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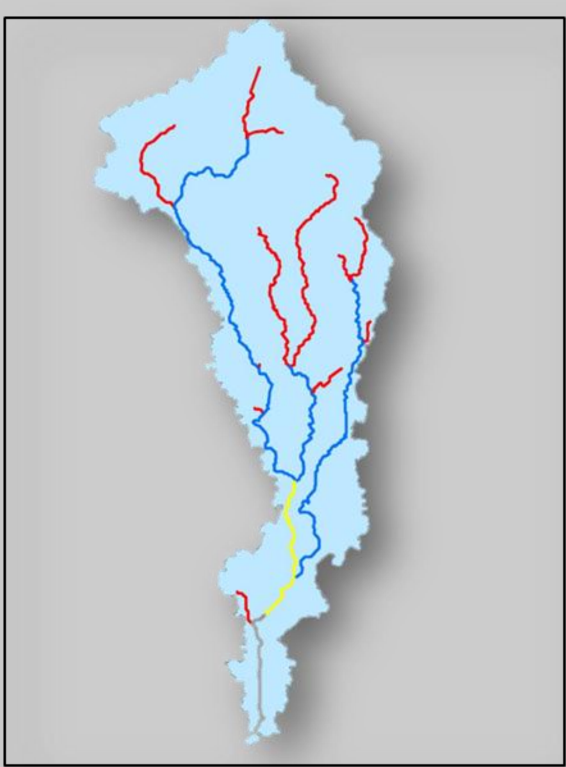
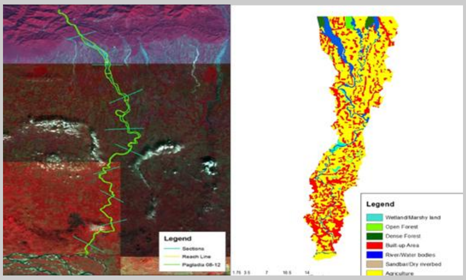
FINAL REPORT

MORPHOLOGICAL STUDY OF RIVER PAGLADIYA USING REMOTE SENSING TECHNIQUE





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Final Report

on

Morphological Study of River Pagladiya using Remote Sensing Technique

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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 creates a problem to the hydraulic engineers during the planning and design of hydraulic structures. For implementing any structural and non-structural measures on a river, the knowledge of fluvial morphology is an indispensable part. The morphological changes of a river generally deal with the shifting of the banklines, aggradation and degradation, change in channel dimensions, change in cross-sectional, formation of ox-bow lakes, cutoff, *etc*. A comprehensive study is thus essential to understand the river characteristics. With this motive, Central Water Commission (CWC), New Delhi is interested to understand the morphological study of the major rivers in India. Thus, a project entitled "Morphological Studies of Rivers Brahmaputra, Subansiri and Pagladiya using Remote Sensing Techniques" was given to IIT Guwahati. **This report contains Morphological Study of River Pagladiya using Remote Sensing Techniques.**

2. Following were the broad objectives of the study

   i. Compile complete river drainage map in GIS by integrating available secondary maps in WRIS of CWC. 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 be integrated with the final river drainage maps.
   ii. Study of shifting of the river course and also the changes in its plan form from the base year (say 1970) till 2010, by collecting 4 sets of satellite imageries at 10 years interval in addition to one set of Survey of India toposheets for the base year on a scale of 1:50,000. In case the toposheets are available for the older period (say 1950), the base year may be shifted accordingly.
   iii. Compile changes in the Land use/Land cover, and study of its impact on the river Morphology.
   iv. Channel Evolution Analysis 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. Work out the rate of bank erosion/deposition in term of erosion length and erosion area w.r.t. base year at 50 km interval.

vi. Assess the present condition of the critical reaches of the main channel of river which may be assessed by conducting ground reconnaissance. Field recon trips may be taken, if required.

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

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

ix. 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.

x. 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.

xi. 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.

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

3. Pagladiya is one of the major tributaries on the northern bank of the river Brahmaputra. The river originates on the southern slopes in the foothills of Bhutan at an altitude of 3000 m above *msl*. After traversing through the hilly terrain of Bhutan, it enters Nalbari district (presently Baksa district) of Assam near Chowki and terminates into the Brahmaputra near a village named Lowpara. The river extends between 91°21'39.68" E to 91°36'19.29" E longitude and 26°18'13.18" N to 26°56'7.55" N latitude. It flows for a length of 19 km in the hilly track of Bhutan and the rest 177.80 km flows through Baksa and Nalbari district of

Assam. The total catchment area of the river is 639.39 km^2. The hilly portion of the catchment area is about 465 sq. km of which 423 sq.km. are in Bhutan and the rest 42 sq.km lies in the Indian Territory.

4. **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. Need and scope of further study for better management of the river has also been highlighted.

5. In this study, SOI toposheets of 1973-74 and 4 sets of satellite data for the period 1976-80, 1993-95, 2003-04 and 2008-11 were used. Out of these 5 datasets, toposheets 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.

6. The hydrological data were obtained for various CWC gauge stations. The daily discharge data at NT Road Crossing were collected from Brahmaputra Board for the period 1998-2004. The probability exceedence curves were then plotted and the percentage exceedance probability for return period of 1.5-year and 2-year is calculated.

7. The river drainage map of Pagladiya River has been prepared showing the major tributaries (Darunga and Matunga) of the river.

8. The bankline of the river at different time were digitized. An exercise of comparative analysis of manual delineation and automatic delineation NDWI and NDVI was performed. From this analysis, it has been observed that the automatic delineation method was not

effective in delineating the river bankline near lateral bare sandbar or vegetated sandbar. 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.

9. The quantification of erosion-deposition analysis of Pagladiya River is not feasible as a tremendous amount of shifting of river course has been observed in many reaches. Decadal bankline shifting has been calculated for both the banks. To do a finer study, section lines are taken at an interval of 2 km from the foothill of Bhutan in Assam border to the confluence point of the river with the Brahmaputra. This study reveals that the average maximum shifting of the river is taking place in eastward direction.

10. Watershed of Pagladiya has been delineated in ArcGIS. The area and the perimeter of the watershed was found to be 639.39 km^2 and 212.85 km respectively. The stream ordering was done using Strahler's algorithm. The bifurcation ratios were then evaluated. The other basin parameters were also calculated.

11. Channel Evolution Process was studied for the Pagladiya River. For the study, 10 km section line were considered from the foothill of Bhutan. At the upstream part in Assam, the river width was found to be 2.3 km which had been reduced to 1.1 km in 2008-11. Some prominent cutoffs were observed in some of the reaches.

12. The longitudinal profile of Pagladiya has been prepared by using Google Earth elevations data.

13. To study the change in the width of the river, the whole river had been divided in section of 10 km reach. The width of the river at each section for all the study periods was measured. A plot of channel width against the river sections is also prepared. From the plot, it can be seen that the width of the river is varying with time and space.

14. The Planform Index (PFI) of the river has been calculated considering 10 km section. From the analysis, it can be seen that the braiding of the river is low as the PFI values are greater than 19. However, in the upstream part when the river just reaches the plains of Assam, the river is moderately braiding.

15. The meandering parameters like meander lengths, meander widths, bankfull widths and meander width ratios are calculated. The maximum meandering length of 4 km has been observed in the year 2003-04 and the minimum length of 0.54 km has been observed in 1973-74. The maximum meandering width of 2.31 km has been observed in 2003-04 at reach 6 and minimum of 0.34 km has been observed at reach 7 in 1976-80. The maximum bankfull width of 437.82m has been observed at reach 4 in 2003-04 whereas minimum bankfull width of 92.8 m has been observed at reach 9. Meander width ratios are also calculated.

16. Landuse-Landcover (LULC) map has been prepared for 1973-74, 1976-80, 1993-95, 2003-04 and 2008-11. From the analysis, it can be observed that there is a decrease in dense forest & agricultural area while the built-up area has been increased over the time. The increase in the built-up area in the downstream portion and reduction of forest cover in the upper catchment of Pagladiya has resulted in siltation in the river.

17. Flood inundation map for the period 1999-2010 has been downloaded from BHUVAN website. Flooding in North East India occur generally due to breaching of embankments. Therefore, an area not getting flooded in these layers may also get affected by severe flood if embankment protecting that area suffers failure. Similarly, an area experiencing flood may not experience it with the same intensity if relevant embankment is repaired or reconstructed to protect that area. These facts need to be considered while preparing policies for flood relief, insurance etc.

18. The most vulnerable area of Pagladiya has been observed as at the confluence point of Brahmaputra. A shift of 4.6 km occurred between 1973-94 and 2008-11.

19. The Pagladiya basin is devoid of any major hydraulic structures. A multipurpose reservoir with the purpose of flood control, irrigation and power generation was planned. However, the project has not been undertaken. Several bridges including railway bridges over the river have been constructed at different locations. However, the span of these bridges is sufficient for conveying the discharge of the river. As such, no major change in the downstream flow scenario has been observed due to the construction of these bridges.

20.

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.

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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 Pagladiya River

Barman (2007) studied the fluvio-morphological impact of Pagladiya-Mora Pagladiya Rivers on rural settlements. The study was conducted using toposheets and Landsat imageries for the period 1971 -2001. He found that Pagladiya and Mora-Pagladiya rivers and their tributaries have changed their courses. From the study, he concluded that the Pagladiya River shows an eastward shifting trend in the past 100 years. The Mora-Pagladiya River was the original course of Pagladiya River which abandoned more than 160 years ago. The morphometric characteristics of Pagladiya River were also analyzed in the study. Barman et. al. (2013), studied the application of Cartosat Stereo DEM for flooding genesis on the Pagladiya watershed in Lower Assam, India. The study focuses on the use of Digital Elevation Models for the analysis of floodplain topography and flooding genesis. The study enunciates the applicability and limitations of DEM by stereo photogrammetric techniques for understanding flooding genesis with flat floodplain topography. The floodplain boundary was delineated by integrating satellite data with SOI toposheets. For the generation of CARTOSAT DEM, the Ground Control Points were collected. The processing of CARTOSAT-I stereo pair in LPS plate form was done incorporating the GCPs collected through DGPS survey for generation of CARTOSAT DEM of the floodplain. The morphometric analysis of the entire watershed is done with special focus on drainage of the floodplain area. The study concluded that the vertical precision of 2.5m is adequate to capture major elevation drops and lift along 64 km long downstream floodplain, whereas the computed hypothetical local relief of 1.05 m has been found.

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.

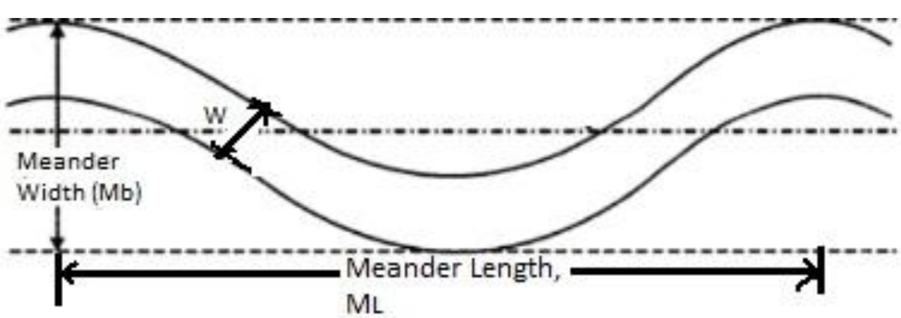


Figure 1: Meandering of a river

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:

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

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

2.2.2 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 characteristic 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:

Straight rivers: Sinuosity index <1.1

Sinuous rivers: Sinuosity index between 1.1 - 1.5

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.

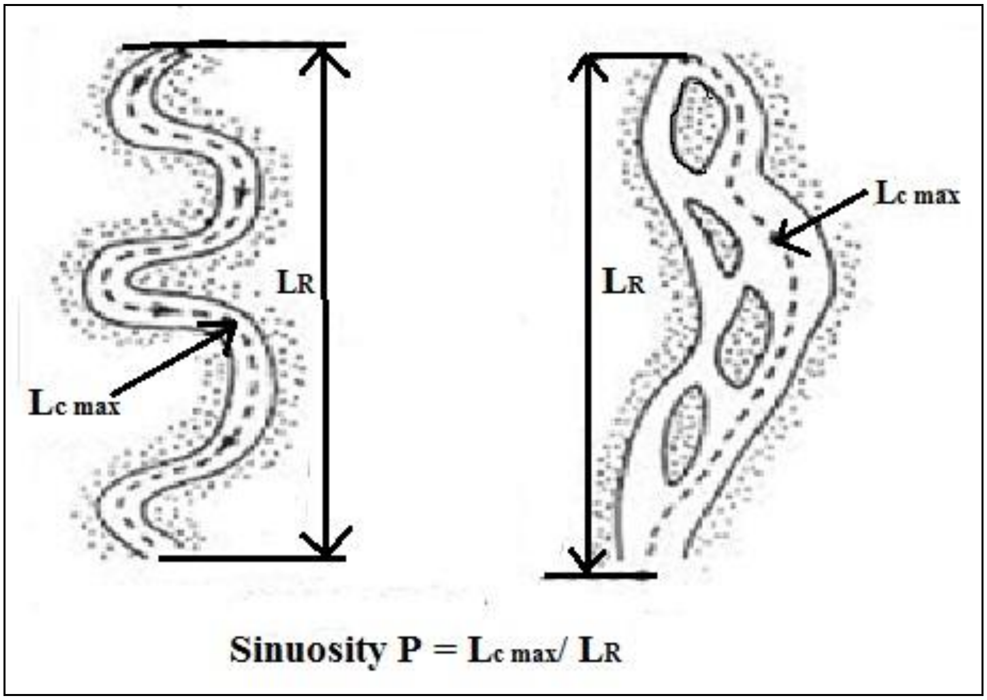


Figure 2: Sinuosity Index in a channel by P.F. Friend and R.Sinha (1993)

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 (Ezizshi, 1999). Mueller (1968) has redefined the index to incorporate hydraulic sinuosity (i.e. that freely developed by the channel uninfluenced by valley-wall alignment) and topographic sinuosity (i.e. imparted by the geometry of the channel).

Parameters taken for Mueller's Sinuosity Index:

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

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

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

CI (Channel Index) = CL / Air

VI (Valley Index) = VL / Air

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

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

SSI (Standard Sinuosity Index) = CI / VI

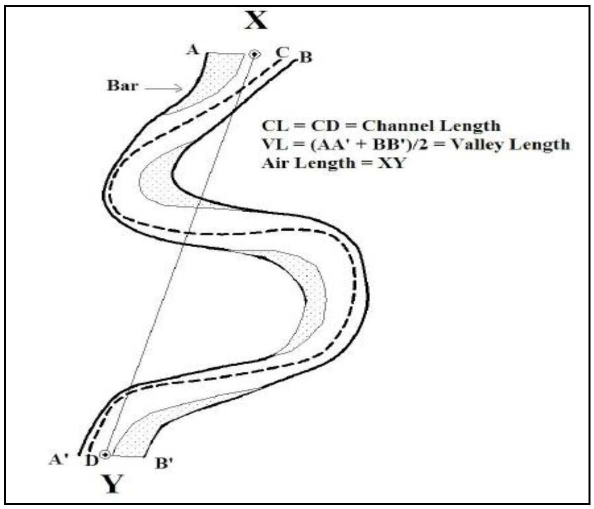


Figure 3: Sinuosity index given by Mueller (1968)

2.2.3 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 b/w banks of channel belt.

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

Rust (1978), measured the braiding parameter as:

$B_p = \sum L_b / L_m$

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.

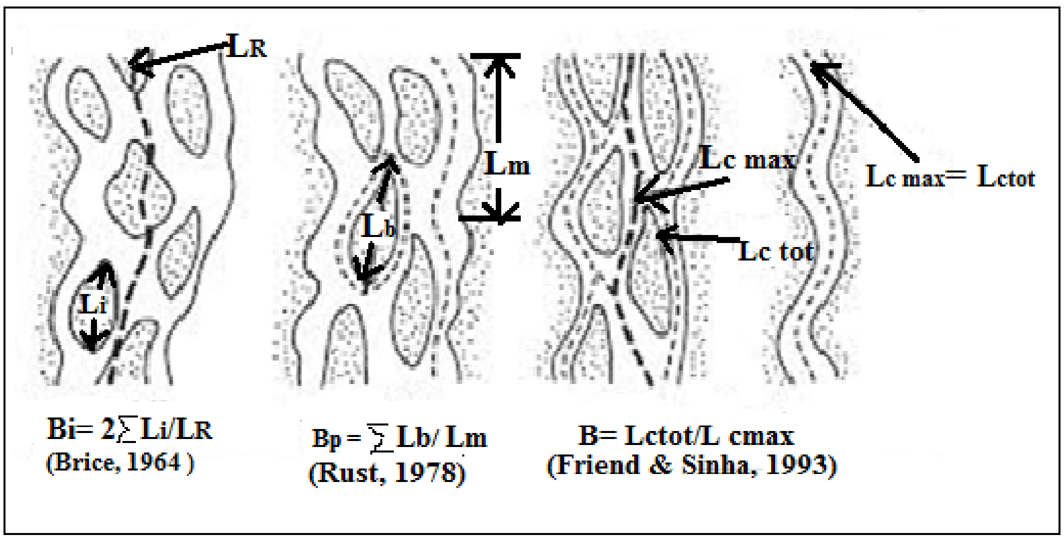


Figure 4: Diagram representing the calculation of the braiding indices of Brice (1964), Rust (1978), Friend and Sinha (1993)

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

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 threshold values for PFI are proposed by Sharma.

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).

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

Where, R_b = Bifurcation ratio, N_u= Number of streams of a given order, N_{u+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

$D_d = \frac{\sum L_u}{A}$(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 (F_s)

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 (L_1)

Basin shape factor is given by

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

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

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

2.2.4.5 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)

$D_f = F_s/D_d^2$

Where, F_s 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) as,

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

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

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

Chapter 3
STUDY AREA

3.1 Study Area

Pagladiya is one of the major tributaries on the northern bank of Brahmaputra River. The Pagladiya, as its name implies, has been a chronic source of trouble due to its frequent changing of flow course. The river Pagladiya originates on the southern slopes in the foothills of Bhutan at an altitude of 3000 m above msl. After traversing through the hilly terrain of Bhutan, it enters the Nalbari district (presently Baksa district) of Assam near Chowki and terminates into the Brahmaputra near a village named Lowpara. The major tributaries that joins the main channel of Pagladiya are Nona, Mutunga, Dimla and Chowlkhowa (NIH, 1999-2000).

The river extends between 91°15' N to 91°30' N latitude and 26°45' E to 26°15' E longitude. It flows for a length of 19 km in the hilly track of Bhutan and rest 177.80 km flows through the Baksa and Nalbari district of Assam. The hilly portion of the catchment area is about 465 sq. km of which 423 sq.km are in Bhutan and the rest 42 sq.km lies in the Indian Territory (Master Plan Report of Brahmaputra Board, Ministry of Water Resources, Govt. of India, 1996). In the hilly portion, slope of the river bed is very steep, being 1 in 75 in the middle reach and about 1 in 200 in the lower reach i.e. from Hajo-Nalbari road to outfall it is 1 in 2600.

Pagladiya is a meandering stream which shows braiding in the upper portion. Studies done by GSI, 1977 revealed that a major shift in the river course to the east occurred due to the 1897 tectonic activity. Before this tectonic activity, this river used to flow in a westerly direction. The relict of the earlier Pagladiya can still be seen in the form of abandoned channel (known as Mora Pagladiya) passing through Khagrabari and Barama. Thus it can be clearly said that the Pagladiya basin has been developed by the actively migrating nature of the stream and resulted in a basin consisting of complex channel migration pattern (Desai et. al., 2006). Pagladiya river system is one of the most problematic sub-basins so far as the sediment load and chronically flood affected areas are concerned. Transportation of heavy amount of sand, silt gravel and aggradation of river bed has been observed to be very prominent phenomena in the basin. Figure 5 shows the Pagladiya catchment along with the international boundary. The study has been conducted within the national boundary.

