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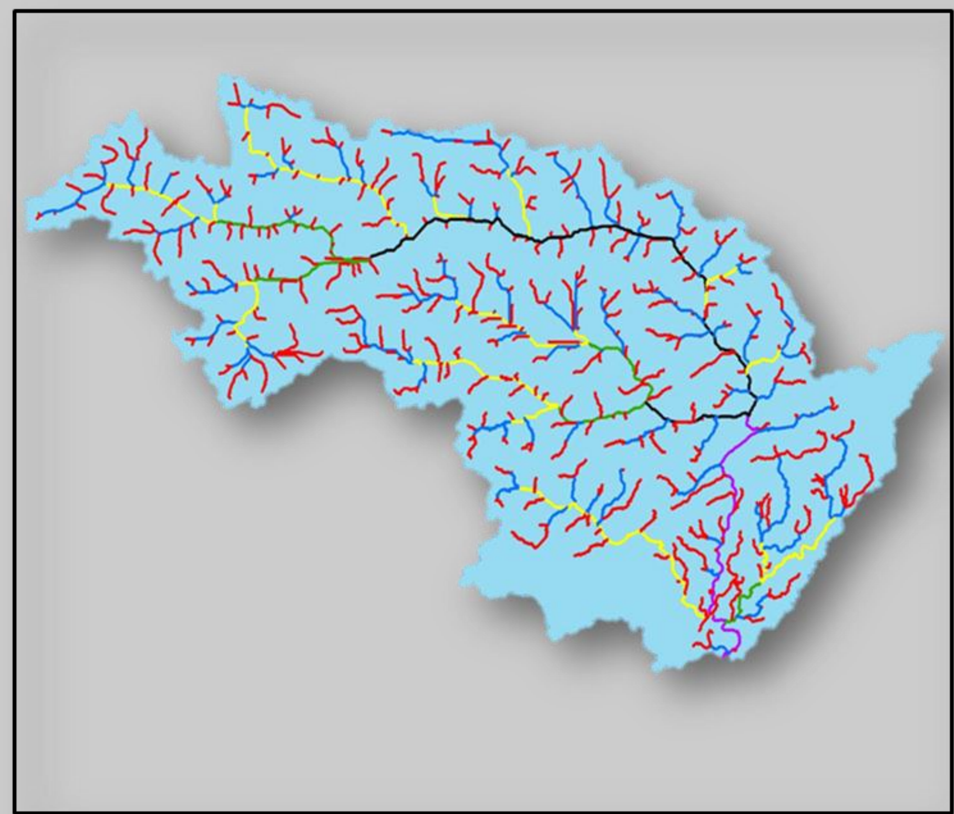
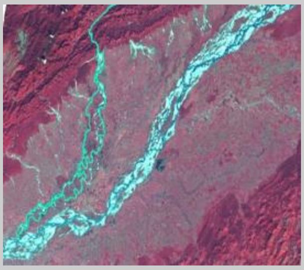
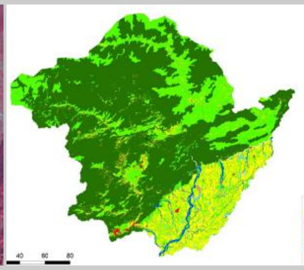
FINAL REPORT

MORPHOLOGICAL STUDY OF RIVER SUBANSIRI USING REMOTE SENSING TECHNIQUE







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Final Report

on

Morphological Study of River Subansiri using Remote Sensing Technique

Department of Civil Engineering

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PROJECT TEAM

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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 create problems to the hydraulic engineers during the planning and design of hydraulic structures. The knowledge of the fluvial morphology of a river is an indispensable part for implementation of any structural and non-structural measures on the river. Morphological changes of a river generally deal with the shifting of the banklines, aggradation and degradation, change in 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, the Central Water Commission (CWC), Govt. of India, New Delhi has initiated the study to understand the morphological changes 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. **The report contains morphological study of the river Subansiri using remote sensing technique.**

2. Following were the broad objectives of the study

   i. 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.
   ii. 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 10years interval in addition to one set of Survey of India topo-sheets for the base year on a scale of 1: 50,000.
   iii. To compile changes in the Land use/Land cover over the years, and study its impact of the river morphology.

iv. 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.

v. 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.

vi. 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.

vii. To evaluate the impacts of the major hydraulic structures on morphological behavior of the river course and its impacts on the river morphology.

viii. To evaluate the braiding pattern of the river by using Plan Form Index (PFI) criteria along with its threshold classifications.

ix. 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). 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) and Radarsat Scan SAR Wide & Narrow (100 m & 50 m) for flood images for Bihar and Assam.

x. Plot probability curve (Exceedance Probability Vs Flow rate) and show the flow rates corresponding to the return period of 1.5 year and 2 years for different CWC H.O. locations. The observed flows need to be normalized before using for analysis.

xi. 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. Study impact of changes in annual rainfall in the basin on river morphology.

xii. Identify crucial and other vulnerable reaches, locations. Analysis of respective rate of river course shifting and based on it, future prediction of river course behaviors.

xiii. Suggest suitable river training works for restoration of critical reaches depending on site conditions.

3. 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.

4. One set of SOI topo-sheets of 1973-74 and 4 sets of satellite data for the period 1976-80, 1993-95, 2003-04 and 2008-11 at around 10-year interval were used. Out of these 5 datasets, topo-sheets and the satellite imageries of 2008-11 (Resourcesat-1, LISS 3) were already available with IITG. Landsat MSS datasets were downloaded for 1976-80. LISS 1 data for 1993-94, LISS 3 data for 2004-04 and LISS 4 data for 2016-17 were procured from NRSC. The topo-sheets were then georeferenced followed by the processing of the satellite imageries.

5. The hydrological data were collected for various CWC gauge stations. The discharge data of the Subansiri river are available for Chouldhowaghat and Lemeking station. The probability exceedance curve has been plotted for the stations mentioned above. The return periods considered are 1.5, 2, 25, 50,100 year.

6. The river drainage map of the Subansiri River has been prepared to show the major tributaries. The tributaries Ranganadi, Dikrong, Boginodi, JiaDhal are shown in the drainage map.

7. The bank lines of the rivers were digitized. An exercise of comparative analysis of manual delineation and automatic delineation using NDWI & NDVI are performed. From this analysis, it has been observed that the automatic delineation method is not effective in delineating the river bank line near lateral bare sandbars or vegetated sandbars. However, in the case of manual digitization, the interpreter can easily demarcate the bankline due to visual differences between the lateral sandbars and the bank landmass.

8. The flow in the upstream of the Subansiri River *i.e.* in the hills of Arunachal, is almost linear. However, on entering the plains of Assam, it flows in a complex braided pattern with a shift in its main flow from east to west in two parallel channels. It is thereby difficult to quantitatively analyze different morphological aspects such as the amount of bank erosion-deposition over different periods.

9. Watershed of Subansiri has been delineated in ArcGIS. The area and perimeter of the watershed were found to be 35364.3 km^2 and 1547.83 km. The stream order was done using Strahler's algorithm. The bifurcation ratios were then evaluated. The other basin parameters were also calculated.

10. Channel Evolution Process was studied for the Subansiri River in Assam. For the study, 10 km section lines were considered from Gerukamukh to the confluence point of the Brahmaputra in Assam. On entering Assam fanning out of river flow is observed. It can be observed that numerous small channels joined the river at different location as well as at different time. Some of them have been disappeared in due course of time.

11. The longitudinal profile of Subansiri has been created from its origin in China. It was prepared using Google Earth elevations at a distance of 10 km.

12. To study the change in the width of the river, the entire river had been divided into sections of 10 km reach and then the width of the river at each section for the study periods was measured. A plot of channel width against the reaches considering the centerline. From the plot, it can be seen that the width of the river is varying.

13. The Planform Index of the river has been calculated considering 10 km sections. From the analysis, it can be seen that the braiding of the river is moderate as the PFIs are lesser than

19. Some of the reaches are highly braided i.e. less than 3 in reaches 4, 5, 6 in 1976-80. However, in the subsequent years, the braiding has considerably lowered.

14. The meandering parameters like meander lengths meander widths, bankfull widths and meander width ratios are calculated. The maximum meander length of 2.48m has been observed in the year 1993-95 at reach1 and a minimum of 0.2 km observed in the 1973-94 at reach 17. Similarly, maximum meander width of 4.1 km can be observed in the 1973-74 and a minimum of 0.36 km in 2003-04. In the case of bankfull width calculation, a maximum width of 0.46 km has been observed in reach 17 and a minimum of 0.14 km observed at reach 1 in 2003-04.

15. Land use Landcover Map has been prepared for 1973-74, 1976-80, 1993-95, 2005-06 and 2011-12(Source: NESAC). LULC indicates that built up area and forest lands are converted to agriculture and waterbodies.It indicates an increasing trend of water utilization in the agriculture sector. So, a detailed study on such flow scenarios can be carried out by hydrological modeling and river flow simulation study.

16. Flood inundation maps have been downloaded from NRSC's BHUVAN website from 1999-2010. Flooding in North East India occurs generally due to the breaching of embankments. 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.

17. The most vulnerable area of the Subansiri has been observed as at the confluence point of Brahmaputra. A shift of 15 km occurred from 1973-94 to 2008-11.

18. The major hydraulic structures located in the Subansiri basin includes the Lower Subansiri Hydroelectric Power Project of 2000MW However, the operation of the dam has not yet started so no major impact on the hydraulics can be observed. Two bridges are located at Chouldhowaghat which are 350 m apart. One is a railway bridge and the other is the road bridge. The portion of the bridge is engineered with typical river training work and as such, the river is flowing within the waterway without any disturbances.

19. 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, educational institutions, etc.

Acknowledgement

At the outset, on behalf of my project team, I would like to express my heartfelt gratitude to Central Water Commission, New Delhi for giving us an opportunity to carry out a national level study on Brahmaputra under the project entitled “Morphological Studies of rivers Brahmaputra, Suabansiri and Pagladiya using Remote Sensing Technique”.

We acknowledge the help and support of SOI, NRSC for providing the toposheets and satellite imageries and also to the regional offices of CWC for providing the hydrological data. Our sincere thanks goes to NESAC, Shillong for providing us the landuse/landcover data for the year 2005-06 and 2011-12.

We offer our heartfelt gratitude to Central Water Commission for providing financial support under the Plan Scheme “Research & Development Program in Water Sector” of Ministry of Water Resources, Govt. of India. Special thanks to all the members of "Consultancy Evaluation cum Monitoring Committee (CEMC)" for their valuable inputs and recommendation.

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Finally, I along with my Co-PI Prof. Rajib Kr. Bhattacharjya and Prof. Subashisa Dutta would like to extend my sincere thanks to our dedicated project staffs and PhD Scholars who were involved in this project and helped in its timely completion. Office staff of R&D section, IIT Guwahati also deserve a special thanks for their support.

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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 for 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 erosion 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 of a channel are sediment load. Weathering of the rocks composing slopes is the main cause of the 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 riverbed 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 the basin.

1.2 Importance of morphological studies

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.

Chapter 2
LITERATURE REVIEW

2.1 Morphological studies on Subansiri River

Dutta et al. (2011), studied the influence of riparian flora on the river bank health of the Subansiri River before being regulated by a large dam. The study found that the meanders of the Subansiri River without riparian vegetation were more susceptible to erosion in comparison to vegetated bends with native amphibian grasses and macrophytes. Certain plant species with numerous small and dense root system protects the bank from erosion and increases bank strength by reinforcing soils in a natural way. Riparian flora not only maintains the healthy river banks by reducing erosion but also provides food, shelter to the wildlife and a wide range of commodities and services to many rural communities. The study remarked that due to massive fluctuation in the downstream flow regime of the Subansiri River after the construction of the Lower Subansiri Dam, there may be compositional changes in the riparian flora which may further affect the ecological integrity of the river and the present riverbank health.

Goswami et. al. (2013), prepared a flood risk zone map of Subansiri sub-basin in Assam, India. The study divided the whole sub-basin into three zones viz. chronically inundated, occasionally inundated and rarely inundated zone. A large part of the agricultural lands and villages of Dhemaji and Dhakuakhana lying on the left bank of the river Subansiri were submerged by flood compared to the right bank. The Zone 1 covered 963 villages, while zone 2 covered 1505 villages and zone 3 covered 780 villages. Out of 963 villages of zone 1, around 784 villages were on the left bank of the Subansiri River, while remaining 187 villages were on the right bank. Heavy rainfall or even a flood of relatively low magnitude was sufficient enough to inundate these areas. Out of 1505 villages of the zone 2, around 1095 villages were on the left bank of the Subansiri river, while remaining 410 villages were on the right bank and out of 780 villages of the zone 3, around 388 villages were on the left bank of the Subansiri river while remaining 396 villages were on the right bank. Geotextile bags (or Geobags) were used for construction of embankments to protect river banks from severe scouring and erosion.

Goswami and Gogoi (2014), studied the channel migration of Subansiri in Assam using Remote Sensing and GIS technology. They observed the pattern of channel shifting as well as various other changes of Subansiri River for the period from 1828 to 2011.For the study Landsat MSS, TM, ETM+ and IRS LISS III were used. Five different types of channel shift were observed in the Subansiri River. They were (i) alternate bar induced shifting, (ii) neck cut-off, (iii) chute cutoff, (iv) meander shift and (v) avulsion or rapid diversion. The study revealed that the Subansiri River in Assam changes continuously and new channels developed in the course of few years. From the study it was concluded that large discharge and heavy sediment load are the main causes of lateral migration.

Devi and Sarma (2015) carried out a study on the channel migration of Subansiri. They studied the shifting of banklines in two years using Remote Sensing and GIS technology. For the study LANDSAT ETM+ imageries dated 11/1 0/2005 and 20/6/2015 were taken. From the study of river bank migration it was observed that maximum erosion occured at Chenimora Kangur which is at the left bank. A maximum deposition occurred at Mudoibil. For the right bank maximum erosion occurred at Badhakua Kachimari and maximum deposition occurred at Kalowani.

The whole geological succession of Arunachal Himalayas has been traversed by Subansiri River and its tributaries. The area comprises of five major lithotectonic units from Assam-Arunachal state boundary in the south to Taliha in the north: 1) Siwalik Group 2)Gondwana Group 3) Lesser Himalayan Sedimentary Sequence (LHSS: Siang-Miri Group) 4) Bomdila Group 5) Sela Group (Fig.1). These major lithotectonic units are delineated by regional thrusts. The Sub Himalaya is represented by the Siwalik Group, which has thrust contacts with the Brahmaputra alluvium in the south and the Lesser Himalaya in the north along the Himalayan Frontal Thrust (HFT) and Main Boundary Thrust (MBT) respectively.

The Siwaliks of Arunachal Pradesh have been divided into Dafla, Subansiri, and Kimin Formations. While the Kimin is predominantly a conglomerate- sandstone association, the Subansiri and Dafla represent a predominantly fluviatile deposits of thick sandstone beds and thin shale beds. The individual formations of the Siwalik are separated by thrusts.

The Lesser Himalaya is separated from the Higher Himalaya by the Main Central Thrust (MCT) and is composed of a narrow belt of Gondwana Group.

LHSS and low to medium grade crystalline rocks of Bomdila Group. Carbonate rocks, quartzite, phyllite and slate are the dominant rock types of Siang-Miri Group that occur as thrust sheets along Tamen-Kamla river downstream section and are also exposed as a tectonic window to the north of Sipi village.

The Bomdila Group tectonically overlies LHSS and are composed dominantly of granitic gneiss (Lesser Himalayan Granitoids interbedded with chlorite–biotite schist, garnetiferous mica schist, quartzite, phyllite and minor amount of amphibolite, whereas Sela Group represents a sequence of kyanite– sillimanite schist/gneiss, graphite schist, marble, garnetiferous gneiss, migmatite, leucogranite and pegmatite (GSI, 2010; Singh, 2012).

2.2. 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.

Bankfull 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.

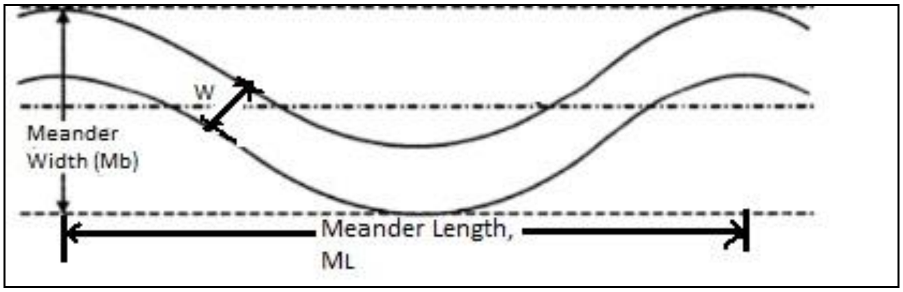


Figure 1: Meandering of a river

2.2.1 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:

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

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

2.2.2 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.

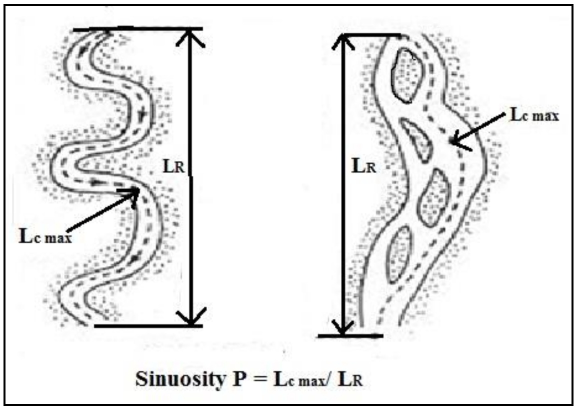


Figure 2: Sinuosity Index in a channel by P.F. Friend and R.Sinha (1993)

2.2.2.1 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 .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 thevalley 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

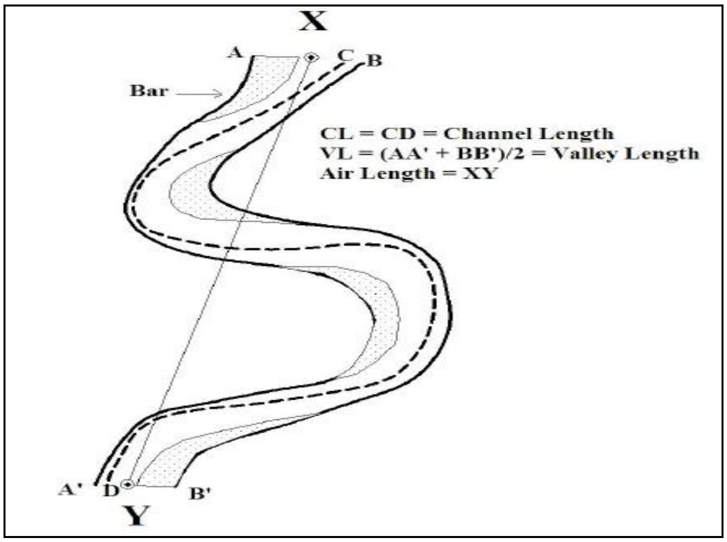


Figure 3: Sinuosity index given by Mueller (1968)

2.2.3 Braiding Parameters

2.2.3.1 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:

$$B.I. = 2 (\sum Li)/ Lr$$

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

Lr = length of reach measured midway between 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:

$$B_p = \sum L_b / L_m$$

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 thalwegs 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.

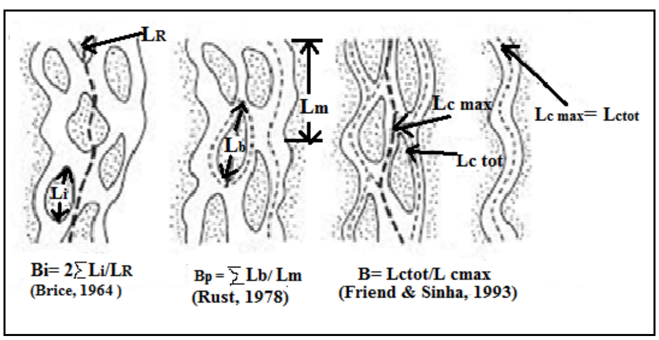


Figure 4: Diagram representing the calculation of the braiding indices of Brice (1964), Rust (1978), Friend and Sinha (1993)

2.2.3.2 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.

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

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

2.2.4. Morphometric Analysis:

2.2.4.1 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).

$$Rb = \frac{N_u}{N_{u+1}}$$

where, Rb= Bifurcation ratio, Nu= Number of streams of a given order, Nu + 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.

2.2.4.2 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

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

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.

2.2.4.3 Stream frequency

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

$F_s = \sum N_u / A$ (km^{-2})

where A is the area of the basin

2.2.4.4 Basin shape factor (Sb)

Basin shape factor is given by

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

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.

2.2.4.5 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.

2.2.4.6 Drainage factor (D_f)

$D_f=Fs/D_d^2$

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

2.2.4.7 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.

2.2.4.8 Elongation Ratio (R_e)

It was given by Schumm (1956)

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

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

The river Subansiri originates from the western part of Mount Pararu in Tibetian Himalaya. The Subansiri is one of the largest tributaries of Brahmaputra. The Subansiri River contributes about

10.3% of discharge observed at Chouldhowaghat with respect to the discharge observed at Pandu in Guwahati. According to NHPC, the average slope of the river bed from foothills to Chouldhowaghat is about 130 cm/km which gradually decreases further downstream, the average from Chouldhowaghat to confluence of Ranganadi is about 24cm/km. This dramatic reduction of slope in plains of Assam experiences tremendous dissipation of energy. The total length of the river Subansiri is 520 km and it drains an area of 37,000 km^2. The length of the river flowing through Assam is 130 km. The Subansiri river in Assam flows through Dhemaji, Lakhimpur and Jorhat districts in between 26°50'-27°35' N and 93°41'-94°23' E.Fig.5 shows the Subansiri basin with national and international boundaries

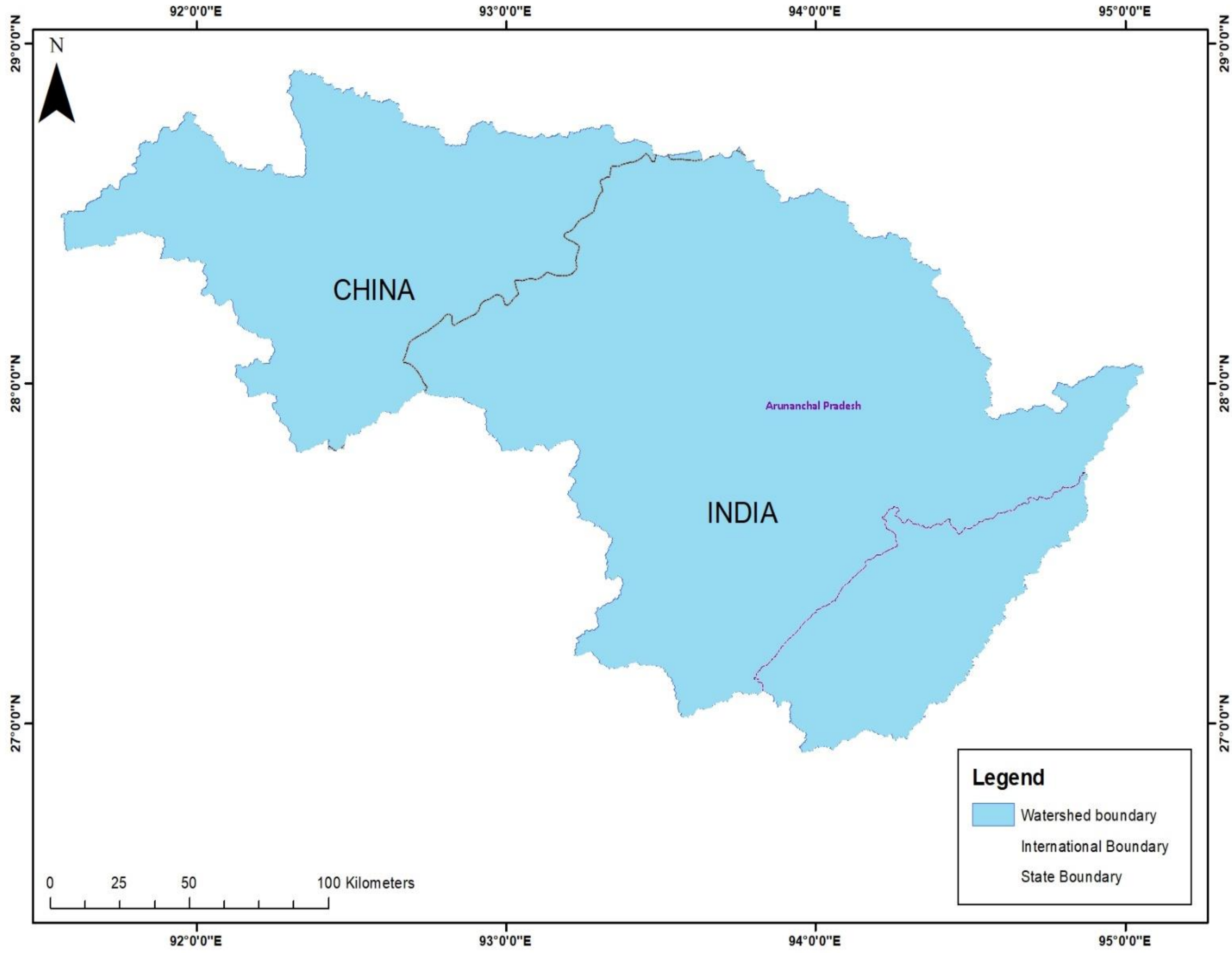


Figure 5: Subansiri watershed with International Boundary

Chapter 4
RIVER BASIN

4.1 Introduction

The river Subansiri originates from the western part of Mount Pararu in Tibetian Himalaya at an elevation of 7090 m above mean sea level. Total length of the river in India is around 326 km up to its confluence with River Brahmaputra in Assam.

The entire Subansiri basin covers an area of 38051.56 sq.km, the extension of which in India is 26.57°N to 28.40° N and 92.42°E to 94.47°E.

Table 1: Details of the Catchment area of Subansiri River

Catchment in India	Catchment in Arunachal Pradesh	Catchment in Assam	Catchment in Siwaliks
23000 sq km	21800 sq km	1200 sq km	810.41 sq km

4.2 River drainage system

Major tributaries of the river are Laro, Nye, Yume, Tsari, Kamla, Jiyadhol, Ranganadi and Dikrong. In the upper reaches of the basin, it is called Nye Chu, which receives its waters from the snow clad peaks of Krakang, Shubuta, Baru and Mata. From its origin, the river flows in south–easterly direction and is joined by Laro Chu near Chayal. After its confluence with Laro Chu the river is called Chayal Chu, which flows in the eastern direction. Tsari Chu River meets Chayal Chu near Siyum and the combined water of these streams flow as Subansiri for about 200 km from this point, its mouth. The. It follows a southeasterly course along the lesser Himalayan zone with an average height of about 3048 m as River Subansiri. The number of its tributaries is more in the Siwalik ranges than in other zones. The Subansiri River debouches into the plains of

Assam near Dulangmukh in Lakhimpur. Before entering the plains, Subansiri cuts a steep gorge through the Siwalik rocks of Arunachal Himalaya (NHPC, 2014)

‘

Chapter 5
METHODOLOGY

5.1 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.

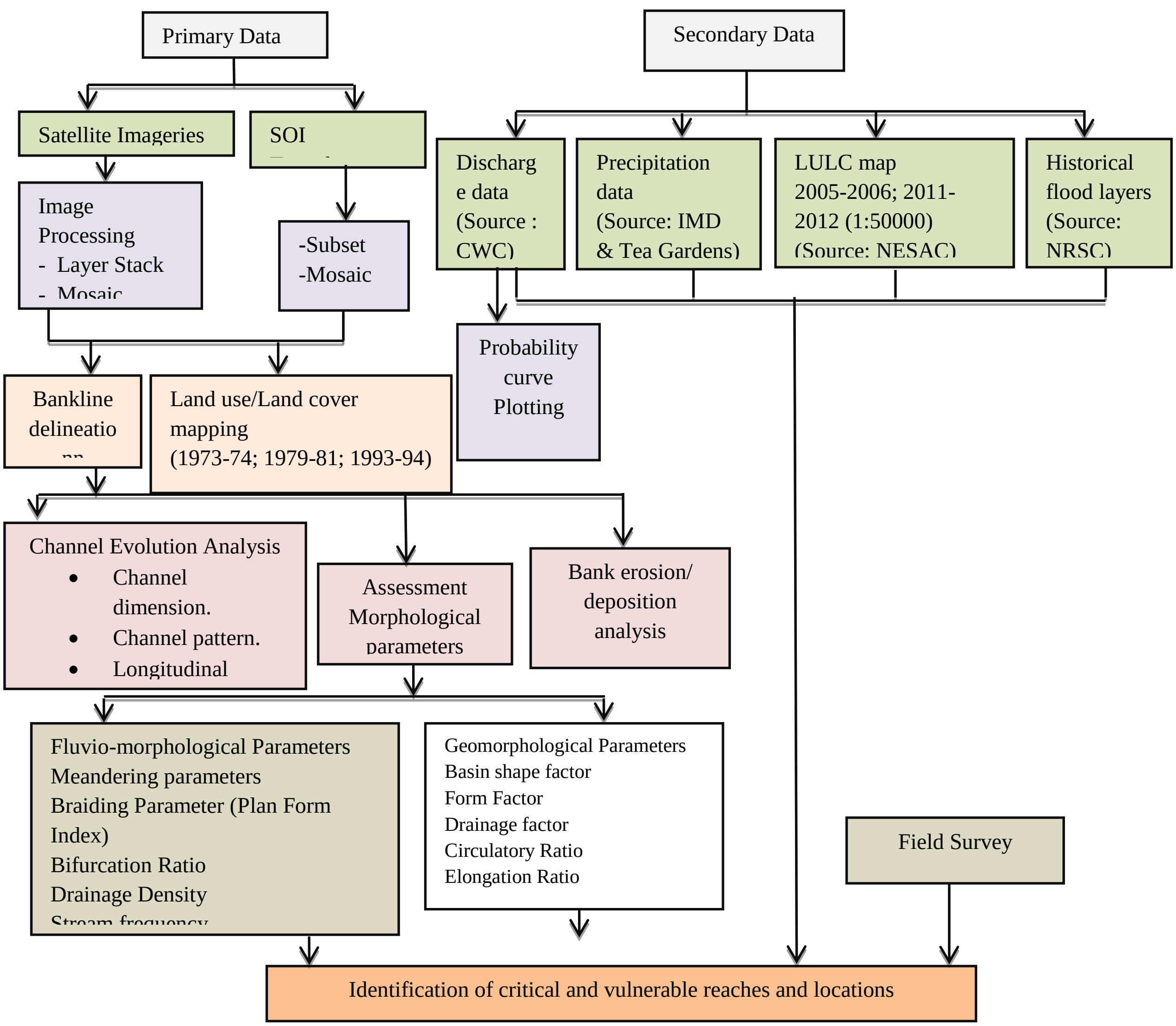


Figure 6: Methodology

Chapter 6
INPUT DATA

6.1 Introduction

With the proliferation of remote sensing and GIS there has been a tremendous demand for remote sensing data sources. The applicationof GIS based study greatly depend upon the reliability of remote sensing data.

6.2 Data collection and Image Processing

6.2.1 Geospatial data

To carry out the 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, a few no. of toposheets and the satellite imageries of 2008-11 (Resourcesat-1, LISS 3) were already available with IITG. The 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 Imagine2015 software. Satellite imageries for the periods 1993-95 (IRS 1B, LISS 1) and 2003-04 (IRS P6, LISS 3) were procured from NRSC, Hyderabad. Few geo-referencing errors were encountered in the 2003-04 dataset which had been corrected subsequently and then layer stacking and mosaicking for both the datasets were done. Few toposheets were procured from Survey of India (SOI), Guwahati and Meghalaya to cover the gaps in the available toposheet repository of IITG. These toposheets were then georeferenced, subset and mosaicked using Erdas Imagine2015. The details of the geospatial data collected are given as annexure.

