113	52	G46F07	2008-11-29
296	Resourcesat 1	LISS 3	113	52	G46F05	2008-11-29
297			113	52	G46F08	2008-11-29
298			113	51	H46X06	2008-11-29
299			113	51	H46X07	2008-11-29
300			113	51	H46X05	2008-11-29
301			113	51	H46X08	2008-11-29
302			113	51	H46R08	2008-11-29
303			114	52	G46L13	2008-10-17
304			114	52	G46F14	2008-10-17
305			114	52	G46F15	2008-10-17
306			114	52	G46F13	2008-10-17
307			114	52	G46F16	2008-10-17
308			113	51	H46X14	2008-11-29
309			114	51	H46X15	2008-10-17
310			113	51	H46X13	2008-11-29
311			114	51	H46X16	2008-10-17
312			113	50	H46R15	2008-11-29
313			113	51	H46R16	2008-11-29
314			113	53	G46R02	2008-11-26

315	Resourcesat 1	LISS 3	113	53	G46R01	2008-11-29
316			113	53	G46L02	2008-11-29
317			113	53	G46L03	2008-11-29
318			113	52	G46L01	2008-11-29
319			113	53	G46L04	2008-11-26
320			113	52	G46F02	2008-11-29
321			113	52	G46F03	2008-11-29
322			113	52	G46F01	2008-11-29
323			113	52	G46F04	2008-11-29
324			113	51	H46X02	2008-11-29
325			113	51	H46X03	2008-11-29

326	Resourcesat 1	LISS 3	113	51	H46X01	2008-11-29
327			113	51	H46X04	2008-11-29
328			113	51	H46R04	2008-11-29
329			114	52	G47A10	2008-10-17
330			114	52	G47A11	2008-10-17
331			114	52	G47A09	2008-10-17
332			114	51	H47S10	2008-10-17
333			114	51	H47S11	2008-10-17
334			114	51	H47S09	2008-10-17
335			114	51	H47S12	2008-10-17

336			114	51	H47M12	2008-10-17
337			114	52	G47A06	2008-10-17
338			114	52	G47A07	2008-10-17
339			114	52	G47A05	2008-10-17
340			114	51	H47S06	2008-10-17
341			114	51	H47S07	2008-10-17
342			114	51	H47S05	2008-10-17
343			114	51	H47S08	2008-10-17
344			114	50	H47M07	2008-10-17
345			114	51	H47M08	2008-10-17
346			115	52	G47A14	2008-12-09
347			115	52	G47A15	2008-12-09
348			115	52	G47A13	2008-12-09
349			115	52	G47A16	2008-12-09
350			114	51	H47S15	2008-10-17
351			115	51	H47S16	2008-12-09
352			114	52	G47A02	2008-10-17
353			114	52	G47A03	2008-10-17
354			114	52	G47A01	2008-10-17
355			114	52	G47A04	2008-10-17
356			114	51	H47S02	2008-10-17

357			114	51	H47S03	2008-10-17
358			114	51	H47S01	2008-10-17
359			114	51	H47S04	2008-10-17
360	Resourcesat 1	LISS 3	114	50	H47M03	2008-10-17
361			114	51	H47M04	2008-10-17
362			115	51	H47T07	2008-12-09
363			115	51	H47T08	2008-12-09
364			115	51	H47T03	2008-12-09
365			115	51	H47T04	2008-12-09
366			107	52	G45E01	2008-12-17
367			107	52	G45E02	2008-12-17
368			107	52	G45E03	2008-12-17
369			107	52	G45E04	2008-12-17

370			107	52	G45E05	2008-12-17
371			107	52	G45E06	2008-12-17
372			107	52	G45E07	2008-12-17
373	Resourcesat 1	LISS 3	107	52	G45E08	2008-12-17
374			107	52	G45E09	2008-12-17
375			107	52	G45E10	2008-12-17
376			107	52	G45E11	2008-12-17
377			107	52	G45E12	2008-12-17

378			107	52	G45E13	2008-12-17
379			107	52	G45E14	2008-12-17
380			107	52	G45E15	2008-12-17
381			107	52	G45E16	2008-12-17
382			107	52	G45K01	2008-12-17
383			107	52	G45K05	2008-12-17
384			107	53	G45K06	2008-10-30
385			107	53	G45K07	2008-10-30
386			107	52	G45K09	2008-12-17
387			107	53	G45K10	2008-10-30
388			107	53	G45K11	2008-10-30
389			107	52	G45K13	2008-12-17
390			107	53	G45K14	2008-10-30
391			107	53	G45K15	2008-10-30

392			108	53	G45K16	2011-11-25
393			108	53	G45L01	2009-11-23
394			108	53	G45L02	2009-11-23
395			108	53	G45L03	2009-11-23
396			108	53	G45L04	2009-11-23
397			108	53	G45L05	2009-11-23
398			108	53	G45L06	2009-11-23

399	Resourcesat 1	LISS 3	108	53	G45L07	2009-11-23
400			108	53	G45L08	2009-11-23
401			108	53	G45L09	2009-11-23
402			108	53	G45L10	2009-11-23
403			108	53	G45L11	2009-11-23
404			108	53	G45L12	2009-11-23
405			108	53	G45L14	2009-11-23
406			108	53	G45L15	2009-11-23
407			108	53	G45L16	2009-11-23
408			108	53	G45R05	2009-11-23
409			108	53	G45R09	2009-11-23
410			109	53	G45R13	2008-10-16
411			109	54	G45R14	2009-10-16
412			109	54	G45R15	2008-10-16

Table 12: List of Resourcesat-2 LISS 4 data

Sl. No.	Satellite	Sensor	Path	Row	Sub Scene	Date of acquisition
1	Resourcesat-2	LISS 4	112	52	C	2016-11-18
2			113	52	A	2016-11-23
3			113	52	C	2016-11-23
4			113	53	A	2016-11-23

5			111	53	C	2017-01-24
6			111	53	A	2017-01-24
7			112	53	A	2017-01-05
8			109	53	C	2017-01-14
9			109	54	C	2017-01-14
10			113	52	B	2017-02-03
11			110	53	C	2017-01-19
12			109	54	A	2017-01-14
13			114	52	A	2017-01-15
14			111	53	B	2016-03-18
15			112	52	B	2016-12-12
16			112	53	B	2017-01-29
17			112	52	D	2017-01-29
18			109	53	D	2017-02-07
19			108	53	B	2017-02-02
20			109	53	B	2017-02-07
21			108	54	D	2016-12-16
22			108	53	D	2016-12-16
23			108	54	B	2016-12-16
24			110	53	B	2015-12-08

Table 13: List of Toposheet used in the project

Sl. No.	**Toposheet No.**	**Scale**

1.	82 H/8	1:50000
2.	82P/ 15	1:50000
3.	82P/16	1:50000
4.	83A/ 7	1:50000
5.	83E/4	1:50000
6.	83E/5	1:50000
7.	83E/6	1:50000
8.	83E/13	1:50000
9.	91D/4	1:50000
10.	91D/8	1:50000
11.	78O/5	1:50000
12.	83B/2	1:50000
13.	83B/6	1:50000
14.	83B/12	1:50000
15.	83C/5	1:50000
16.	83C/6	1:50000
17.	83F/3	1:50000
18.	83F/6	1:50000
19.	83F/13	1:50000
20.	83I/1	1:50000
21.	83I/2	1:50000
22.	83I/3	1:50000