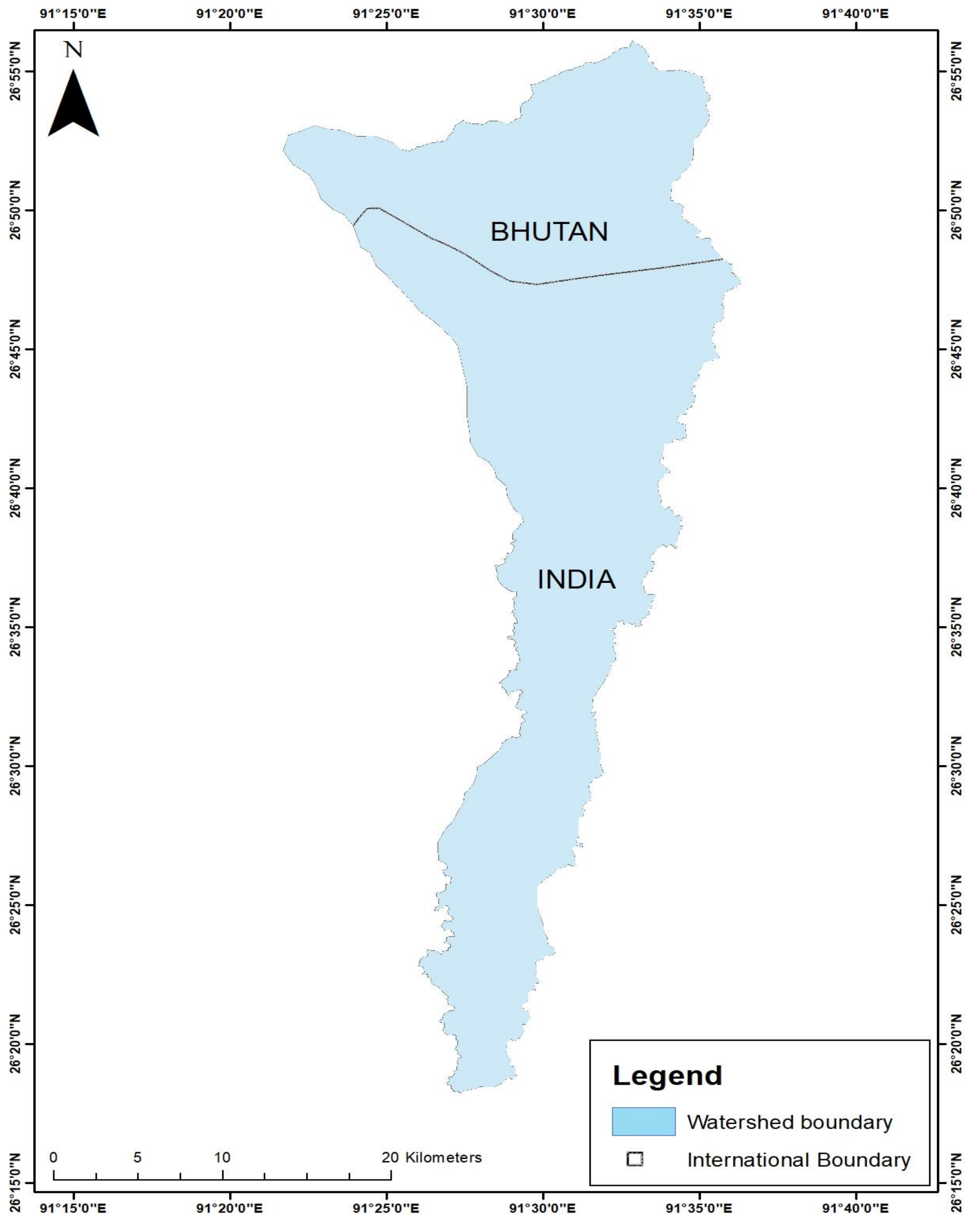


Figure 5: Pagladiya watershed with International Boundary

Chapter 4
RIVER BASIN

4.1 Introduction

The river Pagladiya originates on the southern slopes in the foothills of Bhutan at an altitude of 3000 m above msl. After traversing through the hilly terrain of Bhutan, it enters the Nalbari district (presently Baksa district) of Assam near Chowki and terminates into the Brahmaputra near a village named Lowpara. The major tributaries that joins the main channel of Pagladiya are Nona, Mutunga, Dimla and Chowlkhowa (NIH, 1999-2000). The river extends between 91°21'39.68" E to 91°36'19.29" E longitude and 26°18'13.18" N to 26°56'7.55" N latitude.. It flows for a length of 19 km in the hilly track of Bhutan and rest 177.80 km flows through the Baksa and Nalbari district of Assam. The hilly portion of the catchment area is about 465 sq. km of which 423 sq.km are in Bhutan and the rest 42 sq.km lies in the Indian Territory (Master Plan Report of Brahmaputra Board, Ministry of Water Resources, Govt. of India, 1996). In the hilly portion, slope of the river bed is very steep, being 1 in 75 in the middle reach and about 1 in 200 in the lower reach i.e. from Hajo-Nalbari road to outfall it is 1 in 2600.

4.2 River drainage system

The river Pagladiya originating from the Bhutan hills on entering the plains of Assam get wider. This is due to the fact that due to the sudden change in the slope the water spread area in the alluvial plains of Assam increases. The river after flowing for some area again constricted. The Pagladiya mainstem river is met by two more rivers namely Daranga and Mutunga which combinely meet the mainstem Pagladiya at a place called Namcharia. (Figure 6). The tributary Mutunga joins the Pagladiya river at the upstream of the proposed reservoir [J A Ahmed,2004]

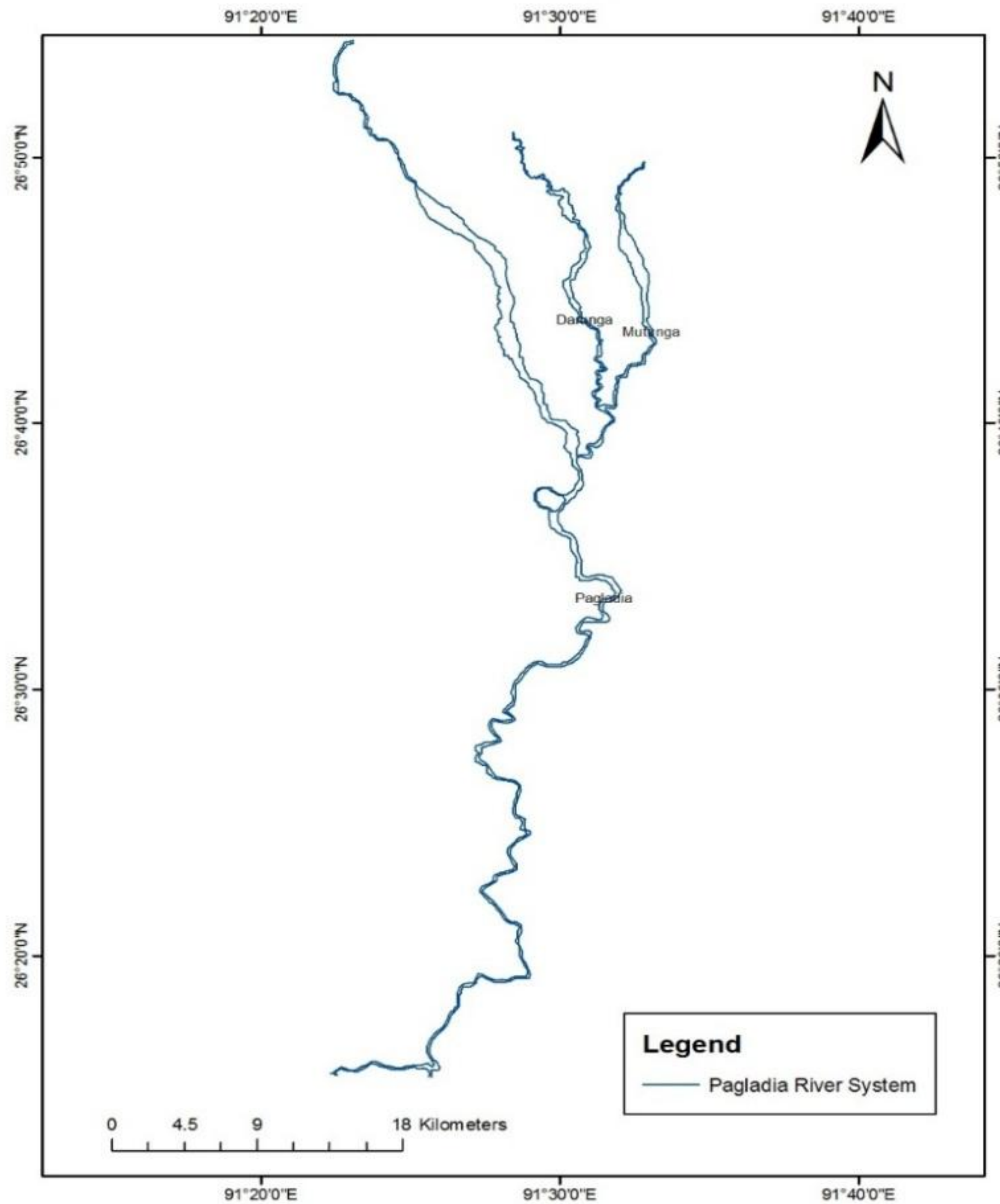


Figure 6: Pagladiya River System showing major tributaries

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:

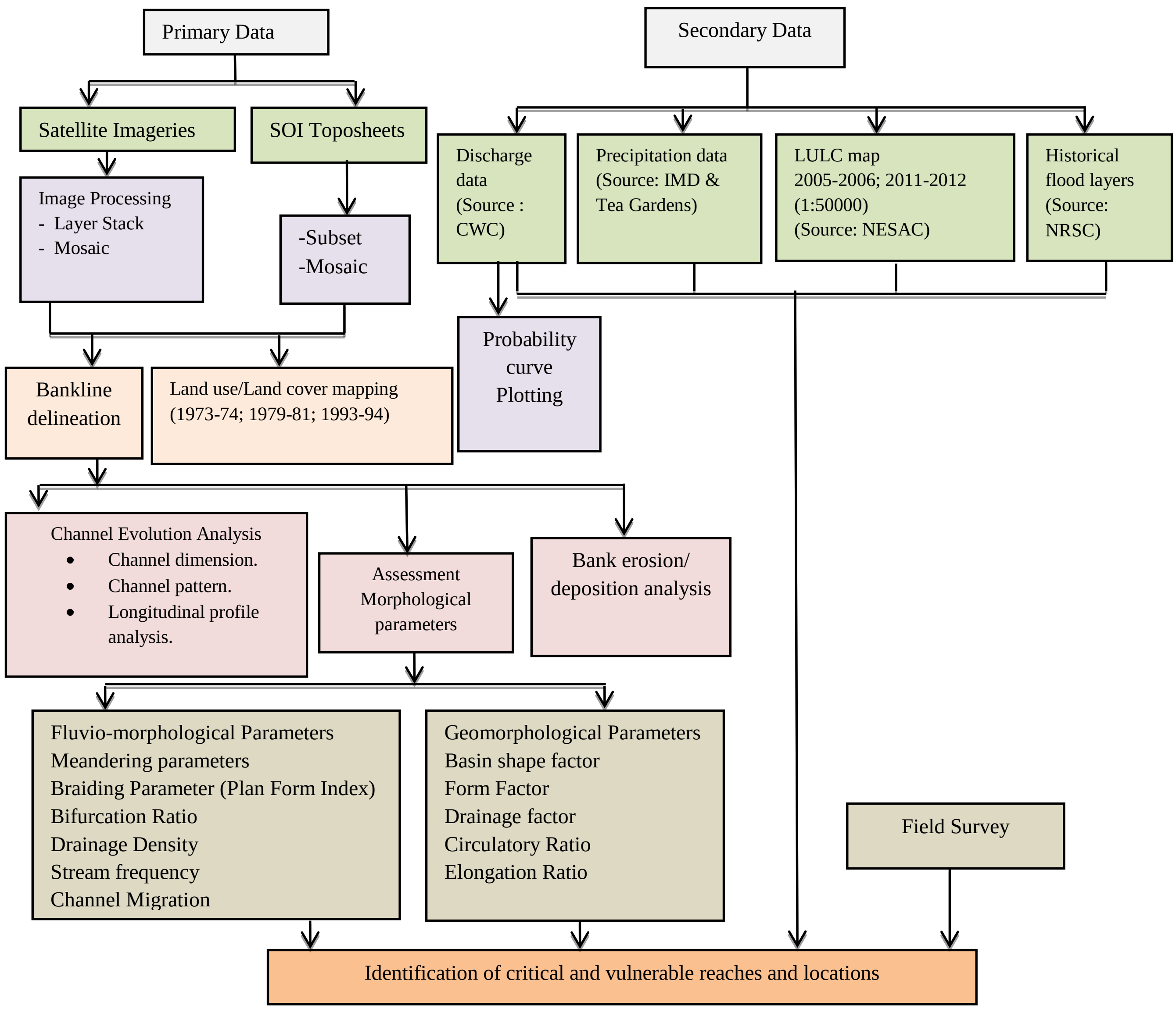


Figure 7: Methodology

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 application of GIS based study greatly depend upon the reliability of remote sensing data.

6.2 Data collection and Image Processing

6.2.1 Geospatial data

In this study, 1 set of SOI toposheets of 1973-74 and 4 sets of satellite data for the period 1976-80, 1993-95, 2003-04 and 2008-11 at around 10 years interval were used. Out of these 5 datasets, toposheets and the satellite imageries of 2008-11 (Resourcesat-1, LISS 3) were already available with IITG. The SOI toposheets were georeferenced using 1st Order Polynomial Model in Erdas Imagine 2015 and keeping the total RMS error less than 1. The subset of the georeferenced toposheets were then taken out and mosaicked to cover the entire watershed. Also, mosaicking had been performed for the 2008-11 LISS 3 datasets. Georeferenced Landsat MSS imageries of 1976-80 were downloaded from the USGS website and then layer stacking and mosaicking of the dataset was carried out using ERDAS Imagine 2015 software. Georeferenced satellite imageries for the periods 1993-95 (IRS 1B, LISS 1) and 2003-04 (IRS P6, LISS 3) 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.

The details regarding the geospatial data used in the study are given in Annexure-I and the specifications of the sensors are given in Table-1.

Table 1: Sensor Specifications

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

Figure 8: Mosaicked toposheet covering Pagladiya River (1973-74)