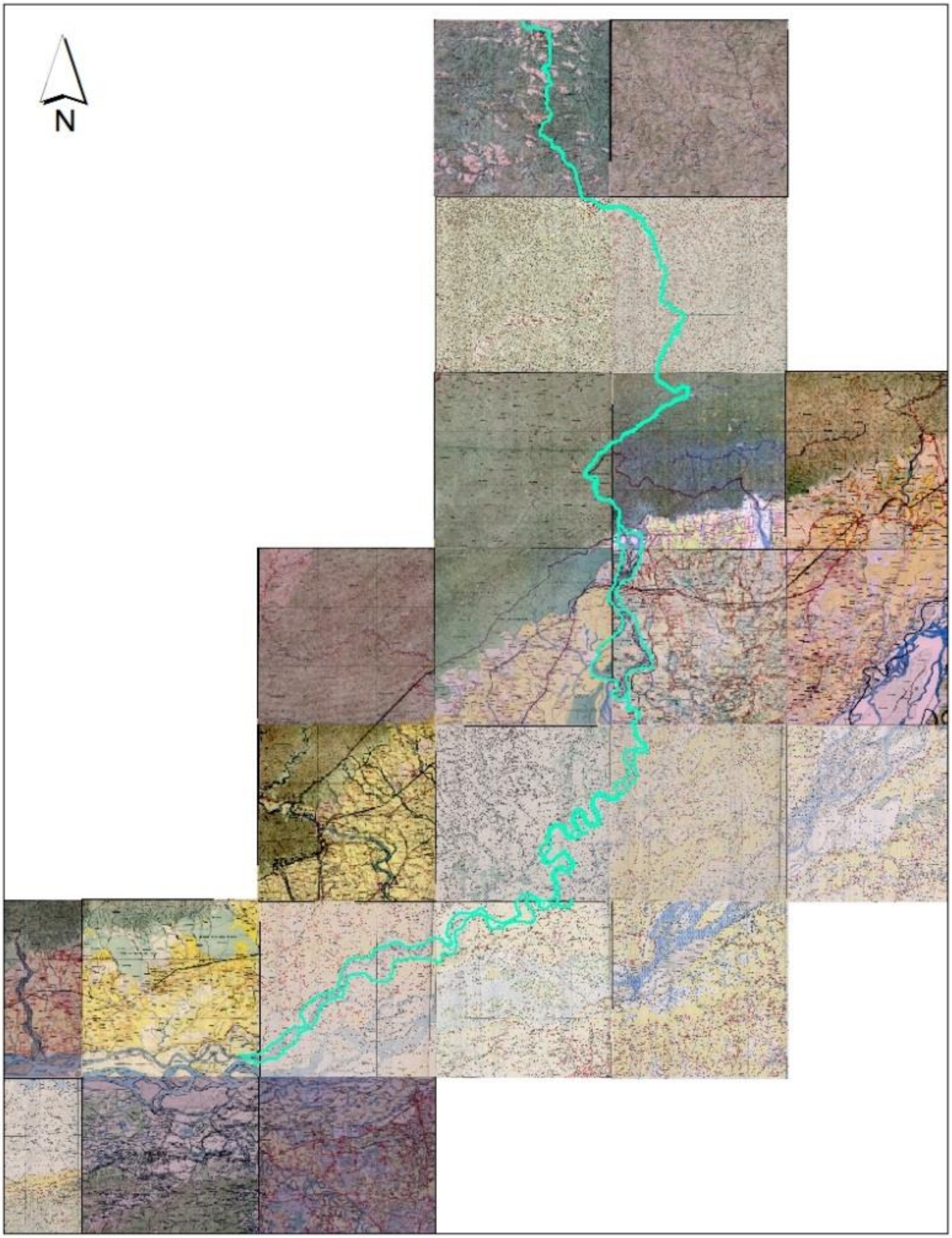


Figure 7: Mosaicked toposheet covering Subansiri river (1973-74)

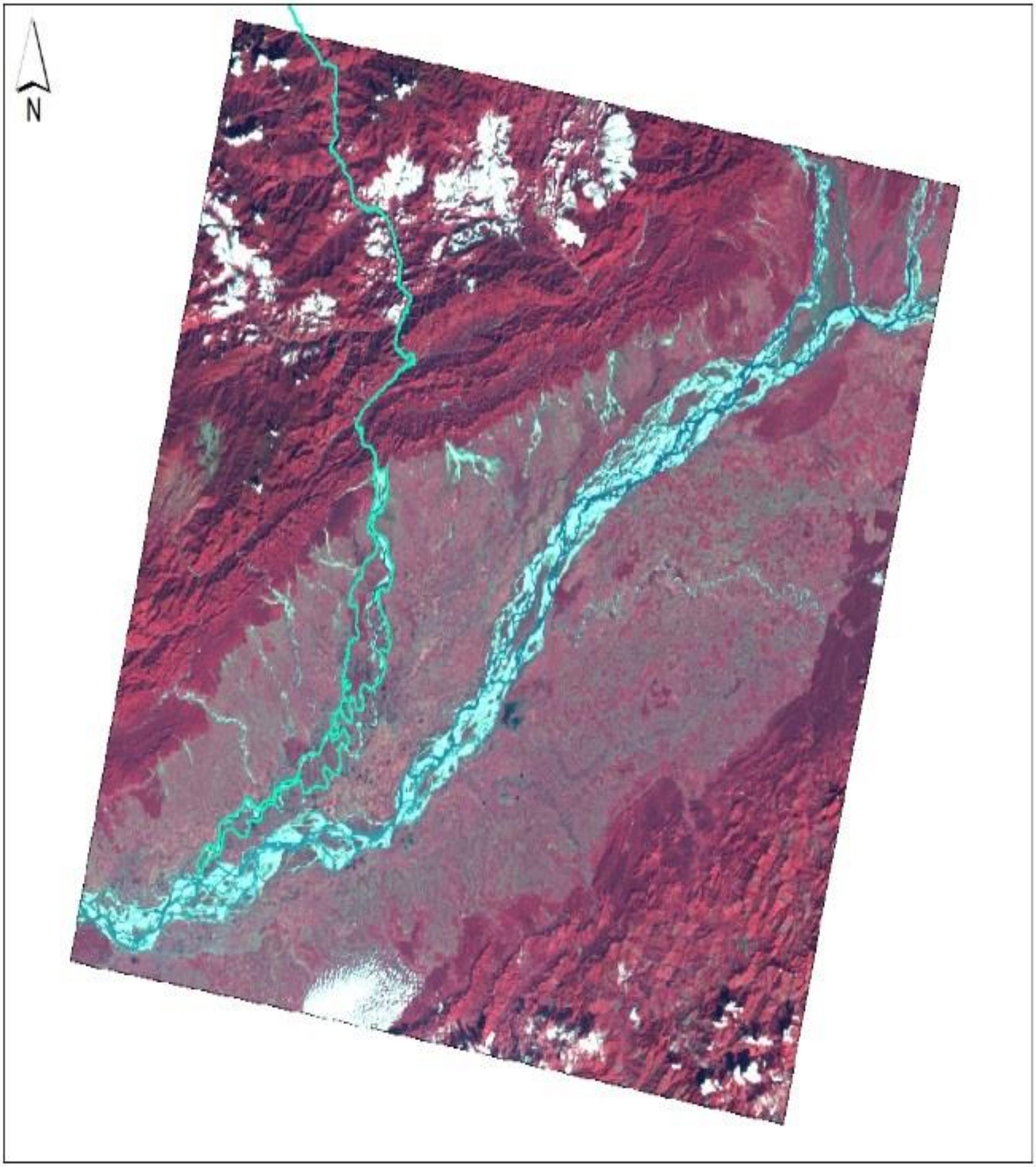


Figure 8: Landsat MSS data of 1976-80

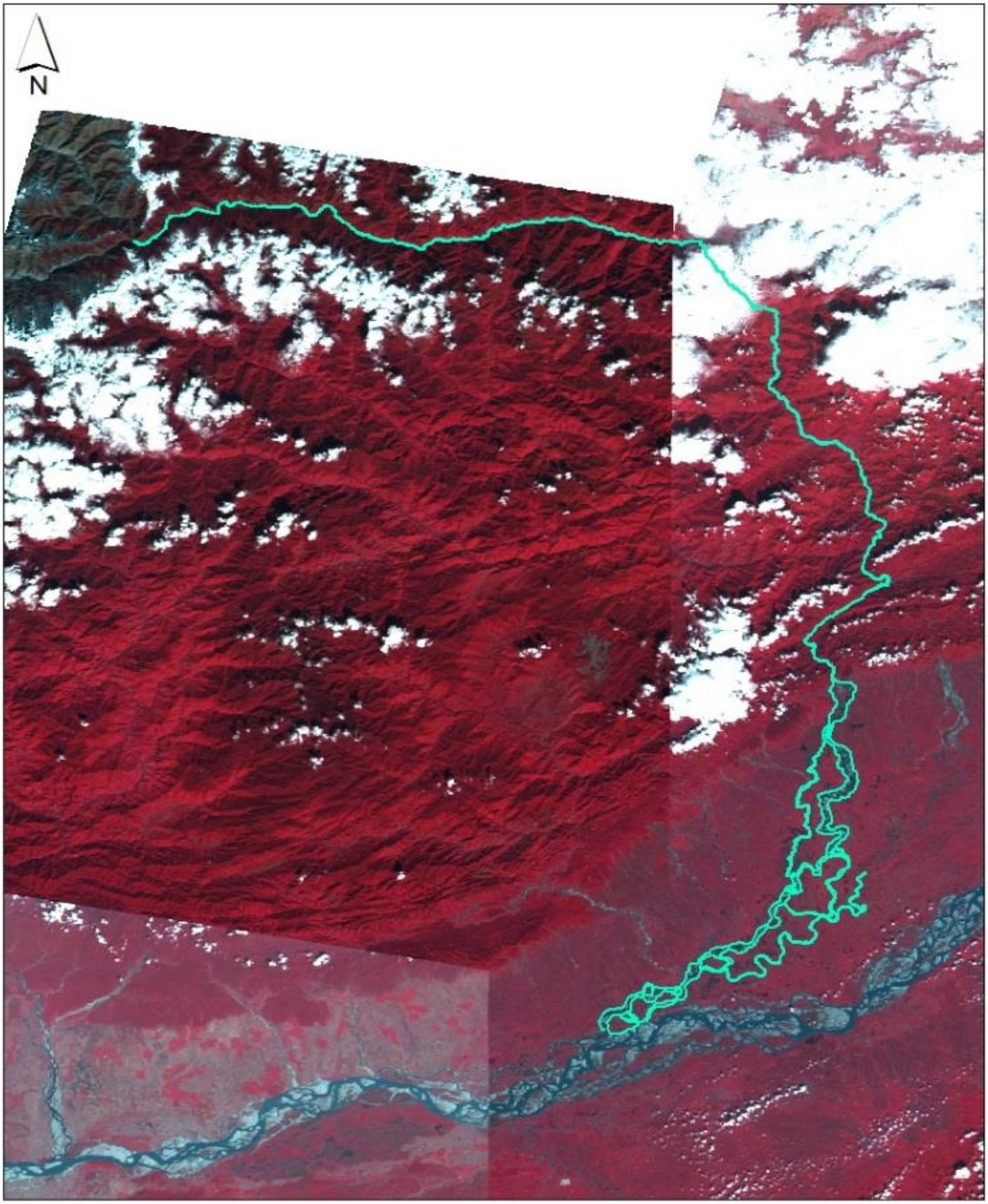


Figure 9: Mosaicked IRS 1B LISS 1 data of 1993-95

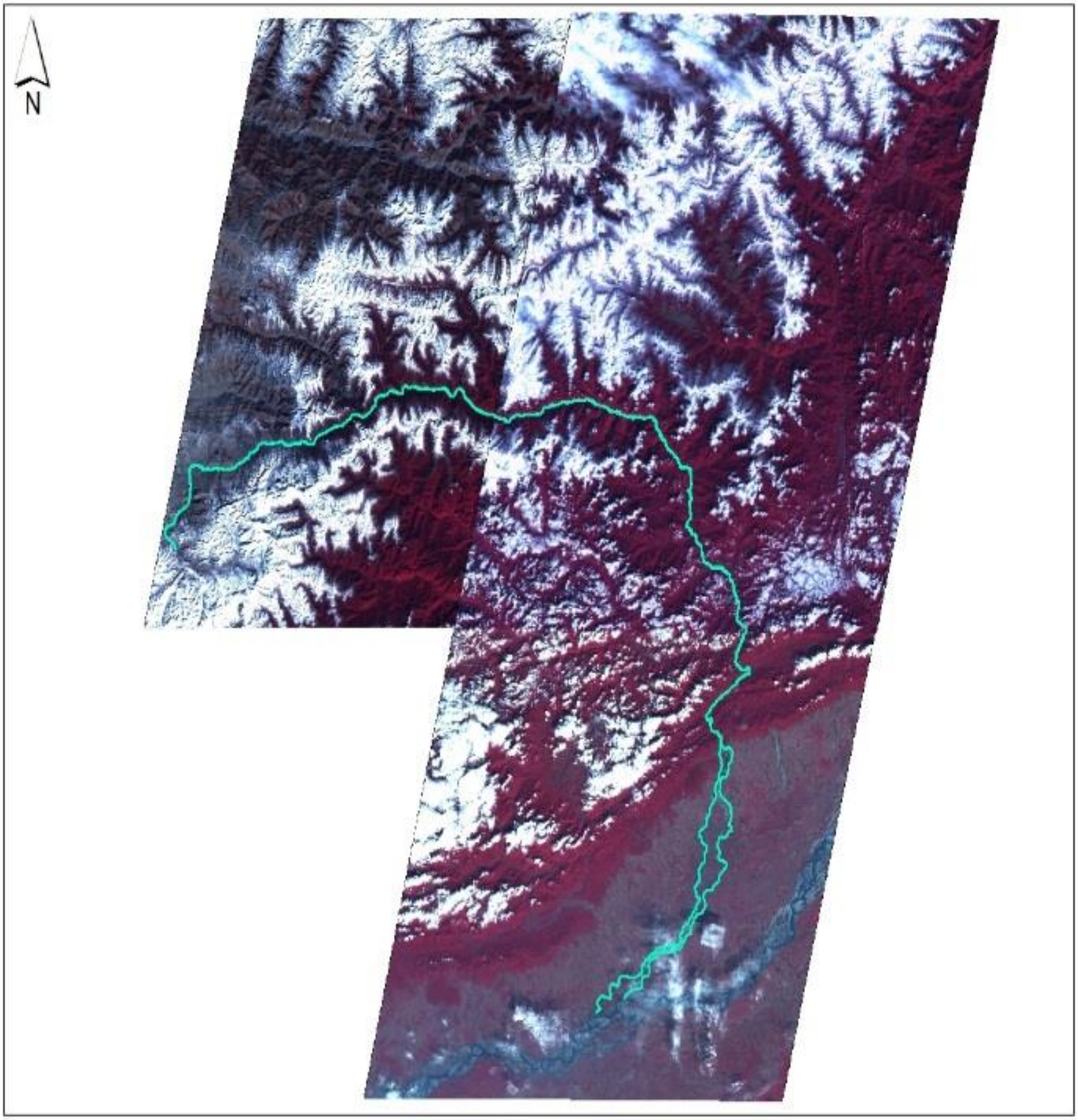


Figure 10: Mosaicked IRS P6 LISS 3 data of 2003-04

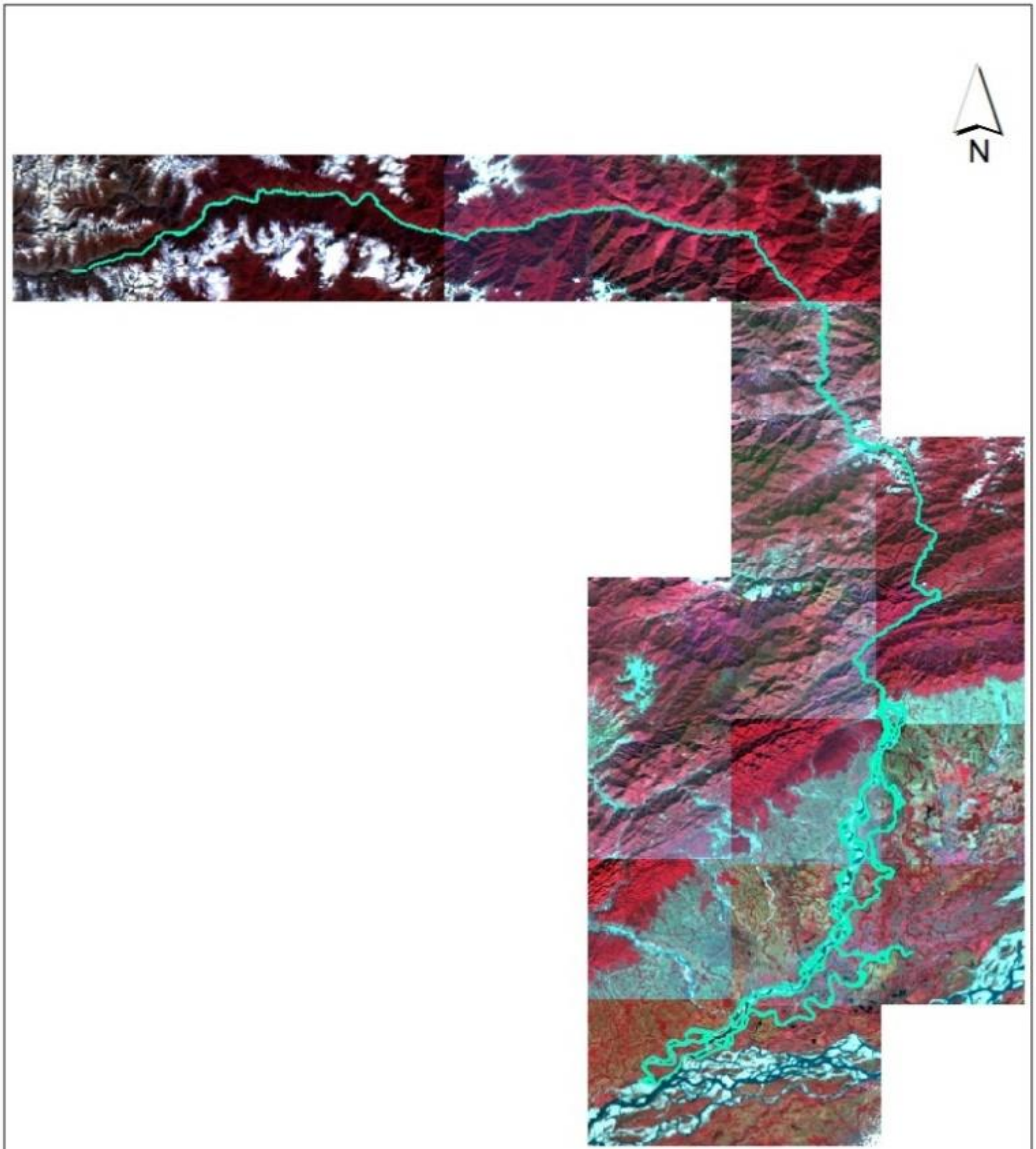


Figure 11: Resourcesat 1 (LISS 3) data (2008-09; 2011-12

6.2.2 Digital Elevation Model (DEM)

CARTO DEM of 30m covering the Subansiri catchment which were downloaded from the Bhuvan website (http://bhuvan.nrsc.gov.in/data/download/index.php). The DEM tiles were then mosaicked and further used for delineation in ArcGIS 10.1.

Chapter 7
HYDROLOGIC DATA

7.1 Introduction

Hydrological data viz. gauge, discharge, silt and x-section data were collected for different stations of river Subansiri from Upper Brahmaputra Division. CWC hydrological data had been received from the Upper Brahmaputra division for the stations Badatighat, Chouldhowaghat, Lemeking and Daporijo. However, long-term 10 daily discharge data are available only for the stations Chouldhowaghat and Lemeking; for Daporijo only one year i.e. 2014-15 discharge data is available and for Badatighat no discharge data is available. Hydrological data collected are shown in Annexure II.

7.2 Climate

The whole of the Brahmaputra valley in Assam including the Lower Subansiri basin forms an integral part of the Southeast Asiatic Monsoon regime having a unique climatic personality in comparison to any other parts of India. Because of the intense spell of heavy rainfall in the upper reaches as well as in lower part of the basin during the months June through September due to the prevailing south westerly monsoon, flood occurs in the lower part of the basin in Assam. This is due to the fact that during the pre-monsoon months of April and May, North East India receives a fairly good amount of rainfall on account of large scale thunder storm activity over this region causing a favourable antecedent condition of saturated ground and nearly bank full stage in rivers which help to a large extent in producing high flood in the month of June. Generally, high floods occur in the months of June, July and August.

The Subansiri basin in Assam is characterised by highest temperatures during the southwest monsoon season i.e. from June to about the beginning of October which begins to drop considerably by the end of November.

7.3 Hydrologic Data Collection

Hydrological data for river subansiri were collected from the CWC, Upper Brahmaputra Division and used to plot the probability exceedance curve. As CWC has GD sites in the Subansiri catchment in Chouldhowaghat and Lemeking, therefore only these two sections the daily gauge level data were used to plot the probability exceedance curve. Details of the hydrological data collected are given as Annexure II.

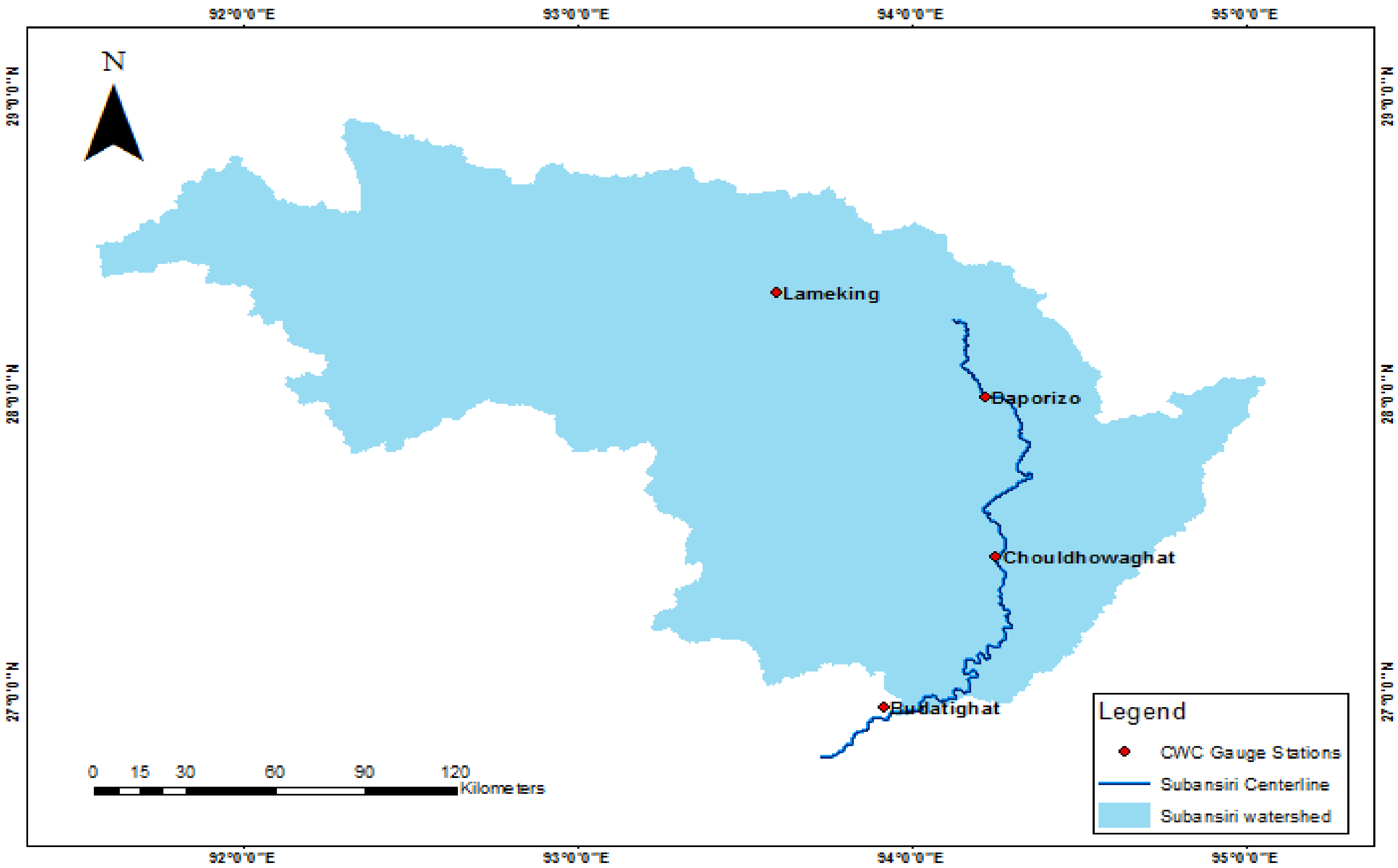


Figure 12: CWC Gauge Stations along Subansiri River

7.4 Probability Exceedence Curve

7.4.1 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).

7.4.2 Methodology

The flow duration curve for the river Brahmaputra was plotted for the sites Chouldhowaghat and Lemeking from the available ten daily discharge data collected from Upper Brahmaputra Division, CWC, Dibrugarh. The discharge data were arranged in descending order of class value. For the stations the total no. of days in each class was shown in column 3 of

in Annexure IV. Column 4 shows the cumulative total of column 3, i.e. the number of days the flow is equal to or greater than the class interval. This gives the value of m. The percentage probability Pp, the probability of flow in the class interval being equalled or exceeded is given by the equation.

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

where Pp = percentage probability of flow magnitude being equalled 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 smallest value of the discharge in each class interval is plotted against Pp in a logarithmic scale.

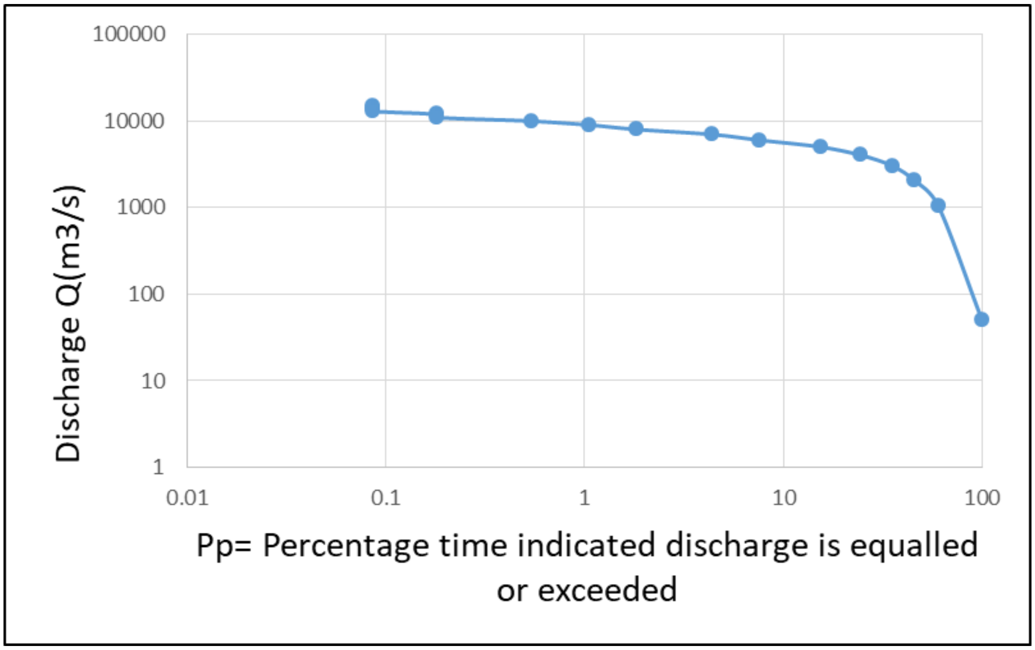


Figure 13: Flow duration curve (Chouldhowaghat)

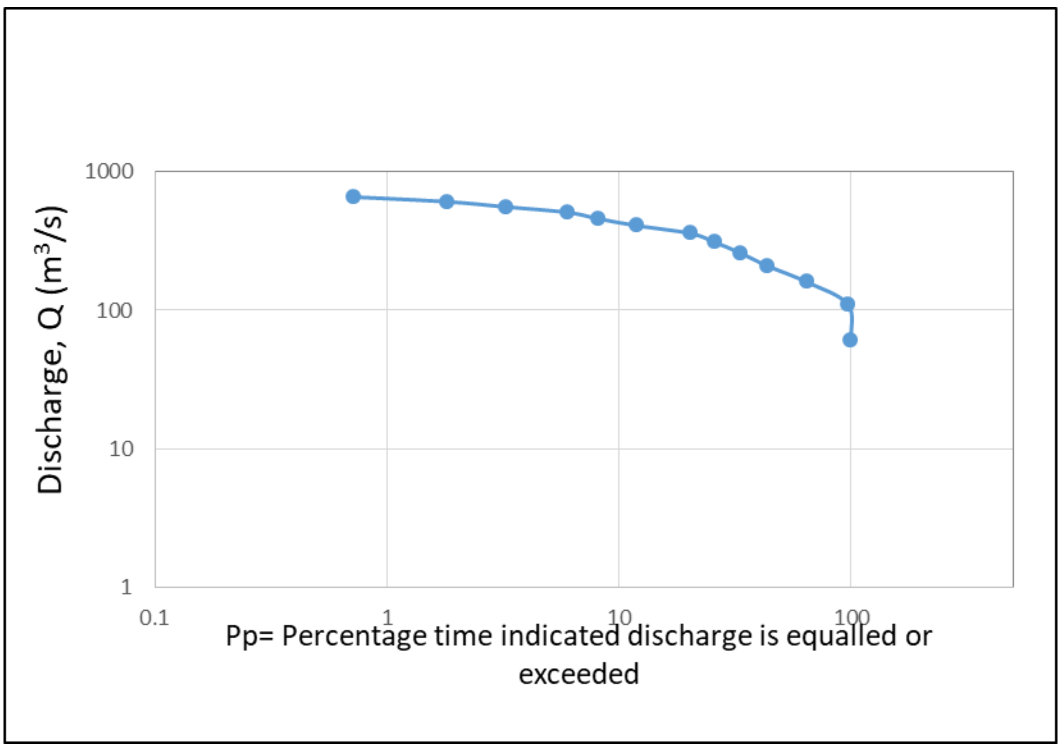


Figure 14: Flow duration curve (Lemeking)

7.5 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).

7.5.1 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

$$P(X \geq X_0) = 1 - e^{-e^{-y}} \qquad (7.1)$$

in which y is a dimensionless variable given by

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

Thus $$y = \frac{1.285\,(x-\bar{x})}{\sigma x} + 0.577 \text{ where } \bar{x} = \text{mean and} \qquad (7.2)$$

σ_x= standard deviation of variate X.

Eq.7.1 can be written as

$$y_p = -\ln[-\ln(1-P)] \qquad (7.3)$$

Considering $T=\frac{1}{P}$ where T is the return period Eq. 7.3 can be written as

$$y_T = -[\ln.\ln\frac{T}{T-1}] \qquad (7.4)$$

$y_T = -[0.834 + 2.303 \log\log \frac{T}{T-1}]$ (7.5)

Rearranging Eq.7.5, the value of variate of X with return period T

$x_T = \bar{x} + K\sigma_x$ where $K = \frac{(yT - 0.577)}{1.2825}$ (7.6)

For practical use Gumbel equation Eq. 7.6 gives the value of variate X with a recurrence interval T used as

$x_T = \bar{x} + K\sigma_{n-1}$ (7.7)

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

K= frequency factor, $\frac{(yT - \bar{y}n)}{Sn}$ (7.8)

where $\bar{y}_n$ = reduced mean, a function of sample size N ; S_n=reduced standard deviation, a function of sample size N.

7.5.1.1 Methodology

From the maximum discharge evaluated per year for Chouldhowaghat & Lemeking sites in Subansiri 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 Taable2

7.5.1.2 Observation

The probability exceedence curves have been plotted from the discharge at Chouldhowaghat and Lemeking considering definite class intervals. At the station Chouldhowaghat, from the frequency analysis, the discharges pertaining to 25, 50 and 100 years are 13307.70, 14753.15 and 16185.92 cumecs respectively. The corresponding percentage probabilities for 25, 50,100 years are 0.106%, 0.048% and 0.021 % respectively.

Similarly, for the station Lemeking the discharges corresponding to 25, 50 and 100 years are 875.28, 962.60, 1049.27 cumecs. The corresponding probabilities are 0.19 %, 0.09%, 0.045%

Table 2: Percentage Probability of exceedence for 1.5 years and 2 years return period

H.O. Sites	Return Period Tp (Years)	Discharge(m^3/s)	Pp (%)
Chouldhowaghat	1.5	6566.96	4.32
	2	7411.92	2.72
	25	13307.7	0.106
	50	14752.15	0.048
	100	16185.92	0.021
Lemeking	1.5	404.85	10.04
	2	460.28	6.42
	25	875.286	0.19
	50	962.604	0.09
	100	1049.27	0.045

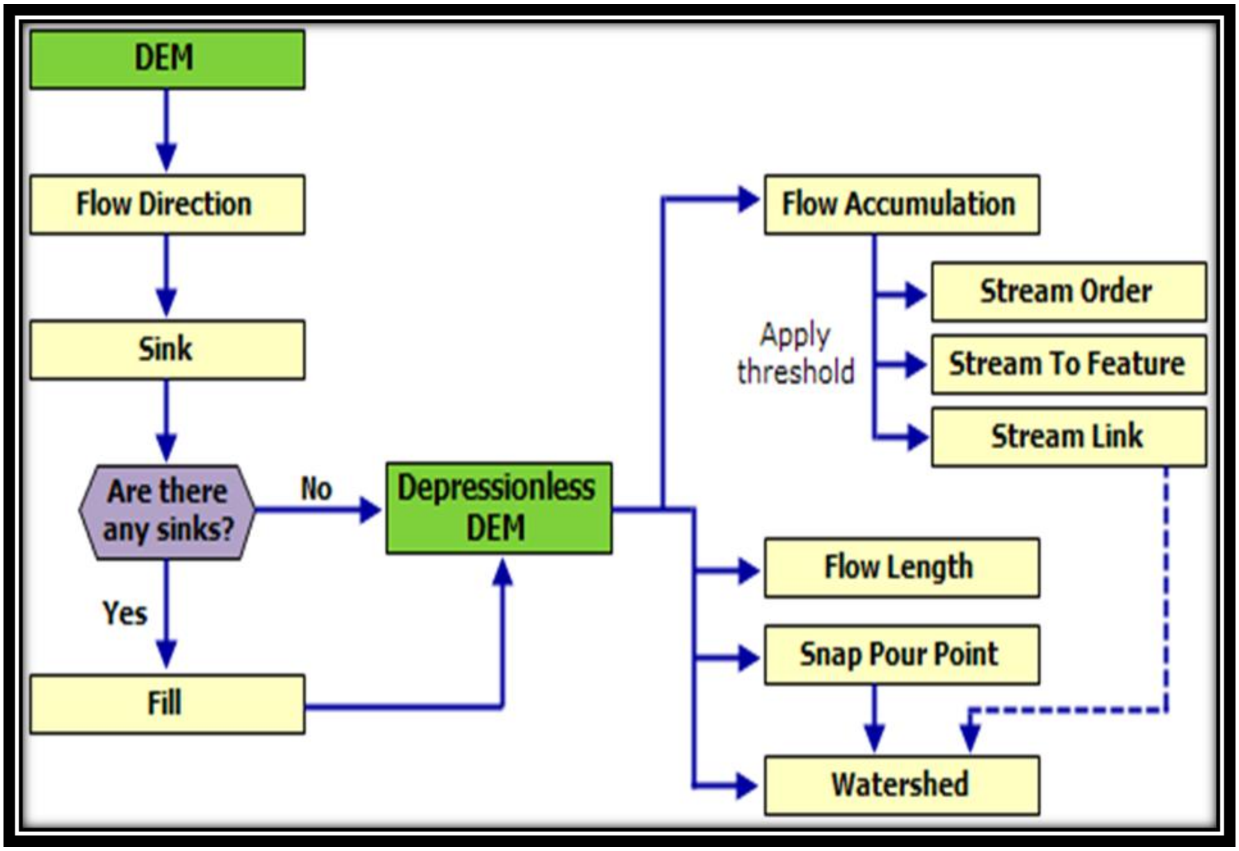
Chapter 8
MORPHOMERIC ANALYSIS OF BASIN

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.

8.1 Watershed Delineation

A watershed is the area of land draining into a stream at a given location [Chow, 1964]. Watershed analysis is very essential for 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.

The watershed delineation in Arc GIS can be done by using the hydrology subtool 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 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 the Figure 16.shows the procedure of watershed delineation from DEM using hydrology tool of ArcGIS.



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

Figure 15: Flowchart showing delineation of watershed

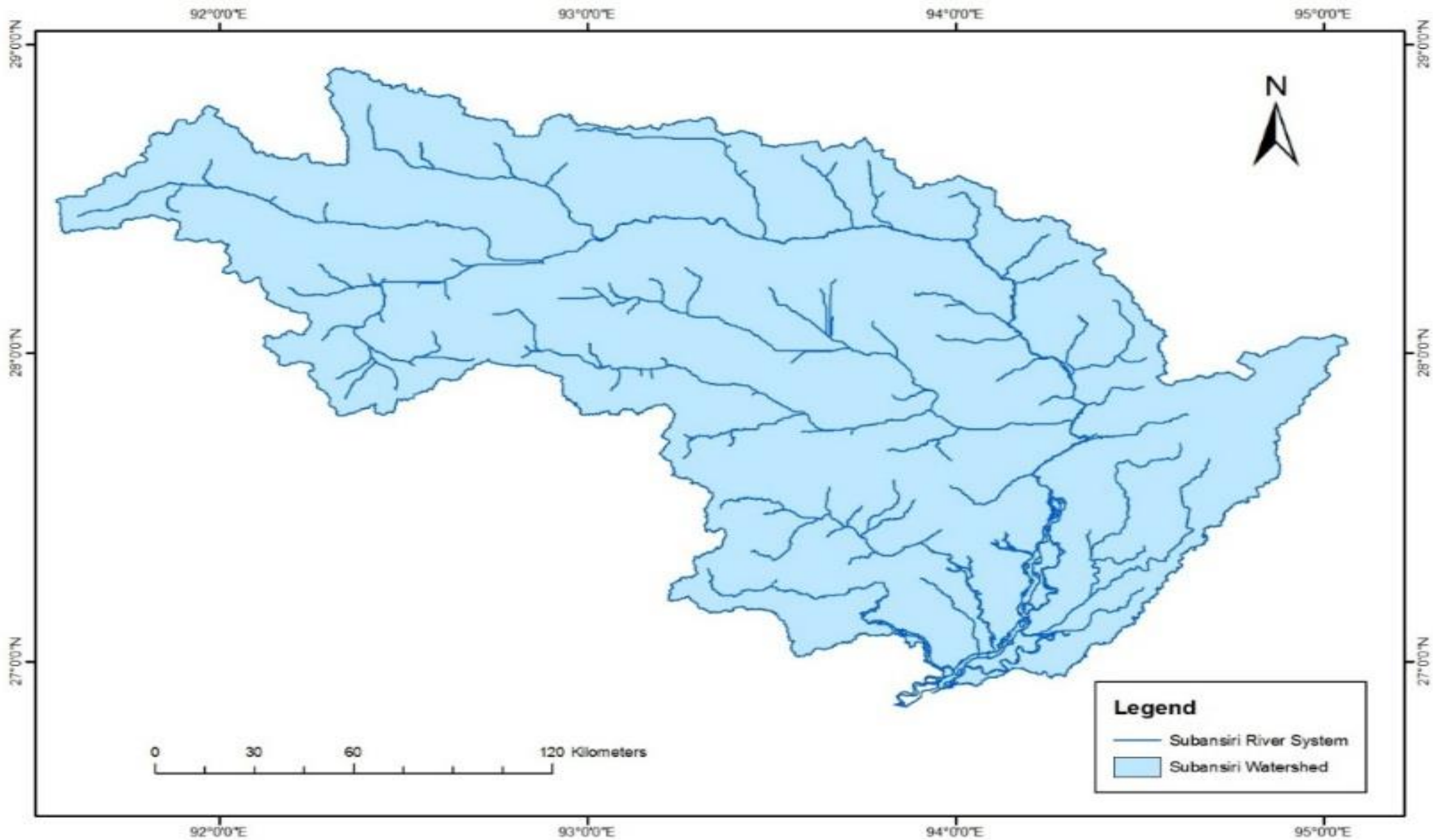


Figure 16: Study area showing the Subansiri Watershed

8.1.1 Observations

The watershed of the Subansiri is delineated using SRTM DEM of 90 m resolution and the flow accumulation and flow direction maps were generated. 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 watershed of Subansiri are found to be 35364.3 km2 1547.83 km respectively.