23.	83I/4	1:50000
24.	83I/5	1:50000
25.	83I/6	1:50000
26.	83I/8	1:50000
27.	83I/12	1:50000
28.	83I/16	1:50000
29.	83J/1	1:50000
30.	83J/5	1:50000
31.	83J/6	1:50000
32.	83J/9	1:50000
33.	83M/2	1:50000
34.	83M/4	1:50000
35.	83M/9	1:50000
36.	83M/12	1:50000
37.	84N/12	1:50000
38.	78 N/16	1:50000
39.	78 J/3	1:50000
40.	78 J/4	1:50000
41.	78 J/6	1:50000
42.	78 J/7	1:50000
43.	78 J/10	1:50000
44.	78 J/11	1:50000

45.	78 J/14	1:50000
46.	78 J/15	1:50000
47.	78 J/16	1:50000
48.	78 N/2	1:50000
49.	78 N/3	1:50000
50.	78 N/4	1:50000
51.	78 N/6	1:50000
52.	78 N/7	1:50000
53.	78 N/8	1:50000
54.	78 N/10	1:50000
55.	78 N/11	1:50000
56.	78 N/14	1:50000
57.	78 N/15	1:50000
58.	82 I/2	1:50000
59.	82 I/6	1:50000
60.	82 I/7	1:50000
61.	82 I/8	1:50000
62.	82 I/10	1:50000
63.	82 I/14	1:50000
64.	82 O/16	1:50000
65.	82 P/6	1:50000
66.	82 P/7	1:50000

67.	82 P/8	1:50000
68.	82 P/9	1:50000
69.	82 P/10	1:50000
70.	82 P/11	1:50000
71.	82 P/12	1:50000
72.	82 P/14	1:50000
73.	83 B/3	1:50000
74.	83 B/6	1:50000
75.	83 B/7	1:50000
76.	83 B/10	1:50000
77.	83 B/11	1:50000
78.	83 B/14	1:50000
79.	83 B/15	1:50000
80.	83 B/16	1:50000
81.	83 C/9	1:50000
82.	83 C/13	1:50000
83.	83 C/14	1:50000
84.	83 E/9	1:50000
85.	83 E/10	1:50000
86.	83 E/13	1:50000
87.	83 E/14	1:50000
88.	83 F/2	1:50000

89.	83 F/4	1:50000
90.	83 F/7	1:50000
91.	83 F/8	1:50000
92.	83 F/9	1:50000
93.	83 F/10	1:50000
94.	83 F/11	1:50000
95.	83 F/12	1:50000
96.	83 F/14	1:50000
97.	83 G/1	1:50000
98.	83 G/2	1:50000
99.	83 G/3	1:50000
100.	83 G/5	1:50000
101.	83 I/7	1:50000
102.	83 I/9	1:50000
103.	83 I/10	1:50000
104.	83 I/11	1:50000
105.	83 I/13	1:50000
106.	83 I/14	1:50000
107.	83 I/15	1:50000
108.	83 M/3	1:50000
109.	83 M/5	1:50000
110.	83 M/7	1:50000

111.	83 M/10	1:50000
112.	83 M/13	1:50000
113.	83 M/14	1:50000
114.	91 D/3	1:50000
115.	91 D/12	1:50000
116.	91 D/16	1:50000
117.	92 A/2	1:50000
118.	92 A/9	1:50000
119.	92 A/10	1:50000
120.	78 K/5	1:50000
121.	78 N/9	1:50000
122.	92 A/3	1:50000
123.	83 M	1:50000
124.	78 G/3	1:50000
125.	78 G/14	1:50000
126.	78 J/9	1:50000
127.	78 J/2	1:50000
128.	78 F/13	1:50000
129.	83 G/6	1:50000
130.	83 G/9	1:50000
131.	83 G/10	1:50000
132.	83 G/13	1:50000

133.	83 J/3	1:50000
134.	83 J/4	1:50000
135.	83 J/7	1:50000
136.	83 J/10	1:50000
137.	83 J/13	1:50000
138.	84 J/2	1:50000
139.	83 A/12	1:50000
140.	83 A/16	1:50000
141.	83 B/5	1:50000
142.	83 E/15	1:50000
143.	83 E/16	1:50000
144.	83 F/1	1:50000
145.	83 F/5	1:50000
146.	83 I/2	1:50000
147.	83 I/3	1:50000
148.	83 I/6	1:50000
149.	83 M/1	1:50000
150.	83 M/11	1:50000
151.	83 M/13	1:50000
152.	83 M/15	1:50000

ANNEXURE II

Table 14: Hydrological data for Brahmaputra River collected from CWC

Sl. No.	Brahmaputra River stations	Type of data	Frequency	Period of data
1.	Pancharatna	Gauge	Daily	1971 to 2015
		Gauge	10 Daily	1971 to 2015
		Discharge	10 Daily	1971 to 2015
		Silt	Monthly	1976 to 2015
		X- Section		1978 to 2015
		Morphological X-Section		2010-2011 to 2014-2015

Sl. No.	Brahmaputra River stations	Type of data	Frequency	Period of data
2.	Pandu	Gauge	Daily	1982 to 2015
		Gauge	10 Daily	1999 to 2015
		Discharge	10 Daily	1998 to 2015
		Silt	Monthly	2004 to 2015
		X- Section		1998 to 2015
		Morphological X-Section		2010-2011 to 2014-2015
3.	Bhomoraguri	Gauge	10 Daily	1993-1994 to 2014-2015
		Discharge	10 Daily	1995-1996 to 2014-2015
		Silt	Monthly	2014-2015
		X- Section	Pre & Post Monsoon	2006-2015
4.	D.C. court, Ghy	Gauge	Daily	June 1971 to May 2015
5.	Goalpara	Gauge	Daily	May 1972 to May 2015
6.	Dibrugarh	Gauge	Daily	01/06/1969 to 31/05/2015
7.	Neamatighat	Gauge	Daily	15/05/1974 to 31/05/2015
8.	Tezpur	Gauge	Daily	15/05/1976 to 31/05/2015
9.	Nagaon	Morphological X-Section		2013-2014 to 2015-2016

ANNEXURE III

Table 15: PFI calculated at the corresponding reach lines for the year 1973-1974

Reach No.	Planform Index	Threshold Indicator
1	3.317	Highly braided
2	5.320	Moderately braided
3	4.790	Moderately braided
4	4.341	Moderately braided
5	2.349	Highly braided
6	3.517	Highly braided