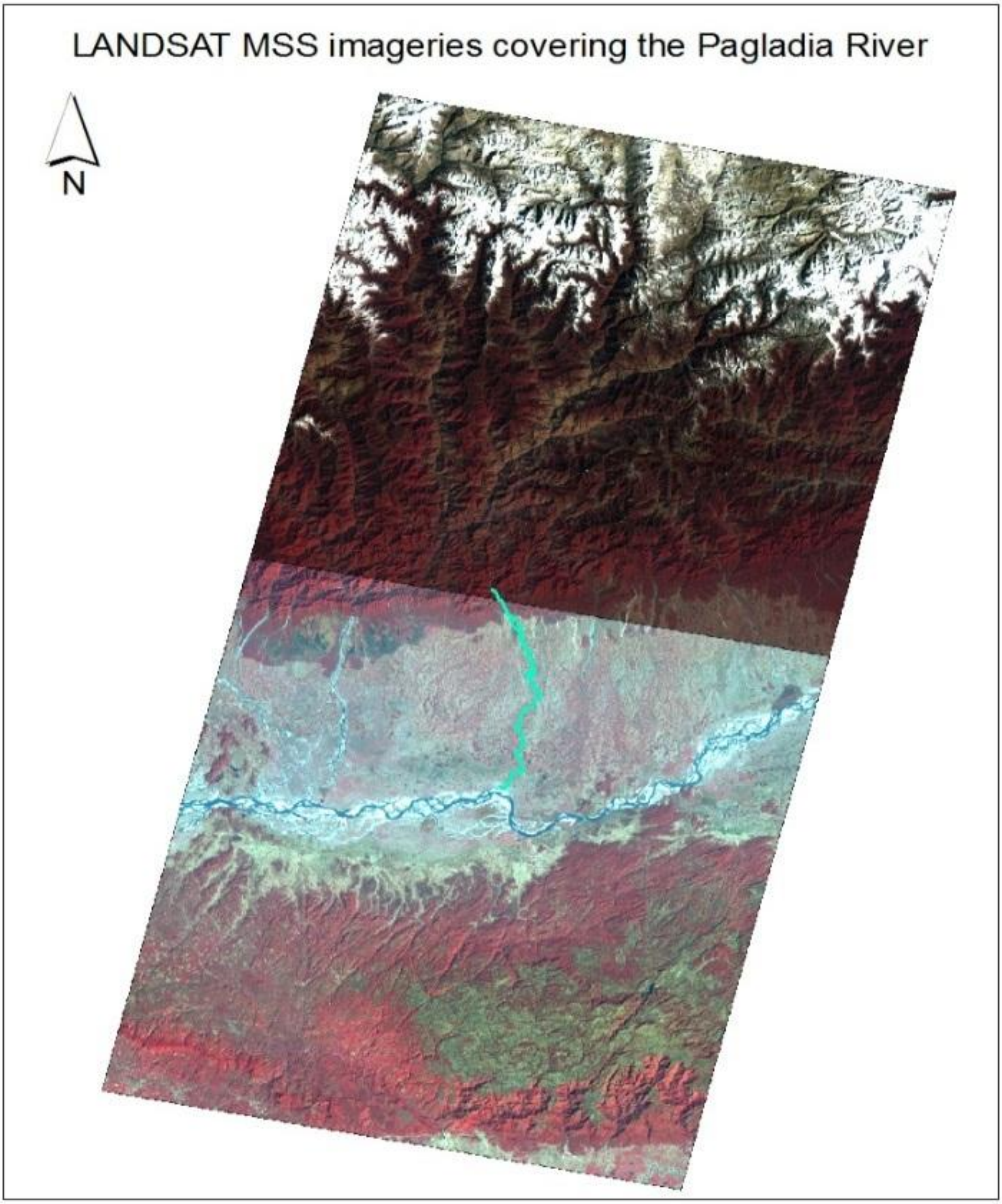


Figure 9: Mosaicked Landsat MSS data of 1976-80

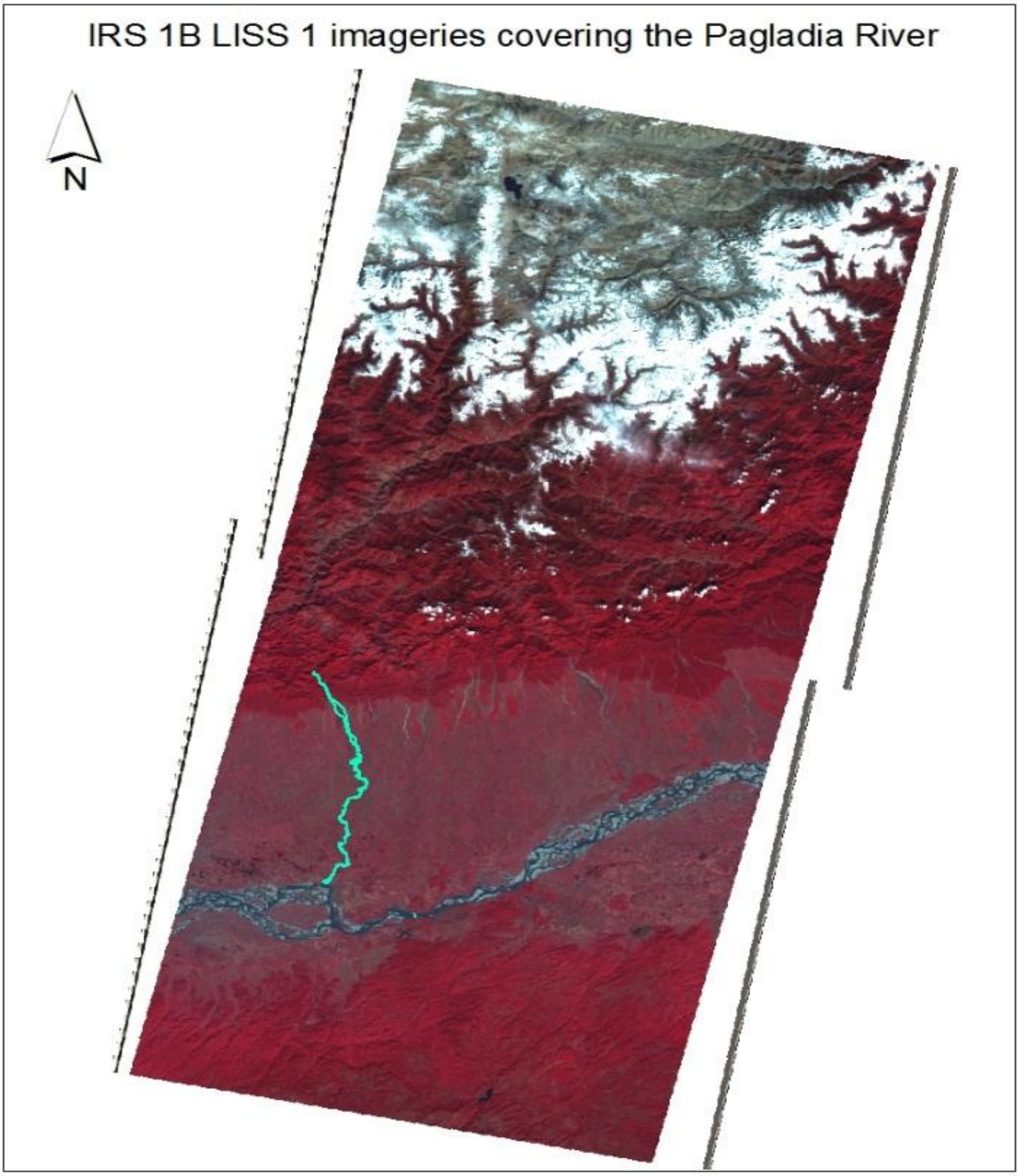


Figure 10: Mosaicked IRS 1B LISS 1 data of 1993-95

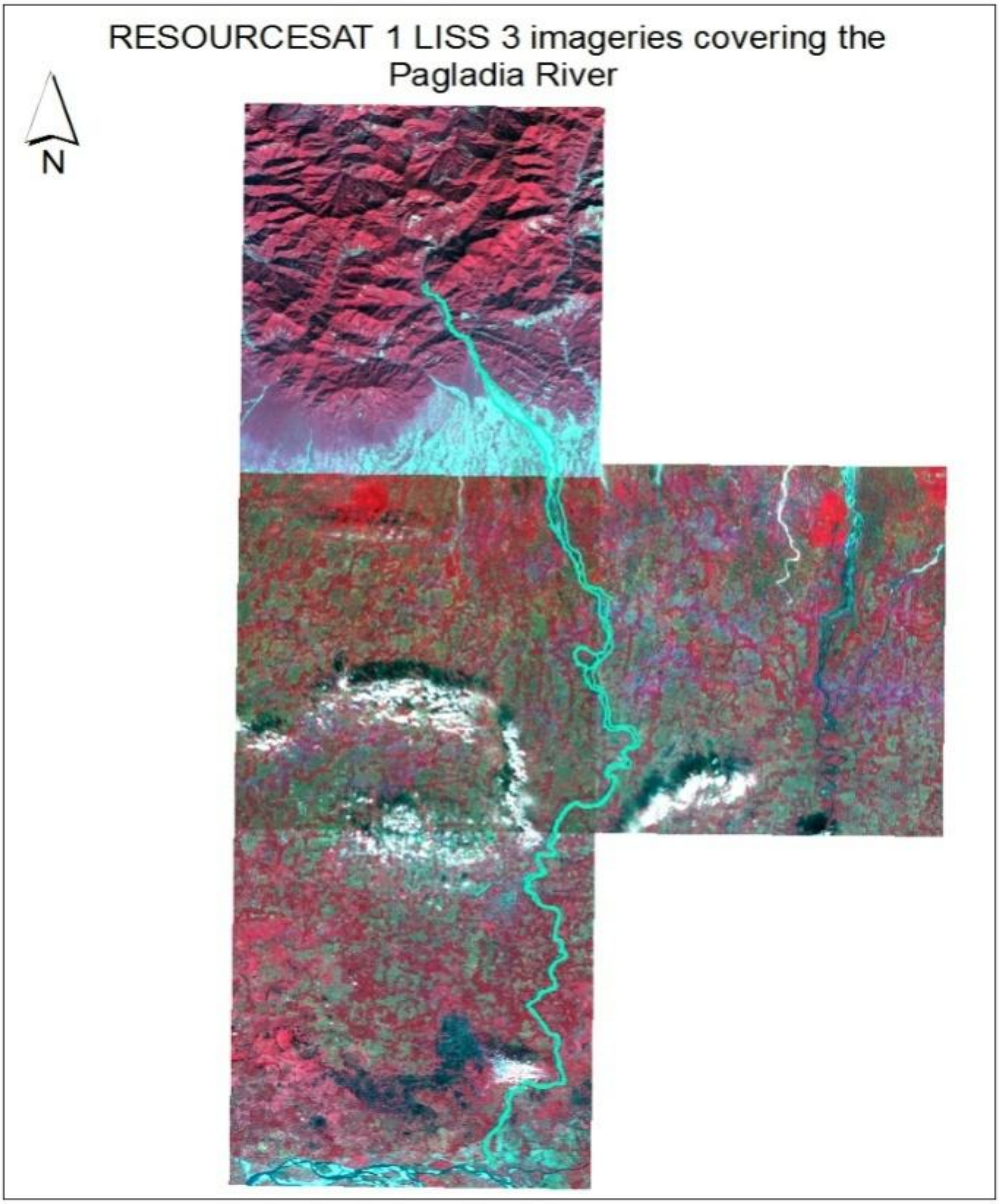


Figure 11: Mosaicked IRS P6 LISS 3 data of 2003-04

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

6.2.2 Digital Elevation Model (DEM)

SRTM DEM data of 90 m resolution covering the Pagladiya catchment was downloaded from the USGS earth explorer (https://earthexplorer.usgs.gov). The DEM tiles were then mosaicked and further used for Pagladiya catchment delineation in ArcGIS 10.1.

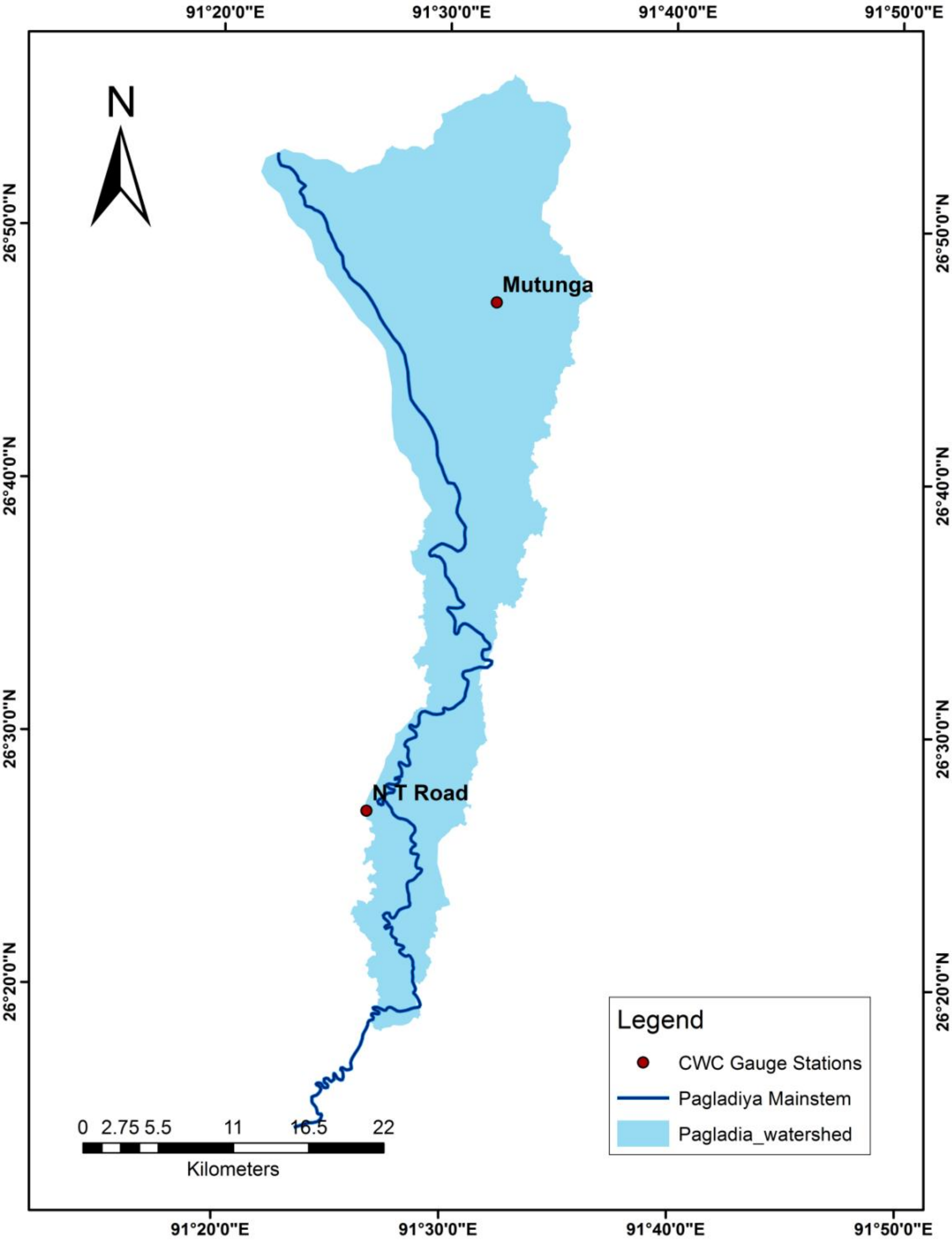


Figure 13: Location Map of the CWC HO sites in Pagladiya

Chapter 7
HYDROLOGIC DATA

7.1 Introduction

Understanding the mechanism of hydrologic cycle and its impact on climate accurate measurement of hydrological variables are of utmost importance. To understand the behavioral, chemical processes long term monitoring of hydrological variables like precipitation, streamflow, groundwater levels, evapotranspiration losses is essential. Reliability of these data greatly depend upon the accuracy of the measuring instrument and also on the skill of the data collector and interpreter which is often a major challenge in hydrology. A model will impart a better performance if the data are reliable. In hydrological sciences it will be one of the greatest future challenge for ensuring longevity, quality, monitoring and continuity of the measuring network. In field of hydrology, remote sensing technique has improved the quality of the data. Satellite based precipitation data e.g. TRMM and GPM (NASA), PERSIANN (NCAR), CSFR (TAMU) have been used by many hydrologists. These data are validated with ground data and has been proved reliable to some of the extent.

7.2 Climate

Climate of the basin is quite similar to the other districts in central Assam, India. The winter is cold, foggy while summer is oppressively hot and humid. The rainfall is substantially high during monsoon, which extends from May to September. Relative humidity in monsoon months (June to September) varies from 79% to 85%. The temperature in winter goes down to 11^0C and in the month of July-August it rises upto 37-38. The main rainfall season of the basin is from May to September during 83 % of annual rainfall occurs. The rainfall during October to April contributes only about 17% of the annual rainfall. The annual rainfall varies from 775 mm to 3447 mm.

7.3 Hydrologic Data Collection

Hydrological data for river Pagladiya were collected from the CWC, Middle Brahmaputra Division and used to plot the probability exceedance curve. As CWC has no GD sites in the Pagladiya catchment, therefore only the daily gauge level data were used to plot the probability exceedance curve. Details of the hydrological data collected are given as Annexure II.

7.5 Probability Exceedance Curve

7.5.1 Flow Duration Curves

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 streamflow 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 a 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) 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.

As discharge data of Pagladiya River was not received, the discharge data of NT Road Crossing of Pagladiya river was collected from Brahmaputra Board from 1998-2004. The year 2001 was missing in their record so an average of all the years were taken into consideration.

7.5.2 Methodology

The stage probability exceedance curve for the river Pagladiya was plotted for the site NT Road Crossing from the available daily stage data collected from Middle Brahmaputra Division, CWC, and Guwahati. The daily stage data available at the NT Road Crossing for the Pagladiya River were arranged in descending order of class value and the total no. of days in each class were marked. Also, the number of days the flow is equal to or greater than the class interval is calculated which gives the value of *m*. The percentage probability (Pp) i.e. the probability of flow in the class interval being equaled or exceeded is given by the equation:

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

Where, Pp = percentage probability of stage magnitude being equaled or exceeded, m = order number of the stages, N = number of data points.

The plot of discharge Q against Pp is the stage duration curve. The smallest value of the stages in each class interval is plotted against Pp on a log-log paper.

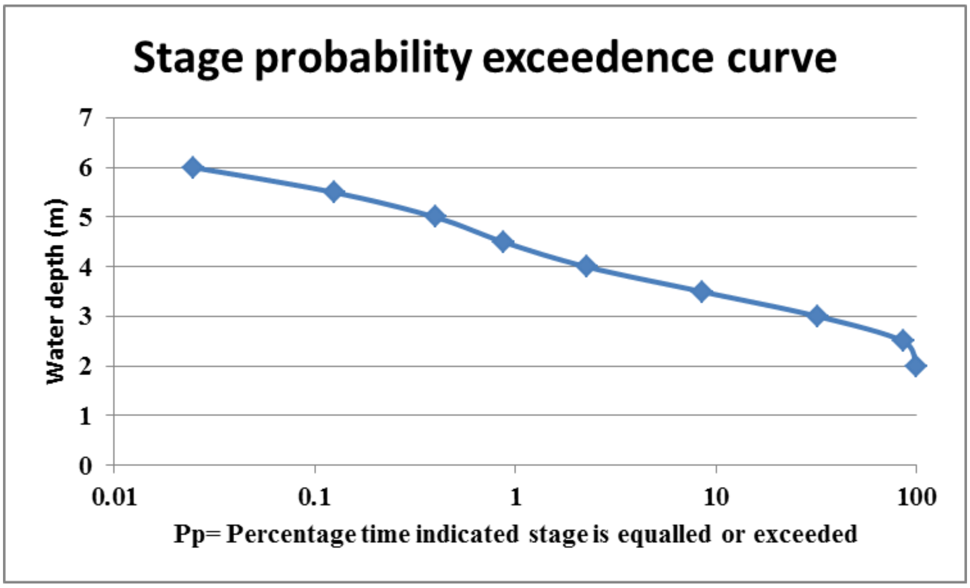


Figure 14: Stage probability exceedance Curve for NT Road Crossing site of Pagladiya River

7.6 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 floodplains (Tumbare, 2000).

7.6.1 Gumbel's Method

Gumbel (1941) introduced the extreme value distribution and is commonly known as Gumbel's distribution. Gumbel defined a flood as largest of 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. According to this theory of extreme events, the probability of occurrence of an event equal to or larger than a value x_0 is

$P(X \geq x_0) = 1 - e^{-e^{-y}}$ in which y is a dimensionless variable given by (7.1)

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

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

(7.2)

σ_x = standard deviation of variate X.

Eq.7.1 can be written as

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

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

$y_T = -[\ln.\ln \frac{T}{T-1}]$ (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 $K = \frac{(y_T - 0.577)}{1.2825}$

(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 = $\sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$

$$K = \text{frequency factor}, \frac{(y_T - \bar{y}_n)}{S_n} \quad (7.8)$$

Where, y_n= reduced mean, a function of sample size N; S_n=reduced standard deviation, a function of sample size N

7.6.1.1 Methodology

From the maximum discharge evaluated per year for NT Road Crossing site in Pagladiya, the discharge values corresponding to 1.5 years and 2 years return period were found out using Gumbel's equations as mentioned above. The percentage probability of flow magnitude being equaled or exceeded was thus calculated from the stage probability exceedance curve corresponding to the stage values for 1.5 years and 2 years return period and is shown in Table 2 below:

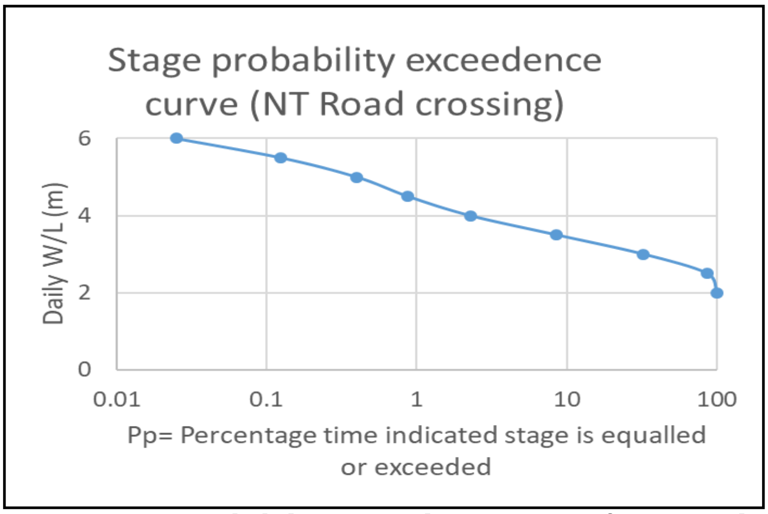


Figure 15: Stage Probability Exceedance Curve of N T Road Crossing

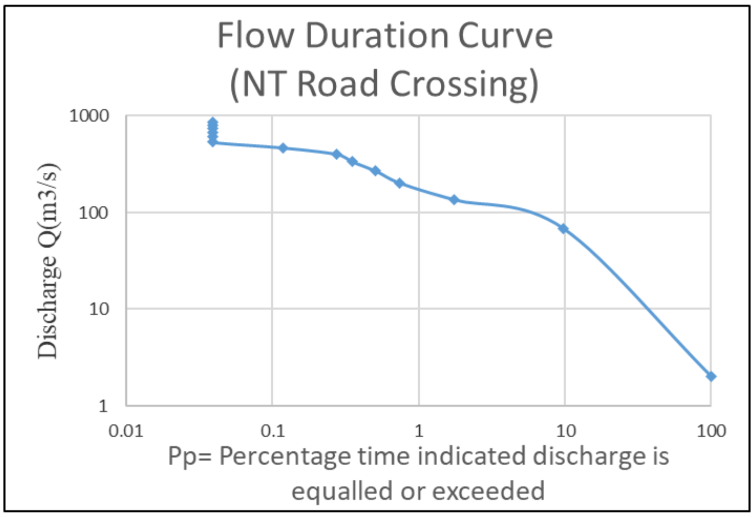


Figure 16: Probability Exceedance Curve of NT Road Crossing

Table 2: Percentage Probability of H.O. sites

H.O. Sites	Return Period Tp (Years)	Pp (%)
NT Road Crossing (Stage)	1.5	0.82
	2	0.36
NT Road Crossing (Discharge)	1.5	1.09
	2	0.53

7.6.1.2 Observations

From this analysis, it can be seen that from the stage probability exceedance curve of NT Road Crossing the percentage probability has been found to be 0.82 % and 0.36 % corresponding to return periods 1.5 and 2 years return period. Whereas, from probability exceedance curve of discharge the percentage probability has been found to be 1.09% and 0.53% respectively.