8.2 Mophometric parameter analysis

Morphometric analysis of Subansiri basin was carried out using SRTM DEM of 90m resolution and the flow accumulation and flow direction maps were generated. A conditional flow accumulation raster (stream raster) was generated using a threshold value of 3000 which was decided by trial and error method. 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. The threshold area is found to be-

Threshold Area= 3000×0.09074×0.09074 km^2 = 24.7 km^2

Table 3: Number of segments and total lengths of all the segments of various orders

Sl. No	**Stream Order**	**Number of Segments (N_u)**	**Length (L_u)**
1	1	391	2502.48 km
2	2	174	1173.59 km
3	3	42	647.89 km
4	4	5	233.25 km
5	5	2	261.91 km
6	6	1	130.38 km

8.2.1 Bifurcation Ratio (R_b)

The bifurcation ratio is defined as the ratio of the number of stream segments of given order 'N_u' to the number of streams in the next higher order (N_u+1) (Strahler ,1964). The lower values of bifurcation ratio characterize watersheds which have suffered less structural disturbances. Also, if the bifurcation ratio of a river network is low, there is a higher chance of flooding (Pareta & Pareta, 2011; Rao, et. Al., 2017). The bifurcation ratio can also show which parts of a drainage basin is more likely to get flooded, comparatively, by looking at the separate ratios. The bifurcation ratio is dimensionless property and generally ranges from 3.0 to 5.0. From Table 1, the R_b values for different stream orders of Subansiri watershed were calculated as follows:

$$R_b = \frac{N_u}{N_{u+1}}$$

R_{b1} = 391/174 = 2.25

R_{b2} = 174/42 = 4.14

R_{b3} = 42/5 = 8.4

R_{b4} = 5/2 = 2.5

R_{b5} = 2/1 = 2

The bifurcation ratios for different stream orders of Subansiri river showed that the ratio is lowest for the stream order 5 i.e. in the downstream region and highest for the stream order 3 which lies in the Himalayan foothills. From these differences in the values it can be inferred that the downstream portion of the Subansiri River i.e. the part of the river flowing through Assam plains is prone to flooding as it exhibits a low value of R_b. However, the higher R_b values were observed for the stream orders 2 & 3 which can be attributed to the structural disturbances in the Himalayan foothill region i.e. near the Tibetan Plateau and Arunachal Hills.

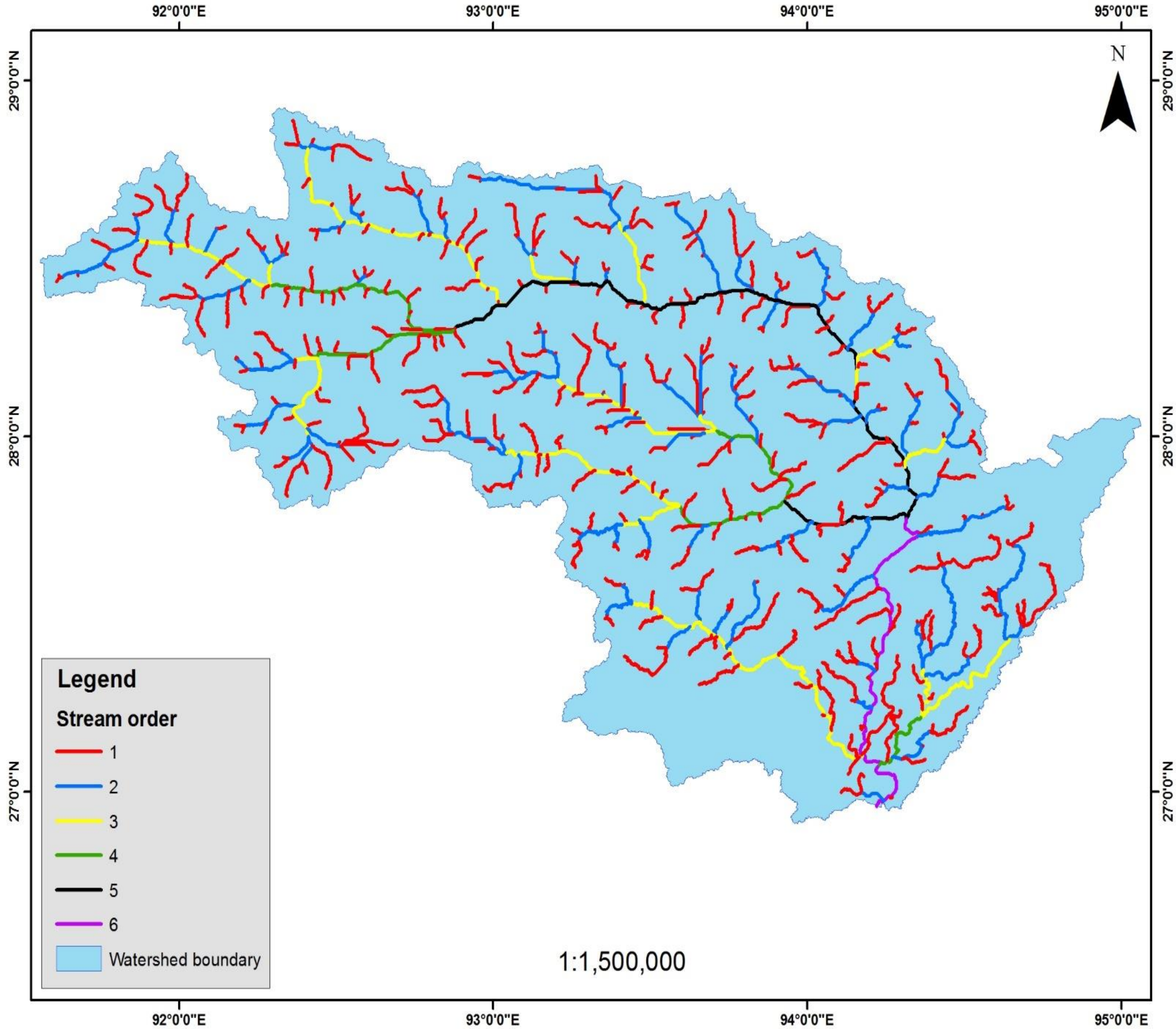


Figure 17: Stream order of Subansiri catchment

8.2.2 Drainage Density (Dd)

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. Generally, 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. Also low drainage density signifies regions of highly permeable sub-soil material, under dense vegetative cover where relief is low whereas, high drainage density is the characteristic of regions with weak or impermeable sub-surface materials, sparse vegetation and mountain relief (Rao, et.al., 2017; Waikar & Nilawar, 2014).

Area of the basin, A = 35364.3 km^2

$$D_d = \frac{\sum L_u}{A} \quad (km/km^2)$$

$$D_d = (2502.48+1173.59+647.89+233.25+261.91+130.38)\ km / 35364.3\ km^2$$

$$= 4949.5/35364.3\ km/km^2$$

$$= 0.14\ km/km^2$$

In case of Subansiri, the drainage density is found to be as low as 0.14 km/km^2 which infer to the highly permeable sub-soil material under dense vegetative cover in the catchment.

8.2.3 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. For Subansiri catchment, the stream frequency is calculated as follows:

$$F_s = \frac{\sum N_u}{A}$$

$$F_s = (391+174+42+5+2+1)/ 35364.3$$

$$= 615/35364.3$$

$$= 0.017$$

8.2.4 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.

Length of the basin, L_b = 470.38 km

$$F_f = \frac{A}{L_b^2}$$

F_f = 35364.3/(470.38)^2

= 0.16

The value is found to be 0.16 which is low. This indicates that the catchment is elongated in shape.

8.2.5 Drainage Factor (D_f)

Drainage factor for the catchment is calculated as below:

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

D_f =0.017/(0.14)^2

= 0.87

8.2.6 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. Circulatory ratio is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and slope of the basin. The value of circularity ratio varies from 0 (in line) to 1 (in a circle).

Perimeter, P = 1547.83 km

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

R_c = 12.566 x (35364.3/(1547.83)^2)

= 12.566 x (35364.3/2395777.7089)

= 0.19

The circulatory ratio for the Subansiri catchment is 0.19 which refers to slightly elongated shape of the catchment.

8.2.7 Basin shape factor (S_b)

The basin shape factor for the Subansiri catchment is calculated as:

L_{ca} = 309.71 km = 192.44 miles

L= 470.38 km = 292.28 miles

$L_l = (LL_{ca})^{0.3} = 26.61$

8.2.8 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).

$$R_e = \frac{2 \times \sqrt{(\frac{A_b}{\pi})}}{L_b}$$

$$R_e = \frac{2 \times \sqrt{(\frac{35364.3}{\pi})}}{470.38}$$

$$= 0.45$$

From this analysis it can be ascertained that most of the factors indicates that the shape of the catchment is elongated in nature

8.2.9 Observations

From the morphometric analysis of the Subansiri catchment it has been observed that the bifurcation ratio is the lowest in the highest stream order i.e. in the downstream portion of the catchment flowing through the plains of Assam and the ratio is highest in the stream order 3 that flows in the foothill region of Himalaya i.e. through the Tibetan Plateau and Arunachal Hills. This indicates higher chances of flooding in the downstream portion of the catchment and presence of structural disturbances in the foothills of Himalaya. The drainage density of the catchment is found to be low i.e. 0.14 km/km^2 which infers to the occurrence of intense rainfall resulting in flashy discharge and flooding. It also signifies that the region exhibits highly permeable sub-soil material under dense vegetative cover. The values of form factor, circulatory ratio and elongation ratio indicates that the catchment is elongated .

Chapter 9
LANDUSE LANDCOVER ANALYSIS

The land use land cover of entire North East area were collected from North Eastern Space Application Centre (NESAC), Shillong for the years 2005-2006 and 2011-2012 (**Error! Reference source not found.** & **Error! Reference source not found.**). For the years 1976-1980 and 1993-1995, supervised classification was carried out to generate the LULC maps for the corresponding periods using Landsat MSS data and IRS 1B LISS 1 data respectively.

9.1 Methodology

Land Use/Land Cover mapping has been carried out within the Subansiri watershed (within Indian territory) for the years 1973-74, 1976-80 and 1993-95 and for the years 2005-06 and 2011-12, the LULC data have been collected from North Eastern Space Applications Center (NESAC), DOS, ISRO, Umiam, Meghalaya. 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. The classified LULC rater data are 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 are for the entire north-eastern states and therefore for the Subansiri watershed LULC data are clipped using the watershed boundary in ArcGIS 10.0. The collected LULC data of 2005-06 and 2011-12 are also at 1:50000 scale. Area of the polygons of different classes is then calculated using calculates geometry in ArcGIS for each year. 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. Therefore, the LULC change analysis in the study has been limited to only for the years 1973-74, 2005-06 and 2011-12. The LULC maps of different years are shown in Figure 18-22

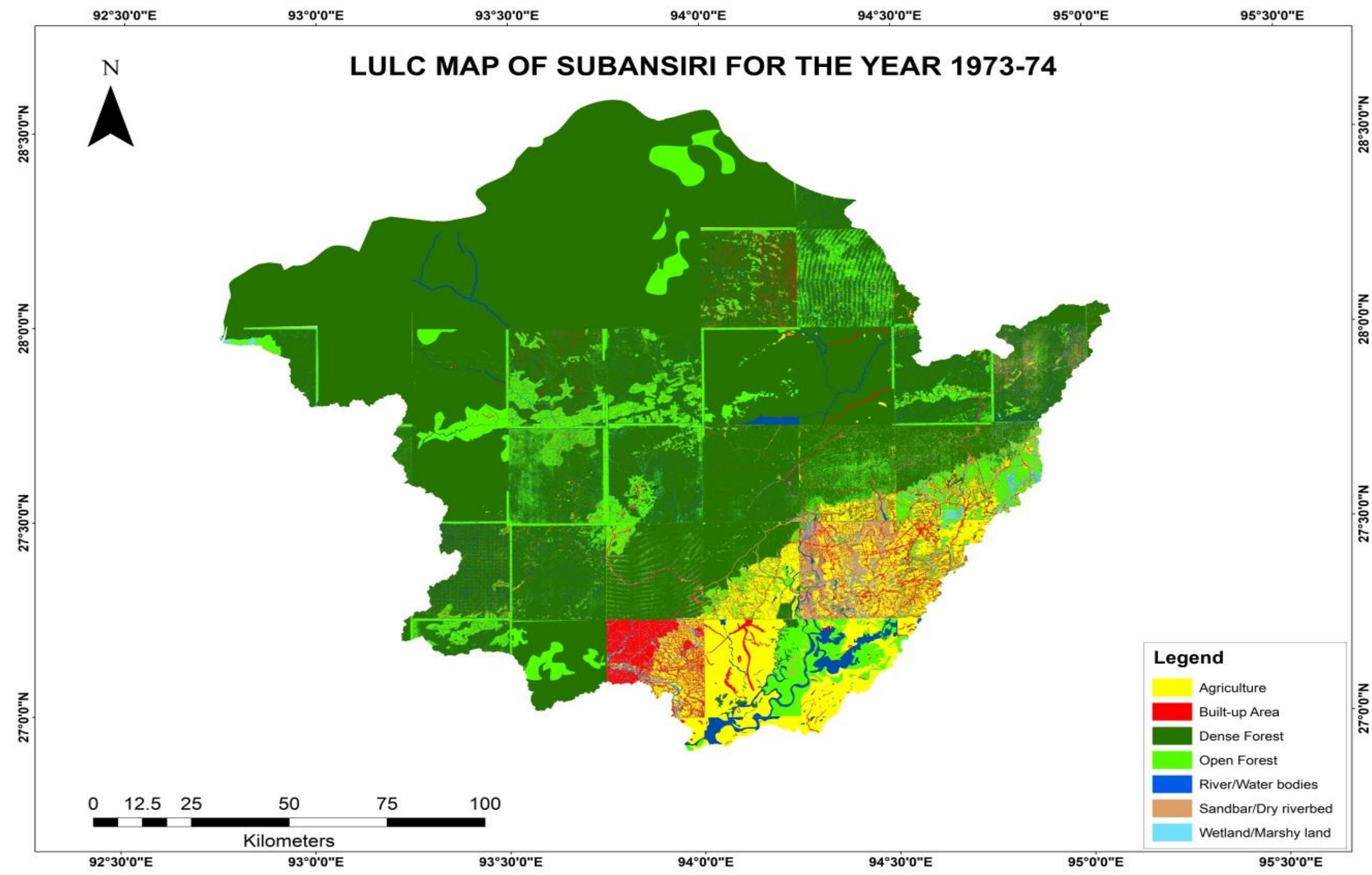


Figure 18: LULC Map of Subansiri 1973-74

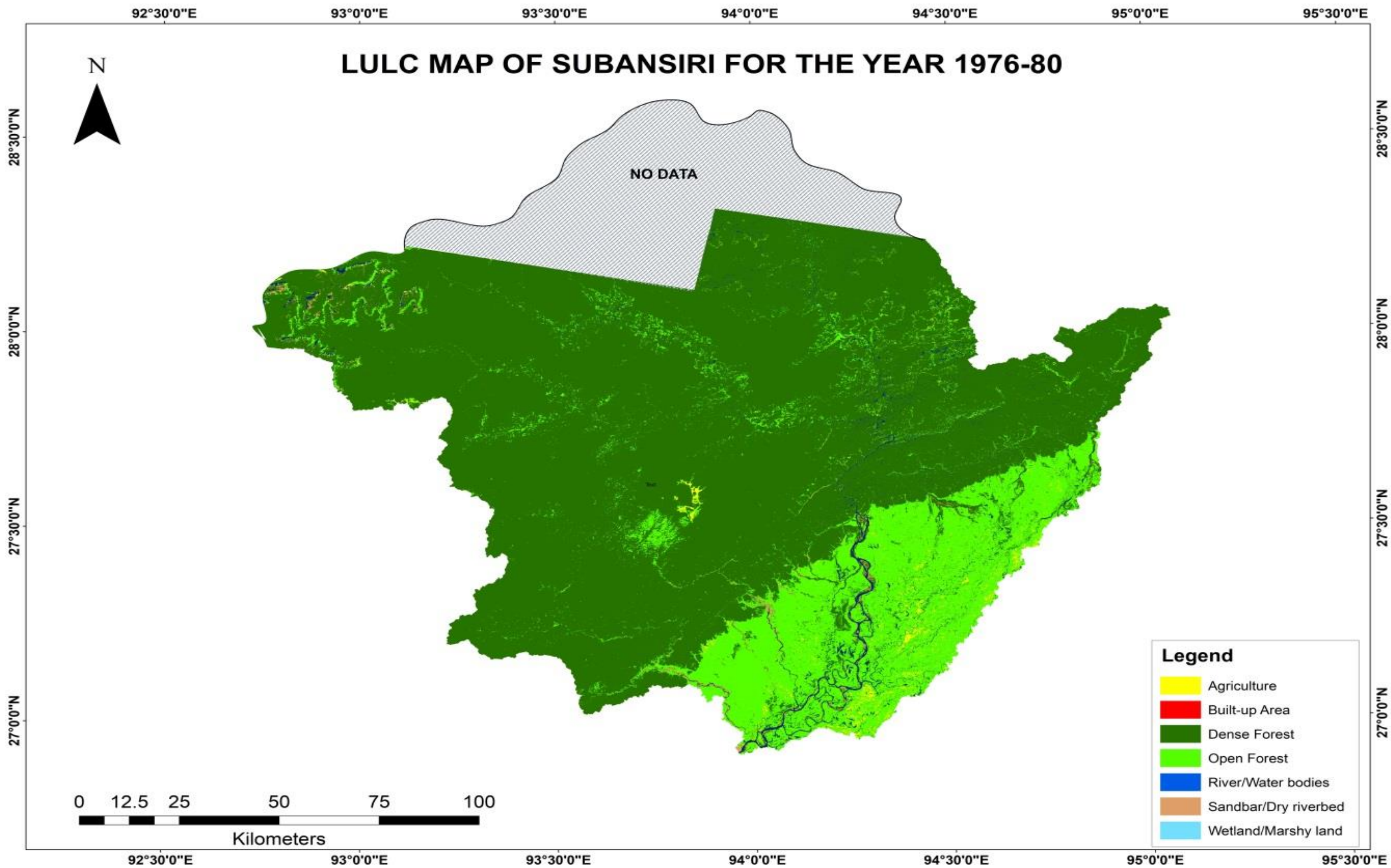


Figure 19: LULC Map of Subansiri 1976-80

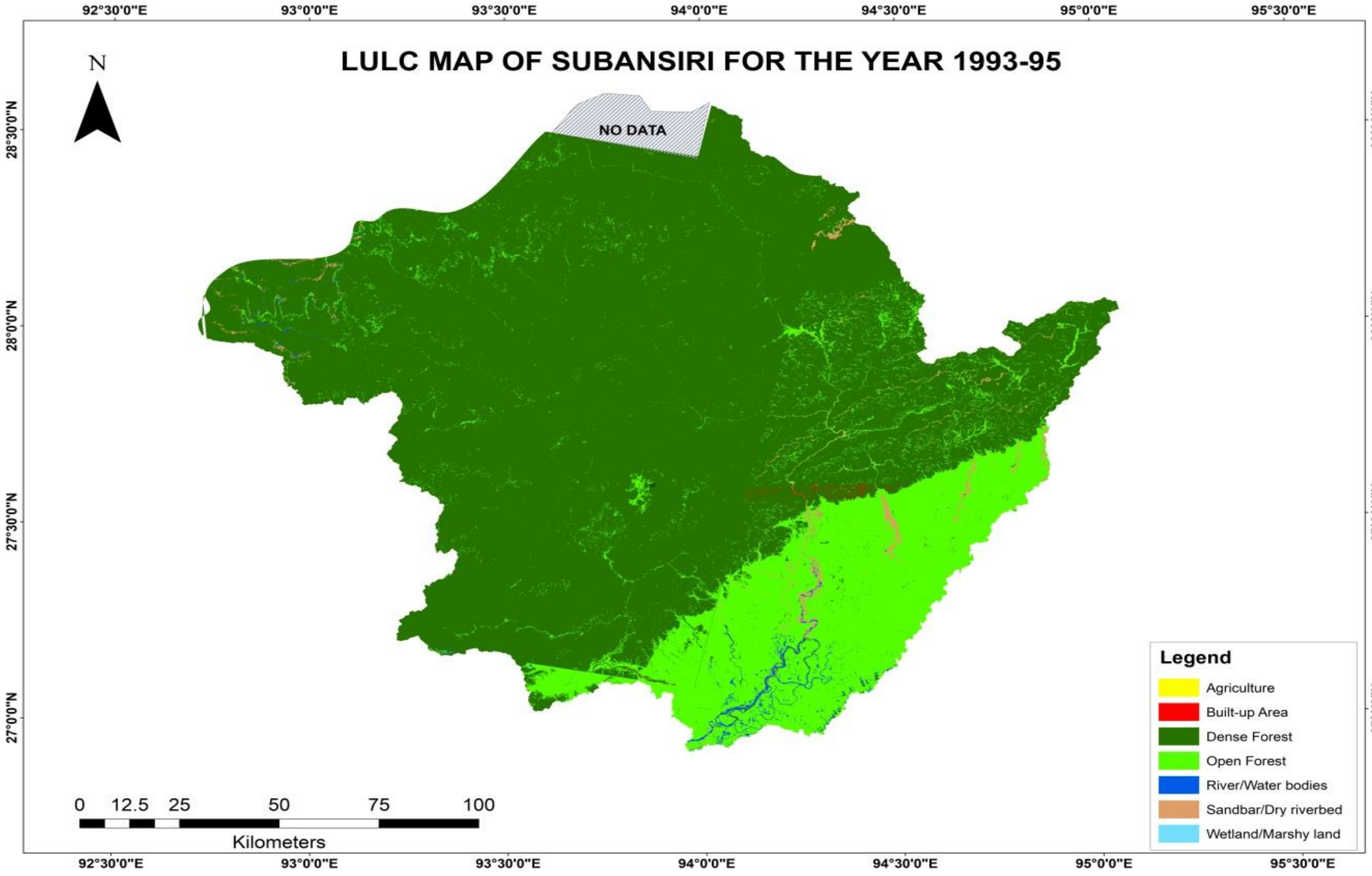


Figure 20: LULC Map of Subansiri 1993-95

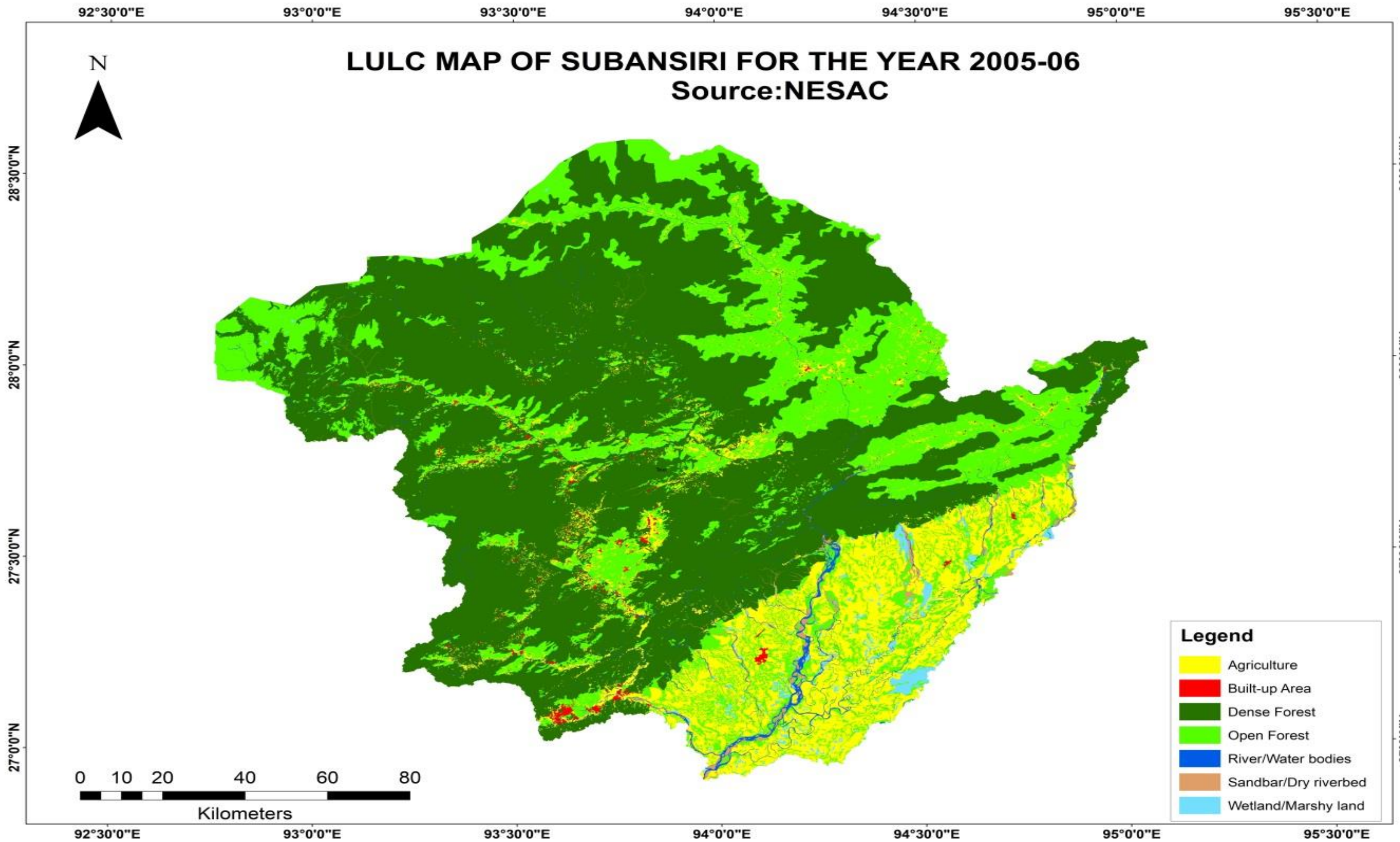


Figure 21: LULC Map of Subansiri 2011-12

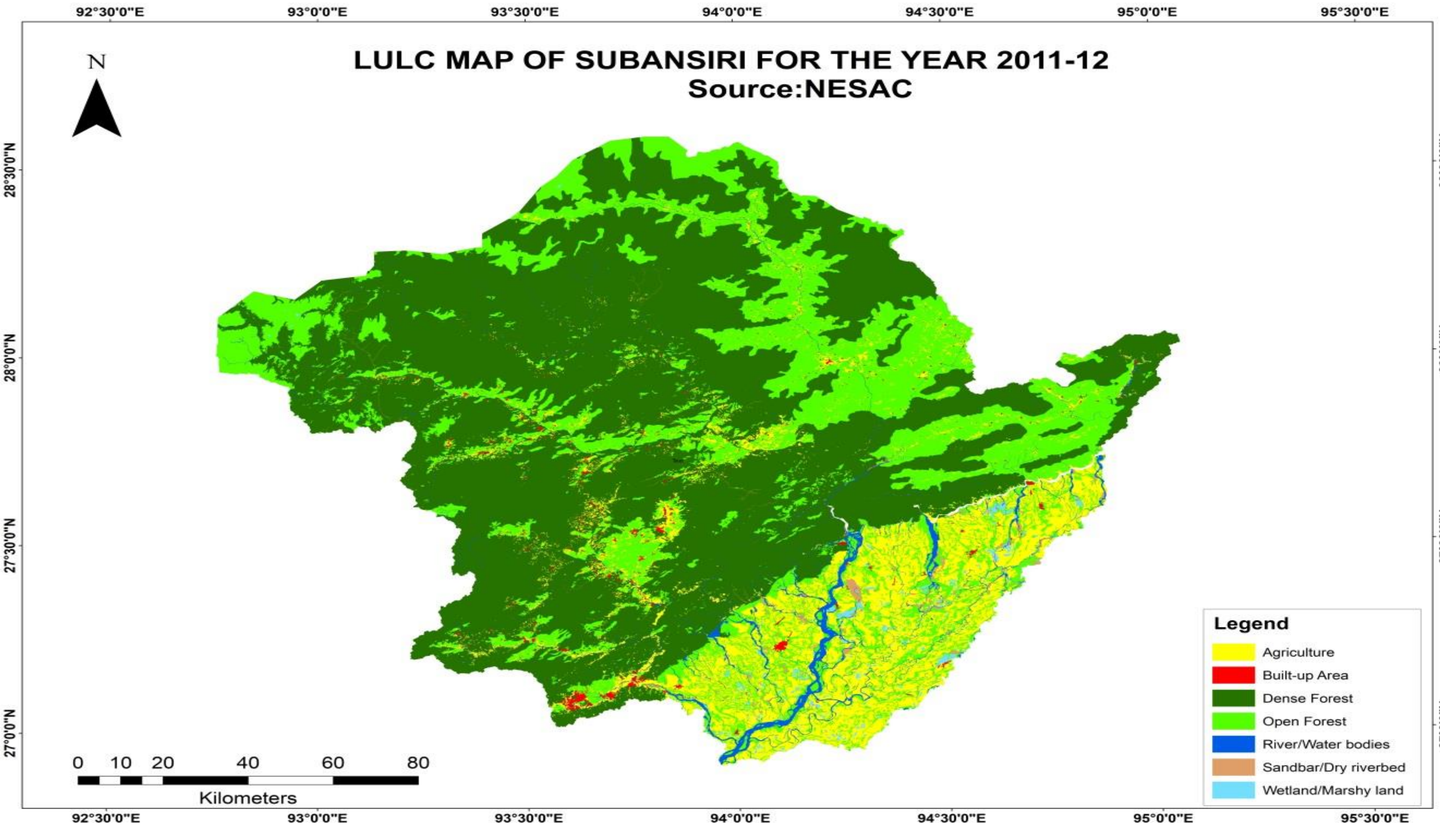


Figure 22: LULC Map of Subansiri 2005-06

9.2 Observations

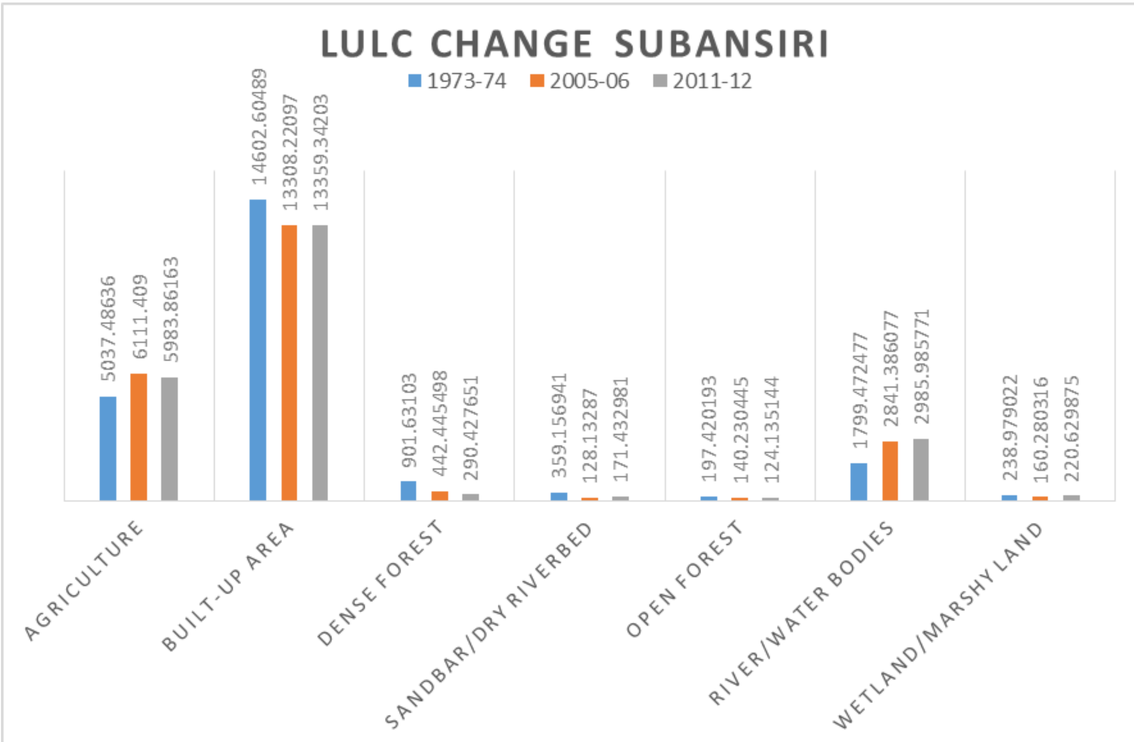


Figure 23: LULC analysis of Subansiri

From the estimation of LULC change over 1973-74 to 2011-12, it has been observed that there is a decrease in dense forest & built-up areas while an increase in the agricultural area (Fig.23). Also, the area occupied by the river has been increased over the years and there is a reduce in the sandbar/dry riverbed area and area under water bodies/marshy land. LULC indicates that built up area and forest lands are converted to agriculture and waterbodies.Its indicate increasing trend of water utilization in in agriculture sector. So, a detailed study on such flow scenarios can be carried out by hydrological modelling and river flow simulation study.

Chapter 10
RIVER MORPHOLOGY

Channel Evolution Process

Being one of the largest northern tributaries of the Brahmaputra river, Subansiri flows in a complex pattern. The flow in the upstream of Subansiri river i.e. in the hills of Arunachal is almost linear while on entering the plains of Assam, it flows in a complex braided pattern with a shift in its main flow from east to west in two parallel channels. It is thereby difficult to quantitatively analyze different morphological aspects such as change in amount of bank erosion-deposition over different time periods. Therefore, to study the channel evolution process of the Subansiri River, section lines were drawn at 10 km interval (Fig. 24) on the part of the river flowing in the Assam plain dividing the river part into several reaches. The changes observed at different reaches are presented below.