7	8.321	Moderately braided
8	5.706	Moderately braided
9	3.403	Highly braided
10	3.570	Highly braided
11	4.009	Moderately braided
12	3.590	Highly braided
13	6.531	Moderately braided
14	11.020	Moderately braided
15	9.086	Moderately braided
16	8.715	Moderately braided
17	6.994	Moderately braided
18	6.800	Moderately braided
19	4.266	Moderately braided
20	11.293	Moderately braided
21	15.860	Moderately braided
22	7.883	Moderately braided
23	7.733	Moderately braided
24	16.571	Moderately braided
25	8.856	Moderately braided
26	9.286	Moderately braided
27	11.419	Moderately braided
28	10.835	Moderately braided
29	13.699	Moderately braided
30	7.452	Moderately braided
31	7.484	Moderately braided
32	4.412	Moderately braided
33	4.880	Moderately braided
34	4.881	Moderately braided
35	12.351	Moderately braided
36	9.209	Moderately braided
37	6.588	Moderately braided
38	5.509	Moderately braided
39	9.930	Moderately braided
40	18.110	Moderately braided
41	9.445	Moderately braided
42	11.649	Moderately braided
43	21.523	Low Braided
44	14.790	Moderately braided
45	14.986	Moderately braided
46	3.219	Highly braided
47	3.671	Highly braided
48	4.690	Moderately braided
49	5.449	Moderately braided

50	9.409	Moderately braided
51	6.443	Moderately braided
52	6.999	Moderately braided
53	9.692	Moderately braided
54	9.111	Moderately braided
55	6.889	Moderately braided
56	10.661	Moderately braided
57	6.703	Moderately braided
58	10.109	Moderately braided
59	4.686	Moderately braided
60	4.627	Moderately braided
61	4.574	Moderately braided
62	2.553	Highly braided
63	2.191	Highly braided
64	3.837	Highly braided

Table 16: PFI calculated at the corresponding reach lines for the year 1976-1981

Reach No.	Planform Index	Threshold Indicator
1	3.649	Highly Braided
2	5.258	Moderately Braided
3	3.905	Highly Braided
4	3.866	Highly Braided
5	5.923	Moderately Braided
6	6.220	Moderately Braided
7	7.670	Moderately Braided
8	5.479	Moderately Braided
9	3.810	Highly Braided
10	3.620	Highly Braided
11	6.244	Moderately Braided
12	7.559	Moderately Braided
13	7.344	Moderately Braided
14	6.663	Moderately Braided
15	6.949	Moderately Braided
16	8.740	Moderately Braided
17	3.660	Moderately Braided
18	6.529	Moderately Braided
19	6.224	Moderately Braided
20	11.010	Moderately Braided
21	6.765	Moderately Braided
22	4.562	Moderately Braided
23	15.889	Moderately Braided
24	11.136	Moderately Braided

25	10.860	Moderately Braided
26	18.466	Moderately Braided
27	9.396	Moderately Braided
28	5.556	Moderately Braided
29	6.224	Moderately Braided
30	11.007	Moderately Braided
31	5.541	Moderately Braided
32	4.635	Moderately Braided
33	5.215	Moderately Braided
34	7.713	Moderately Braided
35	14.344	Moderately Braided
36	12.085	Moderately Braided
37	5.937	Moderately Braided
38	5.628	Moderately Braided
39	18.128	Moderately Braided
40	6.613	Moderately Braided
41	10.745	Moderately Braided
42	15.909	Moderately Braided
43	25.057	Moderately Braided
44	13.672	Moderately Braided
45	11.719	Moderately Braided
46	3.658	Highly Braided
47	3.701	Highly Braided
48	7.505	Moderately Braided
49	16.383	Moderately Braided
50	8.901	Moderately Braided
51	5.063	Moderately Braided
52	6.279	Moderately Braided
53	6.061	Moderately Braided
54	17.862	Moderately Braided
55	8.159	Moderately Braided
56	5.049	Moderately Braided
57	9.533	Moderately Braided
58	7.878	Moderately Braided
59	5.539	Moderately Braided
60	4.391	Moderately Braided
61	7.240	Moderately Braided
62	3.972	Highly Braided
63	3.943	Highly Braided
64	3.826	Highly Braided

Table 17: PFI calculated at the corresponding reach lines for the year 1993-1995

Reach No.	Planform Index	Threshold Indicator
1	2.381	Highly Braided
2	2.985	Highly Braided
3	3.496	Highly Braided
4	4.107	Moderately Braided
5	2.021	Highly Braided
6	2.966	Highly Braided
7	3.520	Highly Braided
8	4.508	Moderately Braided
9	4.009	Moderately Braided
10	5.656	Moderately Braided
11	5.179	Moderately Braided
12	5.215	Moderately Braided
13	3.466	Highly Braided
14	5.353	Moderately Braided
15	7.402	Moderately Braided
16	5.648	Moderately Braided
17	4.720	Moderately Braided
18	9.436	Moderately Braided
19	3.552	Highly Braided
20	3.740	Highly Braided
21	4.377	Moderately Braided
22	6.353	Moderately Braided
23	5.675	Moderately Braided
24	11.199	Moderately Braided
25	11.735	Moderately Braided
26	9.033	Moderately Braided
27	5.105	Moderately Braided
28	8.185	Moderately Braided
29	11.724	Moderately Braided
30	17.123	Moderately Braided
31	7.521	Moderately Braided
32	16.224	Moderately Braided
33	6.160	Moderately Braided
34	8.835	Moderately Braided
35	8.441	Moderately Braided
36	10.739	Moderately Braided
37	16.956	Moderately Braided
38	8.663	Moderately Braided
39	6.777	Moderately Braided
40	13.744	Moderately Braided

41	4.226	Moderately Braided
42	20.426	Low Braided
43	11.879	Moderately Braided
44	19.767	Moderately Braided
45	14.358	Low Braided
46	11.384	Moderately Braided
47	6.367	Moderately Braided
48	7.803	Moderately Braided
49	14.952	Moderately Braided
50	8.081	Moderately Braided
51	12.491	Moderately Braided
52	13.643	Moderately Braided
53	8.363	Moderately Braided
54	10.863	Moderately Braided
55	15.234	Moderately Braided
56	8.530	Moderately Braided
57	9.700	Moderately Braided
58	7.150	Moderately Braided
59	6.984	Low Braided
60	11.665	Moderately Braided
61	5.088	Moderately Braided
62	10.533	Moderately Braided
63	4.338	Moderately Braided
64	4.602	Moderately Braided

Table 18: PFI calculated at the corresponding reach lines for the year 2003-2004

Reach No.	Planform Index	Threshold Indicator
1	1.932	Highly Braided
2	2.156	Highly Braided
3	2.265	Highly Braided
4	2.308	Highly Braided
5	2.674	Highly Braided
6	3.704	Highly Braided
7	5.702	Moderately Braided
8	3.710	Highly Braided
9	3.689	Highly Braided