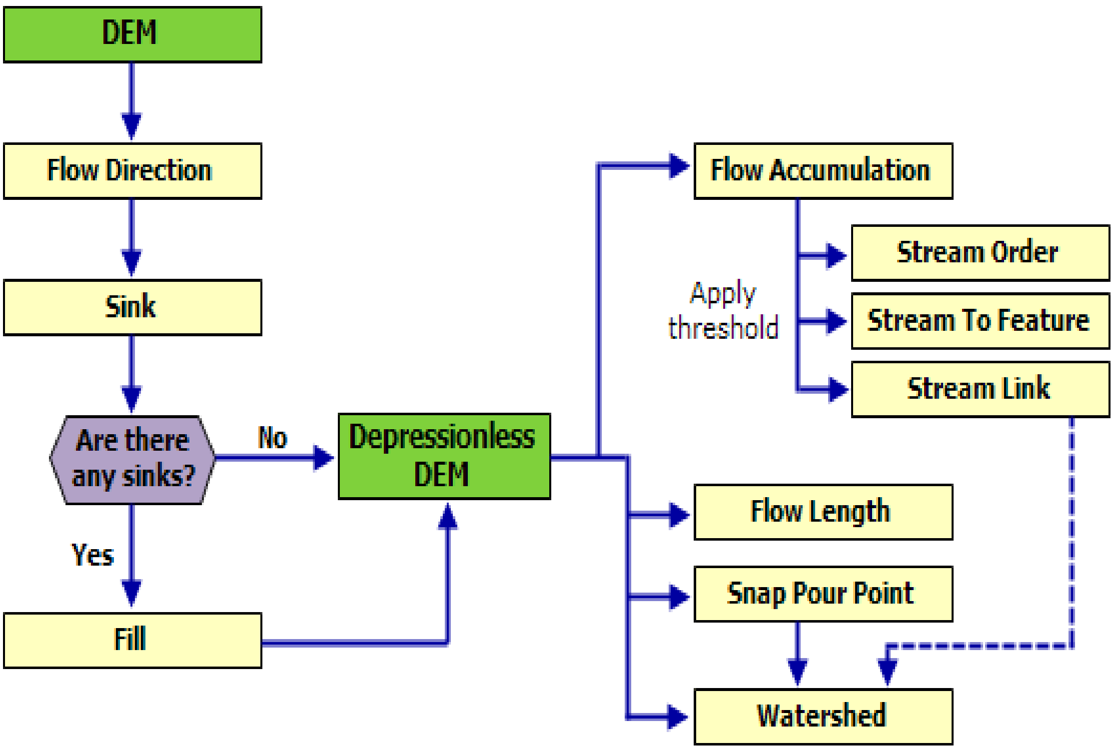
Chapter 8
MORPHOMETRIC ANALYSIS OF BASIN

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 17: Flowchart showing delineation of watershed

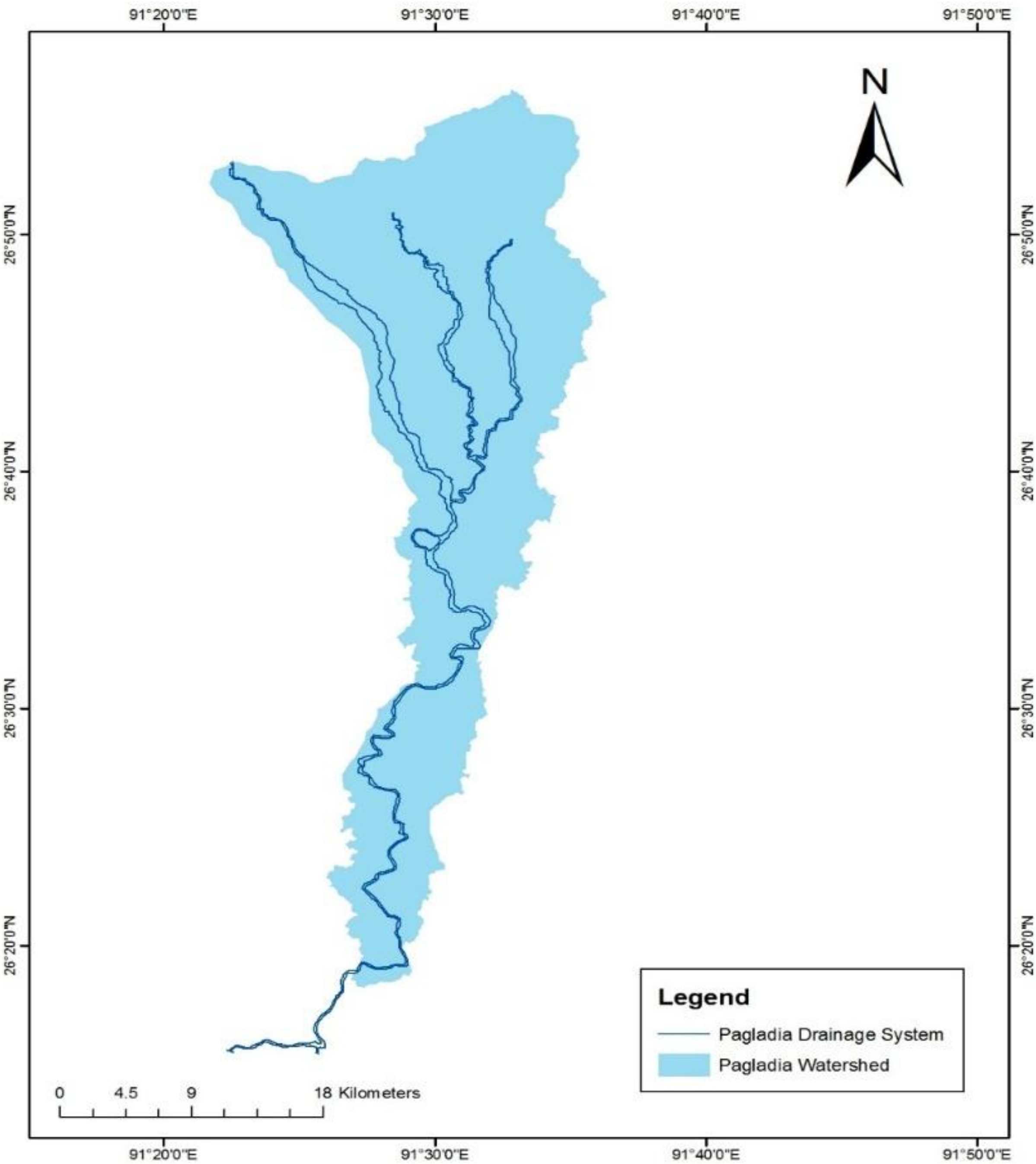


Figure 18: Pagladiya Watershed

8.1.1 Observations

The watershed of the Brahmaputra is delineated using SRTM DEM of 90 m resolution and the flow accumulation and flow direction maps were generated. 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 Pagladiya are found to be 639.31 km^2 212.85km respectively.

8.2 Mophometric parameter analysis

Morphometric analysis of Pagladiya 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 = 27000×0.02974×0.02974 km^2 = 23.88 km^2

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

Sl. No	Stream Order	Number of Segments (N_μ)	Length (L_u)
1	1	6	49.96 km
2	2	4	92.55 km
3	3	1	17.14 km

8.2.1 Bifurcation Ratio (R_b)

According to Strahler, the bifurcation ratio is the ratio of the number of the stream segments of given order 'N_u' to the number of streams in the next higher order (N_{u+1}). 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 are 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 Pagladiya watershed were calculated as follows:

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

R_{b1} = 6/4 = 1.5

R_{b2} = 4/1 = 4

The bifurcation ratios for different stream orders of Pagladiya river showed that the ratio is lowest for the stream order 1 which mostly cover the upstream region of the watershed and highest for the stream order 2 which occupies the downstream part. From these differences in the values, it can be inferred that the upstream portion of the Pagladiya watershed should be more prone to flooding as it exhibits a low value of R_b. However actual flooding depends on the status of embankment and many other factors. Two tributaries of the Pagladiya river viz. Daranga and Mutanga rivers flow through this portion of the watershed.

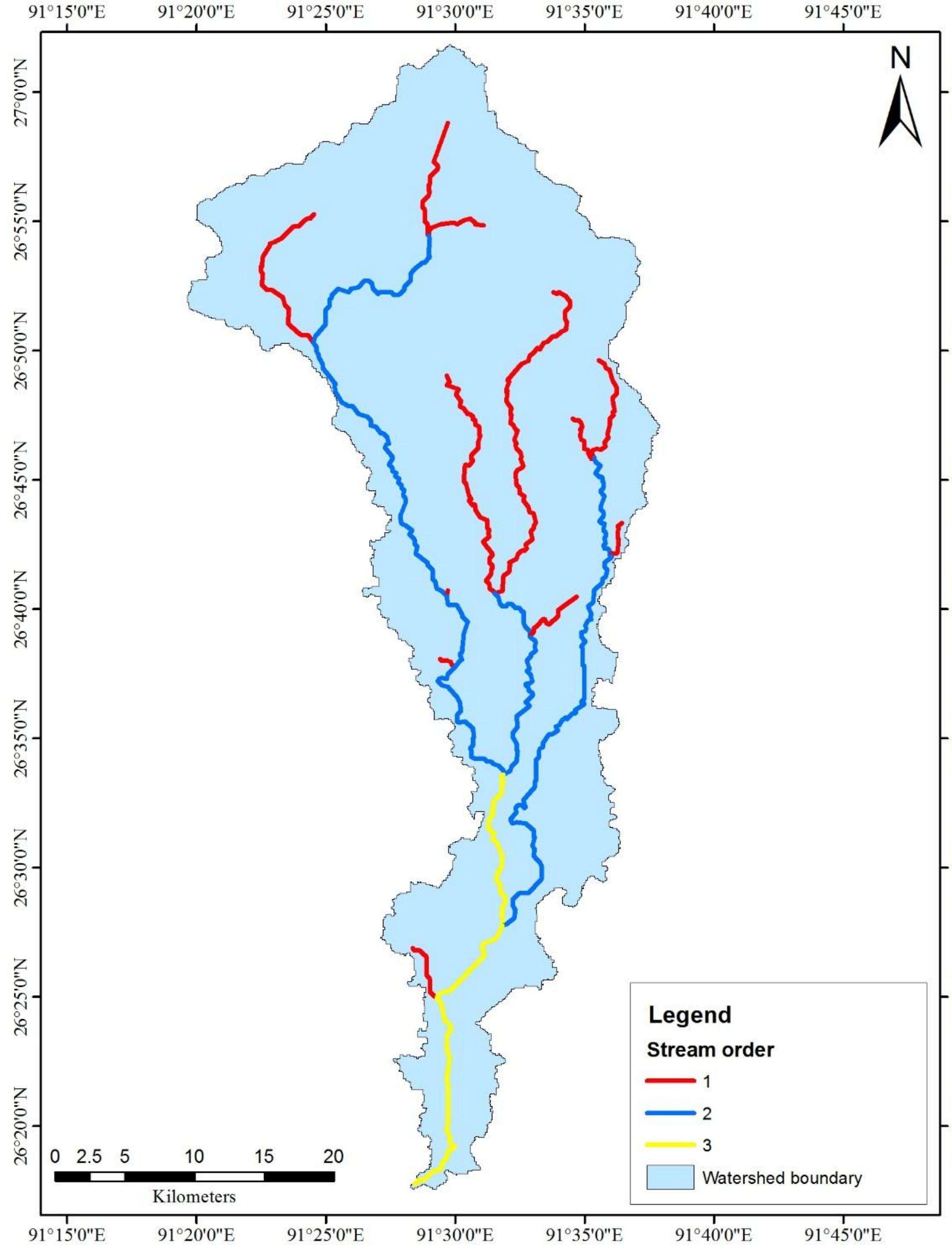


Figure 19: Stream order of Pagladiya catchment

8.2.2 Drainage Density (D_d)

The drainage density, which is expressed as km/ km^2, indicates a quantitative measure of the average length of stream channel area of the watershed. Generally, when the D_d is very low, intense rainfall events are more likely to result in a 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 = 639.31 km^2

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

D_d = (49.96+92.55+17.14)/639.39

= 159.65/639.39 km/km^2

= 0.2497 km/km^2

In Pagladiya catchment drainage density was found to be 0.249 km/km^2 which is low. This infers that the catchment is prone to flash floods in case of intense rainfall and has highly permeable sub-soil material under dense vegetative cover.

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 have the minimum.

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

F_s = (6+4+1)/639.31

=11/639.31

= 0.0172

8.2.4 Form factor (Ff)

The form factor is a 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 a lower peak flow of longer duration. Length of the basin, L_b = 73.07 km

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

F_f = 1056.36/(73.07)^2
= 0.1197

The value is found to 0.1197 which is low. This indicates that the catchment is elongated in shape.

8.2.5 Drainage Factor (D_f)

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

D_f = 0.0172/(0.2497)^2
= 0.2759

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 the same circumference as the basin perimeter. The 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 = 212.85 km

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

R_c = 12.566 x (639.31/(212.85)^2)
= 12.566 x(639.31/45305.1225= 0.18

The circulatory ratio for the Pagladiya catchment is 0.18 which refers to slightly elongated shape of the catchment.

8.2.7 Basin shape factor (S_b)

L_{ca} = 61.058 km = 37.94 miles

L= 73.07 km = 45.403 miles

$L_l = (LL_{ca})^{0.3} = 9.35$

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 the 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 a 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).

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

$$R_e = \frac{2 \times \sqrt{(\frac{1056.36}{\pi})}}{73.07}$$

$$= 0.5019$$

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 Pagladiya catchment, it has been observed that the bifurcation ratio is lowest in the upstream region of the watershed where two tributaries of the Pagladiya river viz. Daranga and Mutanga Rivers flow through. The bifurcation ratio is highest for the stream order 2 which occupies the downstream part. From these differences in the values it can be inferred that the upstream portion of the Pagladiya watershed is more prone to flooding than the downstream region. The drainage density of the catchment is found to be low i.e. 0.249 km/km2 which infers that the catchment is prone to flash floods in case of intense rainfall and has 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 in nature.

Chapter 9
LANDUSE LANDCOVER ANALYSIS

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

9.1 Methodology

Land Use/Land Cover mapping has been carried out within the Pagladiya 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 Pagladiya 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 are then calculated using calculate 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 19-22