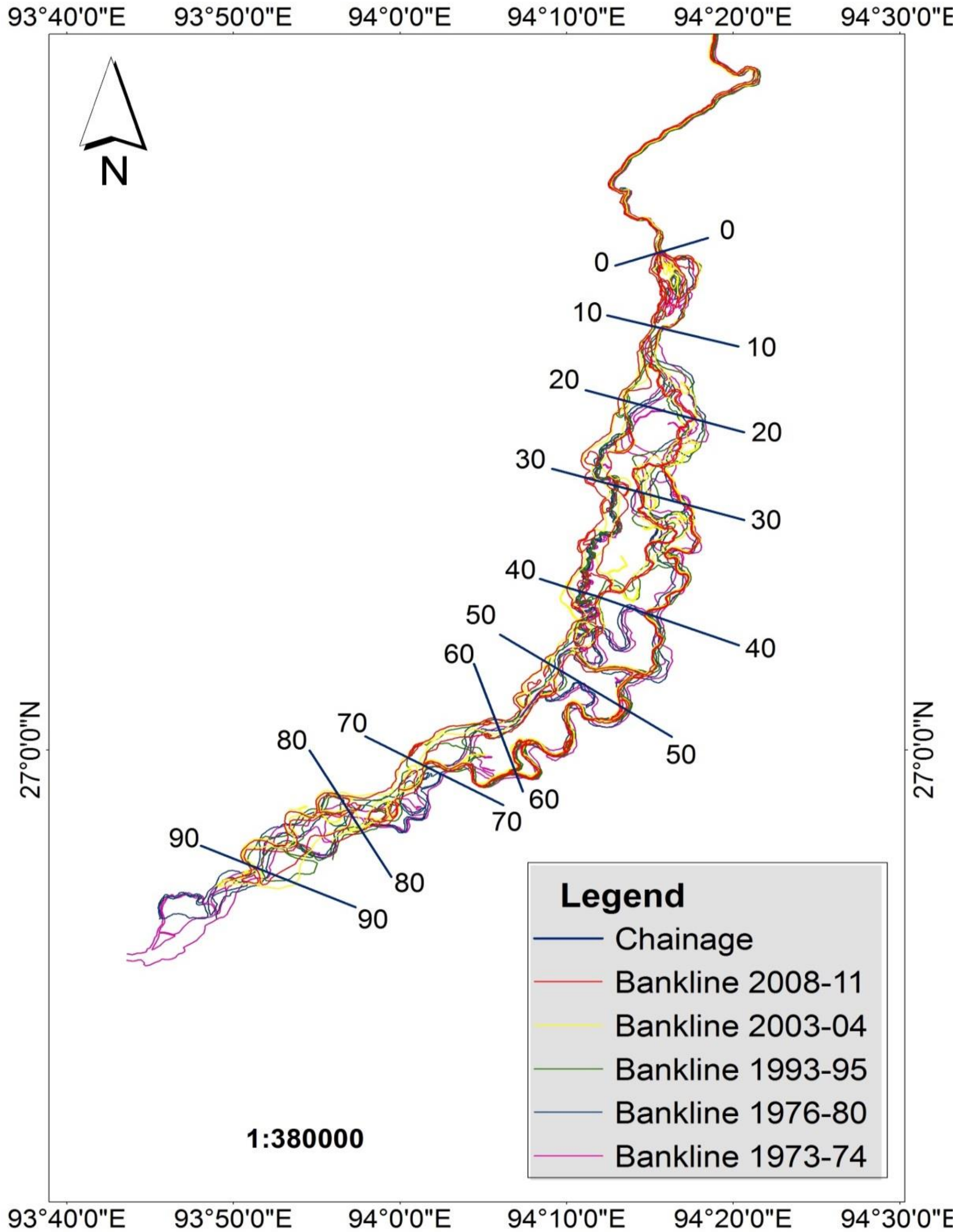


Figure 24: Morphological changes of the river Subansiri in Assam plain at sections of 10 km intervals

10.1 Channel pattern

In Reach-1 i.e. on entering the plains of Assam, fanning out of the river flow was observed forming several braiding channels due to the sudden drop in the terrain height from the Arunachal hills to the Assam plains (Fig. 25).

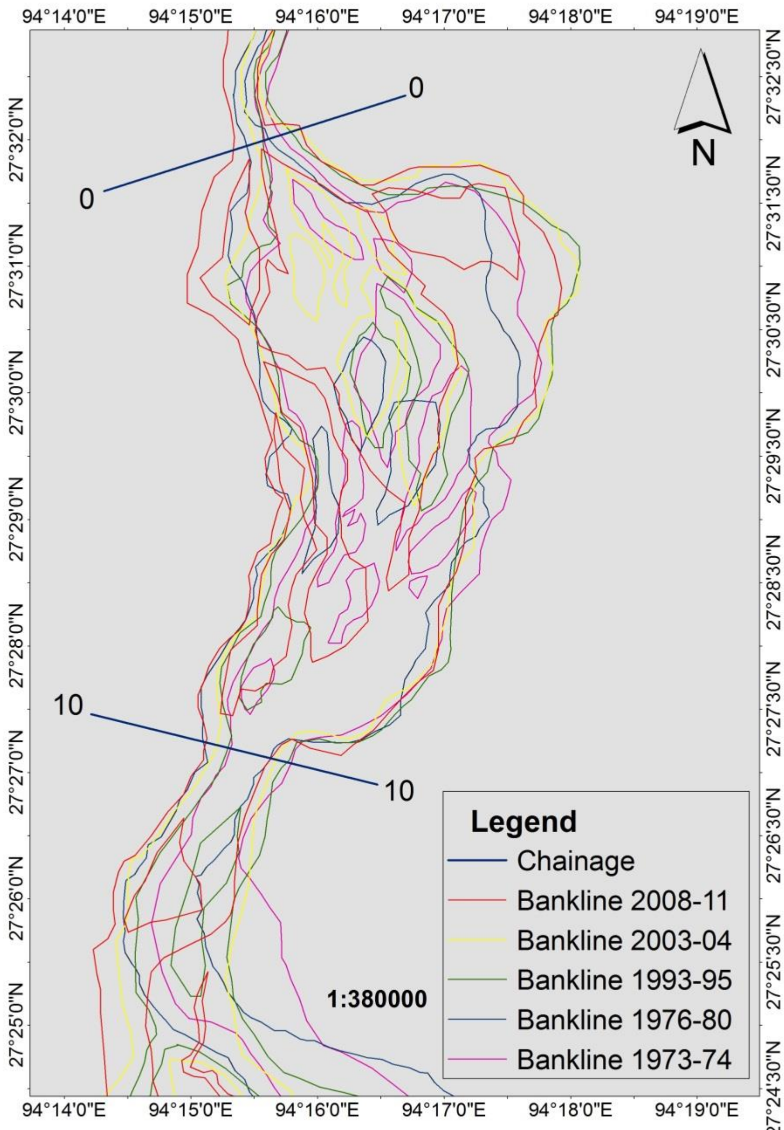


Figure 25: Changes in Reach-1 over 1973-74 to 2008-11

Also, lateral shift in both banks of the river were observed over the years gradually leading to the formation of permanent mid-channel bars**.**

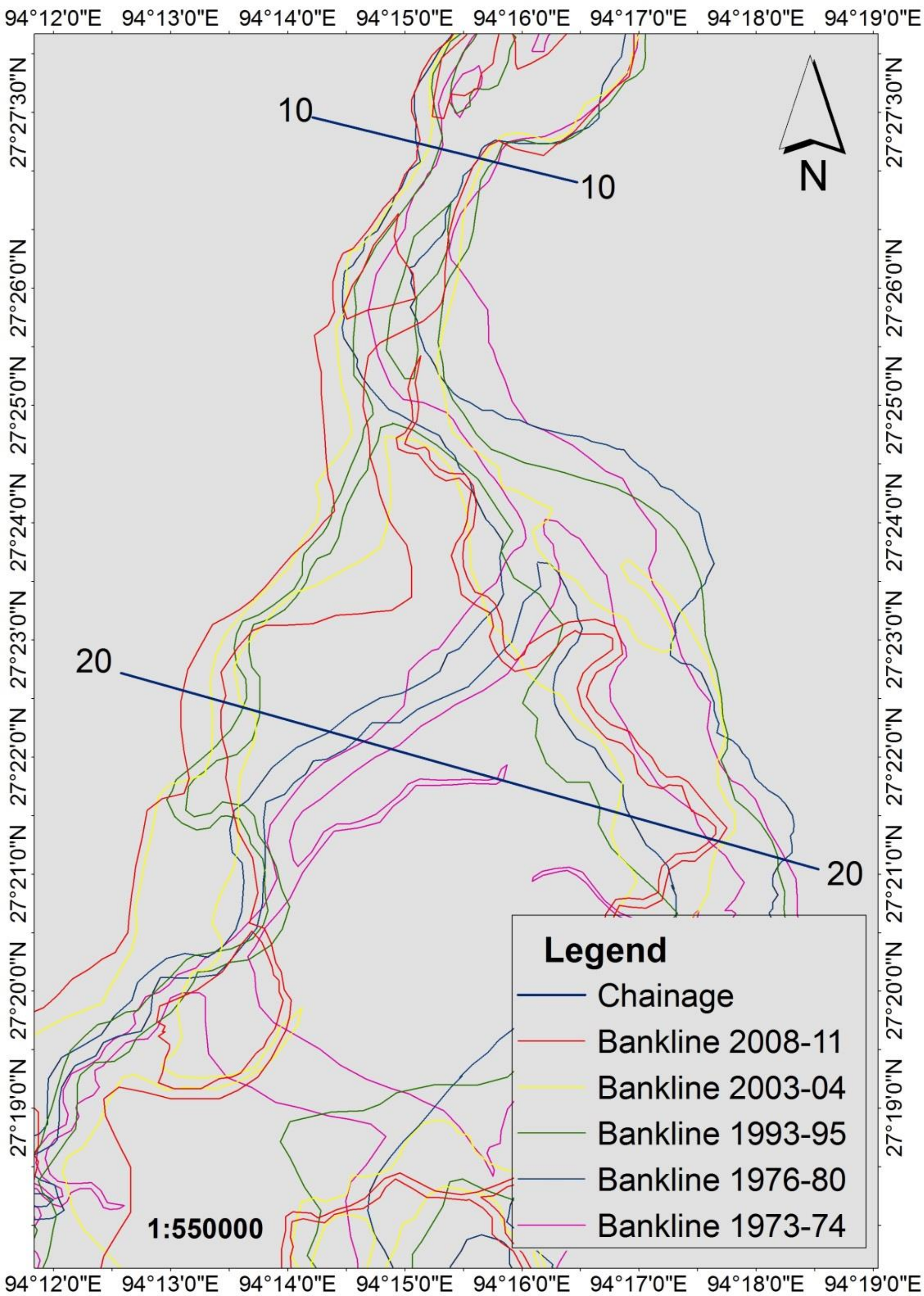


Figure 26: Changes in Reach-2 over 1973-74 to 2008-11

In Reach-2, a westward shift in the flow was observed in the river Subansiri. During 1973-80, in the downstream of the Reach-2 the river used to bifurcate into two parallel channels. This bifurcation was then gradually shifted little up to the west and in 2008-11, the eastern channel almost got separated from the main flow in the west.

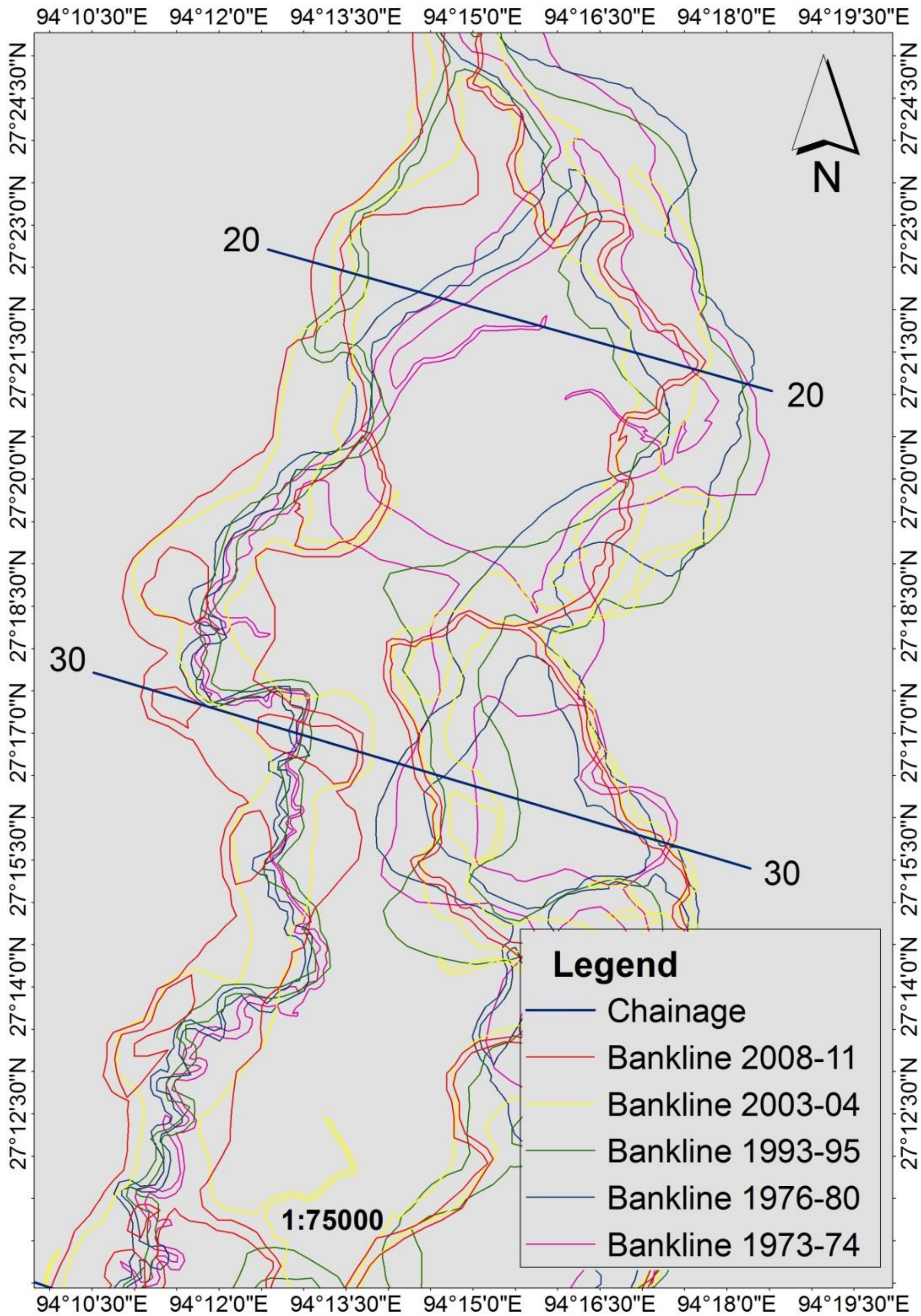


Figure 27: Changes in Reach-3 over 1973-74 to 2008-11

From Fig. 27, it had been observed that during 1973-74 both the eastern and western channels of the Subansiri were connected by a small channel which got disappeared in due course of time. Also, shift in the major river flow from eastern channel to the western channel was observed after 1993-95 which led to the widening of the western channel causing erosion in the right bank. In the downstream of the Reach 3, a bifurcation in the eastern channel was observed during 2003-11.

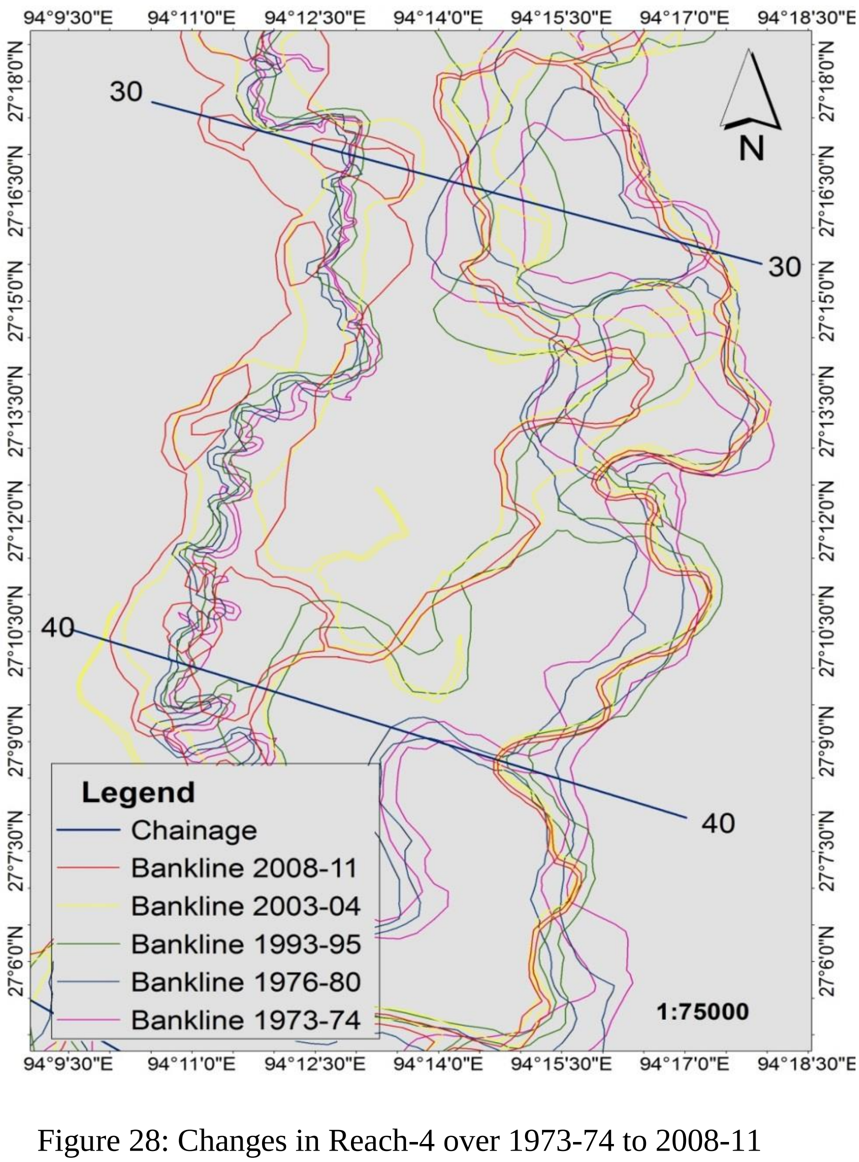


Figure 28: Changes in Reach-4 over 1973-74 to 2008-11

In Reach 4, near the downstream, a bifurcation in the eastern channel was observed during 1993-95. One of these bifurcated channels then again joined the western channel at the junction of the Reach 4 & 5. Also, changes in the river course at different points were observed in this reach.

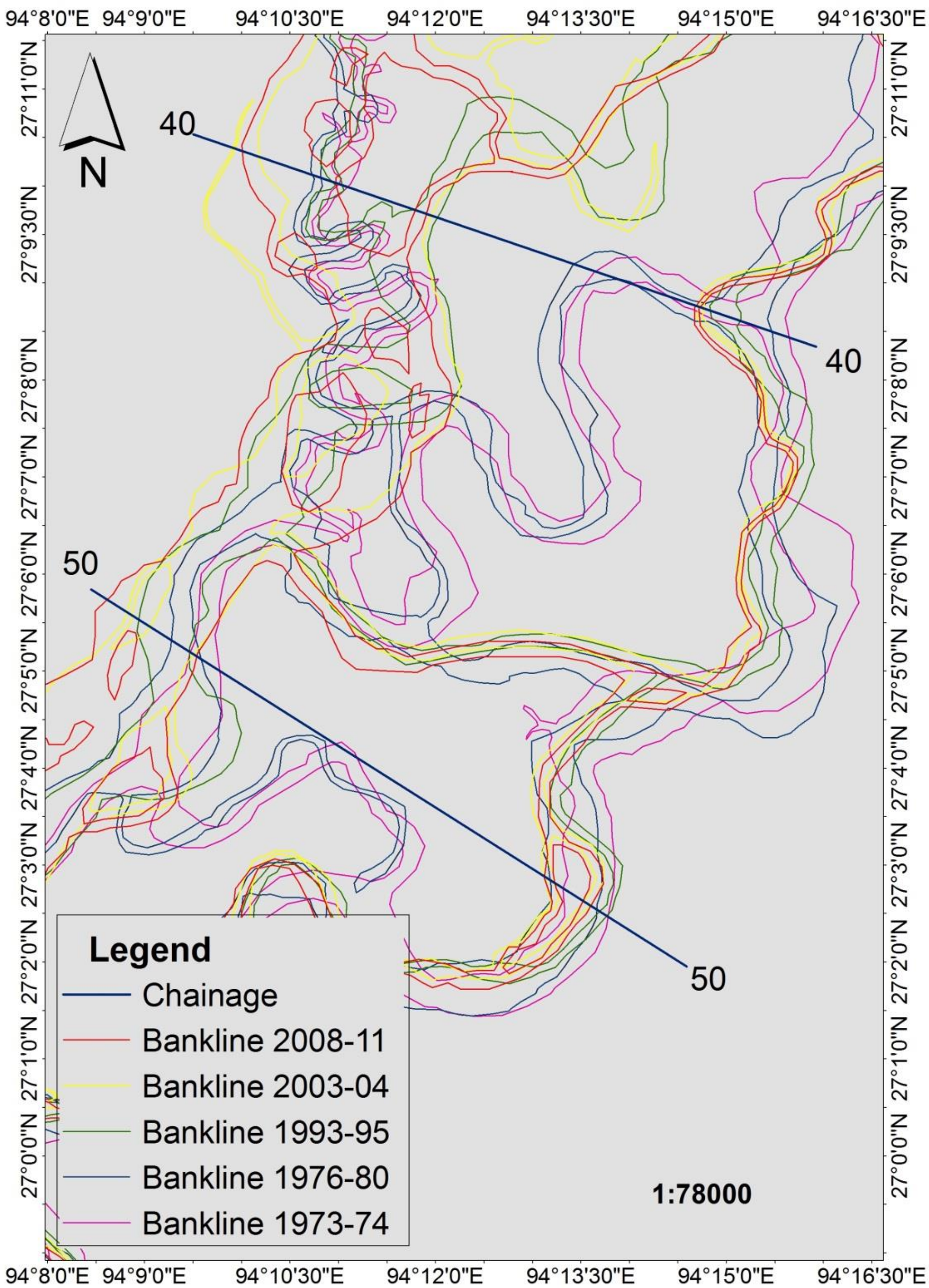


Figure 29: Changes in Reach-5 over 1973-74 to 2008-11

Fig. 29 depicts that the eastern channel of the river Subansiri was bifurcated into two flows at the junction of the Reach 4 & 5, during 1973-80, one meeting the western channel and the other joining the Kherkatia Suti in the east. After 1980, this bifurcation was shifted towards the downstream of Reach 5 to a point where another bifurcation was there in 1976-80. Also, before 1993-95, the western channel was flowing in a narrow meandering pattern which got straightened and widened afterwards**.**

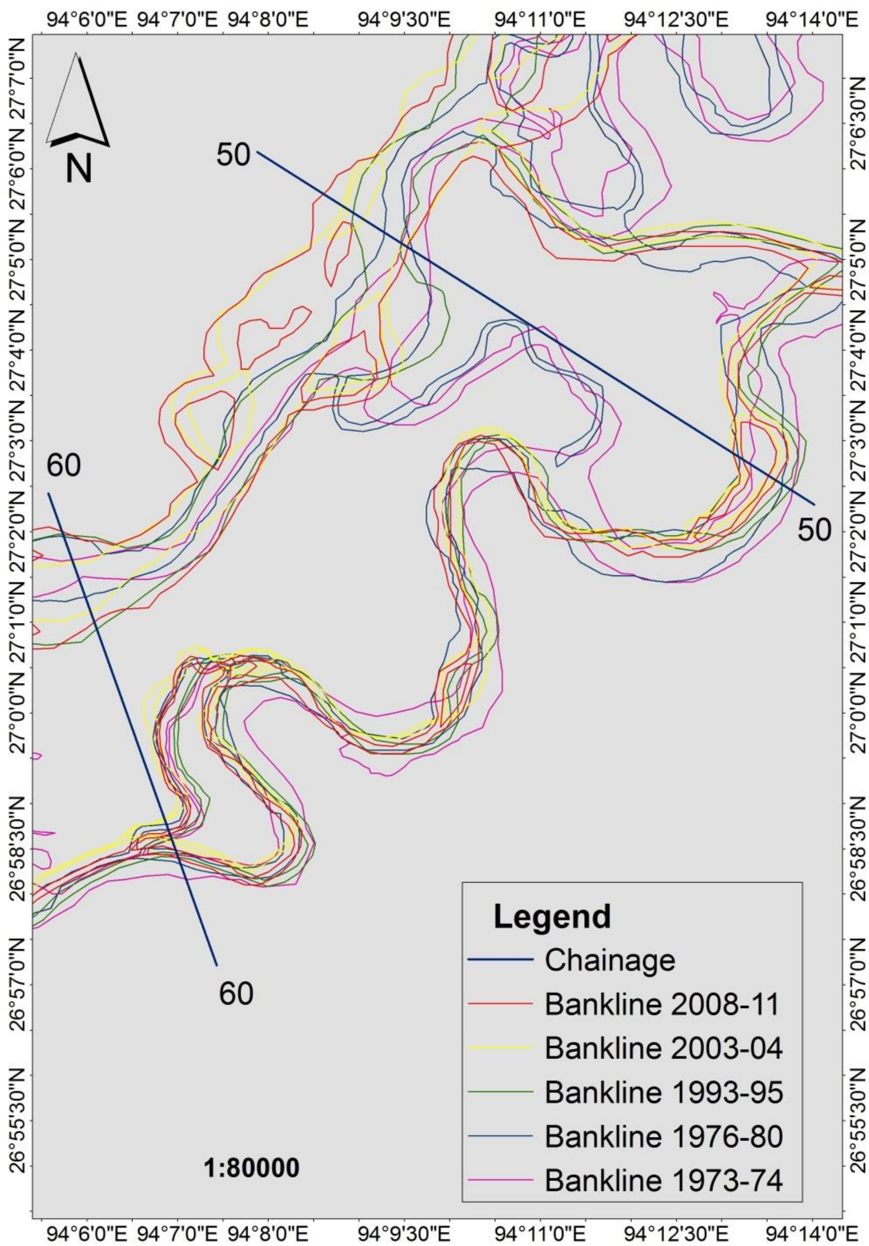


Figure 30: Changes in Reach-6 over 1973-74 to 2008-11

It is evident from Fig.30 that in Reach 6, the river Subansiri was somewhat stable than the upstream reaches. At the upper part of this reach, during 1973-74, a small channel used to connect the eastern channel with the western channel which got disconnected during 1976-80 and disappeared afterwards. Also, it was observed that the eastern channel became narrower after 1976-80 while the western channel got widened after 1993-95 causing bank erosion in that part.

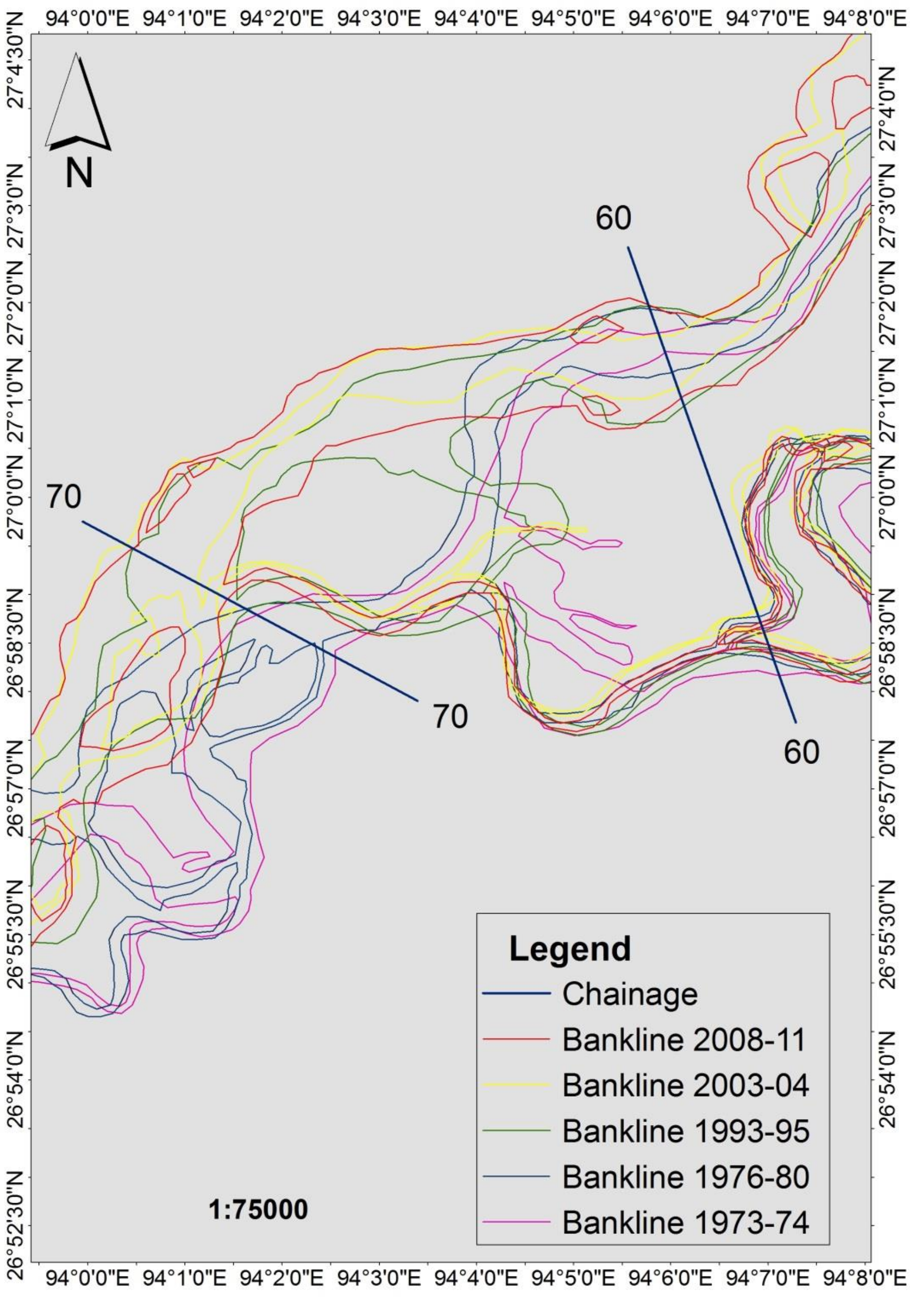


Figure 31: Changes in Reach-7 over 1973-74 to 2008-11

It was observed from Fig.31, that the two parallel channels of the river Subansiri merged to a single channel in Reach 7. After 1976-80, the western channel moved more towards the west than the previous course and the joint of the two channels then shifted towards the downstream of the reach.

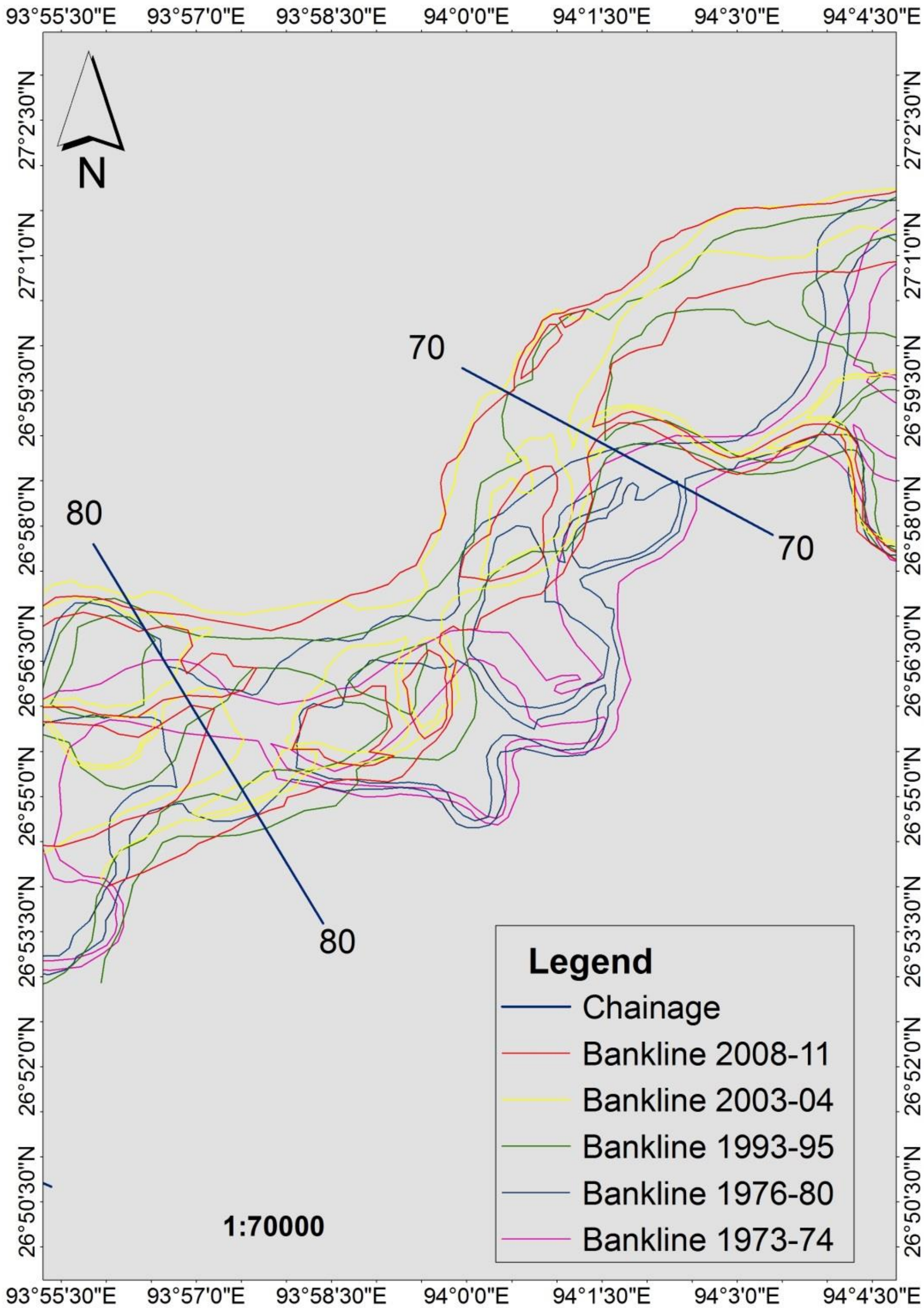


Figure 32: Changes in Reach-8 over 1973-74 to 2008-11

Fig.32 depicts a gradual westward shift in the course of the Subansiri leading to severe bank erosion in the right bank of the river. Also, at the downstream of the Reach 8, continuous widening of the channel was observed over the years.