10	2.862	Highly Braided
11	3.694	Highly Braided
12	3.700	Highly Braided
13	3.131	Highly Braided
14	4.414	Moderately Braided
15	10.202	Moderately Braided
16	2.899	Highly Braided
17	3.494	Highly Braided
18	3.132	Highly Braided
19	3.902	Highly Braided
20	3.988	Highly Braided
21	3.571	Highly Braided
22	3.082	Highly Braided
23	4.300	Moderately Braided
24	10.774	Moderately Braided
25	8.329	Moderately Braided
26	4.461	Moderately Braided
27	4.292	Moderately Braided
28	5.112	Moderately Braided
29	10.312	Moderately Braided
30	7.560	Moderately Braided
31	3.581	Highly Braided
32	3.104	Highly Braided
33	4.945	Moderately Braided
34	5.045	Moderately Braided
35	4.970	Moderately Braided
36	3.886	Highly Braided
37	7.065	Moderately Braided
38	2.178	Highly Braided
39	3.307	Highly Braided
40	21.354	Low Braided
41	10.291	Moderately Braided
42	24.106	Low Braided
43	12.397	Moderately Braided
44	6.987	Moderately Braided
45	3.490	Highly Braided
46	1.254	Highly Braided
47	1.785	Highly Braided
48	2.458	Highly Braided
49	4.279	Moderately Braided
50	3.970	Highly Braided
51	2.027	Highly Braided
52	2.267	Highly Braided

53	5.102	Moderately Braided
54	8.025	Moderately Braided
55	11.613	Moderately Braided
56	4.176	Moderately Braided
57	5.435	Moderately Braided
58	5.086	Moderately Braided
59	2.746	Highly Braided
60	7.404	Moderately Braided
61	3.342	Highly Braided
62	1.759	Highly Braided
63	1.140	Highly Braided
64	1.647	Highly Braided

Table 19: PFI calculated at the corresponding reach lines for the year 2008-2011

Reach No.	Planform Index	Threshold Indicator
1	3.252	Highly Braided
2	3.842	Highly Braided
3	3.855	Highly Braided
4	3.140	Highly Braided
5	3.665	Highly Braided
6	5.897	Moderately Braided
7	7.143	Moderately Braided
8	7.798	Moderately Braided
9	3.736	Highly Braided
10	3.717	Highly Braided
11	4.944	Moderately Braided

12	5.845	Moderately Braided
13	5.771	Moderately Braided
14	6.410	Moderately Braided
15	6.181	Moderately Braided
16	6.650	Moderately Braided
17	3.718	Highly Braided
18	3.925	Highly Braided
19	3.208	Highly Braided
20	2.541	Highly Braided
21	3.727	Highly Braided
22	4.879	Moderately Braided
23	3.657	Highly Braided
24	6.447	Moderately Braided
25	8.309	Moderately Braided
26	6.952	Moderately Braided
27	3.783	Highly Braided
28	9.225	Moderately Braided
29	20.074	Low Braided
30	13.000	Moderately Braided
31	3.854	Highly Braided
32	5.281	Moderately Braided
33	3.885	Highly Braided
34	3.879	Highly Braided
35	5.098	Moderately Braided
36	5.208	Moderately Braided
37	7.244	Moderately Braided
38	3.378	Highly Braided
39	4.438	Moderately Braided
40	10.967	Moderately Braided
41	6.750	Moderately Braided
42	11.436	Moderately Braided
43	10.863	Moderately Braided
44	11.753	Moderately Braided
45	2.523	Highly Braided
46	2.357	Highly Braided
47	2.650	Highly Braided
48	3.915	Highly Braided
49	3.936	Highly Braided
50	3.508	Highly Braided
51	3.876	Highly Braided
52	3.529	Highly Braided
53	6.090	Moderately Braided

54	9.875	Moderately Braided
55	6.527	Moderately Braided
56	5.842	Moderately Braided
57	10.126	Moderately Braided
58	8.193	Moderately Braided
59	7.983	Moderately Braided
60	3.996	Highly Braided
61	3.964	Highly Braided
62	3.183	Highly Braided
63	3.774	Highly Braided
64	3.660	Highly Braided

ANNEXURE IV

Table 20: District-wise deposition length and area on right bank of Brahmaputra

DISTRICT/ YEAR	DEPOSITION LENGTH (m)					DEPOSITION AREA (sq.km.)				
	76-80	93_95	03_04	08_11	16-17	76-80	93-95	03_04	08_11	16-17
DHUBRI	13679.12	11036.73	6734.86	9277.76	6751.943	4.80185	88.046	91.87	88.778	43.489
DHEMAJI	7921.89	25230.51	16037.4	7120.82	8415.63	1.86417	10.011	3.351	1.6594	2.0822
DARRANG	23097.7	36444.49	34943.9	28170.1	31302.32	7.81394	32.844	40.07	28.325	38.793
BISWANATH	19016.09	33799.46	19631.1	15057.4	24668.84	8.32236	16.74	10.03	5.9375	9.7617
BARPETA	15404.61	8237.6	3495.52	4.80365	2.49992	15.156	8.4561	2.614	4.8037	-
DIBRUGARH	1298.39	6158.57	4117.17	993.088	951.7899	0.08658	0.7754	1.162	0.0883	0.1396
GOLAGHAT	5636.98	2514.45	862.25	-	53.69997	1.22764	0.1252	0.037	0.0466	-
JORHAT	14477.34	16830.88	22899.3	20883	22683.91	2.41841	3.1342	10.48	8.0662	17.951
KAMRUP	2035.01	4761.49	2199.04	1880.69	4231.328	0.23396	0.2384	0.661	0.2201	2.6751
KAMRUP M	3630.08	5362.39	10039.6	284.758	3.25204	0.51282	0.7914	0.952	0.0206	-
KOKRAJHAR	240.51	-	-	-	-	0.11304	0.8243	0.824	0.8243	-
LAKHIMPUR	5985.52	1467.67	936.99	-	695.4758	1.11572	0.1504	0.041	-	0.0527
NALBARI	8068.59	4403.37	1263.22	2836.62	6248.667	6.82998	3.4769	0.227	0.6537	2.1966
SONITPUR	8547.47	40934.97	27158.5	15819.1	17038.3	1.83161	24.024	19.52	17.22	16.509
SOUTH KAMRUP	1552.97	4761.49	5186.5	804.251	927.3255	0.34878	0.4627	0.768	0.0802	0.1199
BONGAIGAON	4406.81	17576.01	16803	10456.8	10891.05	0.37572	17.027	7.467	2.9344	2.7316

G0ALPARA	-	14855.28	16062.2	15459.5	6808.743	-	51.387	42.64	38.417	11.466
SIVASAGAR	-	-	-	-	-	-	-	-	-	-
SADIYA	-	-	-	-	-	-	-	-	-	-
NAGAON	-	-	-	-	-	-	-	-	-	-
MARIGAON	-	-	-	-	-	-	-	-	-	-
UDALGURI	-	263.42	410.08	523.053	422.6595	-	0.2458	0.252	0.0954	0.1945