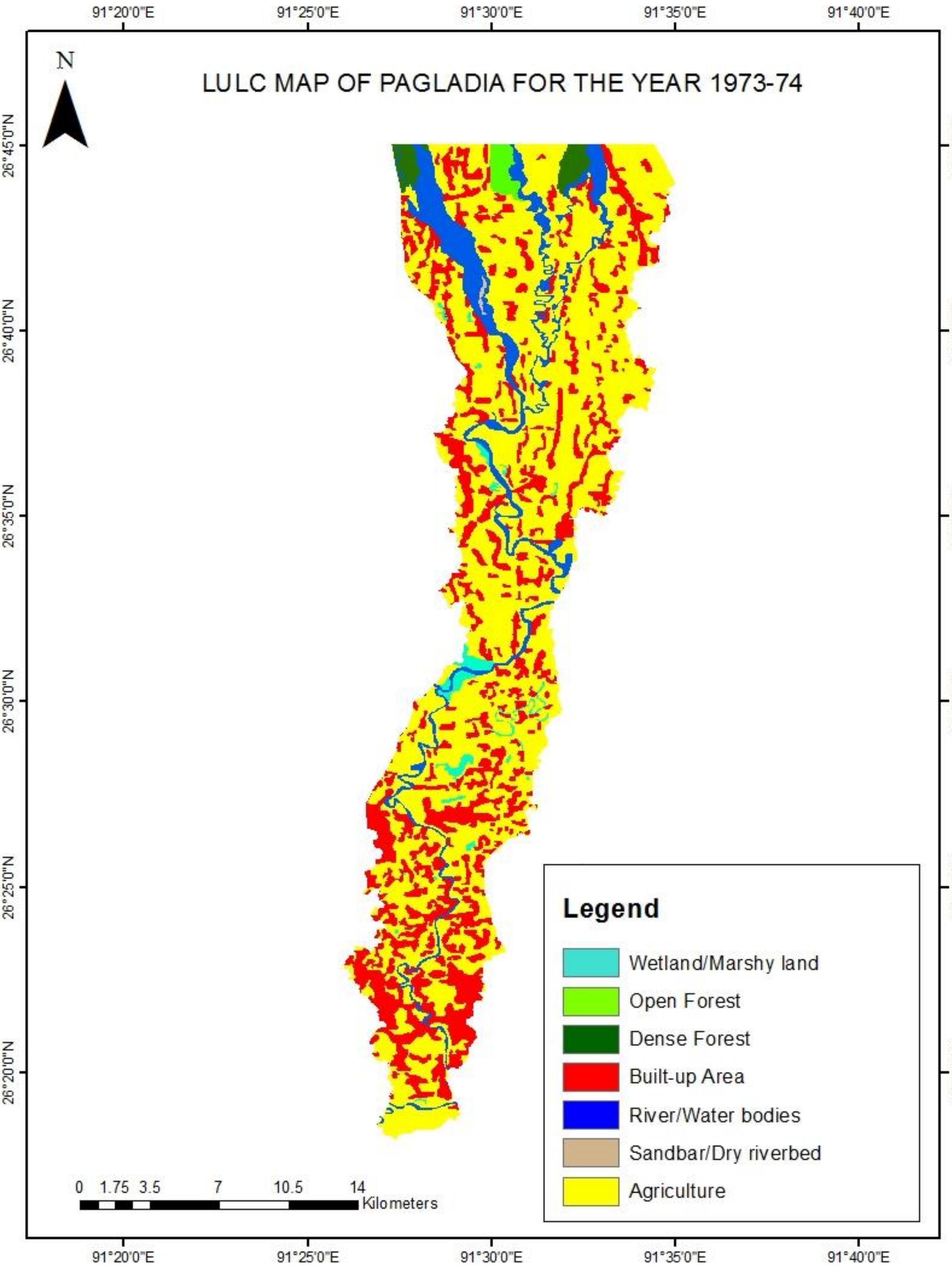


Figure 20: LULC Map of Pagladiya 1973-74

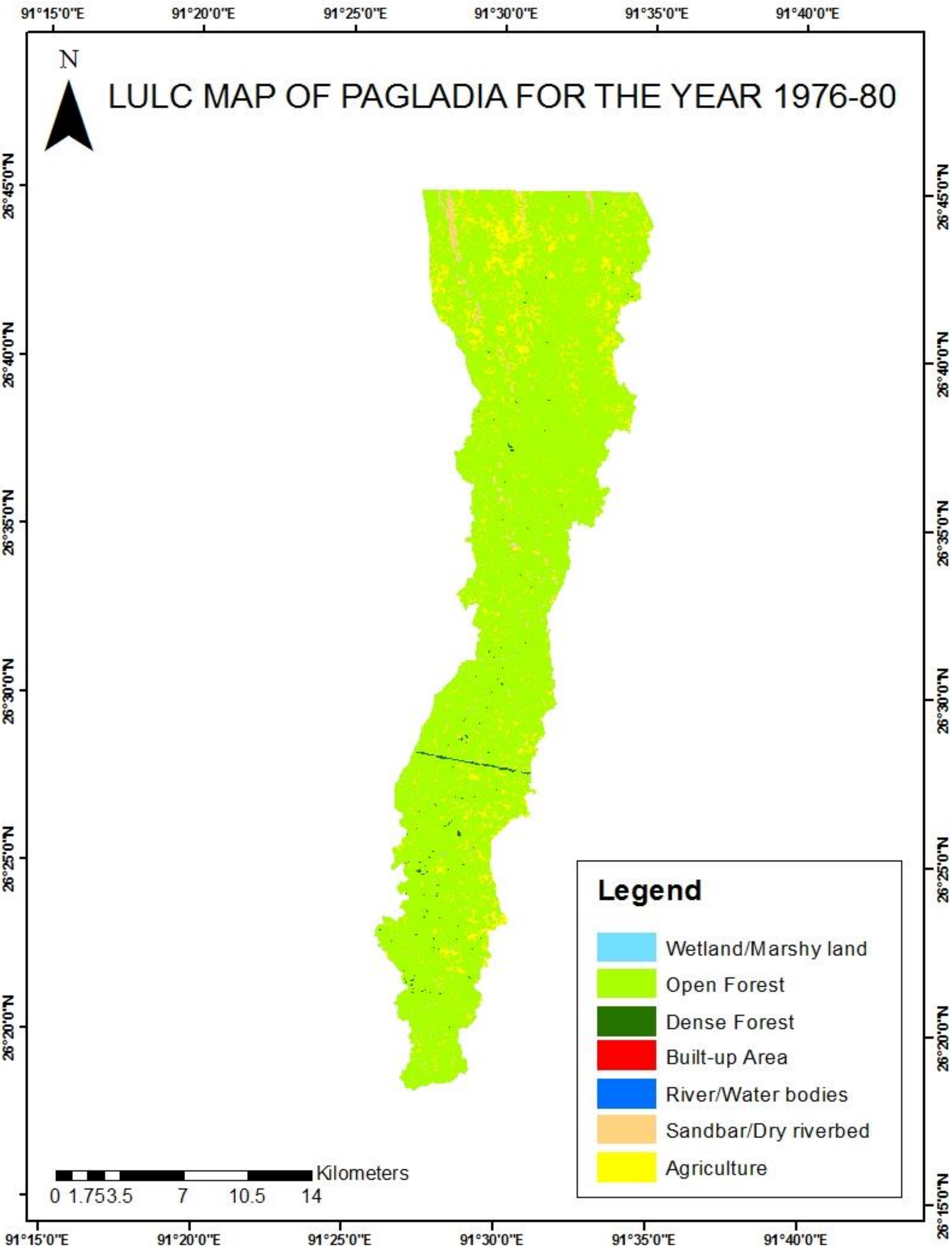


Figure 21: LULC Map of Pagladiya 1976-80

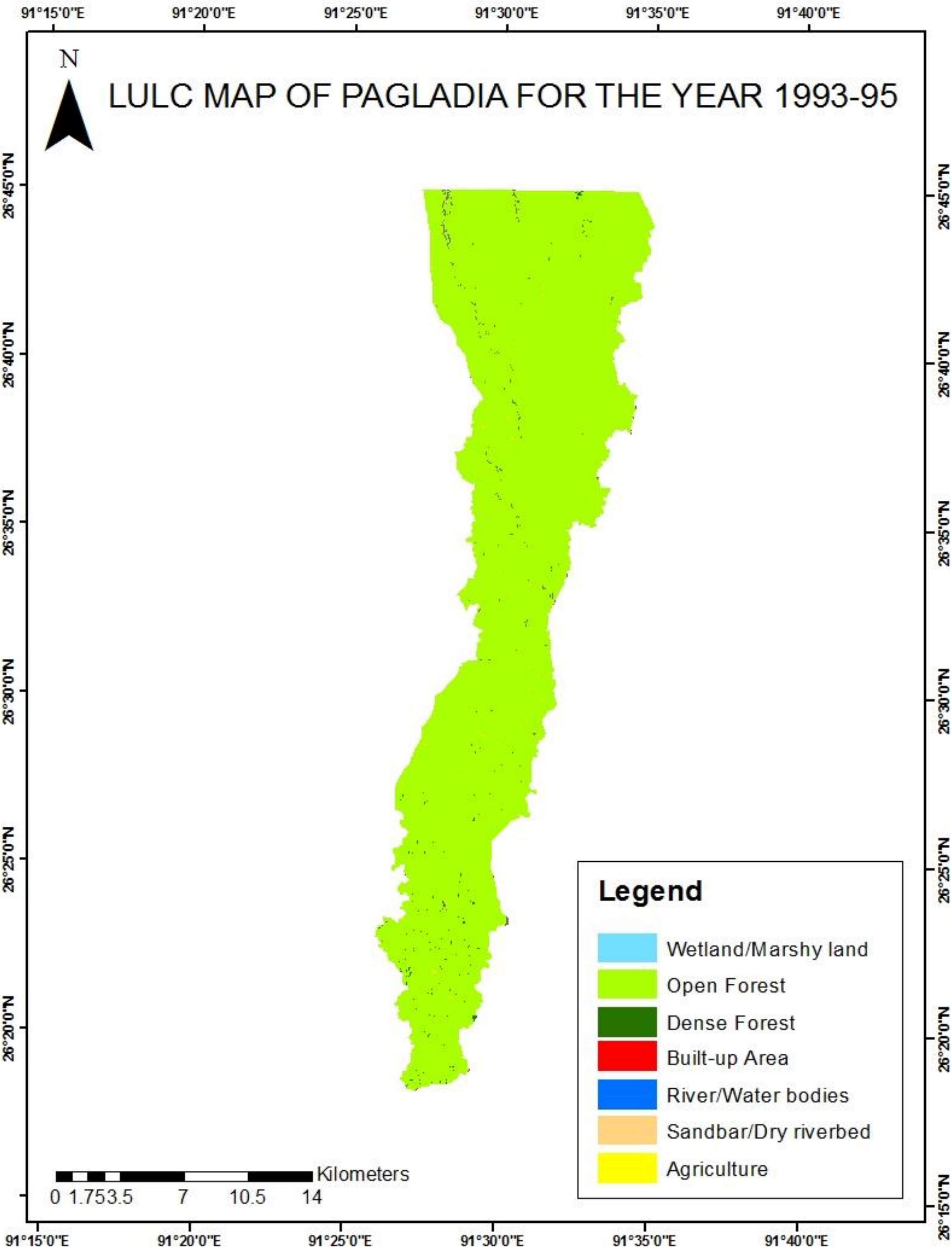


Figure 22: LULC Map of Pagladiya 1993-95

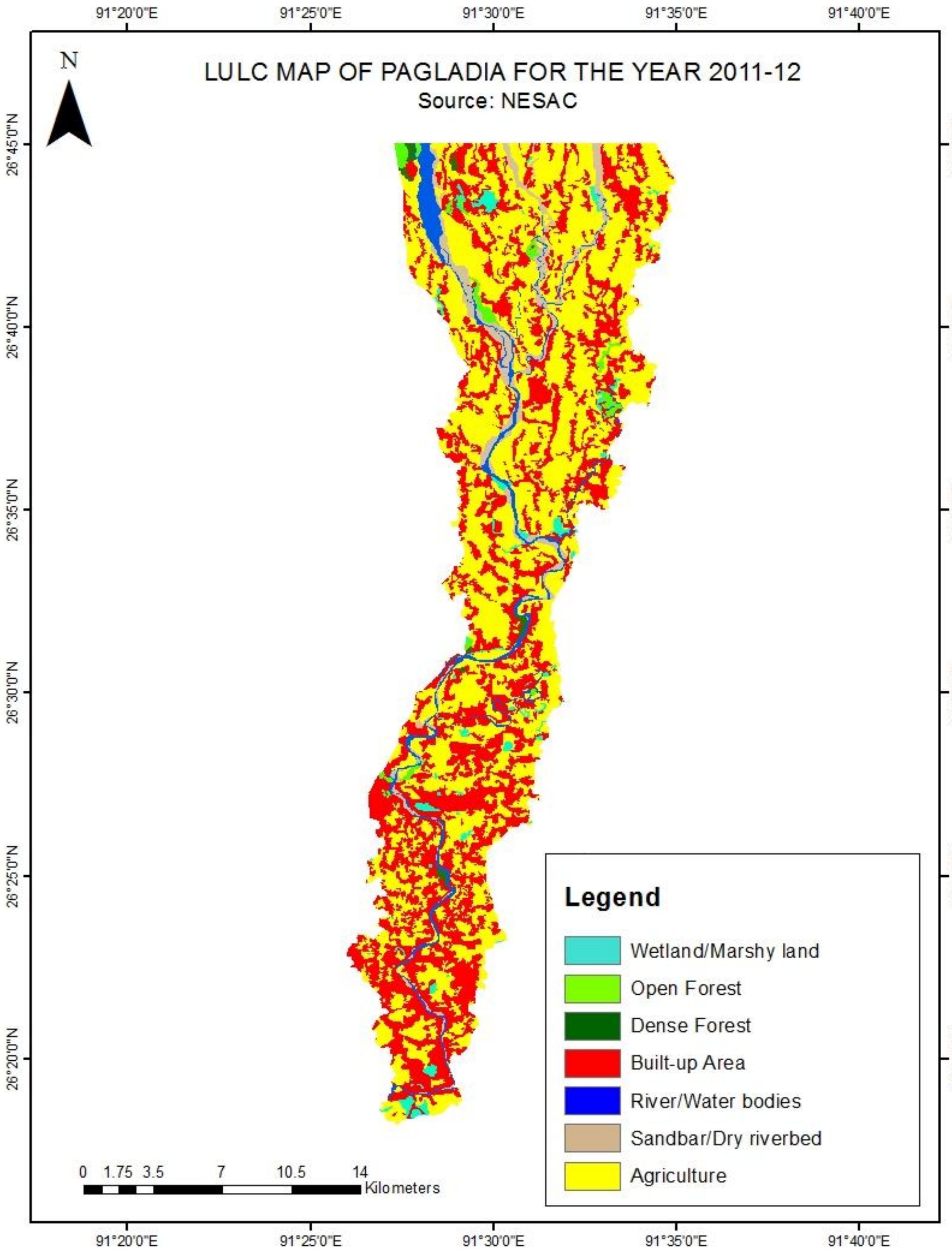


Figure 23: LULC Map of Pagladiya 2011-12

9.2 Observations

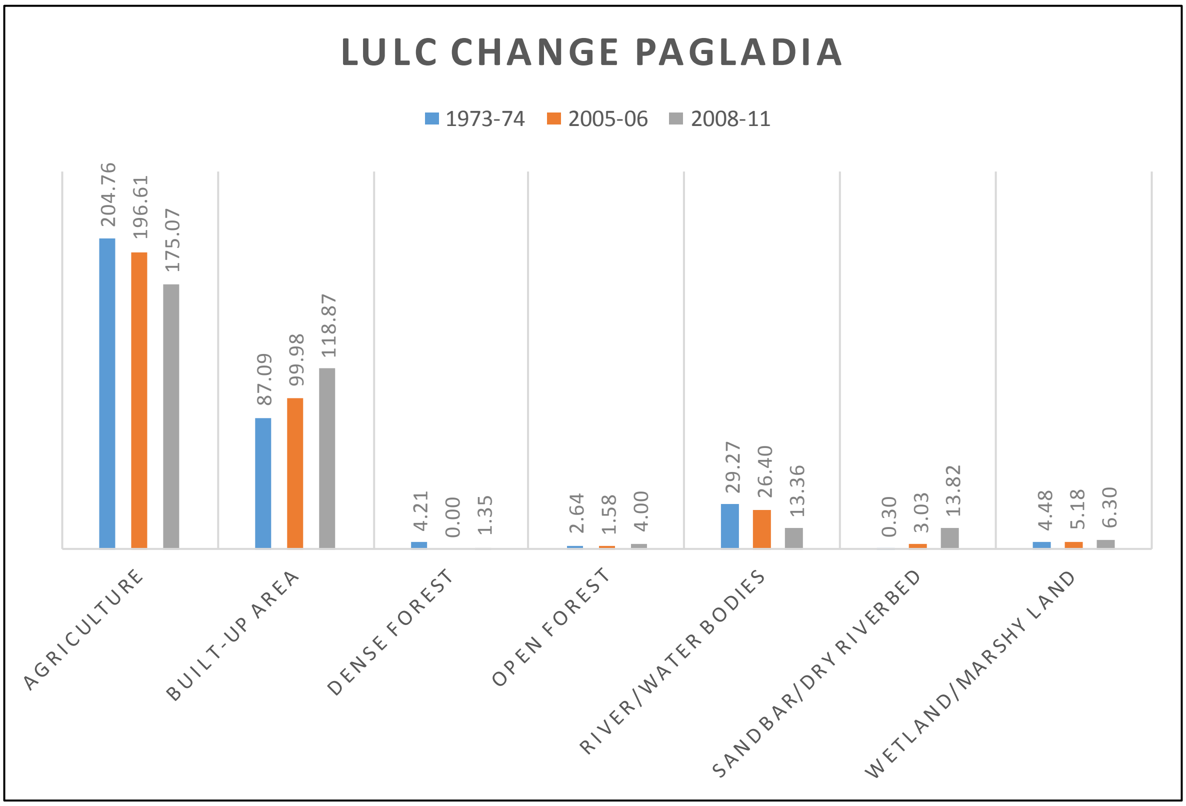


Figure 24: LULC analysis of Pagladiya

From the estimation of LULC change over 1973-74 to 2011-12, it has been observed that there is a decrease in dense forest & agricultural area while increase in the built-up area (Fig.23). Also, the area occupied by the river has been reduced over the years and there is an increase in the sandbar/dry riverbed area and area under water bodies/marshy land. From this analysis it can be inferred that the increase in the built-up area in the downstream portion and reduction of forest cover in the upper catchment of Pagladiya has resulted in siltation in the river. This siltation has further triggered the northward shifting of the confluence point of Pagladiya and Brahmaputra.

Chapter 10
RIVER MORPHOLOGY

10.3 Channel Evolution Process

10.3.1 Channel pattern

It is observed that most of the north bank tributaries of Brahmaputra frequently change their course resulting in riverbank erosion; being a north bank tributary of Brahmaputra, Pagladiya river is also found to be not an exception. From the analysis of bankline shifting (section 6), it was observed that the river was not only shifting the banks laterally but also shifting its course a few places through meander cuts. Due to change in its course a major change in its planform can be observed. However, no major changes were observed in the upstream of the river course as in this region the river is constricted within the Bhutan hills. To study the channel evolution process of the Pagladiya River, the delineated river banklines of different study periods were overlaid in ArcGIS and section lines were drawn at 10 km interval (Fig. 24) for the course of the river flowing through Assam