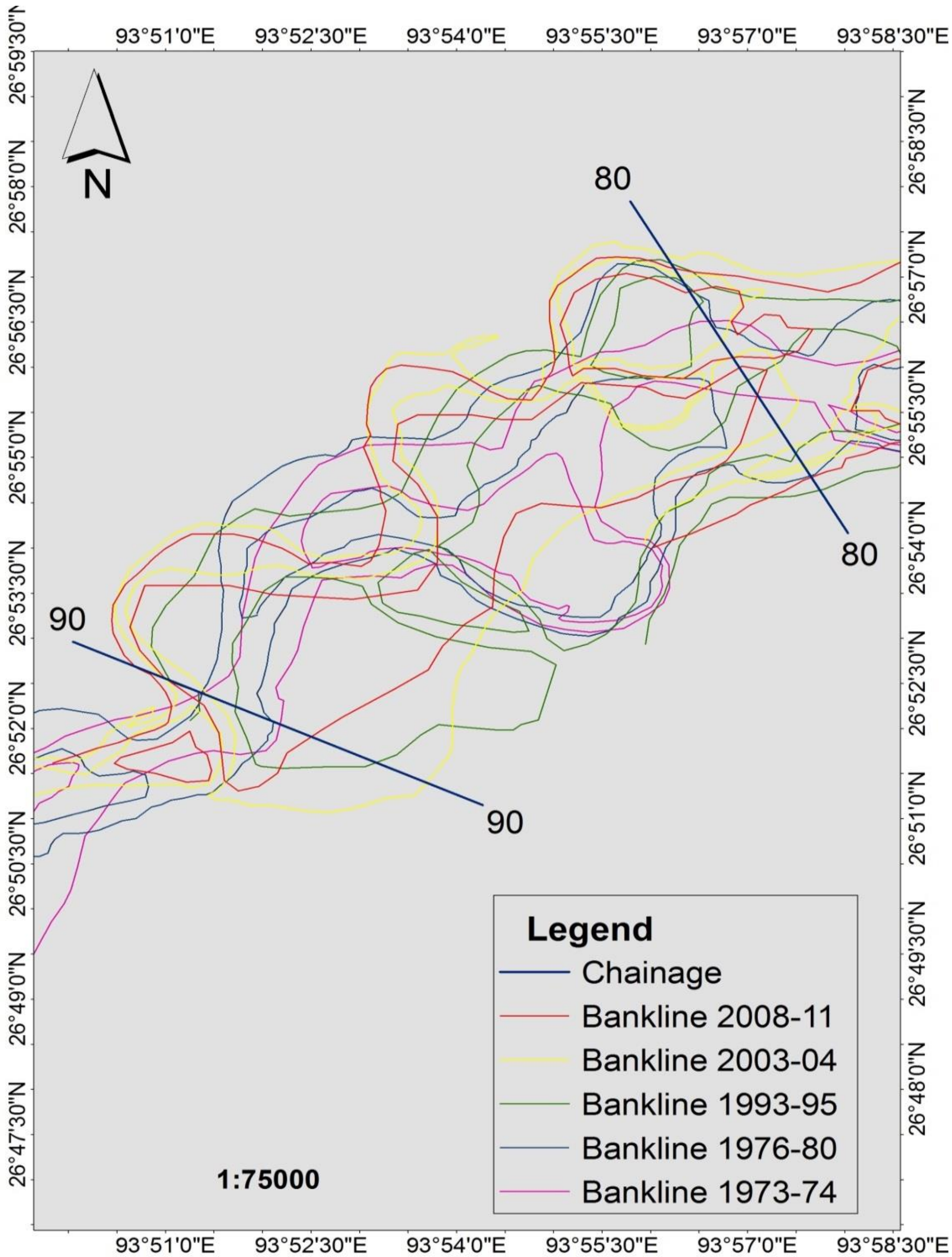


Figure 33: Changes in Reach-9 over 1973-74 to 2008-11

From Fig. 33 &34, it was found that the reaches 9 & 10 were the most critical reaches of the entire river stretch in the Assam plains as these two reaches were continuously witnessing havoc due to bank erosion caused by both the Brahmaputra and Subansiri rivers. Owing to the erosion caused by these two rivers, the confluence point shifted from downstream of Reach 10 during 1973-80 to the upstream of Reach 9 during 1993-2011.

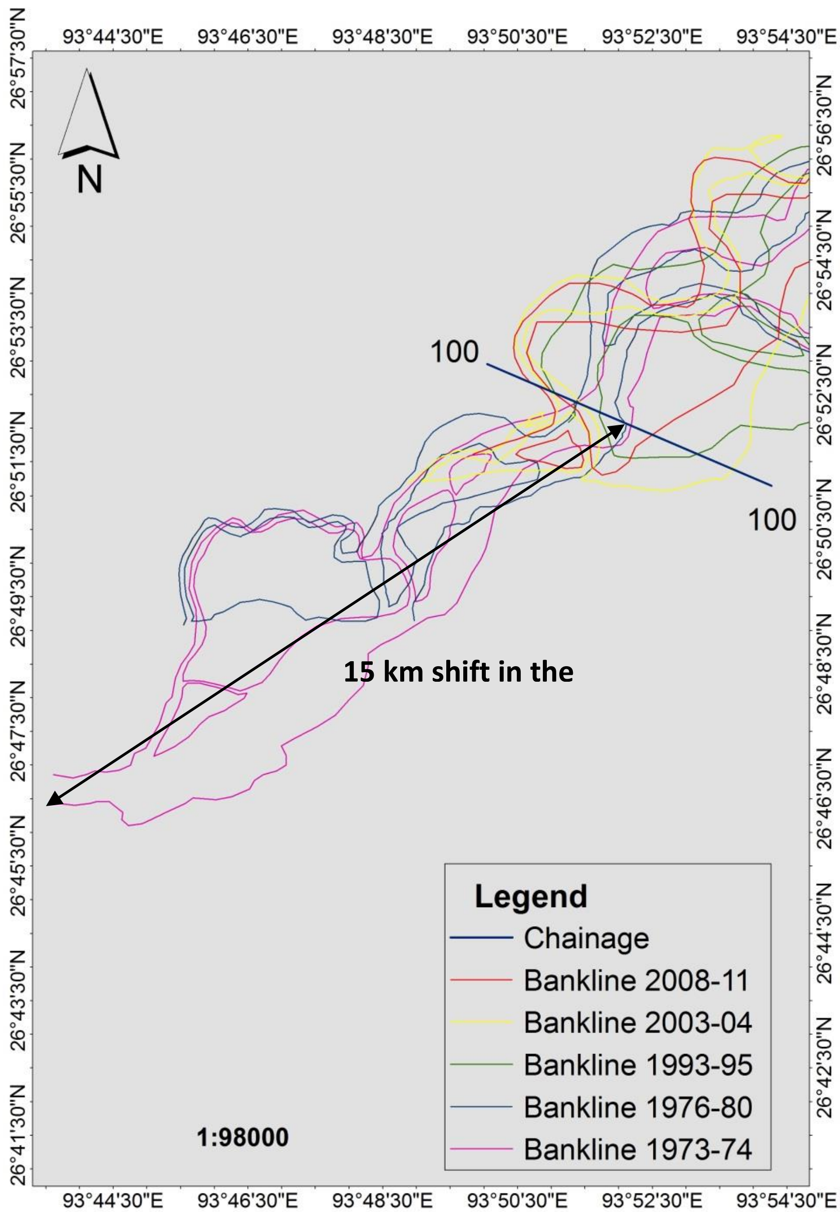


Figure 34: Changes in Reach-10 over 1973-74 to 2008-11

An approx. shift of 15 km has been observed in the confluence point with the Brahmaputra over 1973-74 to 2008-11.

10.2 Channel dimension

To study the changes in the width of the river Subansiri the river from Gerukamukh (Assam-Arunachal Pradesh border) to its confluence with river Brahmaputra is considered. The whole river had been divided into sections of 10 km reach and then width of the river at each section for all the study periods was measured. A plot of the width against each section was then plotted in excel (Figure 33). The plot has been done using the centerline of the river.

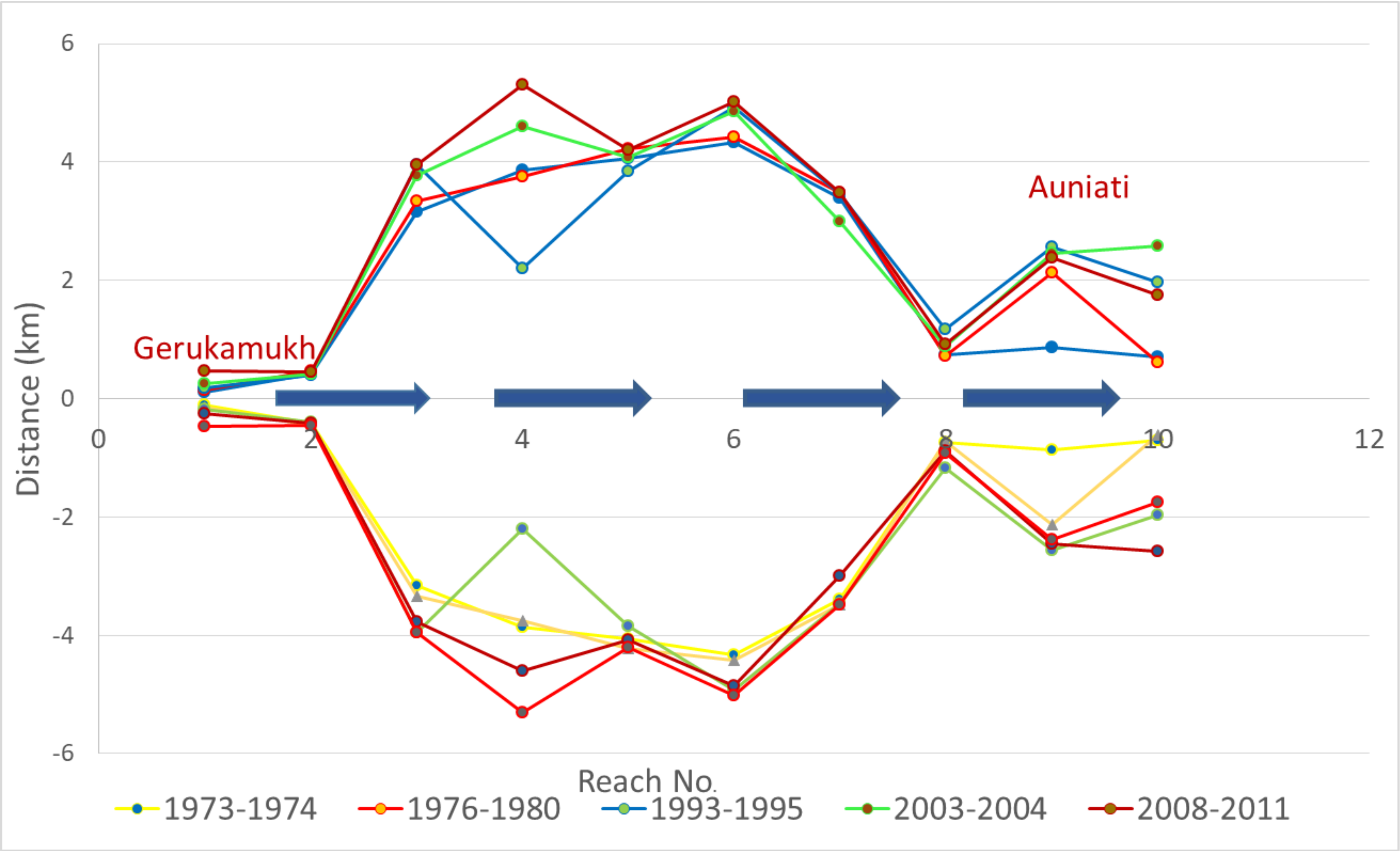


Figure 35 Channel Dimension of Subansiri River

10.3 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.

10.3.1 Methodology

The longitudinal profile has been prepared for the main stem of the Subansiri river(Fig.36). It was prepared from Google Earth by considering the elevations at a distance of 10 km from its origin in China till its confluence with the Brahmaputra at Majuli. The profile shows that the river has a steep slope in its mountainous stage. The slope gradually decreases when it reaches plains of Assam.

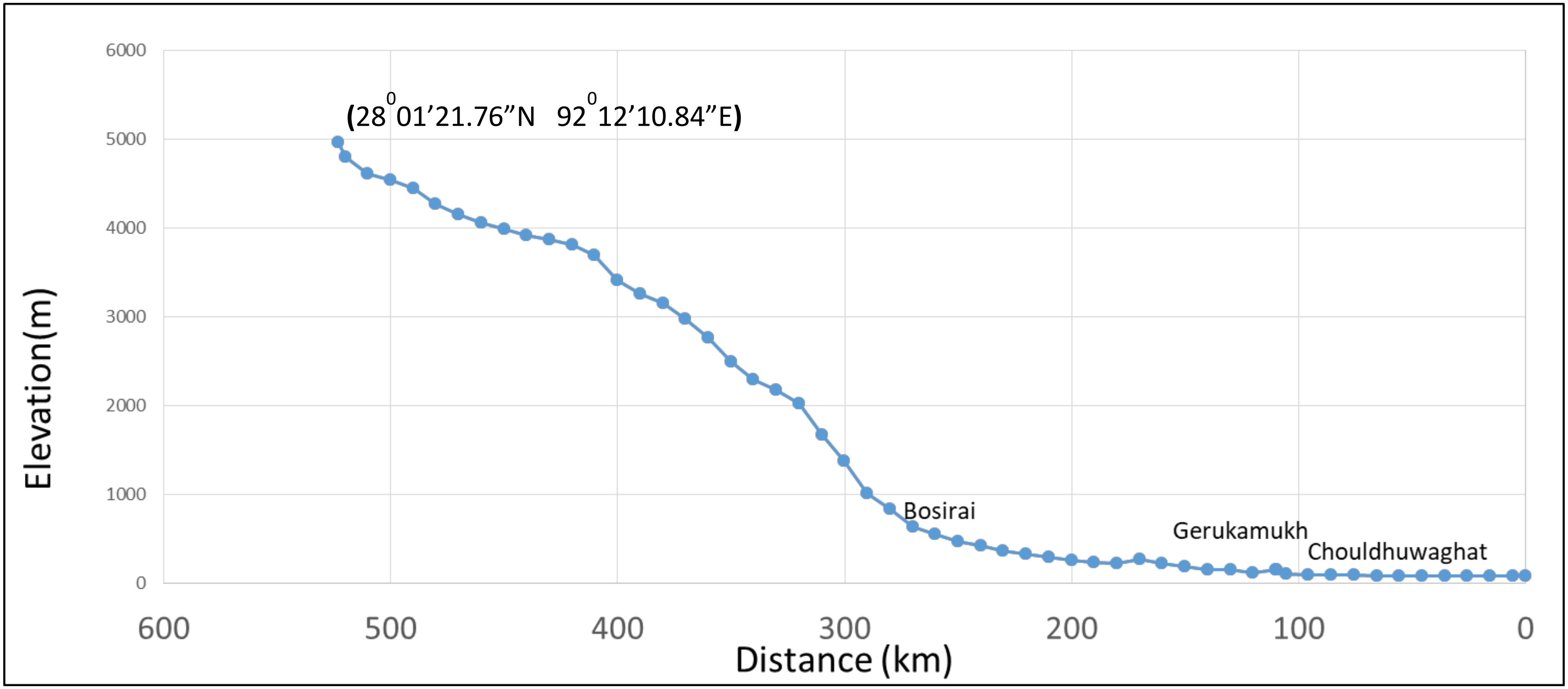


Figure 36 Longitudinal Profile of Subansiri River

10.3.2 Observation

From the plot of the longitudinal profile Subansiri River, it can be observed that the elevation at the upstream part is 4800m. Traversing through the hilly areas of Arunachal Pradesh Gradually on entering Assam the elevation get reduces and finally reached to 78 m above MSL at the confluence point with Brahmaputra River at Majuli. At Gerukamukh in the Assam-Arunachal border, a small hump can be observed at an elevation of 267 m at the location of the Subansiri Lower Hydroelectric Power Project.

10.4 Meander Parameter Analysis

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.

10.4.1 Methodology

The parameters of meander have been calculated by considering sections of 10 km from the origin at Bhutan hills till its confluence with Brahmaputra. A total of 10 reaches are generated. The reaches are selected based on the occurrence meanders. The meander lengths, meander width and bankfull widths are then calculated. The meander width ratios are then calculated from meander width and bankfull width.

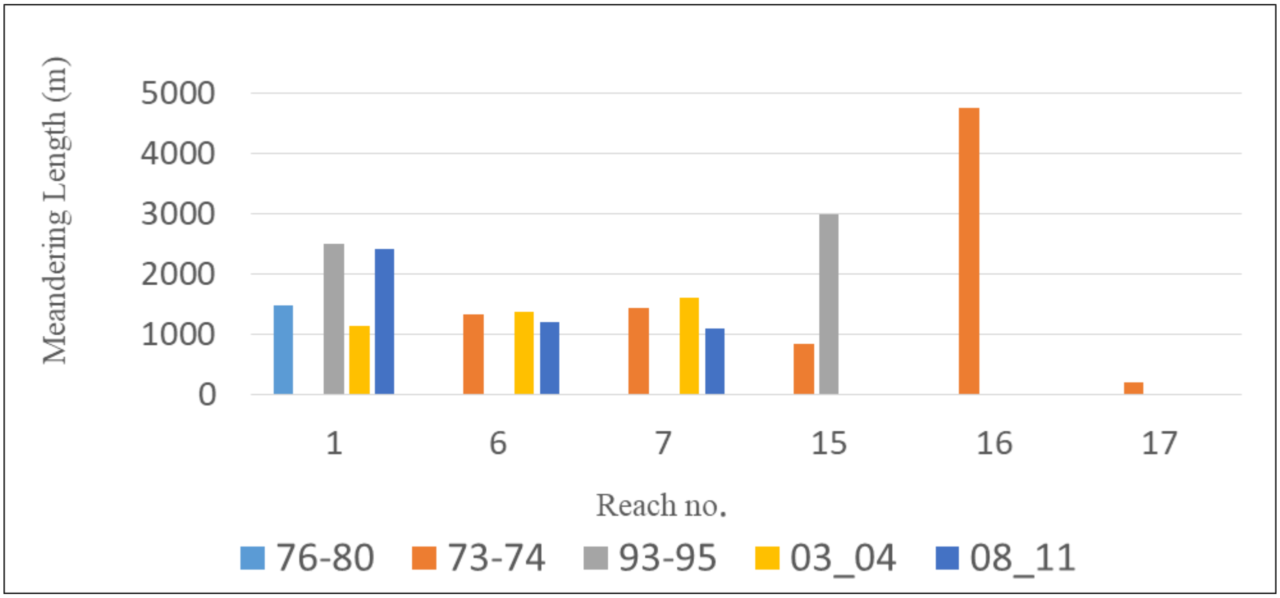


Figure 37: Reach-wise Meandering Length of Subansiri (1976-80 To 2003-04)

Year/ Reach No.	1	6	7	15	16	17
76-80	1468.575	-	-	-	-	-
73-74	-	1336.24	1424.207	848.0977	4743.011	202.5288
93-95	2485.936	-	-	2992.18	-	-
03-04	1144.985	1363.11	1596.824	-	-	-
08-11	2406.74	1205.56	1092.85	-	-	-

Table 4:Reach-wise Meandering Length of Subansiri (1973-74 To 2003-04)

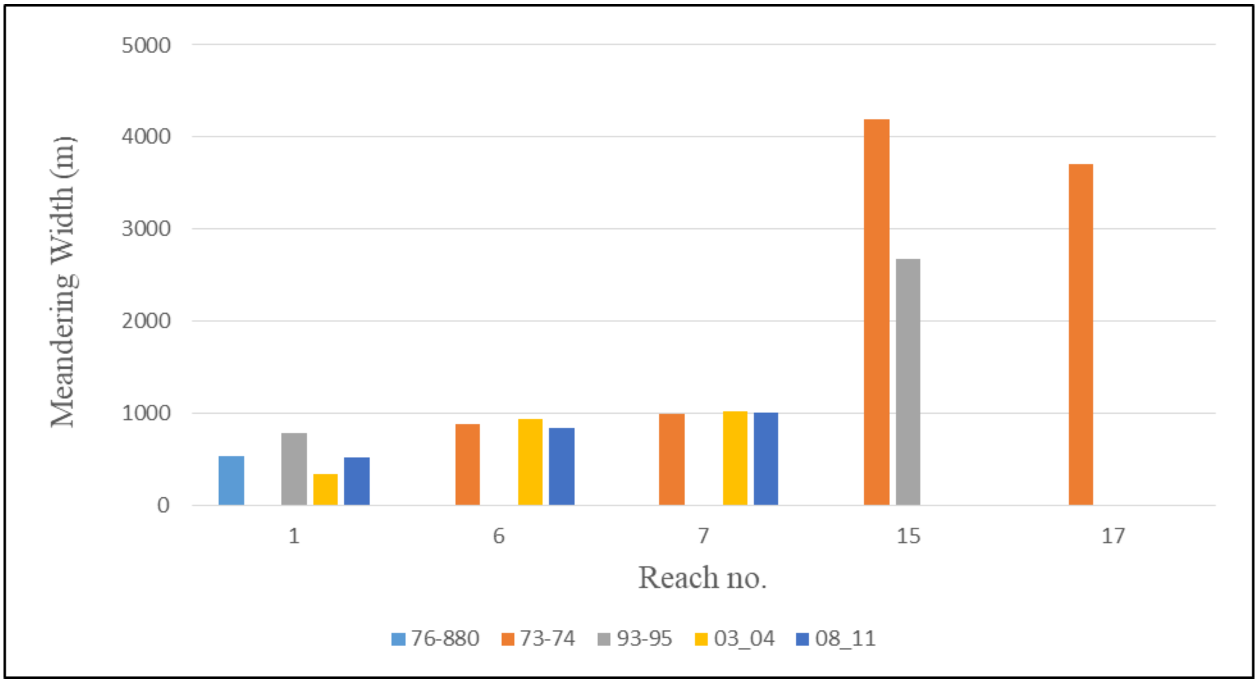


Figure 38: Reach wise Meandering Width of Subansiri (1973-74 to 2008-11)

Table 5: Reach wise Meandering Width of Subansiri (1973-74 to 2008-11)

Year/ Reach No.	**1**	**6**	**7**	**15**	**17**
76-80	538.4413	-	-	-	-
73-74	-	880.9233	999.1992	4188.292	3703.707
93-95	785.3075	-	-	2679.572	-
03-04	336.2929	934.6067	1017.025	-	-
08-11	518.043	846.9009	1014.71	-	-

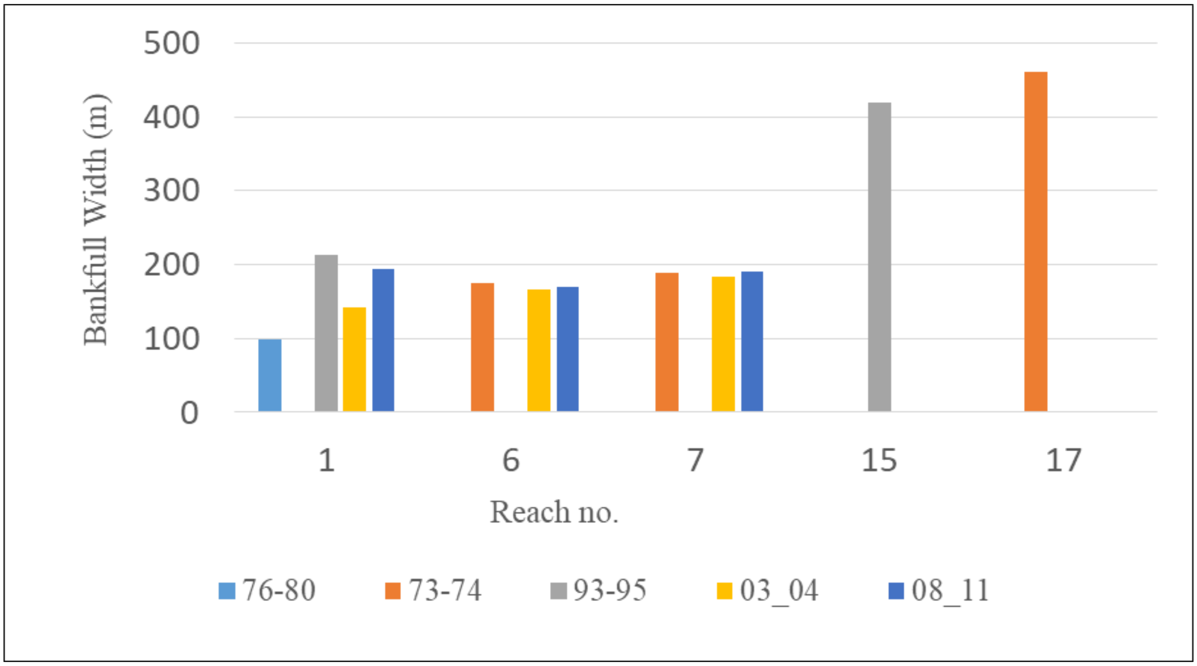


Figure 39: Reach wise Bankfull Width of Subansiri (1973-74 to 2008-11)

Table 6: Reach wise Bankfull Width of Subansiri

Year/ Reach No.	**1**	**6**	**7**	**15**	**17**
76-80	99.40509	-	-	-	-
73-74	-	175.135	188.632		461.1013
93-95	213.181	-	-	418.9949	-
03-04	141.6257	166.8238	184.3565	-	-
08-11	194.2479	169.2537	189.9875	-	-

Table 7: Reach wise Meander ratio of Subansiri

Year/ Reach No.	1	6	7	15	17	Nature Of The Channel
76-80	5.41663	-	-	-	-	Almost Stright
73-74	-	5.02996	5.29708	-	8.03323	Almost Straight To Moderately Meandering
93-95	3.68375	-	-	7.11123	-	Almost Straight To Moderately Meandering
03-04	2.37451	5.60235	5.516621	-	-	Straight To Almost Straight
08-11	2.66691	5.00373	5.34093	-	-	Straight To Almost Straight

10.4.2 Observations

From the analysis, it has been observed that the lengths of the meanders are found to be varying within the years. At reach 1 it can be seen that at 1973-74,1993-5,2003-04,2008-11 the meander lengths of 1.4km,2.48km,1.14 km, and 2.40 km were observed respectively. Reach 15 and 16 experienced the highest meander occurrence.

The meander width of Subansiri is maximum in the year 1973-74 as 4.18 and 3.70 km respectively. In 1973-74 and 1993-94 the bankfull width is maximum at 17 and 15 reach From the analysis of meander width ratio the nature of the channel can be determined. The nature of the channel varied from almost straight to moderately meandering in due course of time.

Chapter 11
STREAM BANK EROSION

11.1 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 of 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.

11.1.1 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.

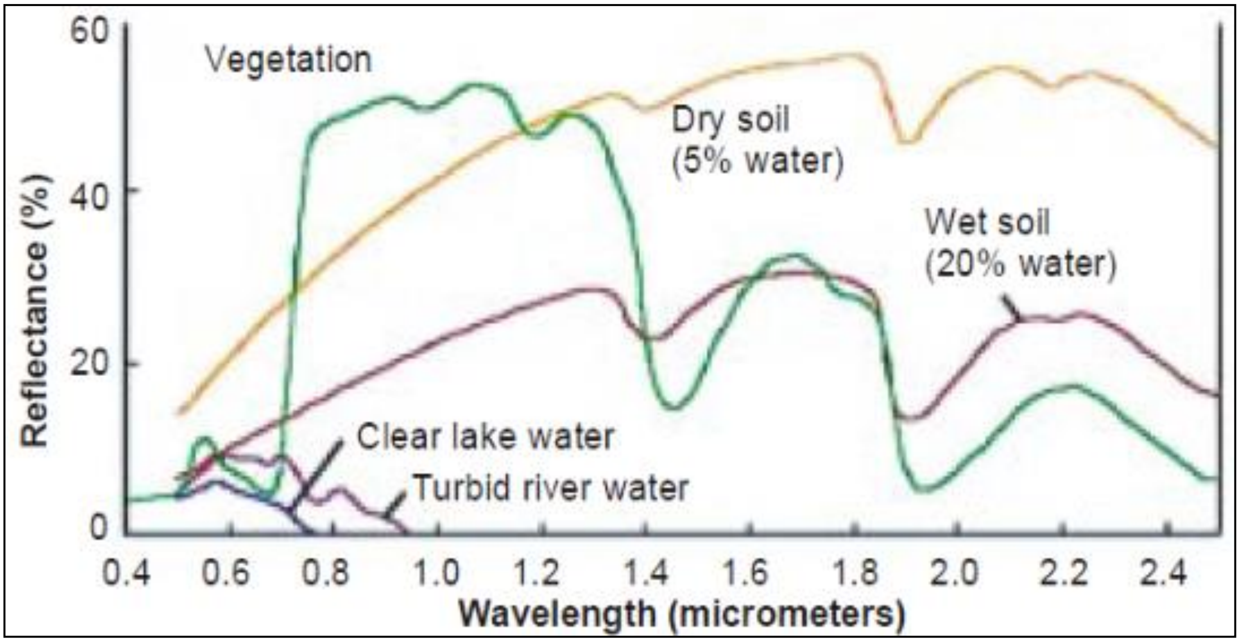


Figure 40: Spectral reflectance curves for different objects

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,

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

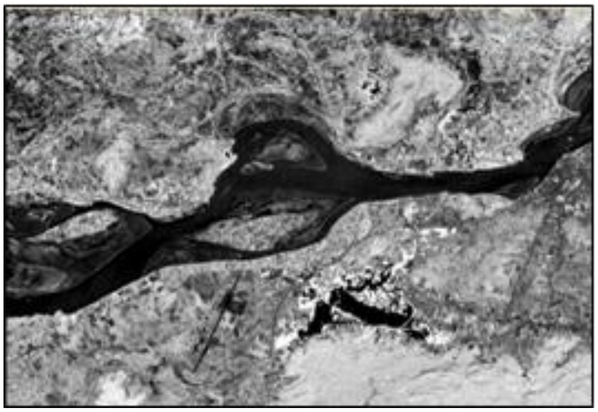


Figure 41: NDWI image derived from LISS 3 imagery using NIR (band 4) and SWIR (band 5) band ratio

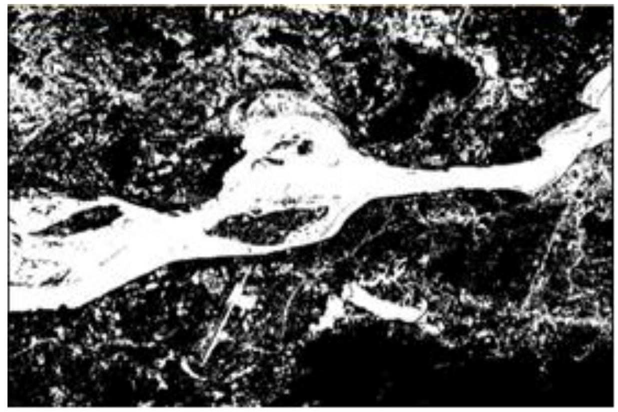


Figure 42: Automatic delineation of water bodies based on NDWI generated form LISS 3 imagery

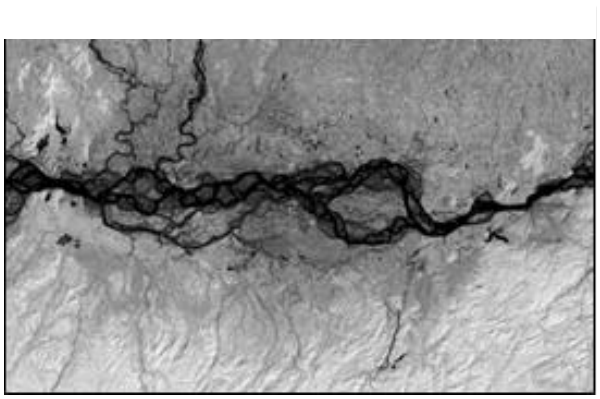


Figure 43: NDWI image derived from TM imagery using NIR (band 4) and Green (band 2) band ratio

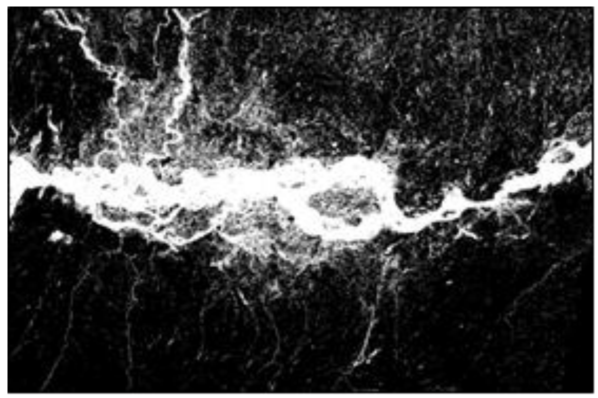


Figure 44: Automatic delineation of water bodies based on NDWI generated from TM imagery

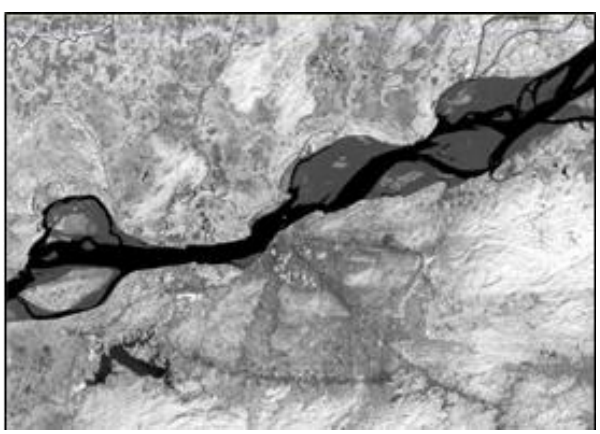


Figure 45: NDVI image derived from LISS 4 imagery using NIR (band 4) and Red (band 3)

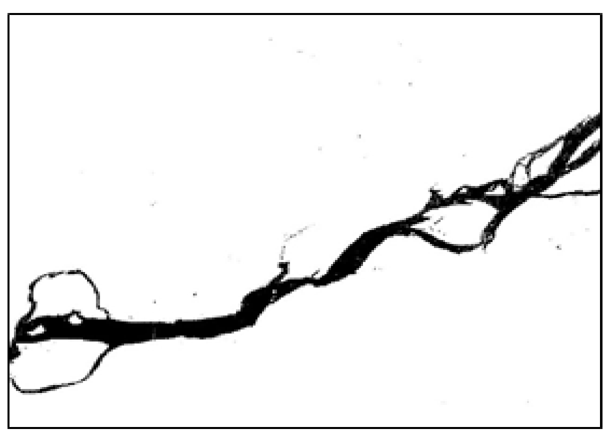


Figure 46: Automatic delineation of water bodies based on NDVI generated from LISS 4 imagery

NDWI output image (Figure 41 & 43), 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 42 & 44). The model used for NDWI and automatic delineation of water bodies in ERDAS is shown in Figure 47.