Table 21: District-wise deposition length and area on left bank of Brahmaputra

DISTRICT/ YEAR	DEPOSITION LENGTH (m)					DEPOSITION AREA (sq.km.)				
	76-80	93-95	03-04	08-11	16-17	76-80	93-95	03-04	08-11	16-17
DHUBRI	-	-	-	-	-	-	-	-	-	-
DHEMAJI	2174.5	-	2682.326	2102.65	552.6156	0.8235	-	1.3356	0.50929	0.0291
DARRANG	39867.28	12075.98	9989.484	21054	23177.58	17.7153	10.508	1.05	3.29264	9.5357
BISWANATH	6867.08	2159.83	6564.503	4801.68	3972.778	1.73745	0.32642	1.871	1.56823	1.7687
BARPETA	5389.16	6991.05	8315.596	6111.25	4555.546	1.91898	6.20912	5.9626	4.80365	2.4999
DIBRUGARH	49802.15	36207.35	36478.78	37989.6	36531.4	21.5088	13.7132	12.02	20.181	16.572
GOLAGHAT	27934.67	21241.14	29286.5	31866.7	20900.38	13.1173	8.57493	33.422	29.1732	14.699
JORHAT	53885.39	18845.74	28492.92	39556	28501.68	12.9869	2.00797	6.1304	10.7592	7.0035
KAMRUP	-	-	-	-	-	-	-	-	-	-

KAMRUP M	21667.58	10031.15	6855.702	22288.9	21373.16	3.78035	0.53902	0.4464	3.22238	3.252
KOKRAJHAR	-	-	-	-	-	-	-	-	-	-
LAKHIMPUR	-	-	-	-	-	-	-	-	-	-
NALBARI	-	-	-	-	-	-	-	-	-	-
SONITPUR	31841.64	29820.12	41212.96	46422.8	10839.36	10.9605	13.977	22.989	27.1286	8.7036
SOUTH KAMRUP	24532.51	4102.59	8173.062	8759.92	6012.601	13.8447	0.72888	8.256	3.85614	1.6905
BONGAIGAON	-	-	-	1136.38	1573.554	-	-	-	0.09061	0.2441
G0ALPARA	42452.36	10063.56	21197.53	31526.7	28535.81	6.41347	2.50697	5.8192	8.78254	9.0889
SIVASAGAR	34537.07	36080.49	29539.3	33215.2	32618.25	14.8416	7.62798	6.9112	11.6536	11.921
SADIYA	10380.53	-	-	-	1576.096	2.35217	-	0.1145	-	0.1391
NAGAON	8010.47	7442.58	4121.874	5058.78	8508.461	3.66586	4.29967	6.286	6.2976	4.38
MARIGAON	8822.81	277.84	3026.937	2624.04	2933.75	5.6292	0.33059	0.373	0.48715	0.6493
UDALGURI	-	-	-	-	-	-	-	-	-	-

Table 22: District-wise erosion length and area on right bank of Brahmaputra

DISTRICT/ YEAR	EROSION LENGTH (m)					EROSION AREA (sq.km)				
	76-80	93_95	03_04	08_11	16-17	76-80	93-95	03_04	08_11	16-17
DHUBRI	41240	29053	21157	35003	33606	32.478	24.708	7.8357	46.209	25.066
DHEMAJI	96174	64122	81812	102021	205448	31.932	21.083	55.359	63.644	47.599
DARRANG	46091	39523	60540	55155	26364	36.075	72.485	57.22	66.193	10.338
BISWANATH	42461	30083	40712	57342	37797	13.688	18.144	25.639	59.084	23.897
BARPETA	47826	59915	55663	66646	64073	190.32	291.61	195.99	431.43	418.39
DIBRUGARH	5857	4795.2	4454.8	3630	3801.4	2.6035	1.3091	2.5994	5.8866	3.0143
GOLAGHAT	31748	21523	32172	15415	20258	85.784	220.15	125.61	232.65	149.93
JORHAT	60620	55106	49311	52280	38171	34.99	58.099	60.418	98.495	95.7
KAMRUP	22431	21453	17891	27055	19557	15.426		24.876	64.067	20.786
KAMRUP M	12151	9486.7	8756.6	15423	17893	2.7917	2.8025	1.2276	5.9119	3.534
KOKRAJHAR	6448.1	-	-	-	631	1.4095				0.0556
LAKHIMPUR	14257	34549	19562	39394	34385	3.4048	41.445	27.857	83.84	40.987
NALBARI	11348	15321	20213	16817	10769	21.539	49.939	27.318	53.209	11.52
SONITPUR	72223	51240	57538	75716	66036	39.804	70.635	74.985	142.72	134.19
SOUTH KAMRUP	7395.4	4809.6	5114.9	6789.3	6505.9	2.9903	60.534	3.1855	8.8286	6.8052
BONGAIGAON	22768	6437.8	9008.1	16998	-	15.308	7.1155	9.8927	27.276	0.0615
G0ALPARA	-	1302.6	6510	182.97	-	10.76	10.572	10.657	21.514	

SADIYA								49.07		
NAGAON	-	-	3747.3	-	-			169.86		
MARIGAON	-	-	38900	-	-			138.26		
UDALGURI	1389.7	-	-	83.64	-	0.6672			0.0022	

Table 23: District-wise erosion length and area on left bank of Brahmaputra

DISTRICT	EROSION LENGTH_m					EROSION AREA_sq.km				
	76-80	93-95	03_04	08_11	16-17	76-80	93_95	03_04	08_11	16_17_
DHUBRI										
DHEMAJI	13423	-	15674	-	-	13.457	55.477	19.508	22.352	48.182
DARRANG	2466.1	5001.5	5301.6	3402.4	2908	1.4721	3.3345	1.4979	1.1577	2.1572
BISWANATH	73.43	-	765.69	382.31	242.73	52.247	52.575	52.571	26.485	52.993
BARPETA	24509	10855	26565	16885	24436	54.013	123.3	56.067	58.483	26.307
DIBRUGARH	29715	39478	34915	35780	36104	11.475	178.97	109.94	114.71	271.84
GOLAGHAT	48124	55493	45838	48472	54647	117.01	190.66	177.51	90.992	146.36
JORHAT	6406.2	37200	23250	19362	21178	3.435	8.9604	9.6369	6.1427	30.291
KAMRUP M	4553.1	25468	20406	4184.4	3897.5	0.7871	5.7974	3.2662	0.4352	0.9625
SONITPUR	13490	14229	12630	15738	14100	10.716	12.079	1.2865	12.339	28.319
SOUTH KAMRUP	29010	53811	38737	43288	49354	10.159	90.209	43.569	40.114	73.822
BONGAIGAON	-	-	-	-	-					

G0ALPARA	45311	80902	58120	69562	51014	18.727	102.54	52.298	52.429	85.862
TINISUKIA	-	34480	-	19727	23815		65.44	21.572	22.322	27.134
SIVASAGAR	4266.5	5873.1	14310	-	16910	0.329	0.4327	2.7717	1.9607	10.627
SADIYA	1474.3	8608.4	9918.2	17235	13295	0.7357	66.062		44.51	103.9
NAGAON	52232	59615	44282	42131	50782	40.895	160.87		93.849	140.3
MARIGAON	29854	51785	49474	55327	52046	38.16	124.03		157.71	308.17

ANNEXURE V

DISSEMINATION WORSHOP ON

'MORPHOLOGICAL STUDIES OF RIVERS BRAHMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE'