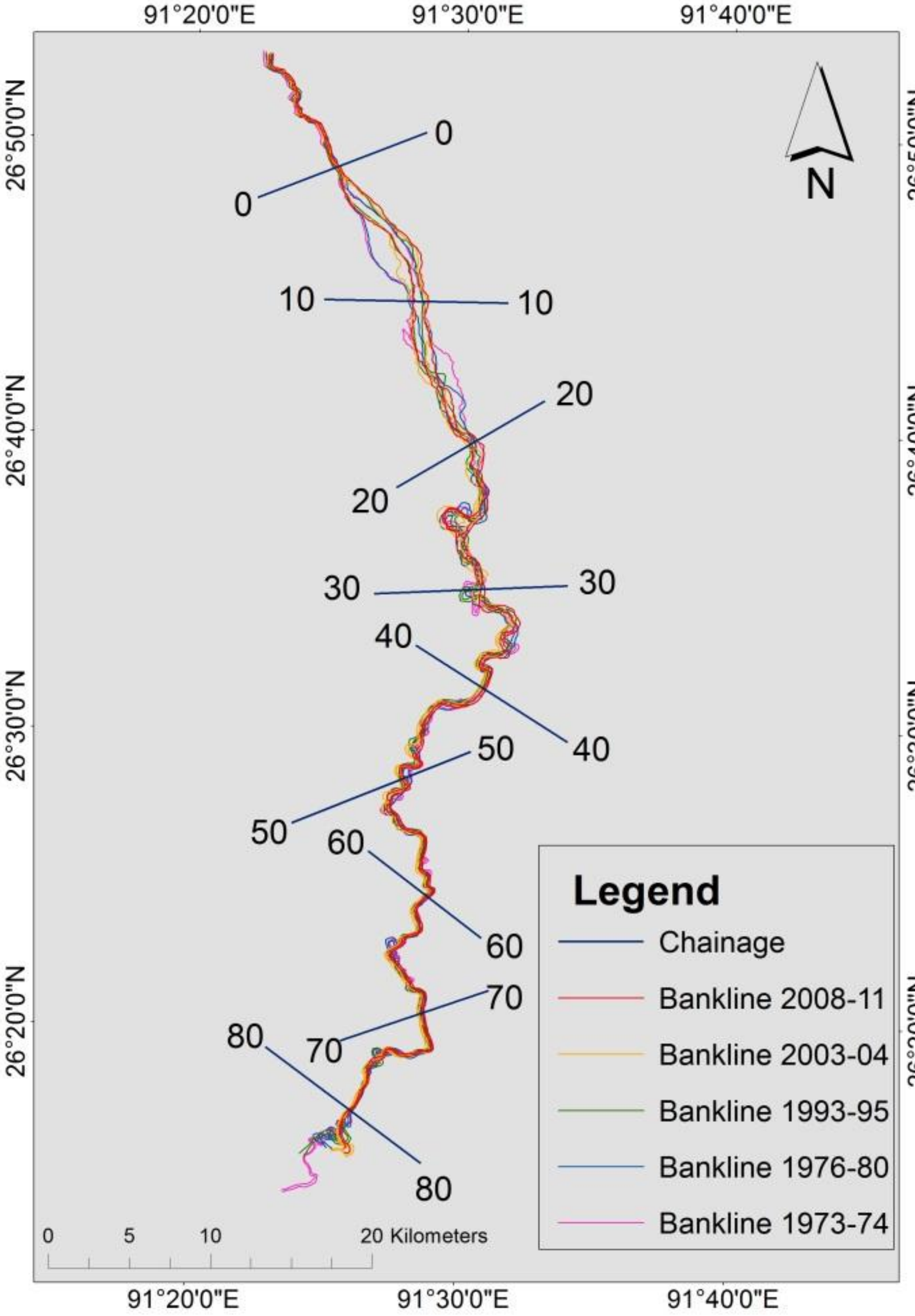


Figure 25: Sections taken for channel evolution analysis

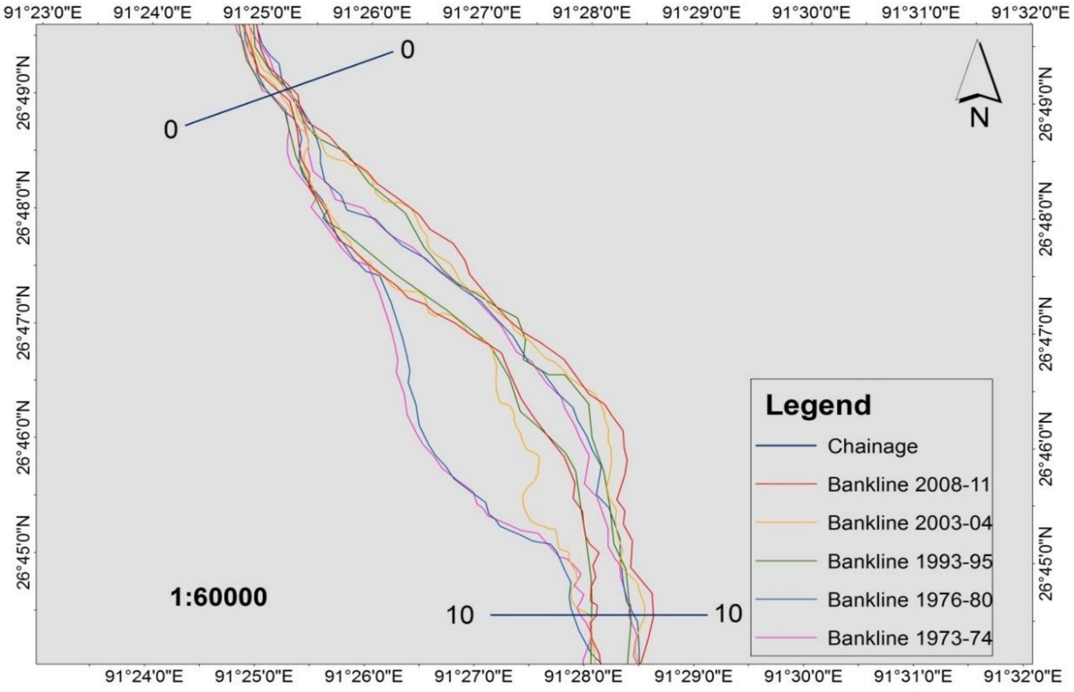


Figure 26: Changes in Reach-1 over 1973-74 to 2008-11

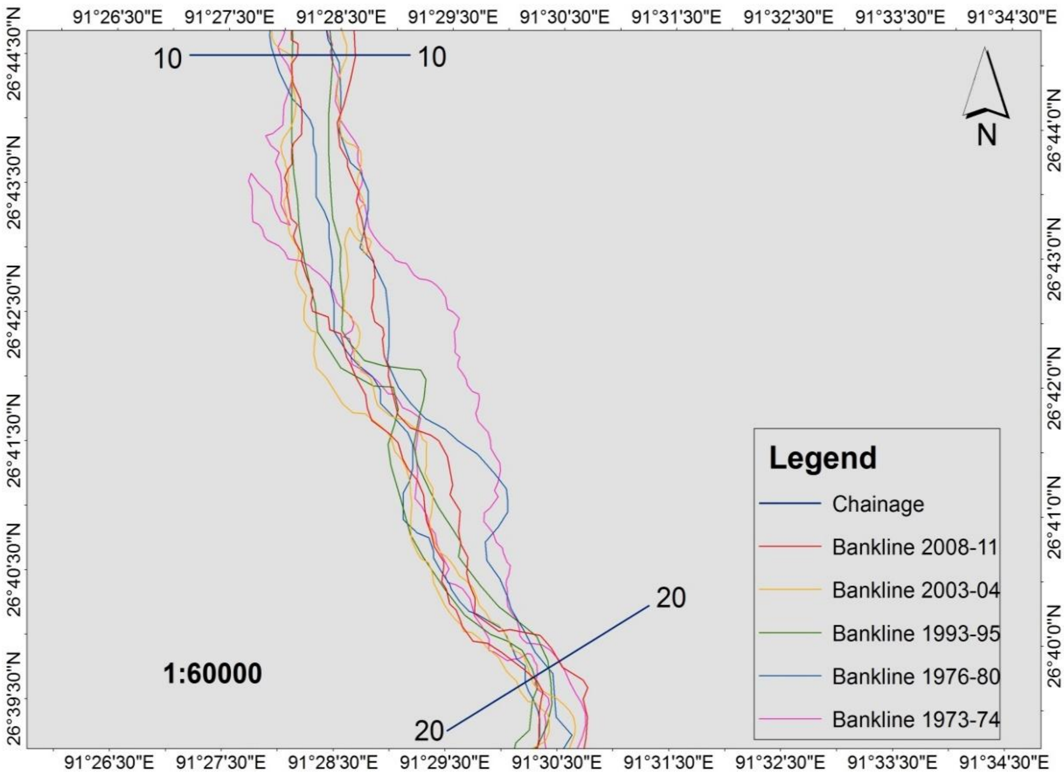


Figure 27: Changes in Reach-2 over 1973-74 to 2008-11

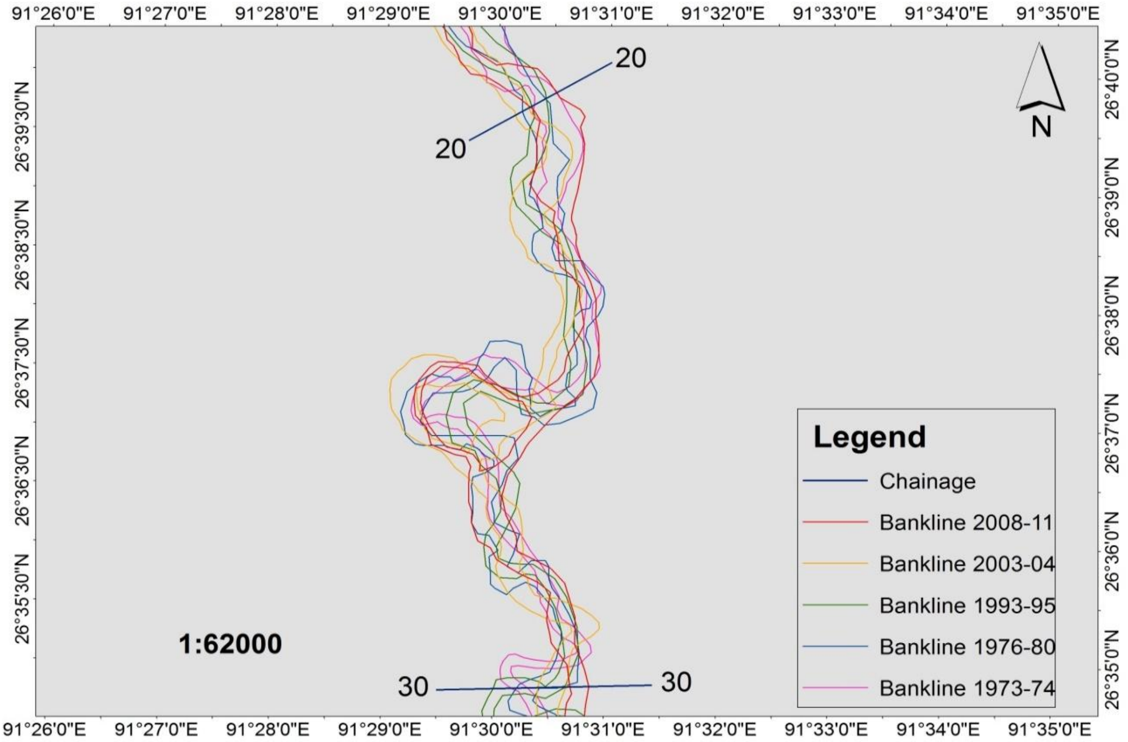


Figure 28: Changes in Reach-3 over 1973-74 to 2008-11

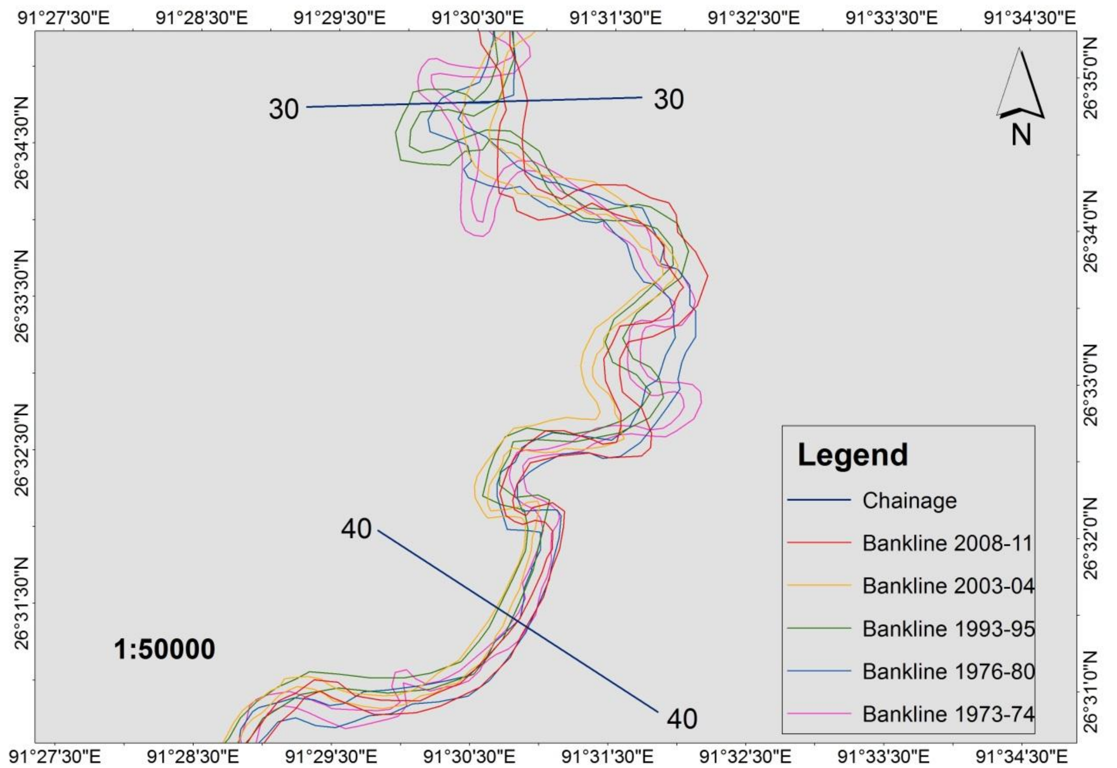


Figure 29: Changes in Reach-4 over 1973-74 to 2008-11

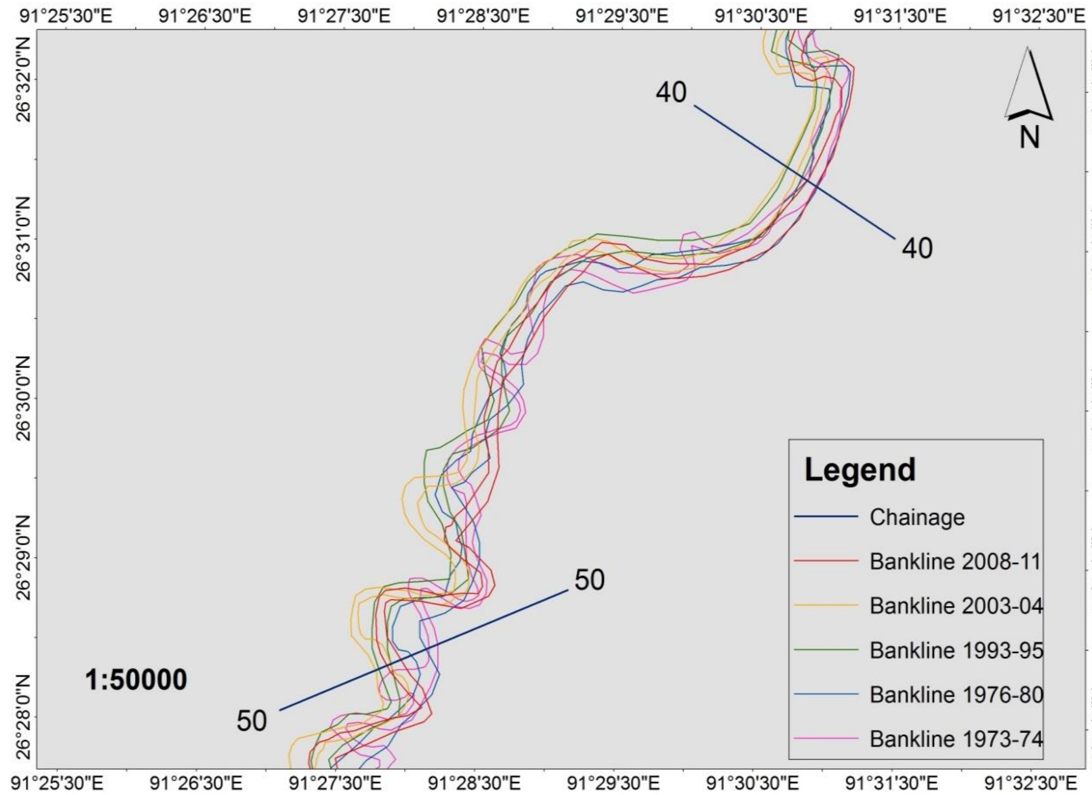


Figure 30: Changes in Reach-5 over 1973-74 to 2008-11

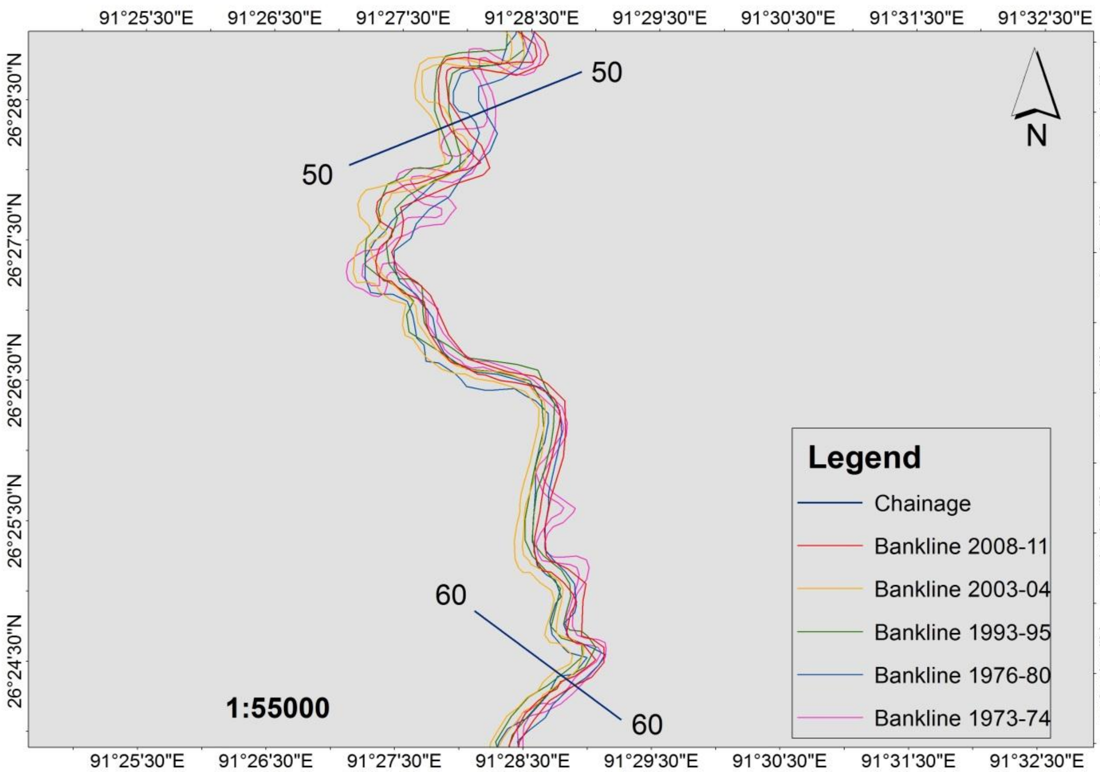


Figure 31: Changes in Reach-6 over 1973-74 to 2008-11

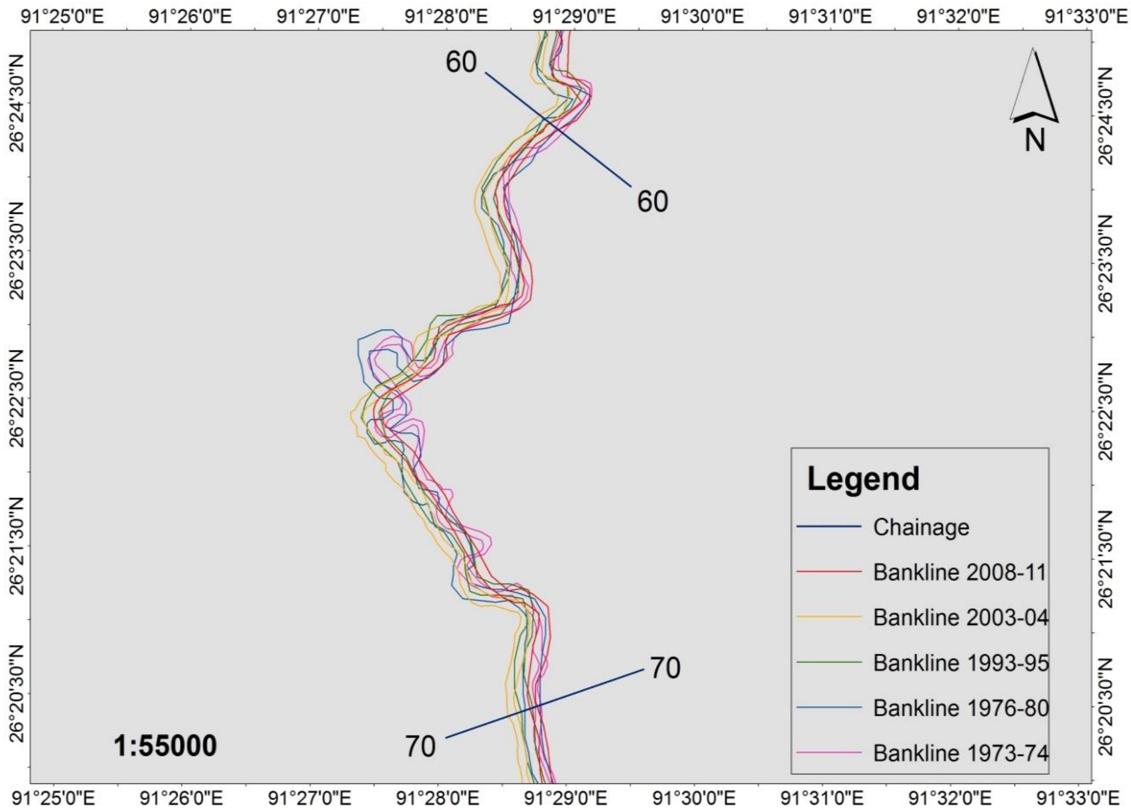


Figure 32: Changes in Reach-7 over 1973-74 to 2008-11

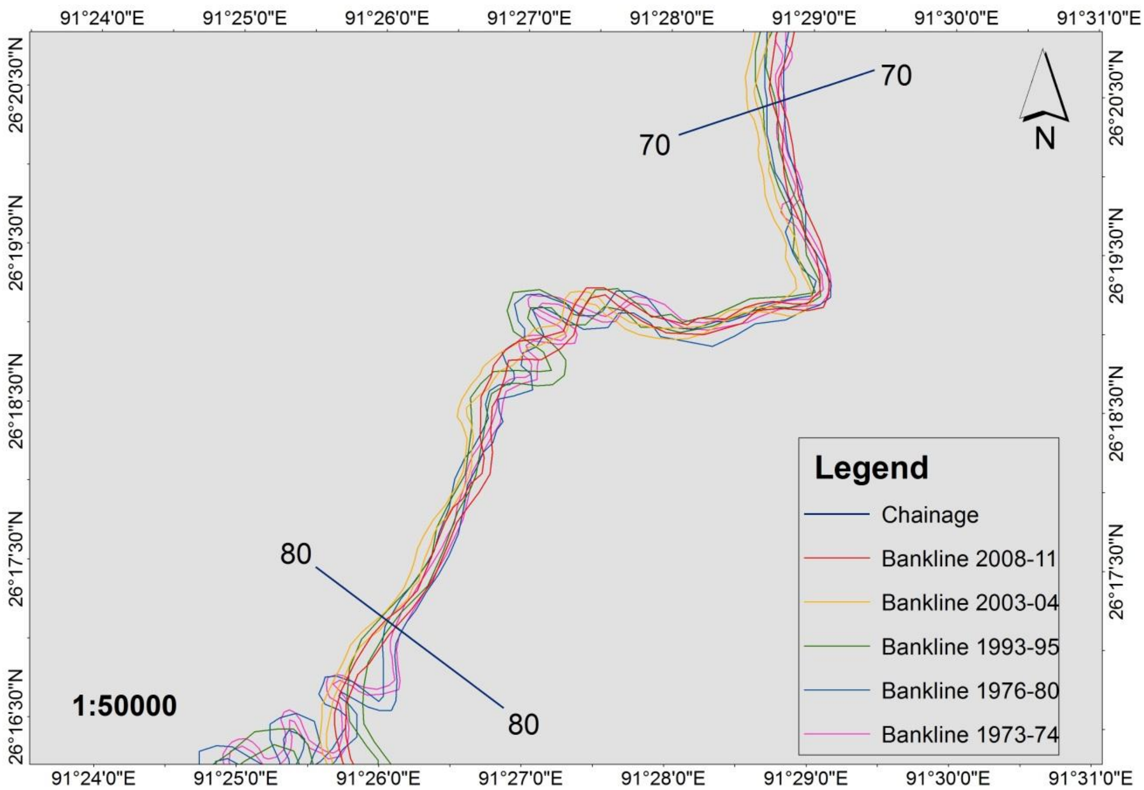


Figure 33: Changes in Reach-8 over 1973-74 to 2008-11

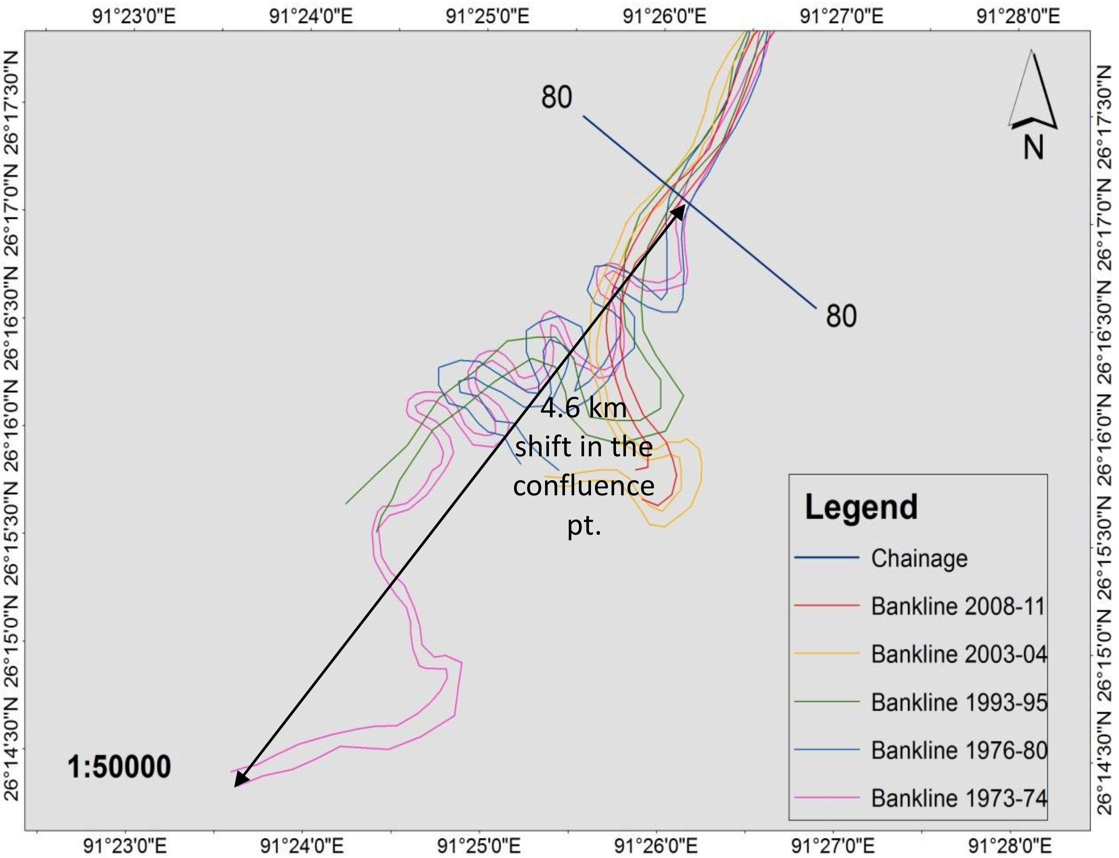


Figure 34: Changes in Reach-9 over 1973-74 to 2008-11

In reach no.1 (Fig.25), it was observed that the river had been constricting in due course of time. The maximum width of the river in the reach in 1973-1974 was found to be 2.3 km which had been reduced to 1.1 km in 2008-11. From Figure 40, it was observed that in reach no.2, the left bank of the river was migrating in the westward direction during 1973-95 resulting in the deposition of sediments and narrowing down of the river reach there. However, after 1995 the left bank of the river again shifted little eastward causing bank erosion in few parts of the river reach. Reach 3 & Reach 4 witnessed a lot of morphological changes over the years due to continuous change in the river course in the reach (Fig.27 & 28). A prominent meander cutoff was also observed in the 2003-04 and 2008-11 satellite datasets of the Reach 3 which remained intact in the previous years. In the upstream part of the Reach 5, not much changes were observed in the river morphology. However, the downstream of the reach witnessed continuous changes in the river course resulting in erosion-deposition over there.

No major change was observed in reaches 6, 7 and 8. A major change can be seen in the last reach. However, after 1976-80 the river course became straightened in these reaches (Fig. 30, 31 and 32).

In Reach 9, continuous shift in the confluence of the river Pagladiya with the Brahmaputra river was observed over the years owing to the relentless riverbank erosion in the right bank of the river Brahmaputra (Fig.33).

10.3.2 Channel dimension

To study the changes in the width of the river Pagladiya the entire river from Bhutan hills 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 (Fig.34).

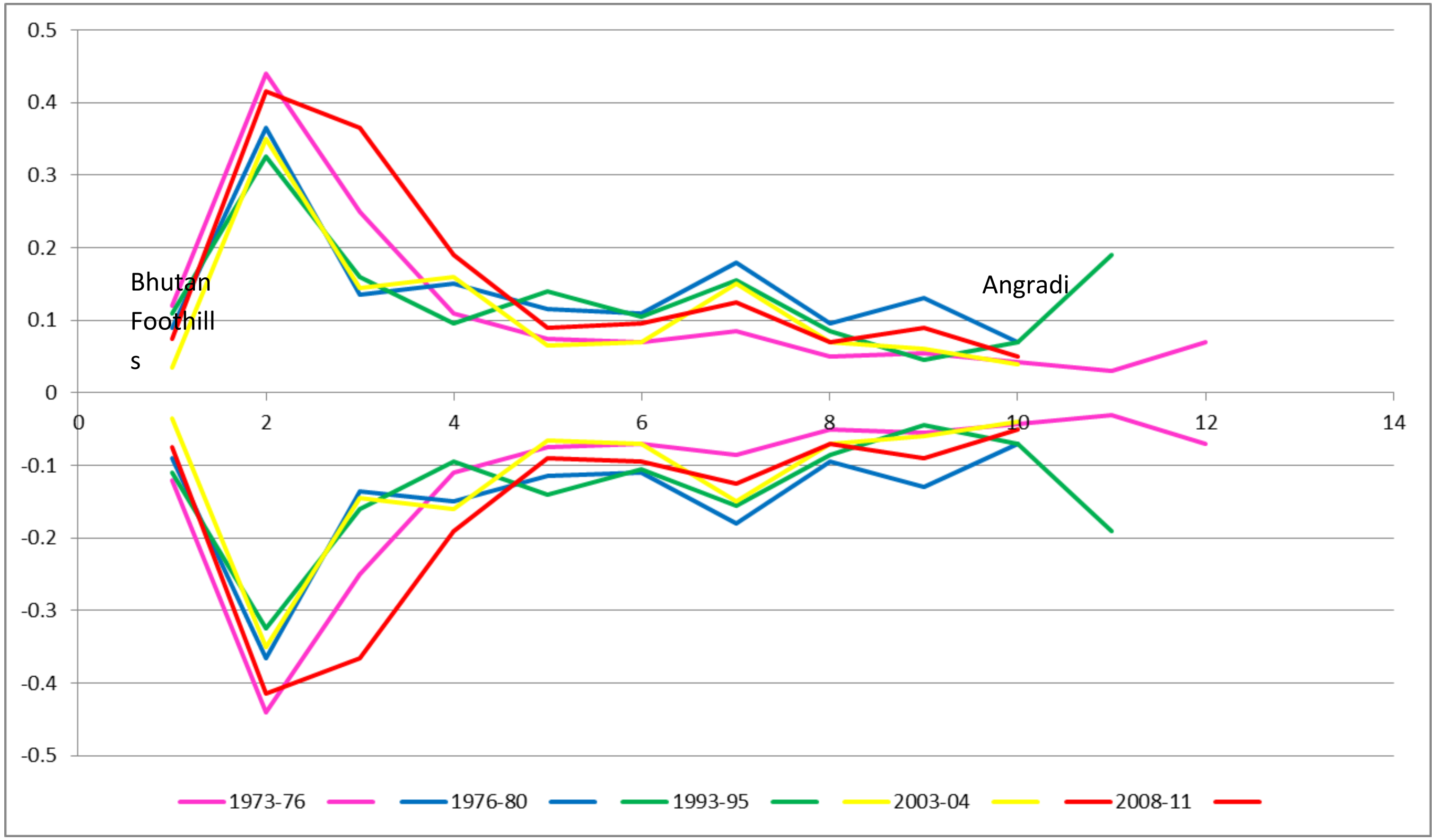


Figure 35: Channel Dimension plot

10.3.3 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.

10.3.3.1 Methodology

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

10.3.3.2 Observations

From the plot of longitudinal profile Pagladiya River it can be observed that the elevation at the Bhutan foothill is around 652 ft. gradually on entering Assam the elevation get reduces and finally reached to 45 ft. above MSL at the confluence point with Brahmaputra river.

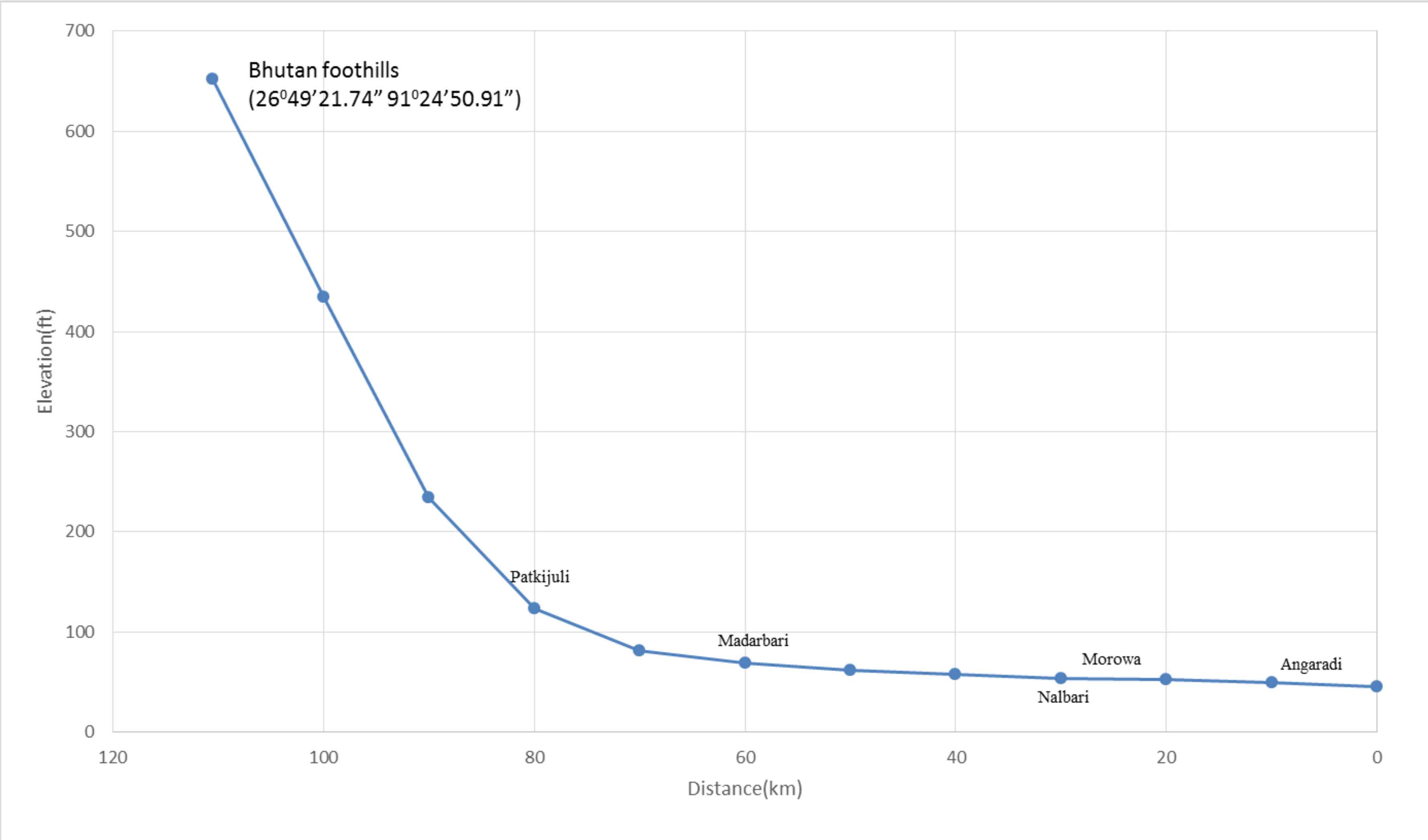


Figure 36: Longitudinal Profile of Pagladiya

10.4 Sinousity Indices

The geometry of the planforms is well studied by Schumm (1963) and Snow (1989). Leopold et al. (1964) proposed that the degradation of river channels could be attributed to the changes in its hydrologic regimes and its channel planform pattern is also influenced by the character of the hydraulic regime. The stream sinuosity indexes are usually derived by dividing the length of a reach as measured along a channel by the length of a reach measured along its valley (Mueller, 1968). The total sinuosity is a combined measure of channel segment sinuosity and degree of braiding (Bridge, 2003). According to Mackin (1956), sinuosity of rivers is determined by width/depth of their channels and it is inversely proportional to width/depth. The study undertaken by Ward et al. (2000) revealed that the Karoo river basin of South Africa was subjected to a rapid change in river morphometry during the Permian – Triassic transition as reflected in the sedimentary facies and channel sinuosity. Prasad (1982) suggested that the channel sinuosity is controlled by channel gradient, sediment load, resistance to lateral erosion of a river and stage of valley development and the structural characteristics of the area through which it flows. The relationship between channel sinuosity and valley gradient for non- forested reaches of the river indicated decreased sinuosity resulting from afforestation. (Murgatroyd and Ternan ,1983) These changes in channel form result from active bank erosion within the forest with coarse material being deposited within the channel as point-bars and mid-channel bars. Active bank erosion is largely attributed to the suppression by the forest of a thick grass turf and its associated dense network of fine roots, and secondly to the river attempting to bypass log jams and debris dams in the stream channel. The study of the sinuosity index of a drainage line helps us in evaluating the effect of terrain over river course and vice-versa (Panda and Bora,1992). Investigations carried out by Ebisemiju (1994) in the Elemi river basin, south western Nigeria suggested that small intermittent streams in the seasonally wet humid tropics have a tendency to develop very sinuous channels characterized by compound and highly convoluted loop and also presented that the dominant factor controlling the degree of sinuosity is channel bank resistance to lateral erosion as influenced primarily by the nature of riparian vegetation and secondarily by the percentage silt/clay in channel bank sediment the river sinuosity of Brazos river of Texas and found that the size of the river bends is influenced more by the composition of the river channels than the peak flows(Gillespie and Giardino ,1997) Hassan et al. (2002) by using aerial photographs studied the fluvial characters of Jordan River and remarkably concluded that the sinuosity of the river has been increased by 25% due to the drop in the mean sea level of Dead Sea. The remarkable sinuosity changes have been found to correlate with discharge and sediment load changes at the interflow of tributaries (Timar, 2003).