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

NDVI is calculated as,

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

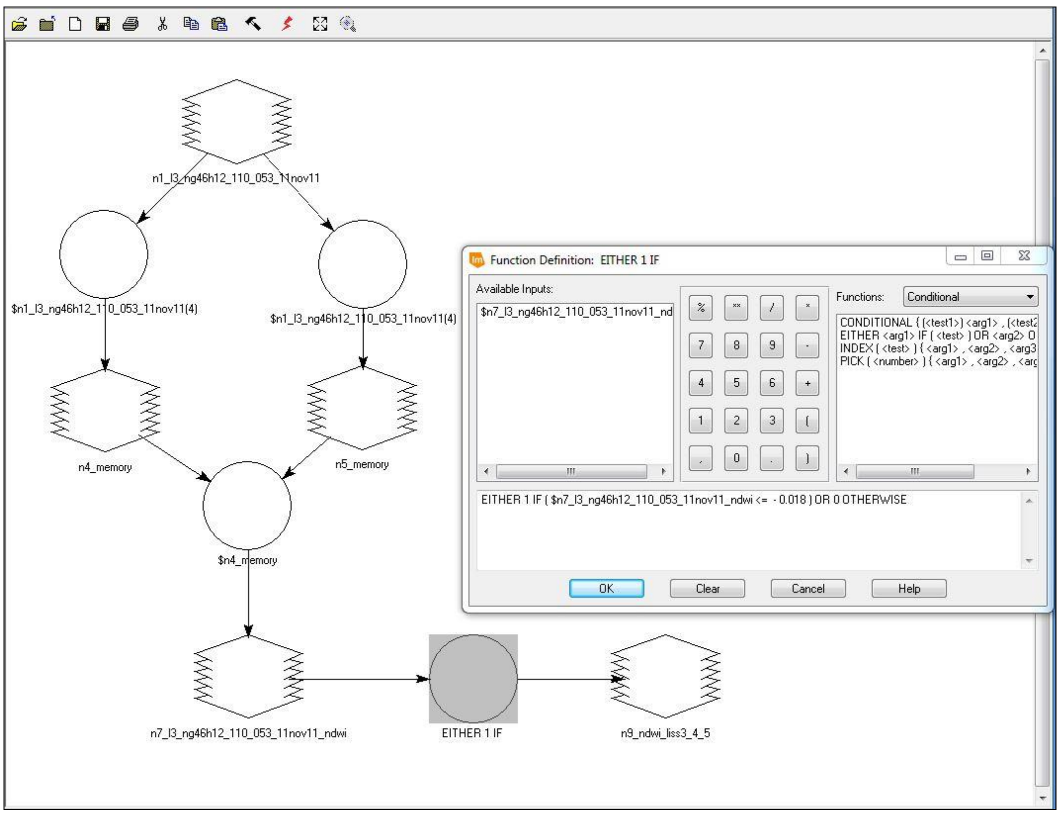


Figure 47: Erdas model used for auto delineation of water bodies

11.1.2 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 (Figur 42). 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.

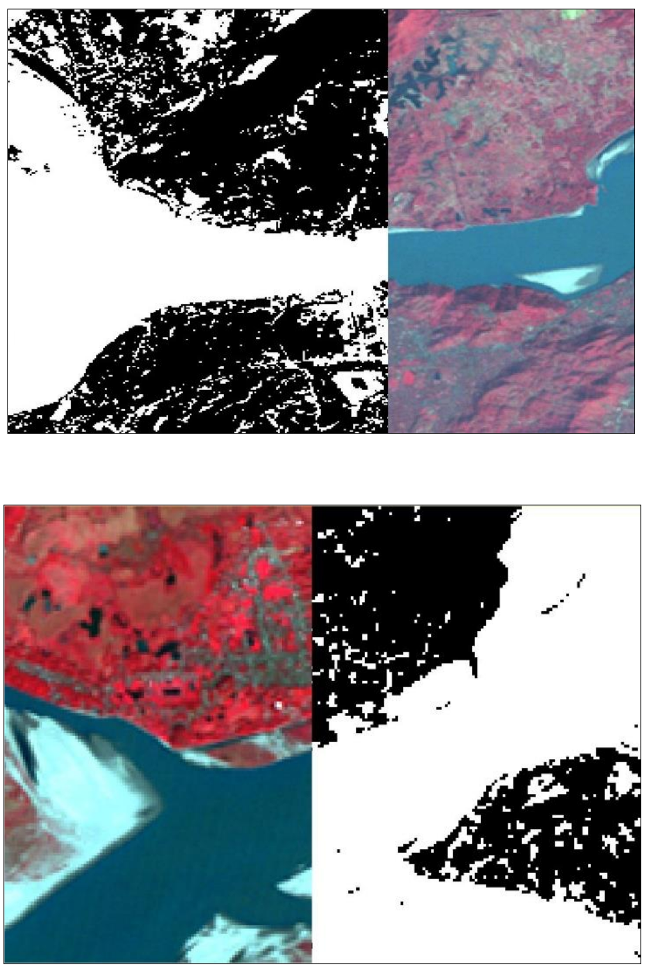


Figure 48: Comparison between real bankline and auto delineated river bankline for two different sensors (a. LISS 3; b. TM)

11.1.2.1 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 modeling, 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 Subansiri has been done for different years using ArcGIS 9.3. The delineated banklines are used to study the channel evolution process and analysis of various morphological parameters.

11.1.2.2 Methodology

The Subansiri River system with the confluence of important tributaries from upstream of Arunachal Pradesh till its confluence with the Brahmaputra was delineated from satellite imagery (Figure 21). The banklines of river Subansiri 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 bankline shifting and to study various morphological parameters. Figure 43 shows the digitized Subansiri River system. The river Subansiri originates from the Himalayas in China and meets the Brahmaputra at Majuli. On entering the plains of Assam the river takes the fan shape. Numerous channels can be observed in this part. This is due to the sudden change in the slope and the area of spread as it is concise within the hills in its upper reaches. The river after flowing for some area again constricted and it's lower reaches numerous anastomosing channels join.

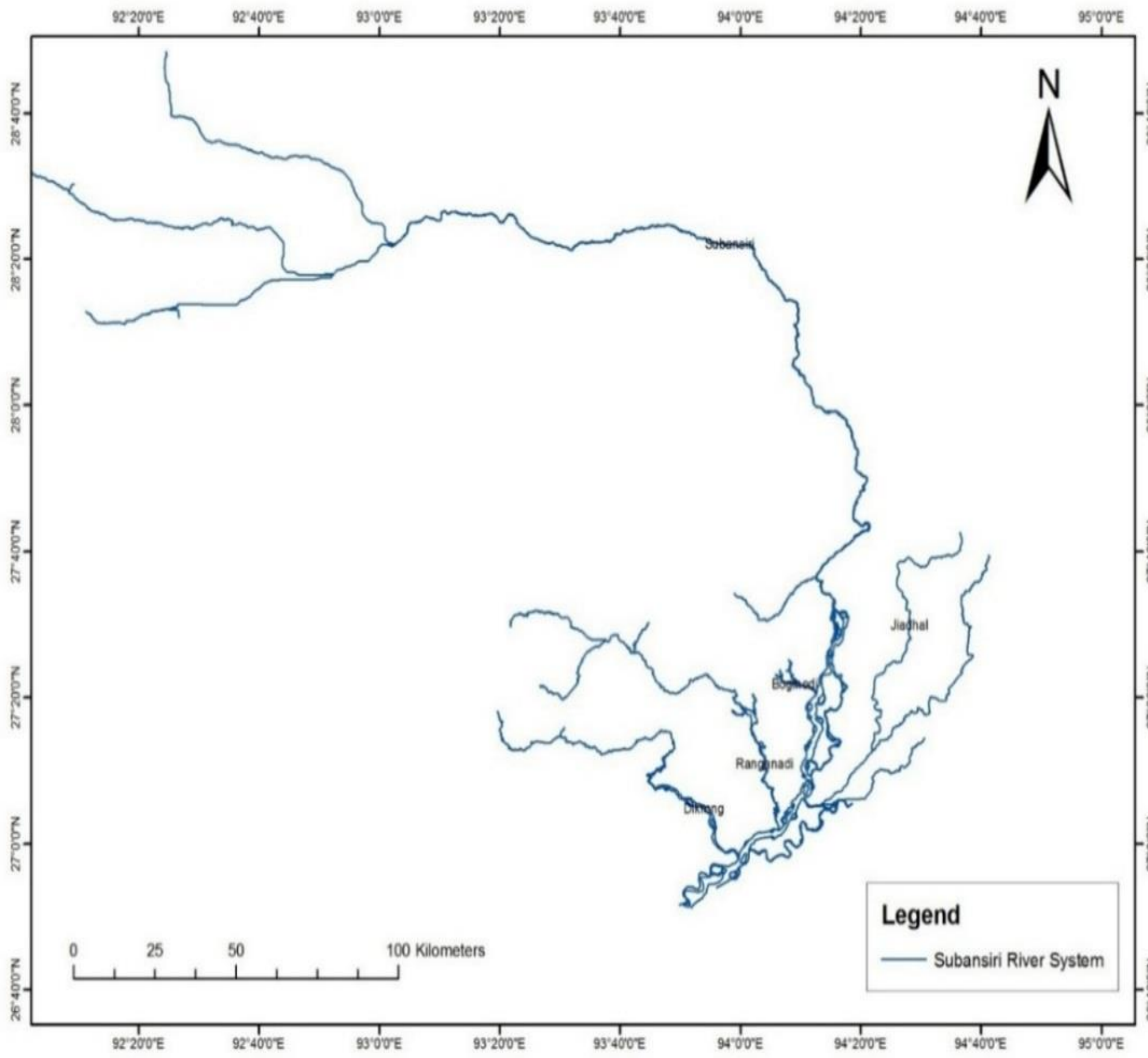


Figure 49: Subansiri River System

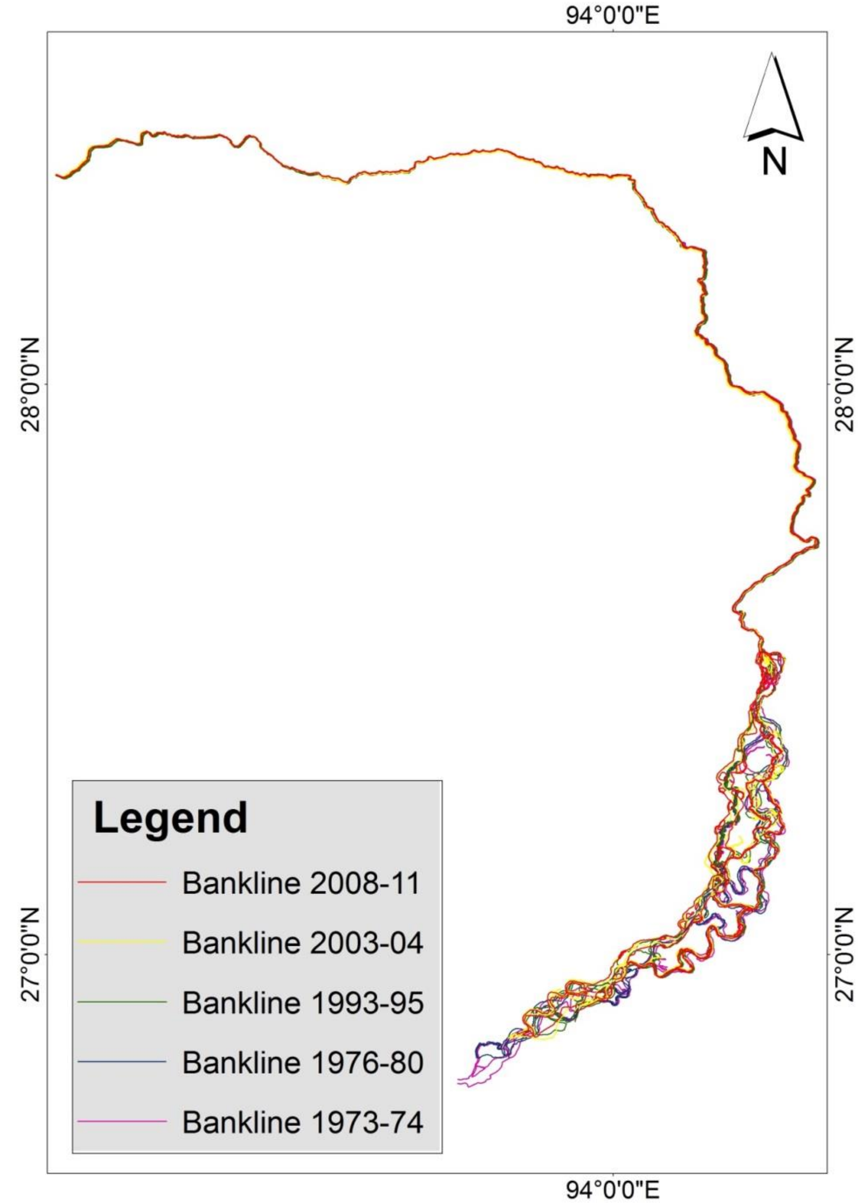


Figure 50: Subansiri banklines at different time periods

11.2 Plan Form Index

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,

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

11.2.1 Methodology

In this study, the Plan Form Indices were computed for every 10 km reach starting from upstream of Subansiri at Gerukamukh near Subansiri Lower Dam Site till it confluence with Brahmaputra at Majuli. . A sample calculation of PFI is shown in (Fig 45)The cross section indicating highest braiding within each reach were selected on the basis of visual analysis and corresponding PFI were compute. These exercise had been performed for all the datasets and were tablulated as ANNEXURE III.

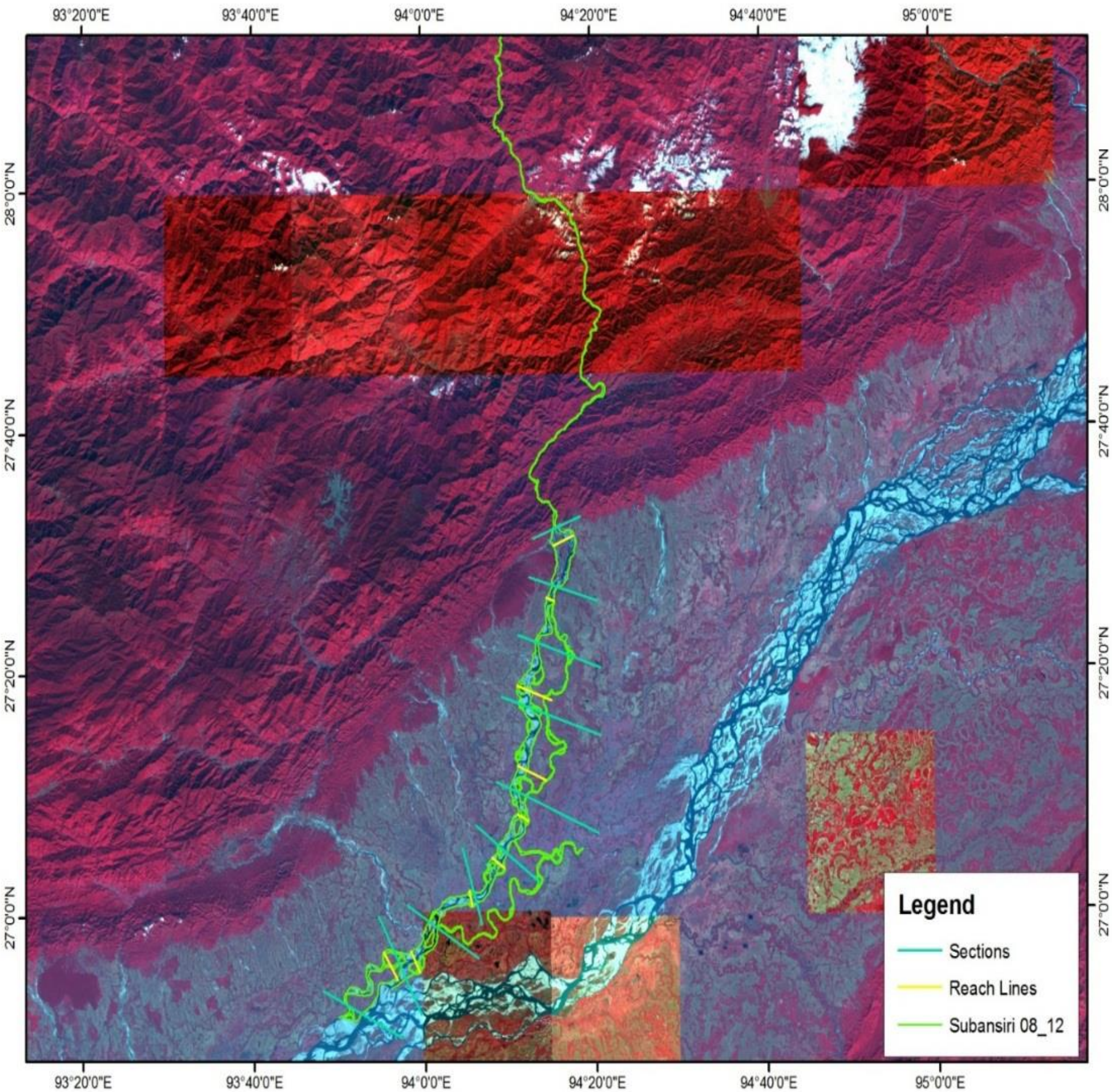


Figure 51: Sections of Subansiri identified for PFI calculations

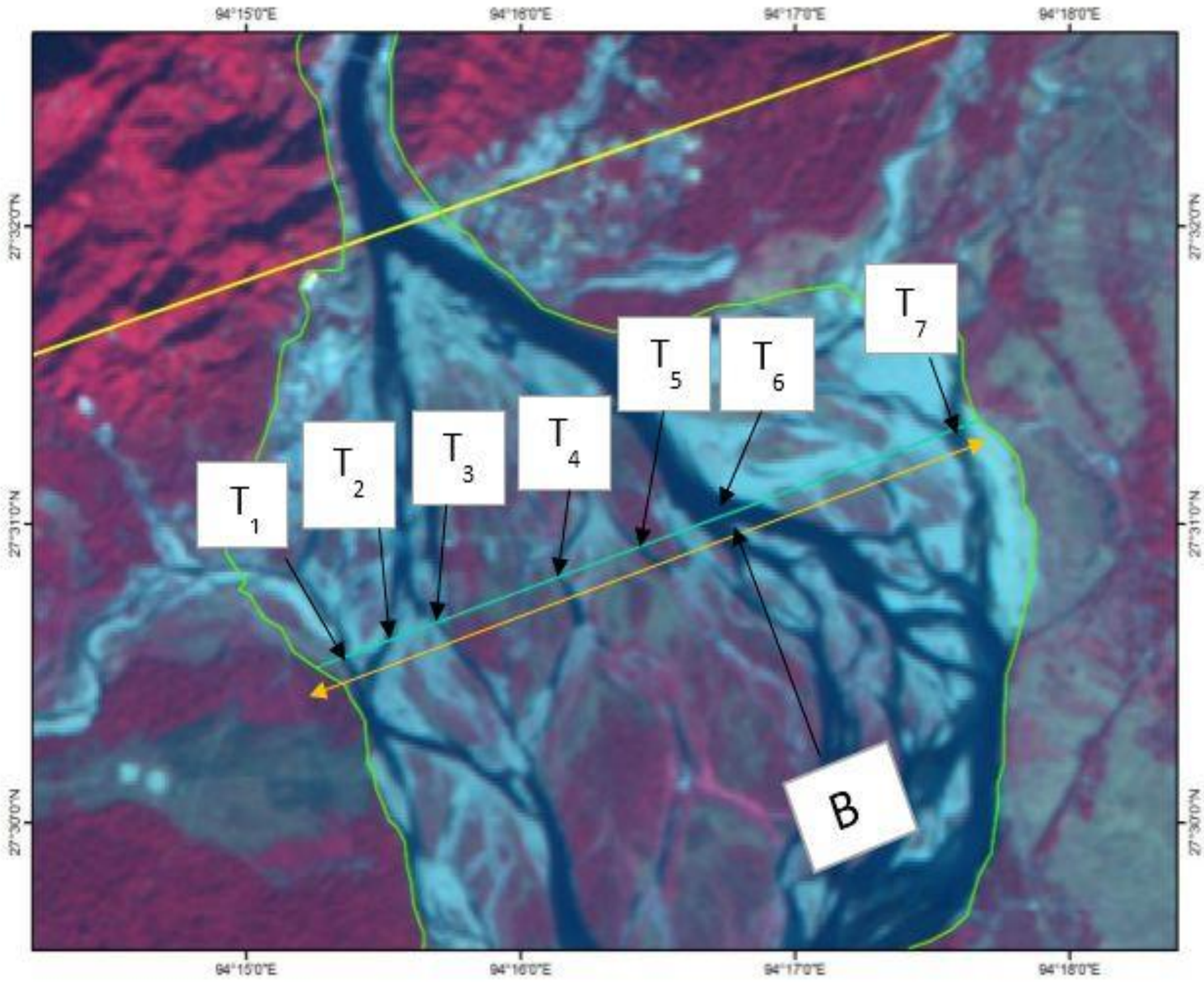


Figure 52: PFI calculation at Reach No. 1 of Subansiri River (2008-2011)

T=T1+T2+T3+T4+T5+T6+T7

= 0.96 km

B = 4.26 km

N = 7

$$PFI = \frac{0.96 \times 100}{4.26 \times 7}$$

=3.21 < 4

Highly Braided

The computed PFI values were plotted against the reach number and is shown in Figure 47 to 50

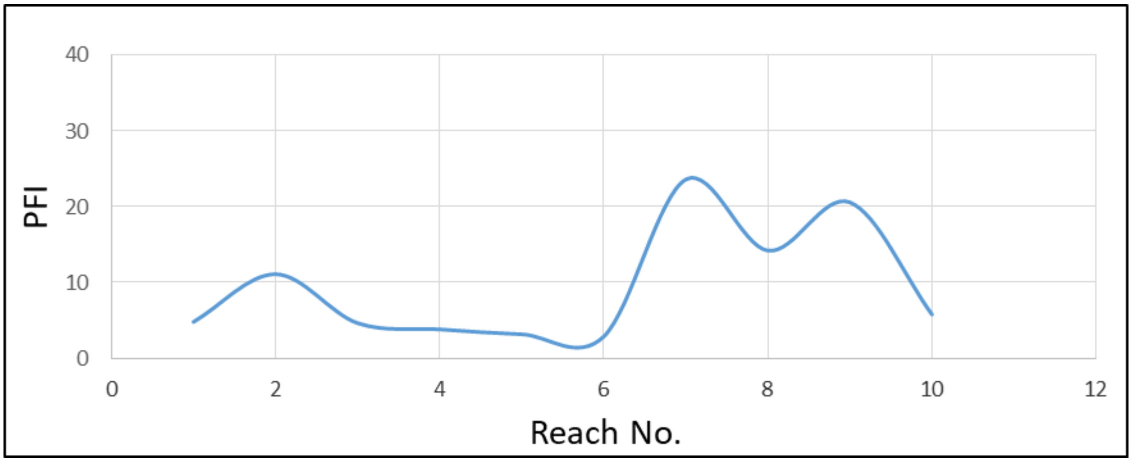


Figure 53: PFI at various sections of Subansiri river 1976-1981

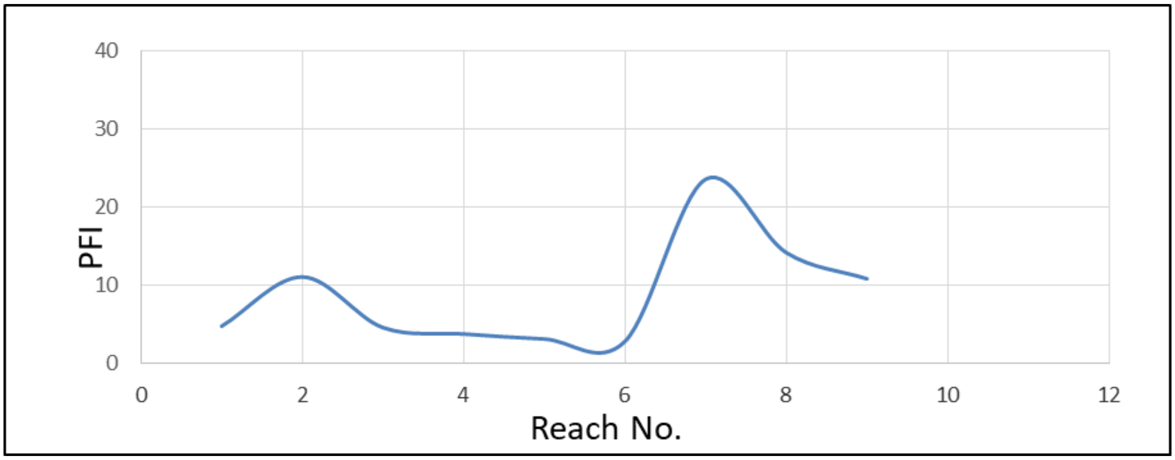


Figure 54: PFI at various sections of Subansiri river 1993-1994

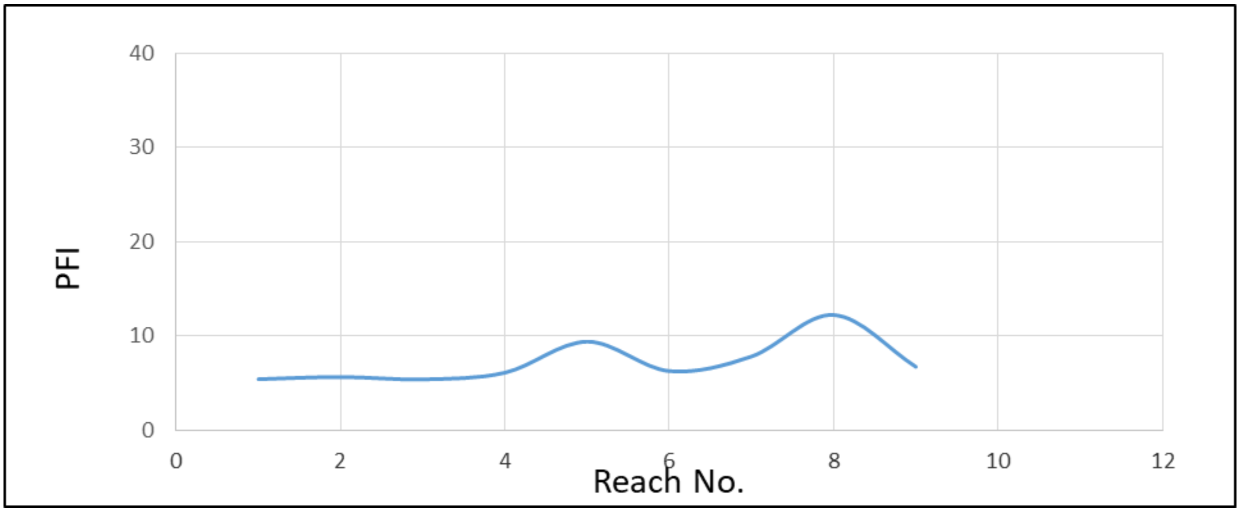


Figure 55: PFI at various sections of Subansiri river 2003-2004

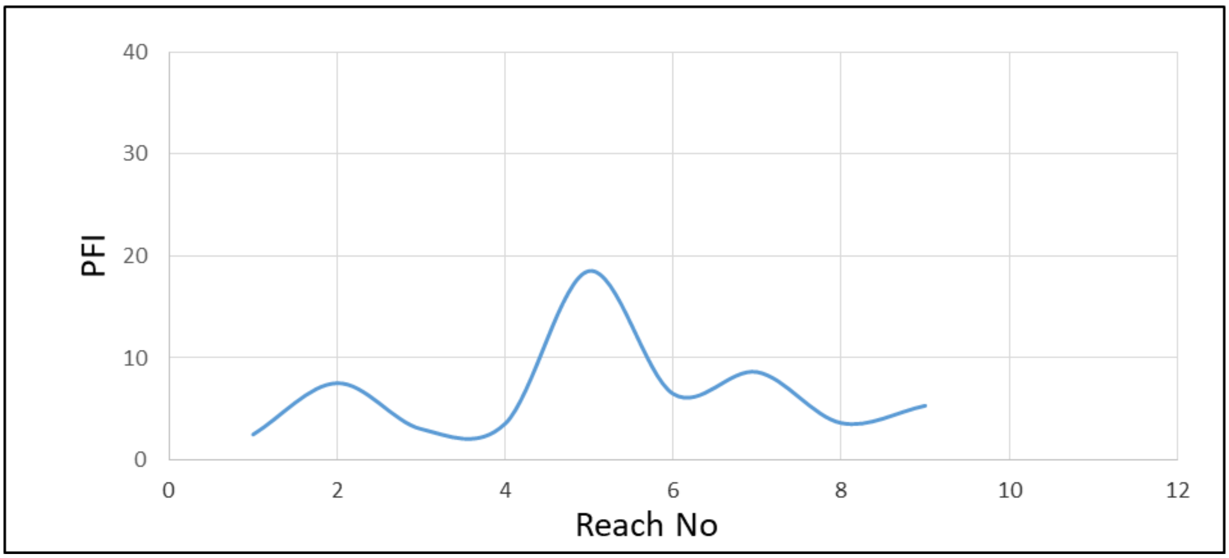


Figure 56: PFI at various sections of Subansiri river 2008-201

11.2.2 Observation

From the analysis, it can be seen that the river is moderately braided as the values generally range between 4 -19. In the year 1976-80, reaches 4, 5, 6 are highly braided and in the subsequent years, the braiding has lowered till 2003-04. However, in 2008-11 reach 4 is highly braided. All the other reaches are moderately braided. However, in the year 2008-11 high braiding can be observed at reach 8.

Chapter 12
IMPACT OF HYDRAULIC STRUCTURES

Hydraulic structures like dam, bridges, groynes influence the river morphology up to a great extent. At the bridge location both for the upstream and downstream it is affected by severe bank erosion, which was not, terminated with usual protective measures (Biswas, 2009)

12.1 Impact of Dams

The major hydraulic structure over Subansiri River includes the Lower Subansiri Hydroelectric Power Project of 2000MW. However, the operation of the dam is not yet started. So, no major impact on the flow of the river is observed. The Ranganadi NHEP constructed on Ranganadi river, which is a tributary of Subansiri River, may have some impact on its immediate downstream.

12.2 Impact of Bridges

The length of the river Subansiri traversing through hills is around 390 km The remaining length of 130 km flows through the state of Assam. On entering the alluvial plains of Assam the river fans out and the maximum width of the river is found to be around 4.16 km. For about 10 km the river is found to be wider and the main channel bifurcates into numerous small channels. All the channels join and the Subansiri mainstem is found to be constricted at Chouldhowaghat where there are two bridges which are around 350 metres away. One is a railway bridge while other is a national highway. The stretch of the river reach encompassing the railway bridge has been engineered with typical river training measures as such the river is flowing within the waterway without any disturbances.

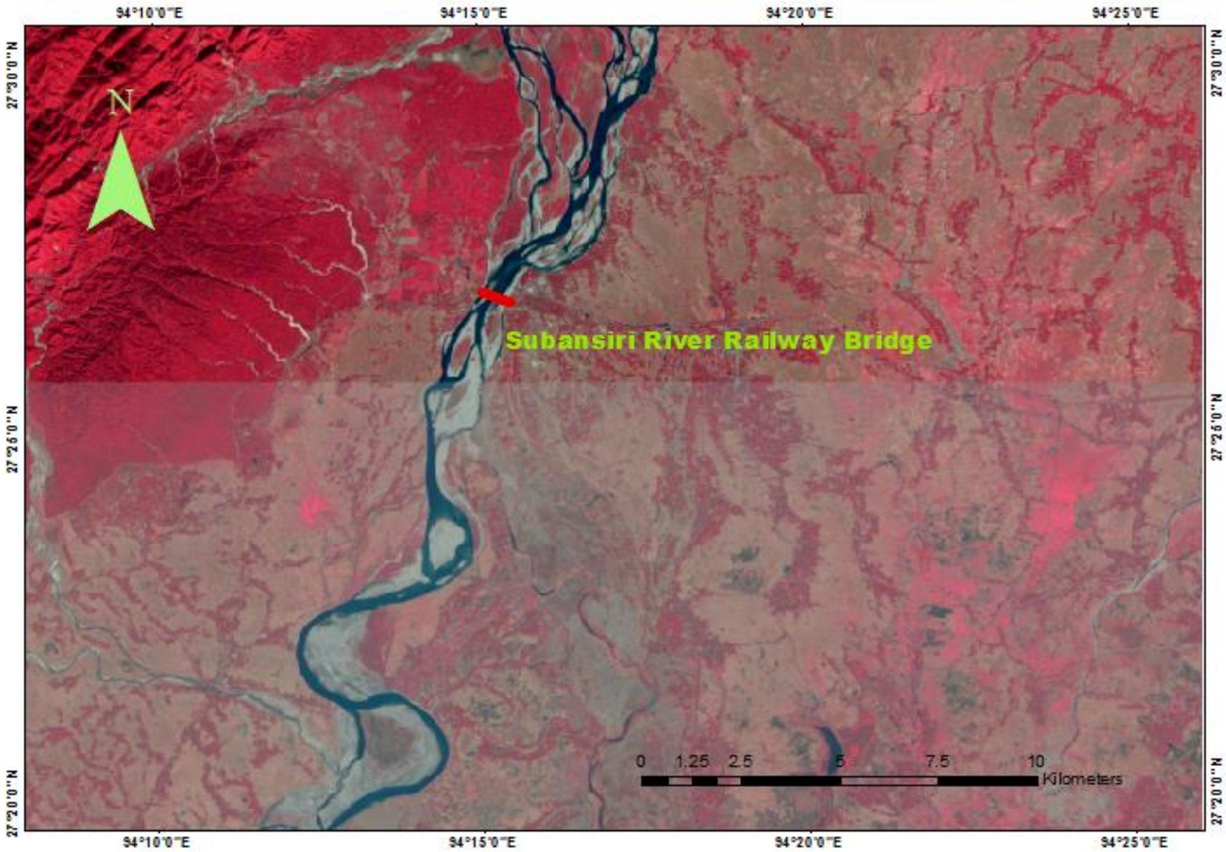


Figure 57: Bridge location along Subansiri River

Chapter 13
FLOOD AFFECTED AREAS

13.1 Flood Inundation Mapping

Flood Inundation map of Brahmaputra Basin in Assam has been downloaded from NRSC's BHUVAN website from the year 1999 to 2010. The flood layers of NRSC are prepared from observed inundation map. 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