3rd MAY, 2019, IIT GUWAHATI

REGISTRATION LIST

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ANNEXURE VI

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Aliul Akhtar

Organisation: Water Resources Department, Assam

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	5
2	Airport within 2km from bank	7
3	Presence of National Park/Wildlife Sanctuary	4
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	6
9	Landuse type: cultivation, village	3, 4
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: SUNIL VERMA

Organisation: Central water Commission

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	5
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	5
7	Presence of Refinery within 2km from bank	4
8	Increasing Rate of Erosion	5
9	Landuse type:	
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Adarsh Shukla

Organisation: Central Water Commission

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	4
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	
9	Landuse type:	
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: UTPAL SARMA

Organisation: ARSAC/ASTEC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	9
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	5
8	Increasing Rate of Erosion	
9	Landuse type:	8
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Gilbert Hinge

Organisation: IIT Guwahati

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	9
4	National Highway within 2km from bank	10
5	Railway Line within 2km from bank	10
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	7
9	Landuse type:	4
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Ashutosh Sharma

Organisation: IIT Guwahati

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	10
5	Railway Line within 2km from bank	10
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	10
9	Landuse type:	8
10	Imp city / airport between 2km and 5km	5
11	Possibility of future climatic changes	7
12	Past records of the losses	7
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Ayush Garg

Organisation: Central Water Commission

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	7
3	Presence of National Park/Wildlife Sanctuary	10
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	9
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	7
9	Landuse type:	9
10		
11		
12		
13		
14		

**DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE**

Name: SONU RAJAK

Organisation: CWC.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	7
3	Presence of National Park/Wildlife Sanctuary	4
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	5
9	Landuse type:	6
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: VSD PRAKASH

Organisation: C.W.C.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	10
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	7
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	10
9	Landuse type:	
10	Farming	10
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Pranjal Pratim Sharma

Organisation: Assistant Executive Engineer, Irrigation.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	5
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	10
7	Presence of Refinery within 2km from bank	2
8	Increasing Rate of Erosion	4
9	Landuse type:	
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Dr. Juran Ali Ahmed

Organisation: W R Deptt. Assam,

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	7
4	National Highway within 2km from bank	6
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	1
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	7
9	Landuse type:	2
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Karuna Dutta

Organisation: Irrigation

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	4
2	Airport within 2km from bank	4
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	9
7	Presence of Refinery within 2km from bank	3
8	Increasing Rate of Erosion	9
9	Landuse type:	
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Maneesh Kumar Gupta

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	8
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	7
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	9
9	Landuse type:	
10		
11		
12		
13		
14		

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Rakesh Singh Raghuwanshi

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	09
3	Presence of National Park/Wildlife Sanctuary	07
4	National Highway within 2km from bank	08
5	Railway Line within 2km from bank	07
6	Presence of Protective Structure	07
7	Presence of Refinery within 2km from bank	08
8	Increasing Rate of Erosion	08
9	Landuse type:	09
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Ravi Shankar Singh, JE

Organisation: HOC, CWC, Guwahati

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	5
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	1
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	3
8	Increasing Rate of Erosion	8
9	Landuse type:	5
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Ashutosh Kumar Mall

Organisation: CWC, Shillong

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	9
9	Landuse type:	7
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: DIKSHANT RANGARI

Organisation: NORTH EASTERN INV. CIRCLE, CWC, SHILLONG

Sl. No.	**Vulnerability Factor**	**Weightage (out of 10)**
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	8
3	Presence of National Park/Wildlife Sanctuary	5
4	National Highway within 2km from bank	6
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	4
7	Presence of Refinery within 2km from bank	7
8	Increasing Rate of Erosion	8
9	Landuse type:	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Samiul Hoque

Organisation: Soil Conservation Dept.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	5
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	10
7	Presence of Refinery within 2km from bank	10
8	Increasing Rate of Erosion	6
9	Landuse type:	7
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: G. R. Das

Organisation: Soil conservation Deptt. Assam.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	9
4	National Highway within 2km from bank	9
5	Railway Line within 2km from bank	9
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	10
9	Landuse type:	8
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: SUBASHISA DUTTA

Organisation: IIT Guwahati

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	6
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	4
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	6
9	Landuse type:	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Kankana Narayan De

Organisation: Dept of DESIGN, IITG

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	9
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	7
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	9
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	8
9	Landuse type:	
10	Sand Bar settlements	9
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Shankar Kr Pathak

Organisation: Water Resources Deptt.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	7
3	Presence of National Park/Wildlife Sanctuary	7
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	8
9	Landuse type:	3
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3/5

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Parismita Saikia

Organisation: Gauhati University

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	8
3	Presence of National Park/Wildlife Sanctuary	9
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	8
9	Landuse type:	7
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Tanishqa Kashyap

Organisation: Gauhati University

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	9
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	7
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	8
9	Landuse type:	7
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Shobhika Singh.

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	6
2	Airport within 2km from bank	5
3	Presence of National Park/Wildlife Sanctuary	4
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion + (Shifting)	8
9	Landuse type:	7
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Devendra Patel

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	6
3	Presence of National Park/Wildlife Sanctuary	7
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	4
8	Increasing Rate of Erosion	6
9	Landuse type:	5
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: SANJEEV KUMAR

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	7
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	9
5	Railway Line within 2km from bank	9
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	9
9	Landuse type:	8
10	Health Infrastrue.	10
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Ajay Kumar Sinha

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	9
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	8
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	8
9	Landuse type:	7
10	~~Monument/ of National~~	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: G. S. Panesar

Organisation: Soil conservation Dept.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	6
2	Airport within 2km from bank	4
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	6
5	Railway Line within 2km from bank	5
6	Presence of Protective Structure	3
7	Presence of Refinery within 2km from bank	4
8	Increasing Rate of Erosion	3
9	Landuse type:	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: RAVI SHANKER

Organisation: CWC

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	9
2	Airport within 2km from bank	9
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	9
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	4
9	Landuse type:	6
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: ATUL SARMA

Organisation: Brahmaputra Board

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	5
2	Airport within 2km from bank	8
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	7
6	Presence of Protective Structure	4
7	Presence of Refinery within 2km from bank	6
8	Increasing Rate of Erosion	8
9	Landuse type:	
10	Defence Installation	7
11		
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Dr. Ratnawali Machahary

Organisation: Dibrugarh University

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	8
3	Presence of National Park/Wildlife Sanctuary	3
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	8
6	Presence of Protective Structure	5
7	Presence of Refinery within 2km from bank	7
8	Increasing Rate of Erosion	10
9	Landuse type:	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Rekhraj Meena

Organisation: CWC, New Delhi

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	8
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	8
4	National Highway within 2km from bank	9
5	Railway Line within 2km from bank	9
6	Presence of Protective Structure	6
7	Presence of Refinery within 2km from bank	7
8	Increasing Rate of Erosion	8
9	Landuse type:	6
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Subhankar Das

Organisation: C.W.C.