One of the outstanding remarks made in connection with the development of river sinuosity is that of Nathan (2005) and according to his merited remarks the unusually high degree of sinuosity exhibited by the American River near its confluence with the Rubicon River is related with the coincidence of hinge zone of moderately to steeply plunging asymmetric folds with the axis of the meanders. Barbour and Stark (2005) evaluated a quantitative relationship between regional climatology and sinuosity and it has been postulated that the rivers, which have more relative variance in discharge, tend to have greater lateral mobility and as the discharge variability is a function of rainfall variability, the mountain river sinuosity in the western North Pacific is controlled by typhoon frequency. The induced channelization of River Raba, Poland has resulted in increased channel depth and reduction in channel gradient as well as increased downward and backward channel erosion for maintaining the equilibrium (Wyzga, 2006). Decrease in floodplain storage and stream power levels higher than the channelization. The size frequency distribution of ox-bow lakes within the floodplains can be predicted using channel sinuosity studies (Constantine and Dunne, 2008)

10.4.1 Mueller's Sinousity Indices

A search of the early literature concerning streams reveals dominantly qualitative works, whereas more recent studies are characterized by quantitative and statistical methods. Unfortunately, most quantitative sinuosity studies restrict their measurements to hydraulic factors of channel behavior, often rendering themselves applicable only to streams whose valleys are beyond the early maturity stage of the cycle of erosion. If streams must adjust their initial courses to the irregularities of the surfaces upon which they flow, then certainly a portion of sinuosity must be topographically controlled. Later, when the streams have down cut sufficiently to allow the formation of a floodplain, additional sinuosity is imminent because of those properties inherent in flowing water which tend to promote lateral migration of the channel upon the floodplain. The latter type of sinuosity owes its peculiarity to hydraulic factors of water behavior and shall hereafter be referred to as hydraulic sinuosity. The topographic sinuosity will continue to persist as long as the valley course remains irregular, and in addition to the hydraulic sinuosity later developed on the valley floor, must be included in an index which measures total stream sinuosity. In contrast, a relationship does exist between the relative importance of each type of sinuosity and the various stages in the cycle of erosion. For example, topographic sinuosity is outstanding during youth when hydraulic sinuosity is negligible; conversely, hydraulic sinuosity is outstanding during the old stage after most of the topographic sinuosity has been removed.

Schumm stated that a straight stream has a sinuosity of 1.0, and this number increases as the stream departs from a straight line. This statement is not true. As long as floodplains do not develop, stream sinuosity measured by the standard index remains at 1.0, regardless of the stream's departure from a straight-line course.

Its purpose is to provide an accurate index of both hydraulic and topographic sinuosity, hereafter referred to as HSI and TSI.

CL = the length of the channel in the stream under study.

VL = the valley length along a stream, the length of a line which is everywhere midway between the base of the valley walls. It will equal CL wherever the water's edge, and will be less than CL wherever a floodplain has developed.

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

CI (Channel Index) = CL/Air or an index of total sinuosity, both hydraulic and topographic.

VI (Valley Index) = VL/Air or an index of total topographic sinuosity.

HSI (Hydraulic Sinuosity Index) = % equivalent of (CI-VI)/(CI-1) or what percentage of a stream's departure from a straight-line course is due to, hydraulic sinuosity within the valley.

TSI (Topographic Sinuosity Index) = % equivalent of (VI-I)/(CI-1) or what percentage of a stream's departure from a straight-line course is due to topographic interference.

The total of HSI added to TSI must always equal 100. Therefore, only one of the two indexes need be calculated, for the unknown can be derived by simple subtraction. If in the process of measurement one finds HSI to be 50, then one-half of a stream's sinuosity is hydraulic; the other one-half must obviously be topographic. It should also be evident that the HSI and TSI are only concerned with the stream's departure from a straight-line course. This accounts for the removal of the value of unity in the formulas for HSI and TSI.