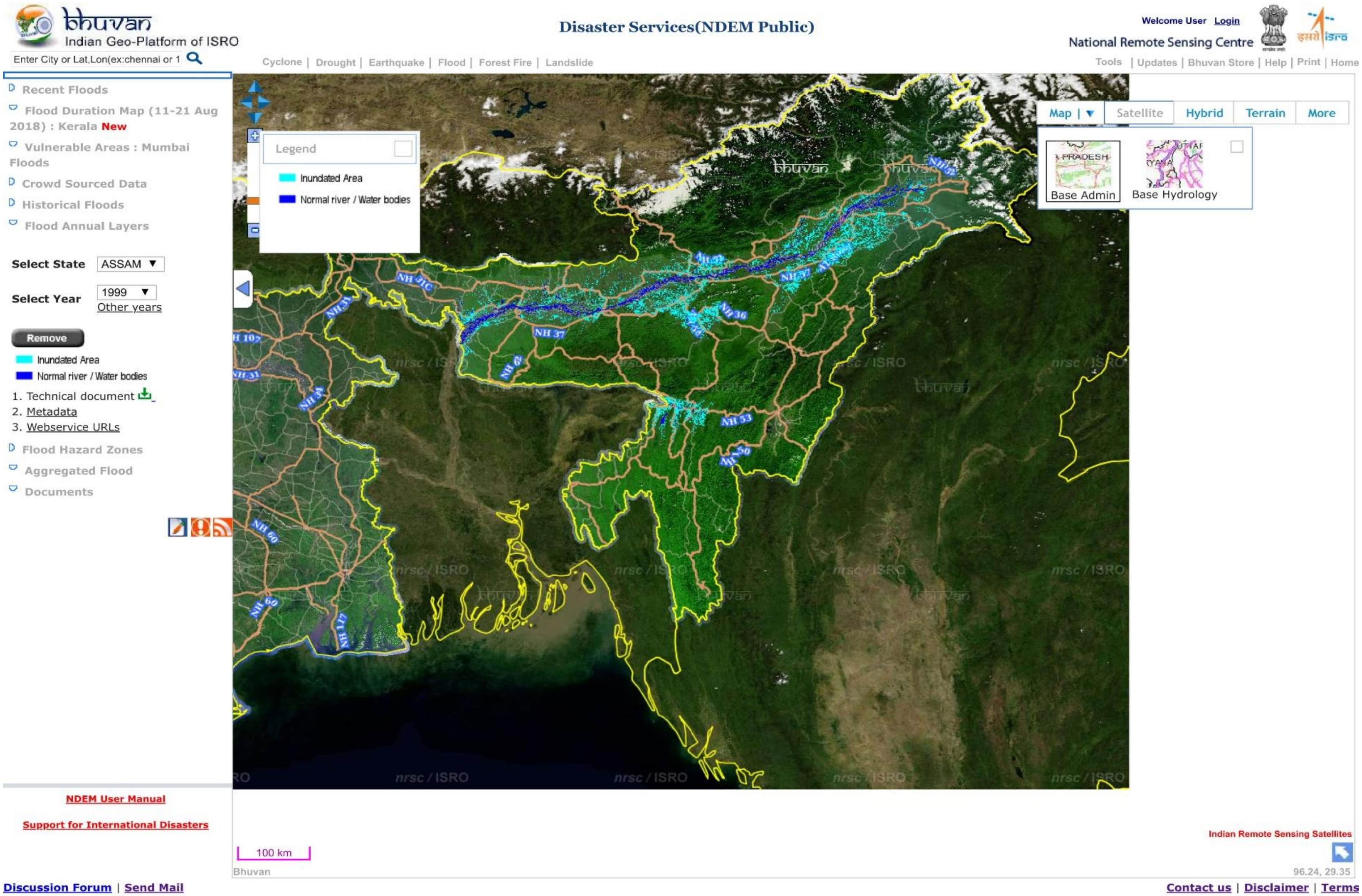


Figure 58:Flood inundation map of Brahmaputra for the year 1999

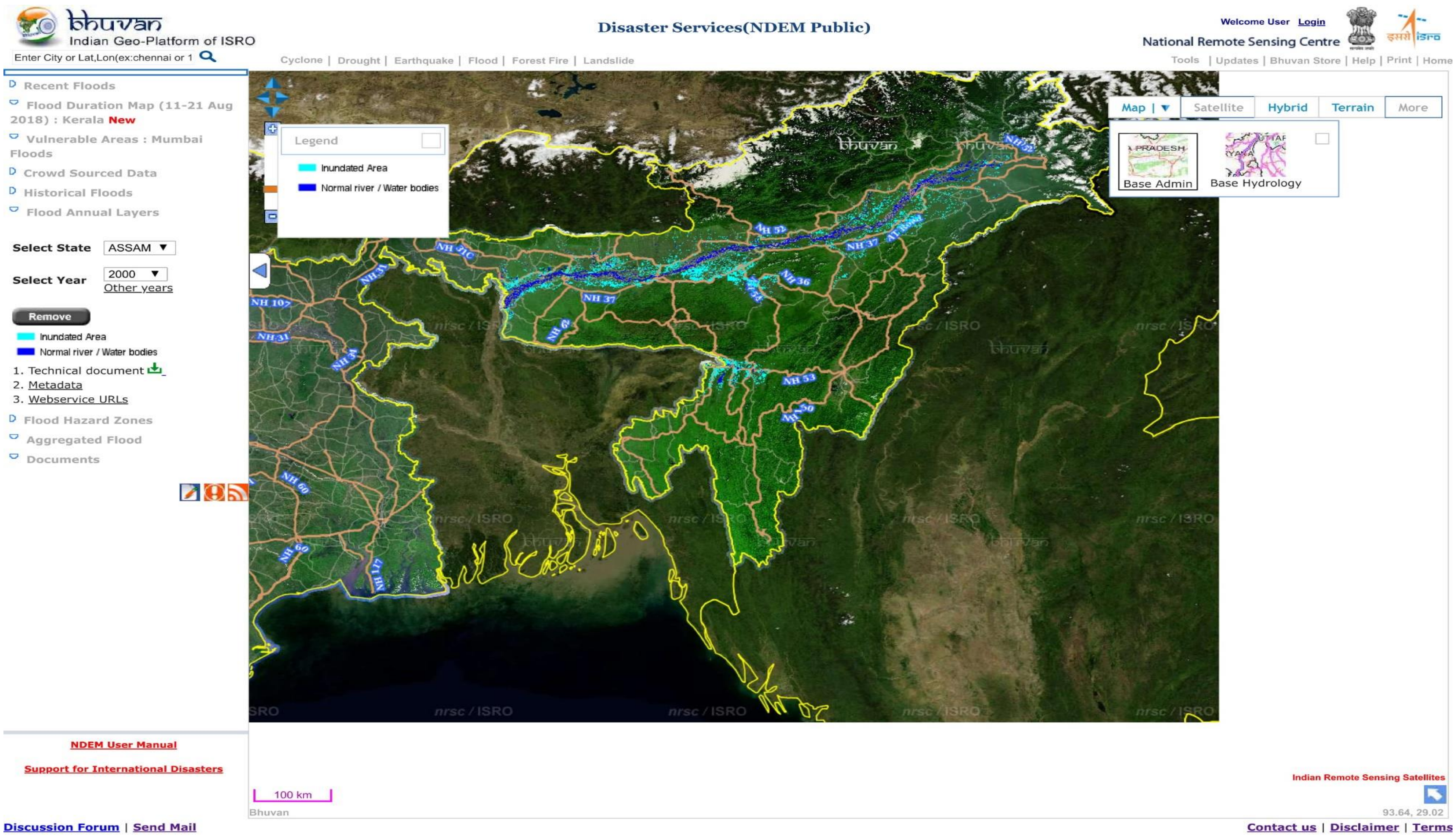


Figure 59: Flood inundation map of Brahmaputra for the year 2000

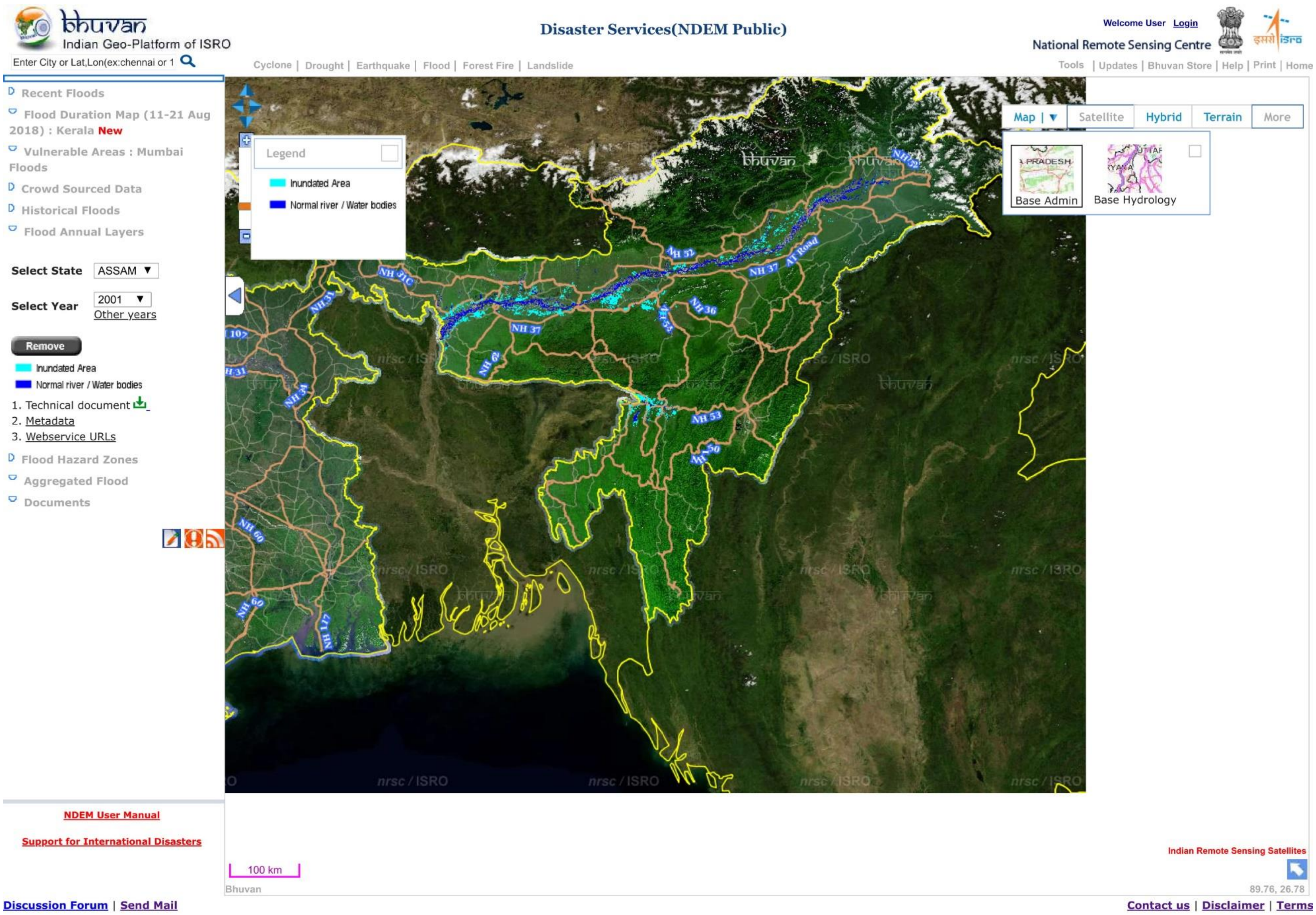


Figure 60: Flood inundation map of Brahmaputra for the year 2001

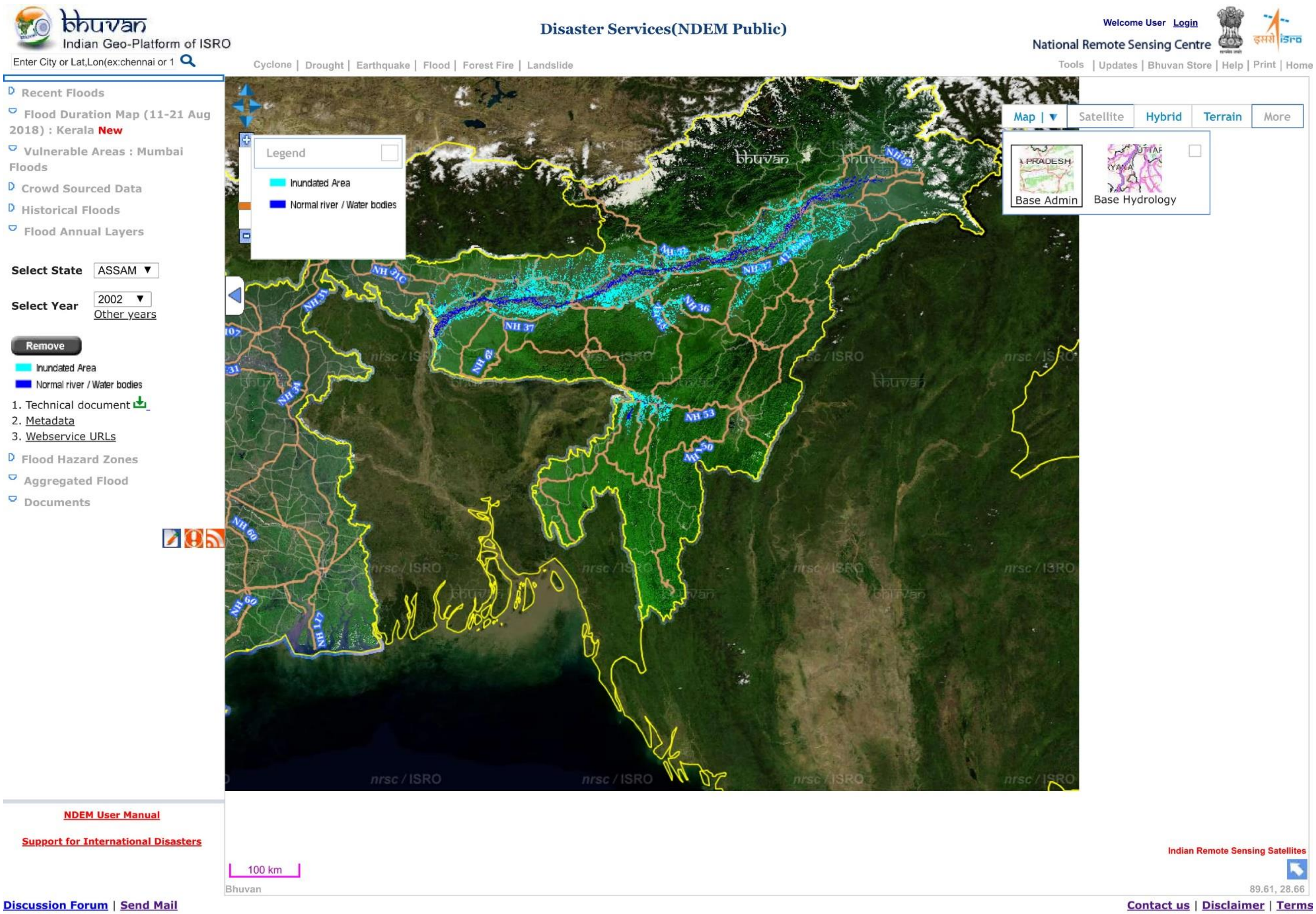


Figure 61: Flood inundation map of Brahmaputra for the year 2002

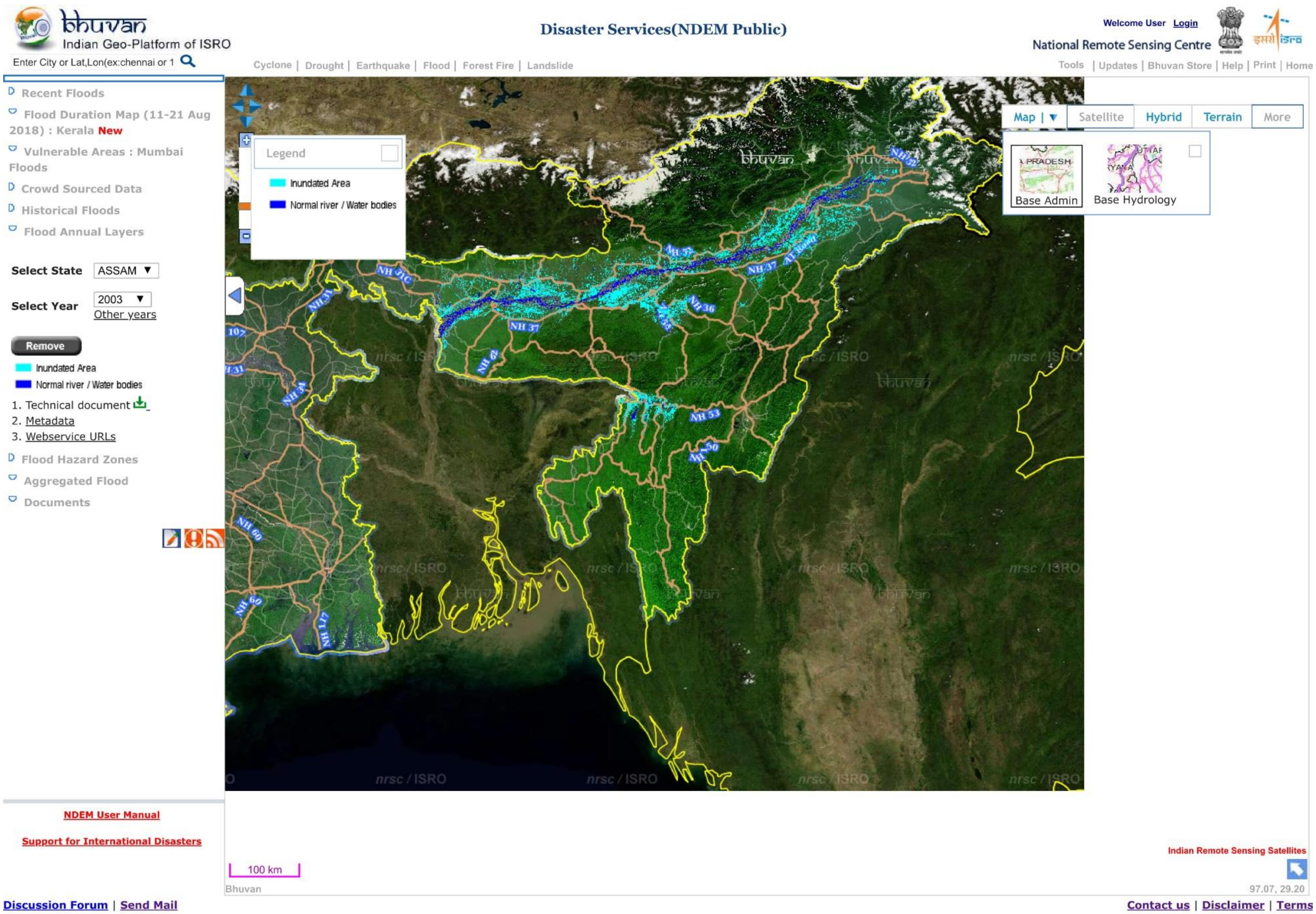


Figure 62: Flood inundation map of Brahmaputra for the year 2003

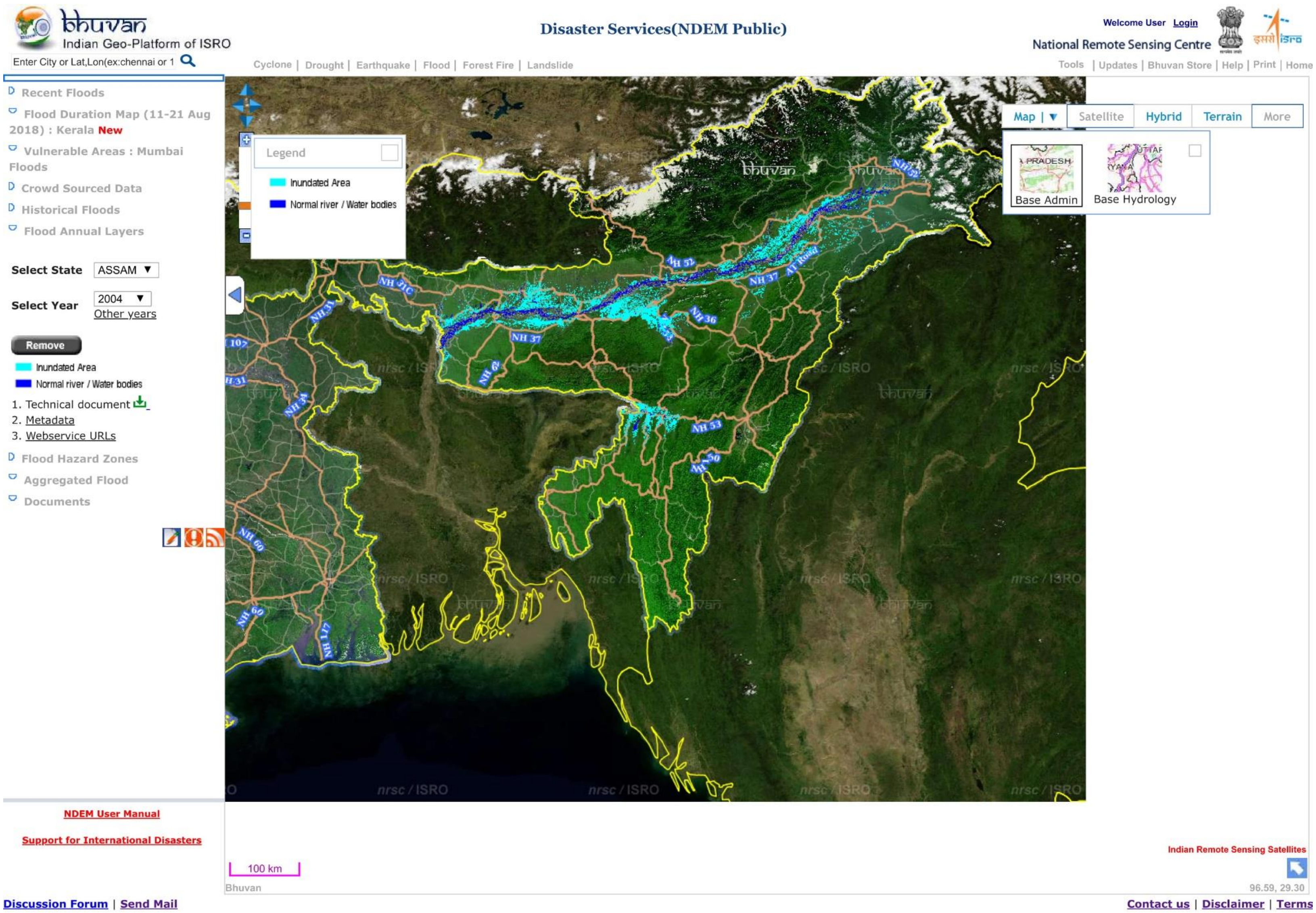


Figure 63: Flood inundation map of Brahmaputra for the year 2004

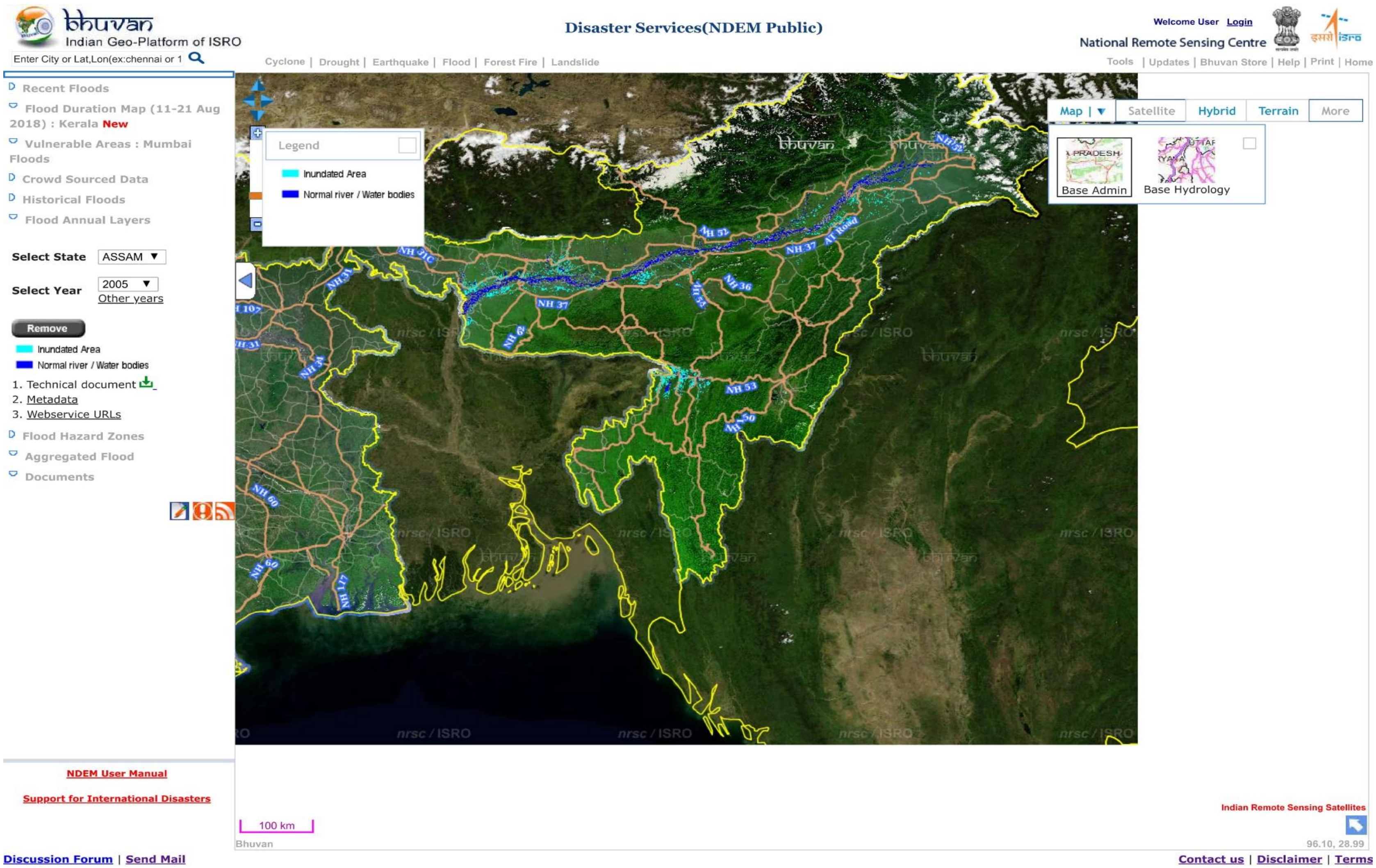


Figure 64: Flood inundation map of Brahmaputra for the year 2005

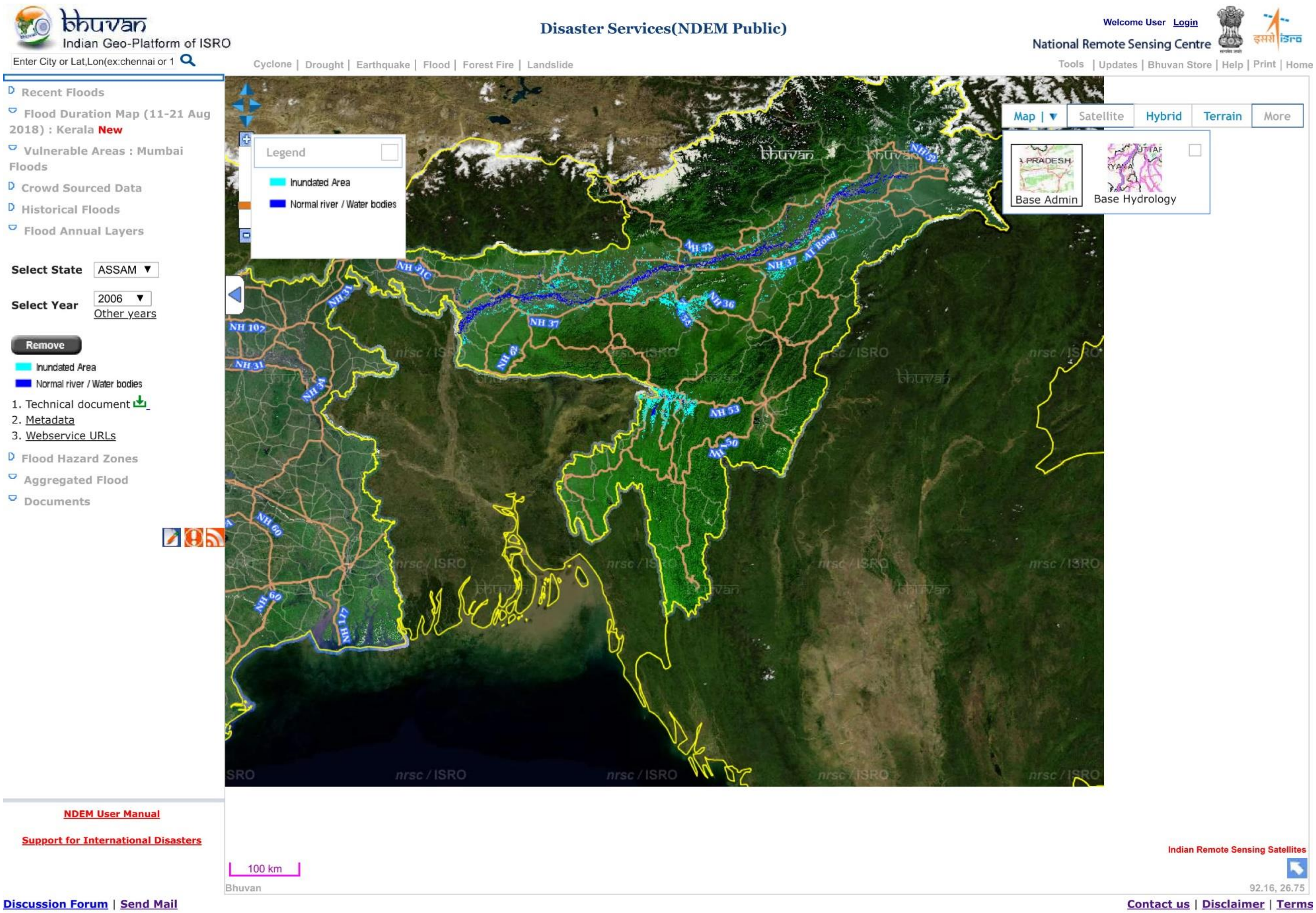


Figure 65: Flood inundation map of Brahmaputra for the year 2006

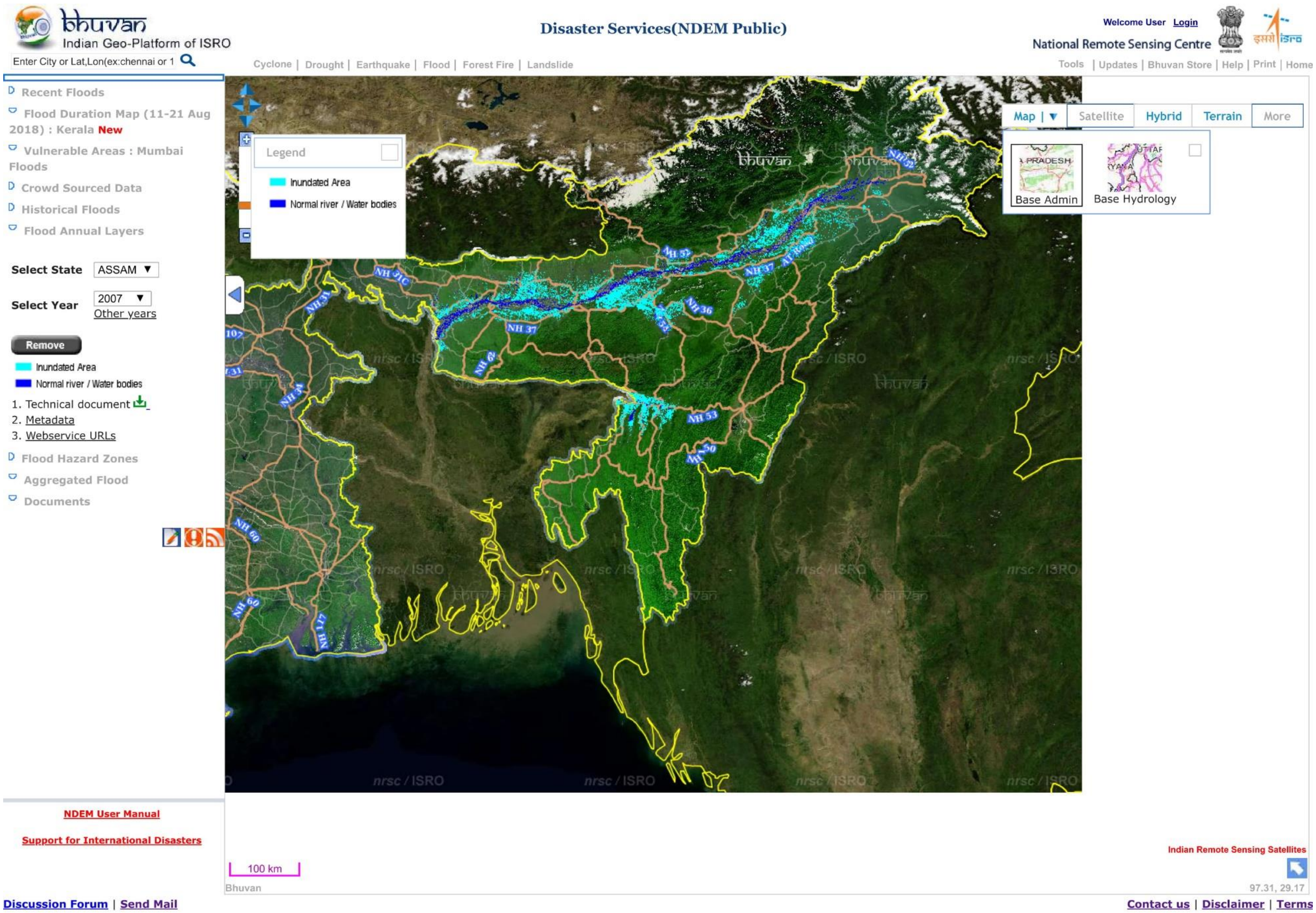


Figure 66: Flood inundation map of Brahmaputra for the year 2007

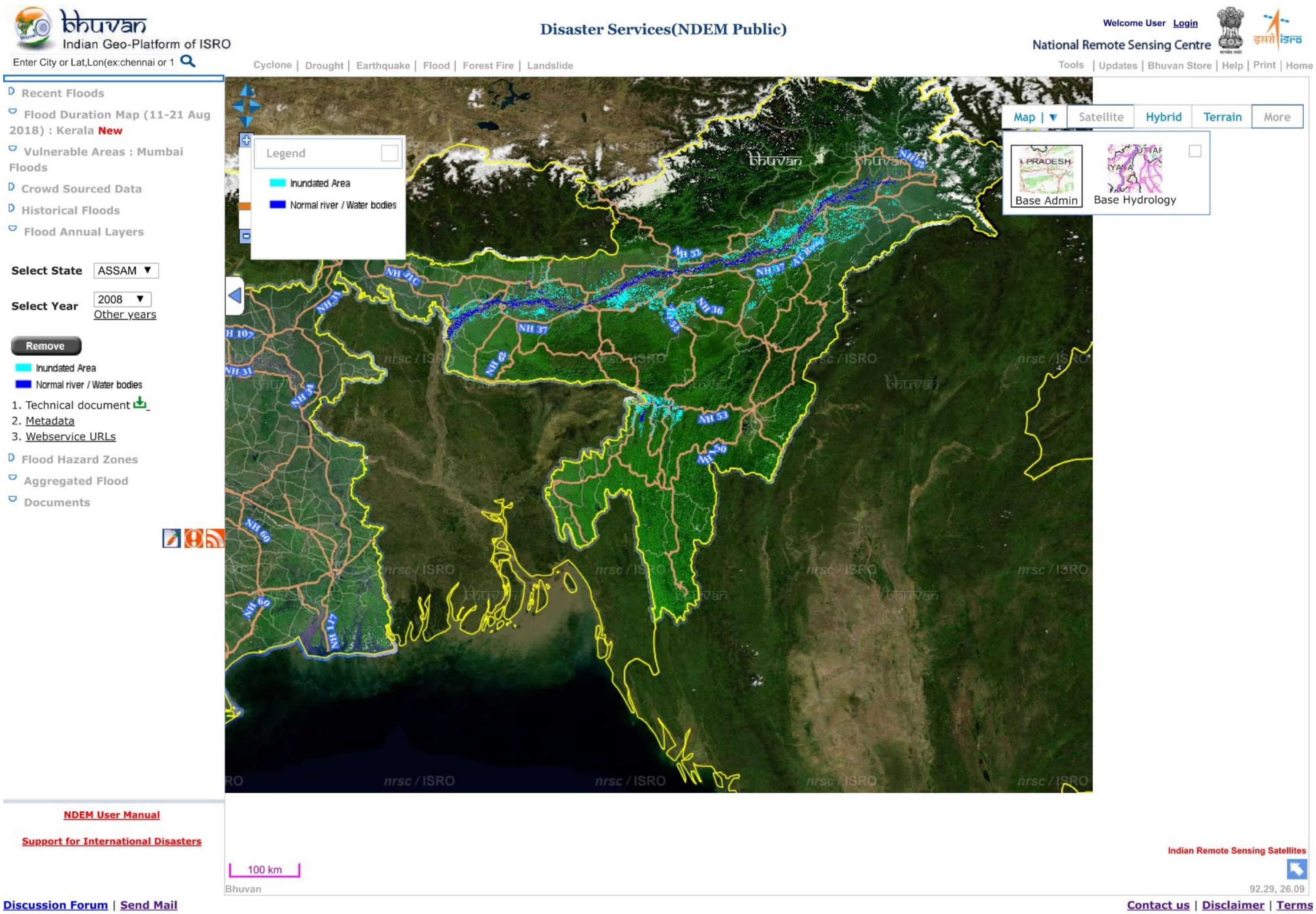


Figure 67: Flood inundation map of Brahmaputra for the year 2008

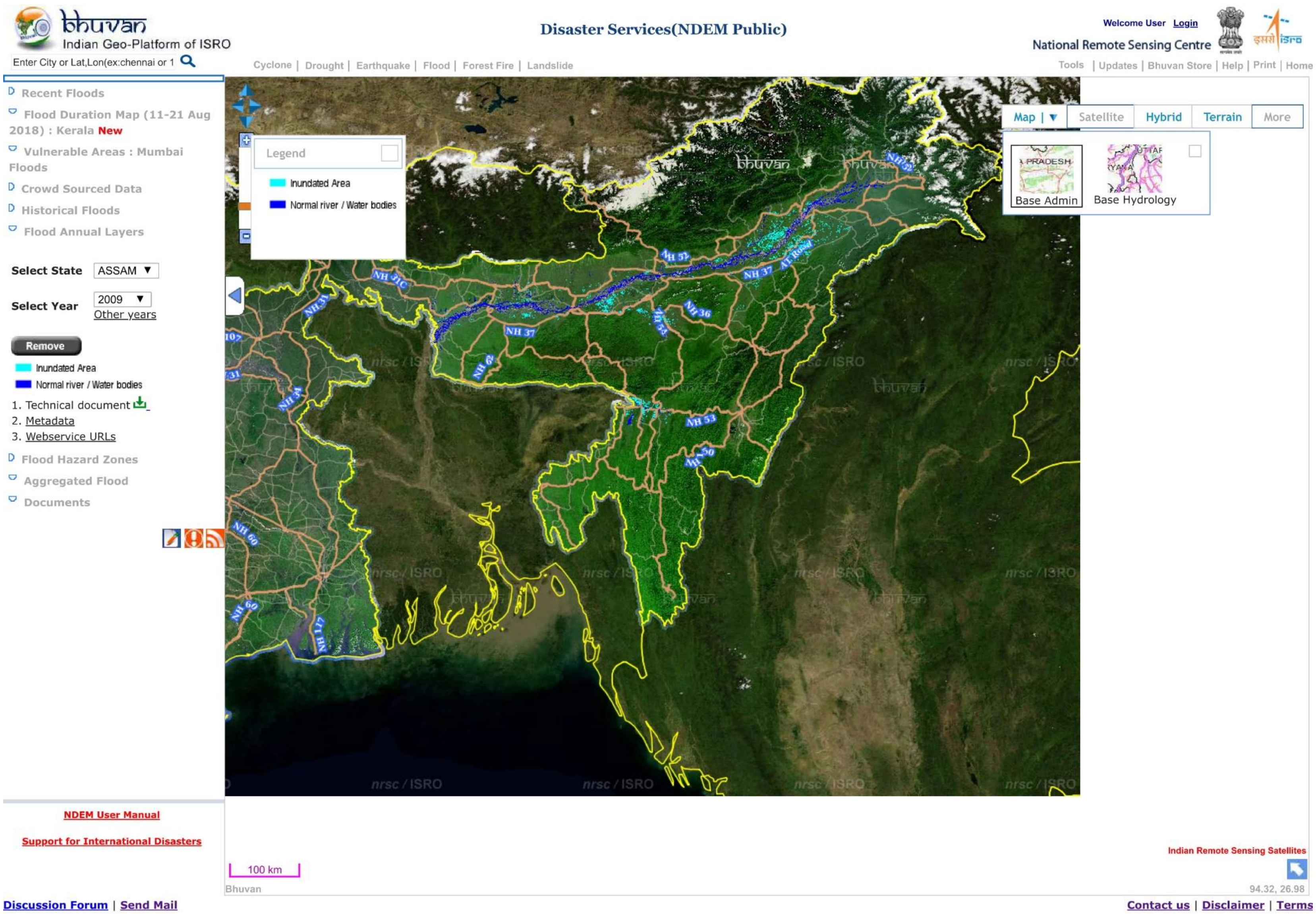


Figure 68: Flood inundation map of Brahmaputra for the year 2009

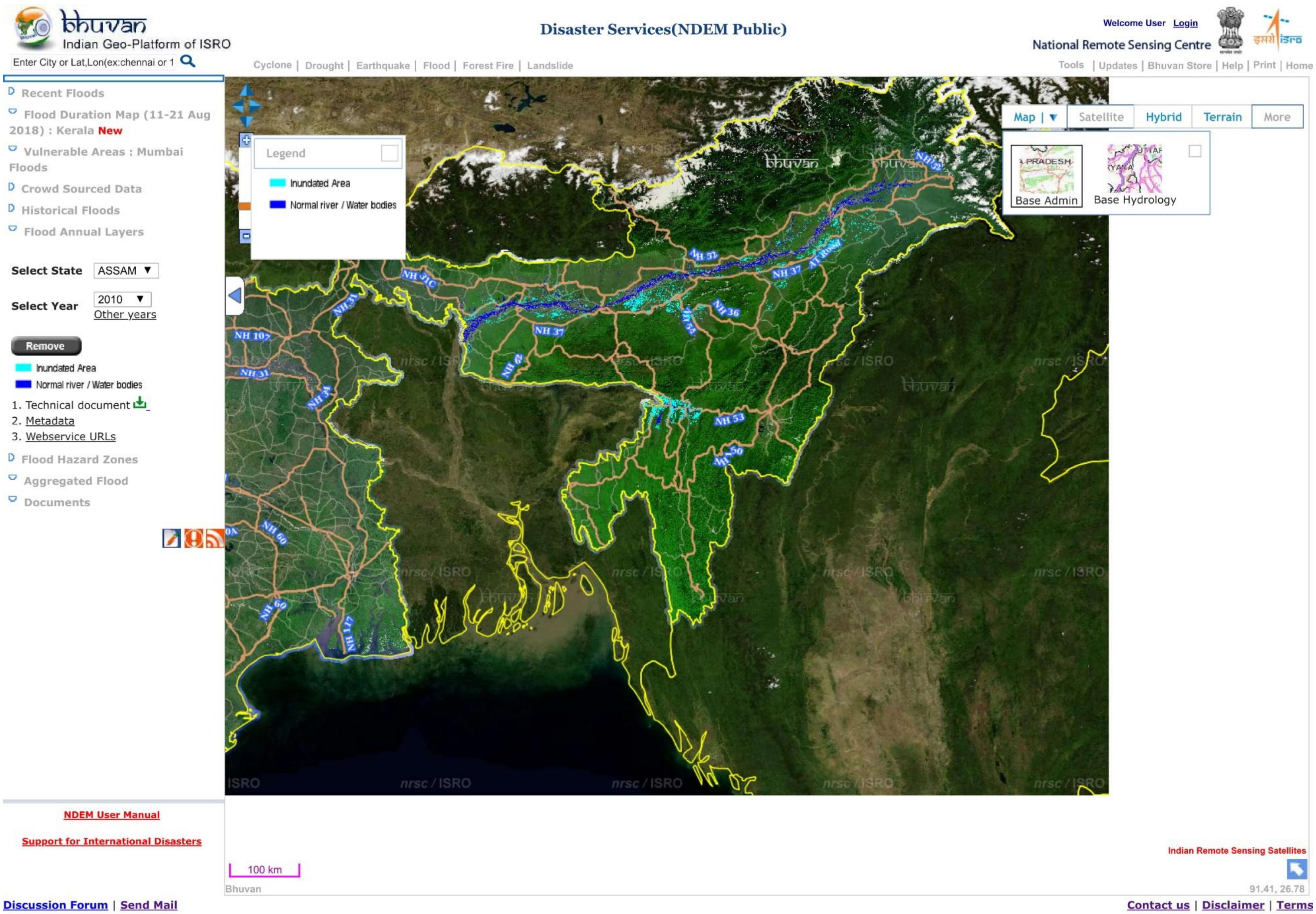


Figure 69: Flood inundation map of Brahmaputra for the year 2010

Chapter 14
MANAGEMENT STRATEGIES

11.1 Sustainable long-term measure

Management of the catchment through Ecological Management Practices (EMP) including afforestation, small cascade reservoir etc. Visible impact of such approach though may take some time and about 5 to 10 years may be necessary to reach the breakeven point

11.2 Immediate short-term measure

Removal of bed sediments through dredging may be applied to divert the main flow from hitting the river bankModel study carried out at Department of Civil Engineering, IIT Guwahati, in 2011, suggested dredging of sand deposition in Morigaon reach along with construction of spurs to push the river away from the bank

Chapter 14
DISSEMINATION WORKSHOP

A project titled 'Morphological studies of rivers Brahmaputra, Subansiri and Pagladiya using Remote Sensing Technique' was undertaken by Department of Civil Engineering, IIT Guwahati sponsored by CWC, New Delhi in 2016. 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:

14.1 Session 1

Prof. Arup Kr Sarma, Principal Investigator of the project welcomed all the participants and the dignitaries and 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 of the study are as follows:

- Avulsion of the Lohit channel is a major morphological change that has been observed in the study. Earlier, 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, meeting the main Brahmaputra again near Rahmoria. This major change in the river morphology took place between 1976-80 and 1993-95. As seen in the toposheet, the present day main Lohit channel was marked as 'Ananta Nala'. 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 shifted to the 'Ananta Nala' converting it to 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. There was a small channel known as Kherkatia suti on the eastern boundary of Majuli. But to check the erosion and flooding problems near Jengraimukh, Majuli, the Kherkatia channel was blocked in 1964, which resulted in

the increase of discharge in Brahmaputra river, which in turn increased the erosion in Subansiri-Brahmaputra confluence point.

- A study done by Sarma & Phukan (2004) 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. At that time, the Kherkatia suti was a prominent channel and it might have caused severe erosion in the northern part of Majuli. Probably, to check this erosion problem, in 1964 a closing dyke was constructed at the meeting point of Kherkatia-Brahmaputra by the Water Resources Department of Assam. Due to this construction, the flow in the Kherkatia suti gradually decreased in due course of time. Also, it has been found that the downstream of Subansiri river, near the confluence with Brahmaputra, is locally known as 'Luit' which is also the name for the upstream of Brahmaputra river. Again, from the historical reports, it is evident that the first satra in Majuli, known as Auniati satra, was located in the Northern part of Majuli. At that time, the main mode of communication was by river. From these evidences, it can be inferred that earlier, the main channel of Brahmaputra was flowing to the north 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 70: Prof. Arup Kr Sarma welcomes the dignitaries and the participants

Figure 71: Felicitation of the dignitaries

Figure 72:Inaugural Address by Prof. Gautam Biswas, Director, IIT Guwahati

Figure 73:Lighting of the lamp

Figure 74:Presentation By Mr Ravi Shankar, CWC

Figure 75:Presentation by Prof. Arup Kr Sarma, PI

14.2 Session 2

The second half of the workshop included a site visit to the erosion prone area of Palashbari and Sualkuchi by boat. An onboard Group discussion was also held. The participants were randomly divided into 9 groups. The purpose of the discussion was to know if the people were aware of different studies done for various rivers, the benefits that can be gained from these studies and their suggestions and recommendations. Prof Arup Kr Sarma and Prof. Rajib Kumar Bhattacharjya were the facilitators of the discussion. A questionnaire was prepared and distributed to each group. The questionnaire included the following questions:

i) Are u aware of such study done elsewhere for these rivers: If any, please provide information?

   From the discussion, it was found that there are several studies that have been conducted from time to time in different rivers. They are as follows:

   - ✓ Bathymetric survey was conducted by IIT Guwahati from Tezpur to Guwahati.
   - ✓ Flood estimation report of Brahmaputra was prepared by CWC.Barak River was carried out.
   - ✓ Morphological studies for 15 rivers are being carried out by CWC in collaboration with various Institutes which includes IIT Guwahati as well.
   - ✓ Studies for rivers like Ghagra and Gandak were done previously.
   - ✓ CWC carries out morphological survey on Brahmaputra at 64 cross sections at an interval of 10 km from Tinsukia to Dhubri each year. Morphological study is also carried out in Subansiri and Pagladia each year.
   - ✓ NESAC has operational flood early warning system for the state of Assam.
   - ✓ Many pilot studies are going on at university levels.
   - ✓ Various organizations such as ISRO/DOS, Gauhati University, IIT Roorkee, Dibrugarh University, Brahmaputra Board are doing these type of studies.
   - ✓ At Rohmoria reach of Brahmaputra River (u/s), change in morphology was studied little bit and also the effect of porcupine screen river cross section was studied.
   - ✓ Similar study for Majuli reach on Brahmaputra was undertaken by IIT Guwahati sponsored by Brahmaputra Board.
   - ✓ IIT Guwahati and Brahmaputra Board are involved in the development of a hydrodynamic and morphological numerical model.
   - ✓ Study of Kaziranga reach was jointly carried out by Brahmaputra Board, SAC Ahmedabad and NRSA.

- ✓ Morphological analysis and geomorphological studies of Brahmaputra were carried out by various researchers.
- ✓ River morphology of Subansiri and Brahmaputra were studied by many academicians from Gauhati University and Dibrugarh University.
- ✓ A PhD degree was awarded on the topic 'Bed form morphology, spatio-temporal variability and erosional vulnerability of Brahmaputra river within Assam' from Gauhati University.

ii) How result of this study can help different organizations

The response given by the different groups can be summarized as:

- ✓ Site selection for various hydraulic structures and river training works.
- ✓ Formulating guidelines for Hydrological Observation sites.
- ✓ Policy making for mitigating erosion in erosion prone areas.
- ✓ Identification and prioritization of areas for protecting important structures.
- ✓ The various data collected through morphological survey can be useful to the Railway Dept., PWD Dept., Irrigation Dept., in study and implementation of micro-macro projects.
- ✓ Proper planning and design of Water resources structures.
- ✓ Base for further studies in future.
- ✓ River restoration works.
- ✓ Flood plain zoning and Flood management
- ✓ Navigation Development
- ✓ Water assessment of the river.
- ✓ Help in understanding the river meandering process.
- ✓ Help the disaster management departments to create awareness for people in flood area.
- ✓ Help in selection of appropriate method/technology for river management.
- ✓ Master plan preparation on the river basin.
- ✓ GIS techniques are useful to analyze quantitatively in some remote areas where it is not physically accessible.

- ✓ 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.
- ✓ Land use planning/Infrastructure development.
- ✓ Identification of 'Ghats.'
- ✓ It can serve as geospatial database for related studies.
- ✓ 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.
- ✓ Strengthen the embankments.

iii) Do you recommend similar study on some other rivers?

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.

iv) Suggestions, if any

The suggestions provided are as follows:

- ✓ More recent data can be used for predicting the future scenario.
- ✓ More morphological case studies of the rivers mentioned above can be taken up for prediction of erosion and morphological action of river.
- ✓ Incorporation of sand bar and sediment load study.
- ✓ Community awareness programme in educational institutes and departments can be held.
- ✓ For better understanding of the river course/shifting, morpho-tectonic/ tectonic studies can be incorporated as a part of the study.
- ✓ Space technology/high resolution satellite data may be utilized for site specific study.
- ✓ Identification of hotspots for scientific sediment mining.
- ✓ A study on effect of climate change on river morphology can be made.
- ✓ Utilizing flood discharge in hydro power generation.

- ✓ Sediment transport model can be made.
- ✓ Prediction of future cutoffs, ox-bow lakes.
- ✓ Collaboration between different organizations.
- ✓ SOI topo sheet can be used for data before 1950, 1:1 mile scale data is available.
- ✓ The data can be provided in public domain for further research studies.
- ✓ Morphological studies can be conducted using latest technology, eg. Drones.
- ✓ Ground control point maybe established to observe neotectonic activity.
- ✓ Morphological survey is very important by manual method.
- ✓ 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.
- ✓ 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.
- ✓ Awareness programs can be planned for various departments and technocrats for hydrological study like Arc GIS/working on toposheet.
- ✓ Study of bank materials as well as bed materials and find the relative silting and scouring.
- ✓ To determine the actual course of erosion, specific site wise.
- ✓ Model study before implementation/execution.
- ✓ Use of aerial photography, ultrasonic sound velocity method to find the change in depth of flow after execution of anti-erosion measures.
- ✓ To study the change in morphology, w.r.t. the bed level before 1950 earthquake.
- ✓ Field verification is essential along with remote sensing techniques to validate the findings.
- ✓ River modelling can be done to find out the vulnerable reach along with remote sensing techniques.
- ✓ 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 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.

Figure 76:The facilitators of the group discussion

Figure 77:Group 1

Figure 78:Group 2

Figure 79:Group 3

Figure 80:Group 4

Figure 81:Group 5

Figure 82:Group 6

Figure 83:Group 7

Figure 84:Group 8

Figure 85:Group 9

Figure 86:Concluding the GD

Figure 87:Certificate distribution

CONCLUSION AND RECOMENDATION

Following conclusions have been drawn from the study:

- ✓ The watershed of the Subansiri is delineated using SRTM DEM of 90 m resolution and the flow accumulation and flow direction maps were generated. 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 watershed of Subansiri are found to be 35364.3 km^2 1547.83 km respectively.

- ✓ The morphometric analysis of the Subansiri catchment has shown that the bifurcation ratio is the lowest in the highest stream order flowing through the plains of Assam, as several 1^{st} order tributaries join the main channel directly in the mainstream of this portion. The bifurcation ratio is highest in the stream order 3 that flows in the foothill region of Himalaya i.e. through the Tibetan Plateau and Arunachal Hills. This indicates that higher chances of flooding in the downstream portion of the catchment and presence of structural disturbances in the foothills of Himalaya. The drainage density of the catchment is found to be low i.e. 0.14 km/km^2 which infers to the occurrence of intense rainfall resulting in flashy discharge and flooding. It also signifies that the region exhibits highly permeable sub-soil material under dense vegetative cover. The values of the form factor, circulatory ratio, and elongation ratio indicate that the catchment is elongated.

- ✓ The drainage map of Subansiri has been digitized showing the major tributaries viz, Ranganadi, Dikrong, Jiadhal, Bogi Nodi.

- ✓ The probability exceedance curves have been plotted from the discharge at Chouldhowaghat and Lemeking considering definite class intervals. At Chouldhowaghat, the discharge for return period 25, 50 and 100 year are 13307.70, 14753.15 and 16185.92 m^3/sec respectively. The corresponding percentage exceedance probabilities for return period of 25, 50,100 years are 0.106%, 0.048% and 0.021 % respectively. Similarly, for the station Lemeking, the discharge corresponding to 25, 50 and 100 year return period are 875.28, 962.60, 1049.27 m^3/sec respectively. The corresponding percentage exceedance probabilities are 0.19 %, 0.09%, 0.045% respectively.

- ✓ Landuse land-cover (LULC) map has been prepared for 1973-74, 1976-80, 1993-95 and for the period 2005-06 and 2011-12 were collected from NESAC. LULC indicates that built up area and forest lands are converted to agriculture and waterbodies. It indicates an increasing trend of water utilization in agriculture sector. As such, it is suggested to carry out a detailed study on such flow scenarios by using hydrological modeling and river flow simulation.

- ✓ The longitudinal profile of the Subansiri river has been plotted. It can be observed that the elevation at the upstream part is 4800m. Traversing through the hilly areas of Arunachal Pradesh, the elevation of the river get reduces on entering Assam. Finally, the elevation of the river reaches 78 m above MSL at the confluence point with the Brahmaputra. At Gerukamukh, near Assam-Arunachal border, a rise in the bed level has been observed at an elevation of 267 m. This hump is near the Lower Subansiri Hydroelectric Power Project.

- ✓ The meander parameter of Subansiri has been calculated. It has been observed that the lengths of the meanders are found to be varying at different years. At reach 1, for the year 1973-74, 1993-5, 2003-04, 2008-11, the meander lengths of 1.4 km, 2.48 km, 1.14 km, and 2.40 km have been observed respectively. Reach 15 and 16 experienced the highest meander occurrence which has been found in the year 1973-74 with meandering width of 4.18 and 3.70 km respectively. In 1973-74 and 1993-94, the bankfull width is maximum at reach 17 and 15. From the analysis of the meander width ratio, the nature of the channel can be determined. The nature of the channel has changed from almost straight to moderately meandering in course of time.