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	10
3	Presence of National Park/Wildlife Sanctuary	6
4	National Highway within 2km from bank	10
5	Railway Line within 2km from bank	10
6	Presence of Protective Structure	7
7	Presence of Refinery within 2km from bank	9
8	Increasing Rate of Erosion	6
9	Landuse type:	
10	Pasture	5.
11	Planned human Settlement.	10
12	Agriculture Land.	8
13	SEZ	10
14	~~Mining~~ Mining	8

DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: AKASH BHARADWAJ

Organisation: C.W.C

Sl. No.	Vulnerability Factor	Weightage (out of 10)
1	Imp City/Town within 2km from the bank	10
2	Airport within 2km from bank	7
3	Presence of National Park/Wildlife Sanctuary	10
4	National Highway within 2km from bank	7
5	Railway Line within 2km from bank	7
6	Presence of Protective Structure	8
7	Presence of Refinery within 2km from bank	8
8	Increasing Rate of Erosion	8
9	Landuse type:	
10	Agriculture	7
11	Industry	7
12		
13		
14		

ANNEXURE VII

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 1

Sl. No	Name	Department/ Organization	Signature
1	DIKSHANT RANGARI	CWC	[signature]
2	ASHUTOSH KUMAR MALL	CWC	[signature]
3	RAVI SHANKAR SINGH	CWC	[signature]
4	AYUSH GARG	CWC	[signature]
5	AKASH BHARADWAJ	CWC	[signature]
6	VED PRAKASH	CWC	[signature]
7	Karuna Dutta	Irrigation	Dutta.
8	Gaurav Talukdar	IITG	
9	Bhaswati Baishya.	IITG	Baishya.

1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

~~No~~. yes. ~~First Experience~~.

1. Bathymetric survey from Ghy to Tezpur

2. flood Estimation report (Brahmaputra Sub zone 2(b)

3. morphological study & cross-section of Barak River & its ~~tributary~~

2. How result of this study can help different organizations

1. Site selection for various Hydraulic structures.
2. It helps. formulating guidelines for H.O. sites.
3. Policy making for mitigating erosion in erosion prone areas.
4. Identification and prioritization for areas for protecting important structures.

3. Do you recommend similar study on some other rivers?

Yes.

For example-

1. Beki River → Barpeta
2. Barak "
3. Jia Bharali in Sonitpur
4. Kolong } - Nogaon
5. Kapili } - Nogaon
6. Ghaghara : in U.P.

4. Suggestions, if any

1. More recent data can be used for predicting the present scenario & future scenario.
2. More morphological case study of above mentioned rivers can be performed for predicting erosion & morphological action of river.
3. Study of Sand Bars Should be incorporated
4. Sediment load study should be incorporated.
5. Frequent Community awareness programme in educational institutional and Departmental level.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 2

Sl. No	Name	Department/ Organization	Signature
1	SANJEEV KUMAR	CWC (HQ), N. DELHI	Kumar
2	SUDIPTA MAHANTY	CWC, Jalbari	[illegible]
3	M. Somorjit Singh	NESAC, Shillong	सोमोरजीत
4			
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

We are not aware of such study done earlier.

2. How result of this study can help different organizations

* The Present Study has been done taking SRTM 90m resolution Data as well as Satellite data.

** The various data collected through morphology Survey help railway Dept, PWD Dept etc, Flood control.

*** It also help Irrigation Dept in study & Implementation of micro-macro Projects.

** The Present Study also helps dept. like Inland Navigation

3. Do you recommend similar study on some other rivers?

As far as our views is concerned this type of Similar Study should be done for all major rivers in the country (Particularly in Northern India)

4. Suggestions, if any

To understand the change of river course/Shifting ~~area~~ Morphotectonic/tectonic studies should be incorporated as a part of the study.

Space Technology/high resolution satellite based input data ~~for~~ may be utilised for site specific study.

GRoup 3.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 3.

Sl. No	Name	Department/ Organization	Signature
1	Shobhika Singh	CWC	[signature]
2	VED PRAKASH	CWC	[signature]
3	DIKSHANT RANGARI	CWC	[signature]
4	Khyali Manjuri Chaudhury	IITG.	[signature]
5			
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

→ CWC is carrying out morphological studies for 15 rivers (including by IIT Guwahati). Studies for rivers like Ghaghra & Gandak has also been done previously.

→ c/s data
- studies by Brahmaputra Board

2. How result of this study can help different organizations

- State Govt, Central Govt.
- local authorities

(a) Proper planning & design of WR structures.
(b) Base for further studies in future.
(c) River Restoration works.
(d) Flood Plain zoning.
(e) Guidelines
(f) Navigation Development

3. Do you recommend similar study on some other rivers?

Yes, it may be recommended for

1) Godavari

2) Jhelum.

3) Barak

4)

4. Suggestions, if any

(a) Identification of hotspots for scientific sediment mining.

(b) Effect of CC on River Morphology.

(c) ~~study on~~ seismic studies - (Inundation maps)

(d) Future cut-offs.

(e) Utilising flood discharge in hydro-power generation.

(f) Sediment Transport Model.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 4

Sl. No	Name	Department/ Organization	Signature
1	Tanishqa Kashyap	Geological Sciences, Gauhati University	T. Kashyap
2	Subhankar Das	Central Water Commission, Guwahati	[signature]
3	Dr. Gopal Sharma	NESAC, DOS	[signature]
4	Devendra Patel	C.WC	Devendra
5			
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7			
8			
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

yes,

① CWC is doing morphological study on Brahmaputra river from Dhubri to Sadiya at 62 no. of cross section and also Subansiri & Pagladia every year.

② NESAC has operational flood early warning system for the state of Assam

③ many pilot study at University levels.

2. How result of this study can help different organizations

① Flood management. – Water Resource department

② It can serve as georeferenced geospatial data base for related studies.

③ Water assessment of the river.

④ Helpful in inland water transportation, construction of bridges, planning of hydropower plant, disaster management.

⑤ Protection measures like river island, embankments can be improved.

⑥ Identification of the most likely eroded areas & premanagement & planning against further erosion by State Government.

⑦ To understand river meandering process.

3. Do you recommend similar study on some other rivers?

Yes

Lohit, Beki, Jiabharali, Kolong, Kopili

4. Suggestions, if any

(1) Erosion may not be always because of the flow of the river, it may also be due to neotectonic activities. Therefore, if such studies could be integrated with tectonics the relevance of this study may increase manyfore.

(2) The collaboration between different organizations in order to avoid dublication of work.

(3) There should be a common platform / database for sharing data / outputs.

(4) High resolution satellite data such as COMPSAT (1m resolution)

(5) SRTM 10m resolution is also freely available that can be effectively ~~used~~ utilize in the present study

90m

Group-5

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No:

Sl. No	Name	Department/ Organization	Signature
1	Rekhraj Meena	CWC	[signature]
2	Dr. Ratimal Machahary	Applied Geology, Dibrugarh University	[signature]
3	Adarsh Shukla	CWC	[signature]
4	Parismita Saikia	Gauhati University	[signature]
5	Apoorva Singh	IIT Guwahati	[signature]
6			
7			
8			
9			

1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

YES →

→ Awarded Ph.D degree on the topic "Bed form morphology, Spatio-temporal variability & Erosional vulnerability of Brahmaputra River within Assam" from Gauhati University

→ River morphology of Subansiri & Brahmaputra studied by many Academicians from Gauhati University & Dibrugarh University.