- ✓ The planform indices (PFI) considering 10 km sections have been analyzed. From this analysis, it can be seen that the river is moderately braided as the PFI value is between 4 and 19. The analysis shows that the reach 4, 5, 6 are highly braided in the year 1976-80. In the subsequent years, the braiding has lowered till 2003-04. However, in 2008-11, reach 3, 4 and 8 are highly braided in nature. All the other reaches are moderately braided during 2008-11.

- ✓ In case of the impact of hydraulic structures on the Subansiri river, following points are observed:
  - o The major hydraulic structure over the Subansiri River includes the 2000MW Lower Subansiri Hydroelectric Power Project. However, the operation of the dam is yet to be started. So, no major impact on the flow of the river is observed so far. Several hydraulic structures are in pipe line. The river Ranganadi has some impact on Subansiri. Though Ranganadi is considered as a major tributary of Brahmaputra, but it joins the Subansiri just before its confluence with the Brahmaputra. This river contains some hydroelectric projects like Ranganadi Hydroelectric Power Project. A comprehensive study of the impact of these structures can be carried out by using simulation-optimization model consisting of reservoir operation and the hydrodynamic model.
- ✓ The length of the river Subansiri traversing through hills is around 390 km. The remaining length of 130 km flows through the state of Assam. On entering the alluvial plains of Assam, the river fans out and the maximum width of the river is found to be around 4.16 km. For about 10 km, the river is found to be wider and the main channel bifurcates into numerous small channels. All the channels converge to a single channel at Chouldhowaghat where two bridges exist at a distance of 350 meters. One is a railway bridge while the other is a national highway bridge. To ensure safety of the railway bridge, proper river training works were executed to guide the river through a single channel in this portion. As such the river is flowing within the waterway without any disturbances.
- ✓ The flood inundation map has been downloaded from BHUVAN. 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, 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.

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ANNEXURE I

Table 8: List of available Landsat (MSS) data (1976-81)

Sl. No.	Satellite	Sensor	Path	Row	Date of acquisition	Status
1.	Landsat	MSS	145	041	1977-01-01	Downloaded

Table 9: List of available IRS 1B (LISS 1) data (1993-1994)

Sl. No.	Satellite	Sensor	Path	Row	Date of acquisition	Status
1.	IRS 1B	LISS 1	14	049	1994-10-27	Received
2.			14	047	1994-05-04	Received
3.			14	048	1994-10-27	Received

Table 10: List of available IRS P6 (LISS 3) data (2003-2004)

Sl. No.	Satellite	Sensor	Path	Row	Date of acquisition	Status
1.	IRS P6	LISS 3	111	051	2004-01-09	Received
2.			112	051	2004-02-07	Received
3.			112	052	2004-02-07	Received

Table 11: List of available Resourcesat 1 (LISS 3) (2008-2011)

Sl No.	Satellite	Sensor	Tile No.	Path	Row	Date of acquisition	Status
1.	Resourcesat 1	LISS 3	G46D15	112	052	2008-12-18	Received
2.			G46D14	112	052	2008-12-18	Received
3.			G46K01	112	052	2008-12-18	Received
4.			G46D16	112	052	2008-12-18	Received
5.			G46E02	112	052	2008-12-18	Received
6.			G46E04	112	052	2008-12-18	Received
7.			G46E06	112	052	2008-12-18	Received
8.			G46E07	112	052	2008-12-18	Received
9.			G46E08	112	052	2008-12-18	Received
10.			G46J13	112	052	2008-12-18	Received
11.			G46E03	112	052	2008-12-18	Received
12.			G46E01	112	052	2011-11-21	Received
13.			G46E03	112	052	2008-12-18	Received
14.			G46E05	112	052	2011-11-21	Received
15.			H46W04	112	051	2008-11-24	Received
16.			H46W03	112	051	2008-11-24	Received
17.			H46V15	112	051	2008-11-24	Received
18.			H46V07	111	051	2008-11-19	Received
19.			H46V11	112	051	2008-11-24	Received
20.			H46V03	111	051	2008-11-19	Received
21.			H46U15	111	051	2008-11-19	Received

ANNEXURE II

Table 12: Hydrological data for Subansiri River collected from CWC

Sl No.	Subansiri River Stations	Type of data	Frequency	Period of data
1	Badatighat	Gauge	Daily	1/11/1981 – 31/05/2015
2	Chouldhowaghat	Gauge	10 Daily	1976-1977 to 2014-2015
		Discharge	10 Daily	1983-1984 to 2014-2015
		Silt	Monthly	1988-1989 to 2014-2015
		X- Section	Pre & Post Monsoon	1995 to 2015
3	Lemeking	Gauge	10 Daily	2007-2008 to 2014-2015
		Discharge	10 Daily	2007-2008 to 2014-2015
		X- Section	Pre & Post Monsoon	2007 to 2015
4	Daporizo	Gauge	10 Daily	1979-1980 to 2014-2015
		Discharge	10 Daily	2014-2015
		Silt	Monthly	2014-2015
		X- Section	Pre & Post Monsoon	2014-2015

ANNEXURE III

Table 13: List of PFI for the corresponding reach lines 1976-1981

Reach No.	Planform Index	Threshold Indicator
1	4.785	Moderately Braided
2	11.098	Moderately Braided
3	4.620	Moderately Braided
4	3.793	Highly braided
5	3.156	Highly braided
6	2.852	Highly braided
7	23.596	Low Braided
8	14.203	Moderately Braided
9	20.588	Low Braided
10	5.763	Moderately Braided

Table 14: List of PFI for the corresponding reach lines 1993-1994

Reach No.	**Planform Index**	**Threshold Indicator**
1	5.516	Moderately Braided
2	9.173	Moderately Braided
3	5.421	Moderately Braided
4	5.645	Moderately Braided
5	4.440	Moderately Braided
6	15.144	Moderately Braided
7	20.857	Low Braided
8	12.519	Moderately Braided
9	11.381	Moderately Braided

Table 15: List of PFI for the corresponding reach lines 2003-2004

Reach No.	Planform Index	Threshold Indicator
1	5.395	Moderately Braided
2	5.631	Moderately Braided
3	3.368	High Braided
4	6.091	Moderately Braided
5	9.383	Moderately Braided
6	6.261	Moderately Braided
7	7.805	Moderately Braided
8	12.216	Moderately Braided
9	6.708	Moderately Braided

Table 16: List of PFI for the corresponding reach lines 2008-2012

Reach No.	Planform Index	Threshold Indicator
1	2.504	High Braided
2	7.547	Moderately Braided
3	3.042	High Braided
4	3.571	High Braided
5	18.542	Moderately Braided
6	6.488	Moderately Braided
7	8.625	Moderately Braided
8	3.631	High Braided
9	5.325	Moderately Braided

ANNEXURE IV

Table 17: Percentage probability exceedence of flow at Chouldhowaghat for the period 1983-2015

Daily mean discharge (cumecs)	**No. of days in each class interval (Col. 2)**																															**Total no. of days**	**Cuml. Total**	**Pp (%)**
	1983-1984	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015			
15050-16050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10	10	0.09
14050-15050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0.09
13050-14050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0.09
12050-13050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	11	21	0.18
11050-12050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0.18
10050-11050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	10	0	0	42	63	0.54
9050-10050	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	10	0	0	31	0	0	0	0	61	124	1.06
8050-9050	0	0	0	0	0	0	0	0	0	10	0	0	10	0	0	10	10	0	0	0	0	0	0	0	0	0	11	10	20	10	0	0	91	215	1.84
7050-8050	0	0	21	0	32	10	0	0	10	0	31	0	0	10	0	31	10	0	0	20	20	20	0	0	0	10	30	0	10	11	21	0	297	512	4.38
6050-7050	0	11	20	10	20	11	0	10	20	10	0	0	20	10	0	20	41	0	11	11	10	0	11	0	0	20	11	30	11	41	20	0	379	891	7.62
5050-6050	20	50	10	10	30	21	40	41	40	21	81	30	31	31	30	11	21	31	20	20	21	40	20	10	31	30	10	20	40	40	20	41	912	1803	15.42
4050-5050	41	0	30	51	20	20	72	51	21	30	20	30	32	30	20	10	41	40	10	70	72	20	30	61	60	51	70	10	20	20	0	20	1073	2876	24.60
3050-4050	32	42	41	21	31	51	20	60	52	40	32	82	81	41	30	52	30	31	71	31	31	41	41	10	20	51	41	11	20	10	62	41	1250	4126	35.30
2050-3050	60	50	10	61	10	30	20	21	20	41	40	30	21	41	63	30	21	61	39	21	18	60	58	81	53	51	31	31	52	32	41	41	1239	5365	45.90
1050-2050	41	60	69	50	60	51	69	20	30	51	41	42	10	82	72	30	60	51	51	59	60	62	61	89	11	38	72	90	31	50	50	61	1674	7039	60.22
50-1050	172	152	164	162	163	171	144	162	163	162	120	151	161	120	150	161	132	151	163	133	134	122	144	114	181	114	89	100	141	141	151	161	4649	11688	99.99

Table 18: Percentage probability exceedence of flow at Lemeking site for the period 2007-2015

Daily mean discharge (cumecs) (Col.1)	**No. of days in each class interval (Col. 2)**								**Total no. of days (Col.3)**	**Cuml. Total (Col.4)**	**Pp (%) (Col.5)**
	2007-2008	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**			
610-660	11	0	0	0	10	0	0	0	21	21	0.71844
560-610	22	0	0	10	0	0	0	0	32	53	1.813206
510-560	0	0	0	31	11	0	0	0	42	95	3.250086
460-510	0	0	30	51	0	0	0	0	81	176	6.021211
410-460	0	0	31	0	30	0	0	0	61	237	8.108108
360-410	30	10	10	40	0	10	0	10	110	347	11.87137
310-360	10	34	60	20	71	10	20	21	246	593	20.28738
260-310	50	41	32	0	0	20	0	21	164	757	25.89805
210-260	11	52	10	30	31	10	10	61	215	972	33.25351

ANNEXURE V

DISSEMINATION WORSHOP ON

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

3rd MAY, 2019, IIT GUWAHATI

REGISTRATION LIST

Sl. No.	Organization	Name	Designation	E-mail	Contact no.	Signature
1	AWRMI, WRD Assam	Dr. Juran Ali Ahmed	Assistant Executive Engineer	juranahmed@gmail.com	94351 01544	
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Figure 88:Registration List of Workshop

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6	Dibrugarh University	Dr.(Mrs.) Ratamali Machahary	Assistant professor	machahary.ratamali@gmail.com	9957400988	
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12	CWC	Mr Ravi Shankar	Chief Engineer, P&D Organization, New Delhi	cepd-cwc@nic.in	9868271759	
13	CWC	Mr Ajay Kumar Sinha	Director, M&CC, CWC, New Delhi	dirmorpho-cwc@nic.in	9560444535	
14	CWC	Mr Ravi Ranjan	SE, HDC,Guwahati	raviranjan-cwc@nic.in	9810884756	

15	CWC	Mr Sanjeev Kumar	DD, M&CC, CWC, New Delhi	dirmorpho-cwc@nic.in	7070890860	[signature]
16	CWC	~~Mr~~ Ms Shobika ~~r~~ Singh SHOBHIKA.	AD, M&CC, CWC, New Delhi	dirmorpho-cwc@nic.in	8130986942	[signature]
17	CWC	Mr Devendra Patel	AD, RC Dte, CWC, New Delhi	rcddte-cwc@nic.in	8800294621	[signature]
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19	CWC	~~Mr Ikar Nyori~~ Ravi Shankar Singh	~~SDE,~~ JE HOC, Guwahati	ravishankarsingh-cwc@gov.in	9415169268	[signature] 3/5/2017
20	CWC	Mr Sonu Rajak	JE, UBD, Dibrugarh	sonurajak-cwc@nic.in	9756302439	[signature]
21	CWC	Mr Ayush Garg	JE, M/SD-1, Shillong	ayushgarg-cwc@gov.in	9013877356	[signature]
22	CWC	Mr Ashutosh Kumar Mall	JE, B&BBO, CWC, Shillong	ashutoshmall-cwc@nic.in	9452690129	[signature]
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24	CWC	Mr Dikshat Rangari DIKSHANT	JE, NEIC, Shillong	dikshant291@gmail.com	8555822695	[signature]
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31	CWC	Mr Akash Bharadwaj	JE, A.P. Ghat Site M/SD-II, Silchar	akkyy.44@gmail.com	9045200769	Akash.
32	CWC	Mr Pankaj Kumar	JE, Kibitu Site under UBD, Dibrugarh			
33	CWC	Mr Ved Prakash	JE, Dawki Site under M/SD-1, Shillong	vedprakashpharswan@gmail.com	7579219149	[signature]
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35	NESAC	Dr. Gopal Dharma	SC/SE-C	gops.geo@gmail.com	7895149250	[signature]
36	NESAC	Shri P.L.N. Raju	Director			

37	Soil Conservation Dept., Assam	G.S. PANESAR.	DIRECTOR.	dgmassam @gmail.com.	94350 80857	[signature]
38	ASTEC	Dr. Arup Kumar Mishra on behalf UTPAL SARMA, Head i/c ARSAC	Director	usarma552 @gmail.com	94350 18977	[signature]
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40	AEC	Dr. BipulTalukdar	Associate Professor	bipul.ce @aec.ac.in	98640 80965	[signature]
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42	Irrigation Department, Assam	Mr. Karuna Dutta	Assistant Engineer	karunadutta90@gmail.com	9707833774	[signature]
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46.	GAUHATI UNIVERSITY	TANISHQA KASHYAP	Student	tanikash45@gmail.com	9706535651	T.Kash
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52	Dept of Civil Engg, IIT-Ghy	Anupal Baruah	Ph.D student	anupalbaruah@iitg.ac.in	8721886129
53	Dept. of Civil Engg. IIT Ghy	Gaurav Talukdar	PhD	gauravt@iitg.ac.in	8472979101
54.	Dept of Civil Engg IIT Ghy	Amit Kalita	JRF	amit_kalita@iitg.ac.in	8638182995
55.	Dept. of Civil Engg, IIT Ghy.	KHYATI MANJURI CHAUDHURY	Asst Project Engineer.	khyati@iitg.ac.in	9401380409
56.	Dept. of Civil Engg, IIT Ghy	Dipsikha Devi	PhD Scholar	ddevi@iitg.ac.in	9864561841
57.	Dept of Civil Engg, IIT Ghy	BHASWATEE BAISHYA		bhaswatee11@iitg.ac.in	9706783935
58.	"	APOORVA SINGH	MTECH	singh174104117@iitg.ac.in	998469909

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

Name: Khanindra Barman

Organisation: WRD, 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	8
3	Presence of National Park/Wildlife Sanctuary	7
4	National Highway within 2km from bank	5
5	Railway Line within 2km from bank	6
6	Presence of Protective Structure	
7	Presence of Refinery within 2km from bank	5
8	Increasing Rate of Erosion	5
9	Landuse type:	3
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Figure 89:Weightage of Vulnerability Factor provided by the dignitaries

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
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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:	
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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:	
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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
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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
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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
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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
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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
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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
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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:	
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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
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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	4
7	Presence of Refinery within 2km from bank	3
8	Increasing Rate of Erosion	4
9	Landuse type:	
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Manesh 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:	
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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:	
10		
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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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12		
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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
10		
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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
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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
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DISSEMINATION WORKSHOP
ON
MORPHOLOGICAL STUDIES OF RIVERS BRAHAMAPUTRA, SUBANSIRI AND PAGLADIYA USING REMOTE SENSING TECHNIQUE

Name: Dr. Ratumali 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
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