✱

2. How result of this study can help different organizations

→ Academic based data for further studies.

→ State WRD → for design of different hydraulic & similar ~~stru~~ structures depth.

→ For disaster management departments; for ~~answers~~ awareness of people ~~st~~ lying on flood area & flood protection & management.

✱ Have done morphological survey along Brahmaputra from Neamatighat to Dibrugarh. ~~[illegible]~~ B&RD, CWC.

3. Do you recommend similar study on some other rivers?

→ Large tributaries of North Front of Brahmaputra Jiabharali, Jiadhol, Becki (Lohit, Dibang & Dihang)

→ Left Bank tributaries of Ganga. Gan like Gandak, Ghagra etc.

4. Suggestions, if any

→ Source - SOI toposheet can be used for data before 1950, 1:1 mile scale data is available.

→ Provide data in public domain for further research studies.

→ Morphological surveys can be conducted using (drones) latest technology.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 6

Sl. No	Name	Department/ Organization	Signature
1	UTPAL SARMA	ARSAC/ASTEC	Utpu
2	KUNTALA BHUSAN	NESAC, UMIAM	[signature]
3	RANJIT DEKA	BRAMAPUTRA BOARD	[signature]
4	SUNIL VERMA	CWC	Sunil
5	Ravi Shanker Singh	CWC	RSingh
6			
7			
8			
9			

1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

Yes
~~Under~~ Various organisations are doing these type of study
ISRO/DOS, Guwahati university, IIT Roorkee.
Dibrugarh university., Brahmaputra board, CWC.

2. How result of this study can help different organizations

1. It will help in master plan preparation on the river basin.
(ii) Erosion protection measures.
(iii) Land use planning./ Infrastructure development
(iv) identification of Ghats.
(V) It may help to establish a functional relationship for prediction of Erosion prone area, and deposition
(VI)

3. Do you recommend similar study on some other rivers?

YES

All tributaries of the Brahmaputra

4. Suggestions, if any

* Detail Tectonic Study
* Proper G.C.P may be established to observe neotectonic activity.
* High Resolution DEM / Flood Season Bank.
* Morphological Survey is very Important by manual method.
* Bathemetry.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 07

Sl. No	Name	Department/ Organization	Signature
1	A K Sinha	Central water commission	[signature]
2	ATUL SARMA	BRAHMAPUTRA BOARD	[signature]
3	Sony RAJAK	CWC	[signature]
4	Rakesh Singh Raghuwanshi	CWC	[signature]
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

Similar study for Majuli reach on Bramhaputra undertaken by IIT Guwahati. sponsered by Brahmaputra Board. They working on mathematical 2-D Model of River Morphology.

Study of Kaziranga reach jointly by Br. Board, SAC, Ahmedabad and NRSA

10 km interval — 32 sec^{n} — 6? sec^{n} — UBD

2. How result of this study can help different organizations

1. for flood management 2. To ~~proor~~ indentify and priortise vulnerable location 3. for selection of appropriate Method/Technology for River management.
4. planing of River Training work.
5. Land use.

3. Do you recommend similar study on some other rivers?

1. Jia Bharali – flood prone
2. Beki –
3. Aie –

4. Suggestions, if any

Presently Mikir Gaon area in Morigaon District is one of the most erosion prone area along Brahmaputra. Special emphasis in this reach for delineation of bank line, its causes and appropriate approach to be given in the study.

Construction of solid spurs in erosion prone reaches often become counter productive. This is because of river changing its flow direction after erosion and making the spurs attractive which were otherwise constructed as deflecting.

Awareness program can be planed for various Department & Technocrats. for Hydrological Study like Arc GIS / working on Topo sheet.

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No: 8

Sl. No	Name	Department/ Organization	Signature
1	AYUSH GARG	CWC	[signature]
2	RAVI RANJAN	CWC	[signature]
3	Pranjal Pratim Sharma	Irrigation	[signature]
4	Maneesh Kr. Gupta	CWC	[signature]
5	Prof. P. K. Khaund	JEC, Jorhat	[signature]
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

At Rohmoria reach of Brahmaputra river (u/s), change in river morphology was studied little bit & also the effect of procupine screen river C.S was studied.
CWC also does morphological survey at 64 C/S at interval of 10 Km from Tinsukia to Dhubri on River Brahmaputra.

2. How result of this study can help different organizations

Based on the river morphology, anti-erosion schemes were evaluated, whether those were properly designed/ executed & evaluated the % of success/achivements of the schemes.
This study can help to strengthen the embankments;

3. Do you recommend similar study on some other rivers?

- Jiabharali
- Burhidihing & Dishoo
- Dhansiri river.

4. Suggestions, if any

1) Study Bank materials as well as bed materials. & to find relative silting & scouring.

2) To determine the actual cause of erosion, specific site wise. [transverse flow, cause]

3) Model study before implementation/execution.

4.) Use of aerial photographs, ultra sonic sound vel. method to find the change in depth of flow after execution of anti-erosion measures.

5) To study the change in morphology, w.r.t the bed level in 1950 before the earthquake.

G-9

TECHNICAL SESSION II: ONBOARD GROUP DISCUSSION, 3rd May 2019

Morphological Studies of River Brahmaputra, Subansiri and Pagladia using Remote Sensing Technique

Group No:

Sl. No	Name	Department/ Organization	Signature
1	BHABESH MAHANTA	IRRIGATION	[signature]
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3	Anupal Baruah	Student	[signature]
4	Dhruba Jyoti Sarmah	Project Staff, IITG	[signature]
5	Dipsikha Devi	PhD Student, IIT GHY	Dipsikha
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

Morphological analysis and geomorphological studies of Brahmaputra were carried out by various researchers. Leopold (1944) studied the geomorphological changes of Brahmaputra. IITG is also working with a numerical model named BRAH... Various other researches are going on in GU which include the flood hazard mapping of Subansiri and also the bankline shifting. In Pagladiya we were not aware of morphological studies using remote sensing tech...

2. How result of this study can help different organizations

These studies are essential for planning of river training works and other hydraulic structures. For eg. Majuli island has been eroded at an alarming rate. Remote Sensing & GIS techniques are ~~very~~ useful to analyse quantitatively in some remote areas where it is not ~~easily~~ physically accessible.

The vulnerability index calculated ~~is used for~~ can be useful for protection of vulnerable reaches.

3. Do you recommend similar study on some other rivers?

yes, this type of study can also be implemented in some other rivers like Beki, Ranganadi Manas, etc. Dibang river, Jaia Bharali.

4. Suggestions, if any

Field verification is essential along with remote sensing techniques to validate the findings.

Along with remote sensing techniques river modelling can be done to find out the velocity in any vulnerable reach.

For modelling purpose high resolution DEM will give better result.

Sense of belongingness of the area is necessary

Study to see the relation betn morphological changes and seismic activity