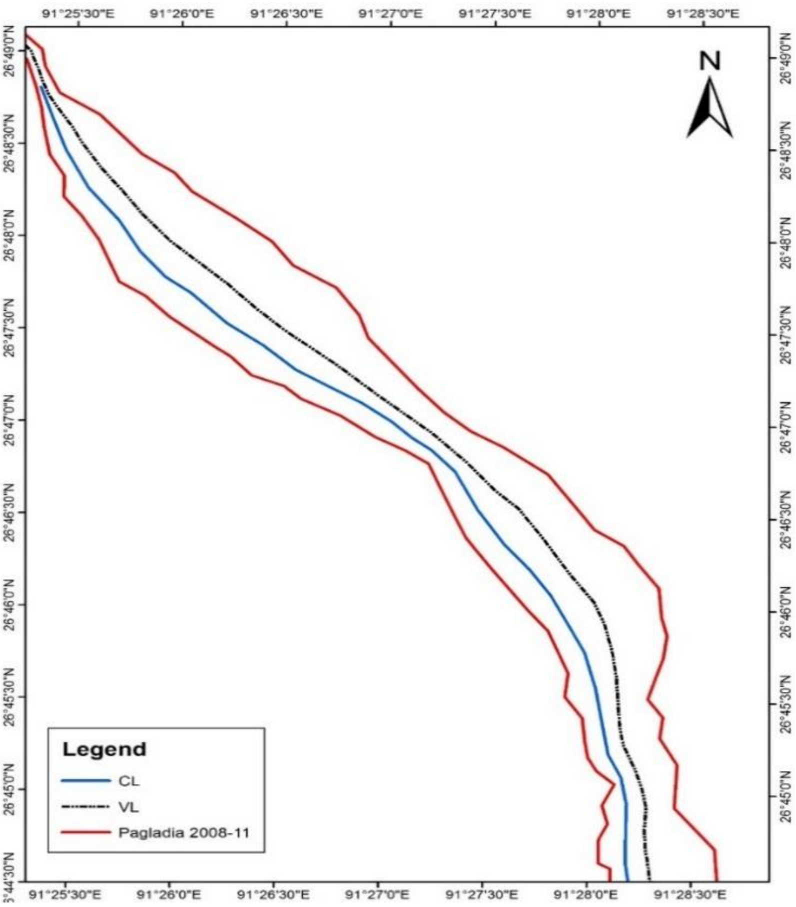


Figure 37: Reach showing the parameters for the calculation of sinousity indices

10.4.2 Methodology

The centerline and the thalweg of the whole river were digitized from the foothills of Bhutan till its confluence with Brahmaputra. The centerline is divided into 10 equal parts. The sinuosity indices were then calculated for each reaches of 10 km using the formulas give Mueller (1968).The sinuosity indices for the different datasets are shown in ANNEXURE I

10.4.3 Results and Discussions

For the analysis, the base year toposheet 1973-74 lacks the upstream portion of the Pagladiya. For this reason, the analysis is done from Reach 2. The sinuosity indices calculated are shown in ANNEXURE IV. From the computation of sinuosity, it can be seen that the sinuous pattern of the river Pagladiya is almost the same from the base year 1973-74 till 2008-11. No major changes can be seen as it is taking the same path. It can be observed that Reaches 5 and 9 have high sinuosity indices for all the different datasets. In these reaches, the topographic sinuosity index is more predominate than hydraulic sinuosity index. Reaches 3, 4, 8 have higher channel index which means significant deviation can be observed from its straight course.

10.5 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.

10.5.1 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.

10.5.2 Observations

From the analysis it has been observed that the lengths of the meanders are found to be varying within the years. At reach 4 it can be seen that at 1973-74 and 2003-04 the meander lengths of 1.3 km and 4 km were observed respectively. However, in other years there was no meander observed in this reach. Reach 6 and 7 experienced the highest meander occurrence. From 1973-74 till 2008-11 there is an increase of meander length in due course of time. This can be attributed to the fact that some portions of reaches have straightened. At reach 10 there was a sufficient meander length was observed in 1973-74. However, due to the shifting of confluence point of the river, the reach has slowly extinct in due course of time.

The meander width of Pagladiya has been found to be maximum in the year 2003-04 as 2.31 km. However, in 2008-11 the meander length has been found to be 2.12 km.

In 1993-94 the bankfull width was found to be 435.01m at reach 6.In the year 2003-04, the bankfull width has been found to be 437.80 m at reach 4.In 2008-11 the bankfull width has been found to be 344.45 m and 294.05m at reach 6 and 7 respectively.

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.

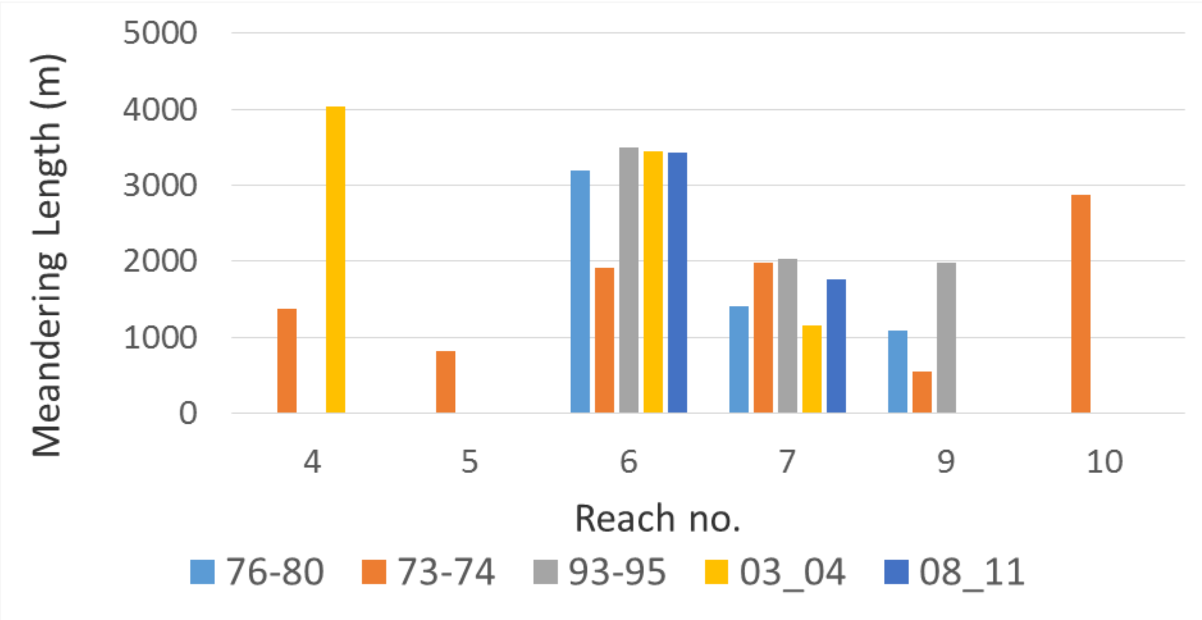


Figure 38: Reach-wise meandring length of Pagladiya (1976-80 TO 2008-11)

Table 4: Reach-wise meandring length of Pagladiya (1976-80 to 2008-11)

Year/ Reach No.	4	5	6	7	9	10
76-80			3192.81	1408.72	1082.67	
73-74	1373.39	819.15	1909.99	1974.87	546.24	2871.52
93-95			3495.41	2029.54	1973.42	
03-04	4034.26		3449.49	1161.68		
08-11			3423.87	1756.46		

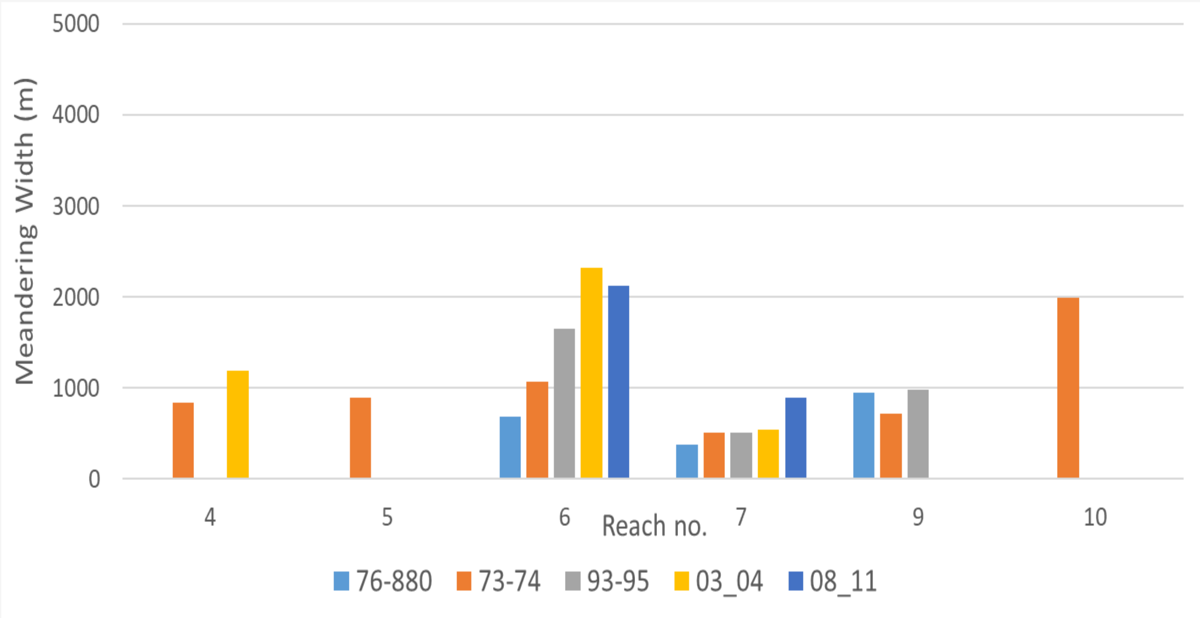


Figure 39: Reach-wise meandering width of Pagladiya (1976-80 TO 2008-11)

Table 5: Reach-wise meandring widths of Pagladiya (1976-80 to 2008-11)

Year/ Reach No.	**4**	**5**	**6**	**7**	**9**	**10**
76-80			679.39	373.06	942.90	
73-74	830.61	892.99	1066.11	509.36	714.21	1992.47
93-95			1642.84	503.35	982.36	
03-04	1181.49		2317.47	543.44		
08-11			2121.85	887.29		

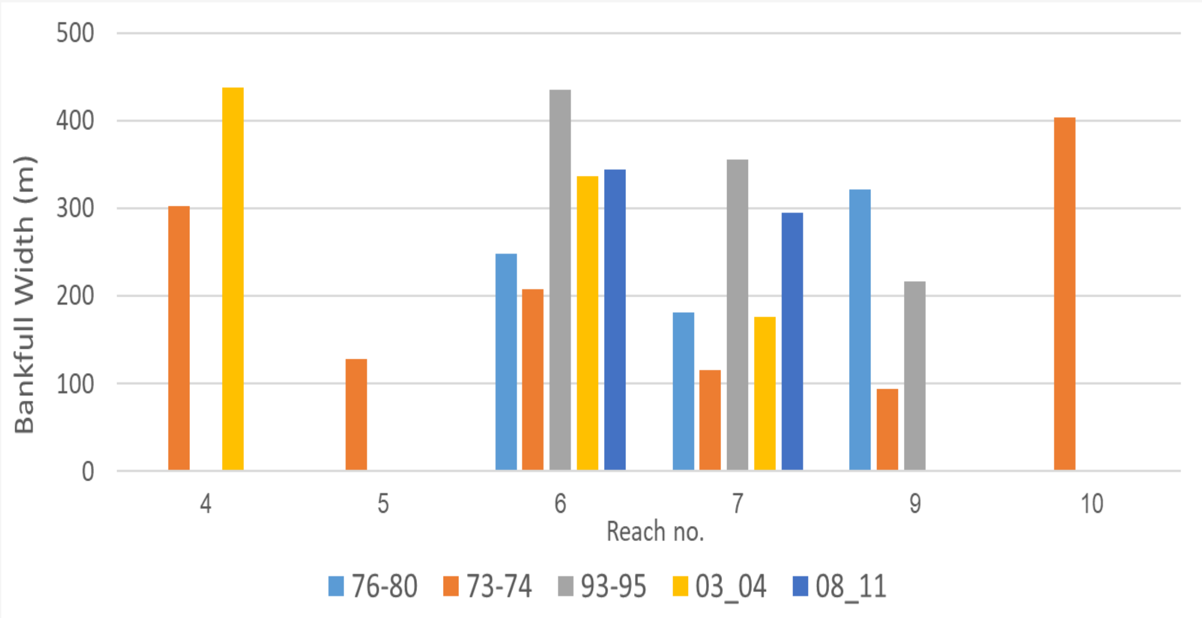


Figure 40:Reach-wise bankfull width of Pagladiya (1976-80 TO 2008-11)

Table 6: Reach-wise bankfull width of Pagladiya (1976-80 to 2008-11)

Year/ Reach No.	**4**	**5**	**6**	**7**	**9**	**10**
76-80			247.66	180.31	321.79	
73-74	302.14	127.89	207.17	114.95	92.98	403.53
93-95			435.01	355.96	216.75	
03-04	437.82		337.02	175.68		
08-11			344.45	294.05		

Table 7: Meandering width Ratio

Year/ Reach No.	4	5	6	7	9	10	Nature Of The Channel
76-80	-	-	2.74327	2.06891	2.93014	-	Almost Straight
73-74	2.74908	6.98225	5.14582	4.43093	7.68055	4.93755	Almost Straight To Moderately Meandering
93-95	-	-	3.77657	1.41408	4.53211	-	Straight To Almost Straight
03_04	2.698553	-	6.87631	3.09332	-	-	Almost Straight To Moderately Meandering
08_11	-	-	6.160038	3.0748	-	-	Almost Straight To Moderately Meandering

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.

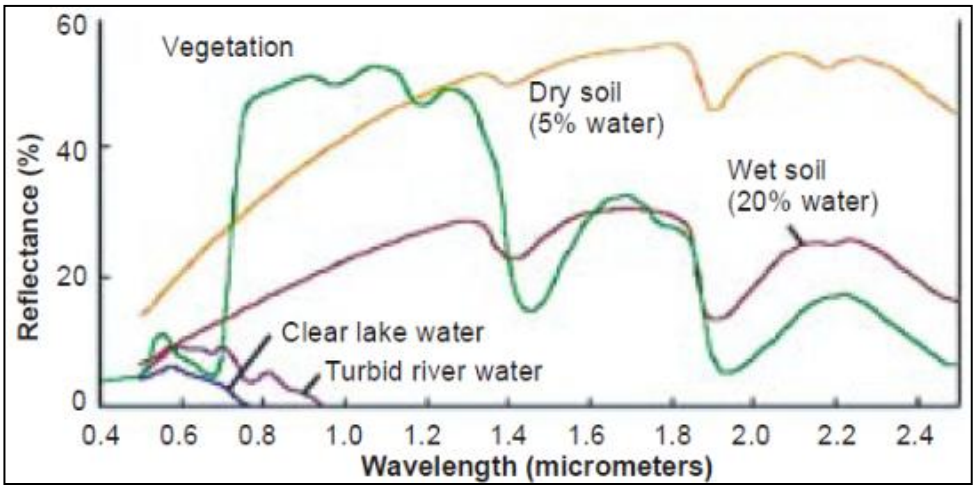


Figure 41: Spectral reflectance curves for different objects

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,

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

For TM imagery NDWI is calculated as,

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

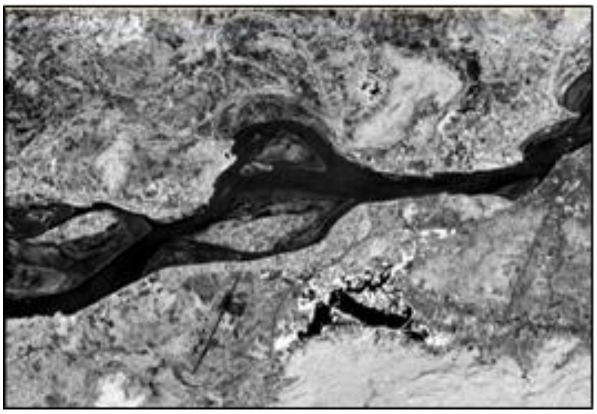


Figure 42: NDWI image derived from LISS 3 imagery using NIR (band 4) and SWIR (band 5) band ratio

Figure 43: Automatic delineation of water bodies based on NDWI generated form LISS 3 imagery

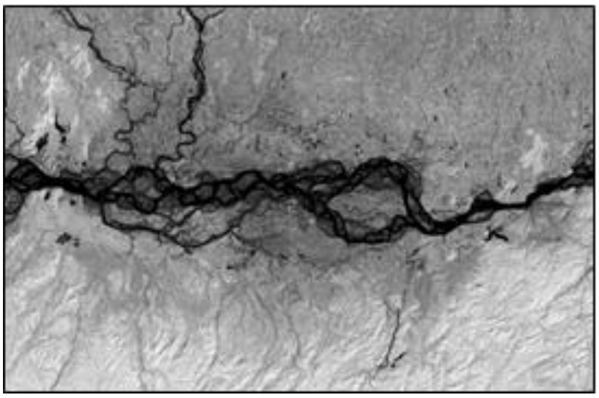


Figure 44: NDWI image derived from TM imagery using NIR (band 4) and Green (band 2) band ratio

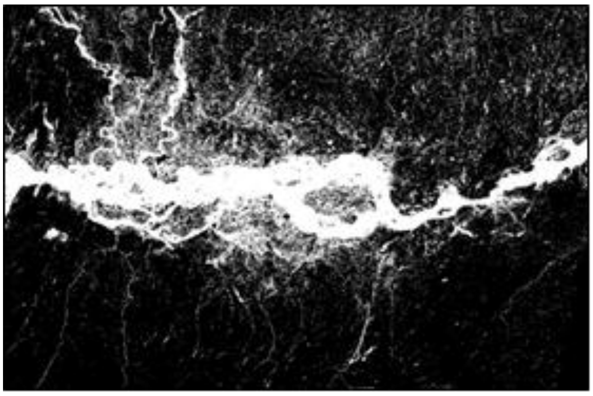


Figure 45: Automatic delineation of water bodies based on NDWI generated from TM imagery

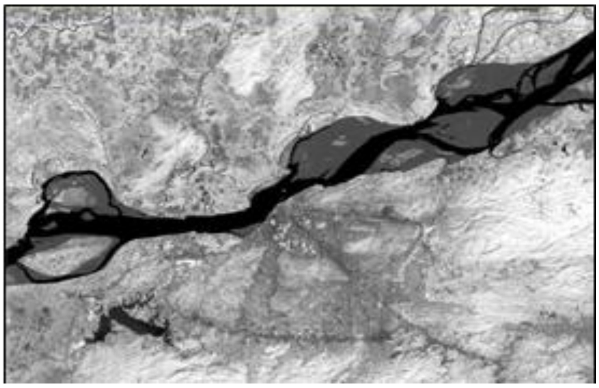


Figure 46: NDVI image derived from LISS 4 imagery using NIR (band 4) and Red (band 3) band ratio

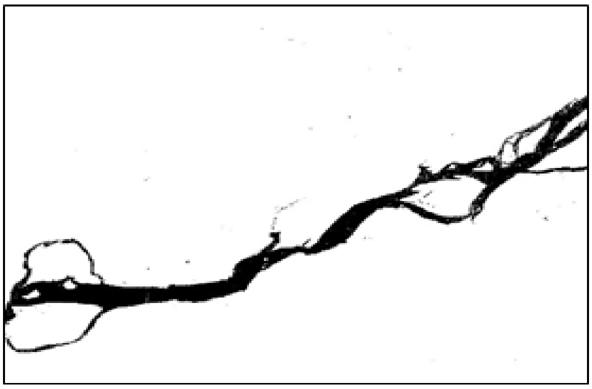


Figure 47: Automatic delineation of water bodies based on NDVI generated from LISS 4 imagery

NDWI output image (Figure 42 & 44), 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 43 & 45). The model used for NDWI and automatic delineation of water bodies in ERDAS is shown in Figure 48.

The Normalized Differential Vegetation Index (NDVI) is also generated to extract the water bodies from LISS IV imagery. In the NDVI output, value of the water bodies ranges between -1 to 0, bare soil has a value of 0 and that of soil with vegetation ranges between 0 to 1 (Figure 46 & 47).

NDVI is calculated as,

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

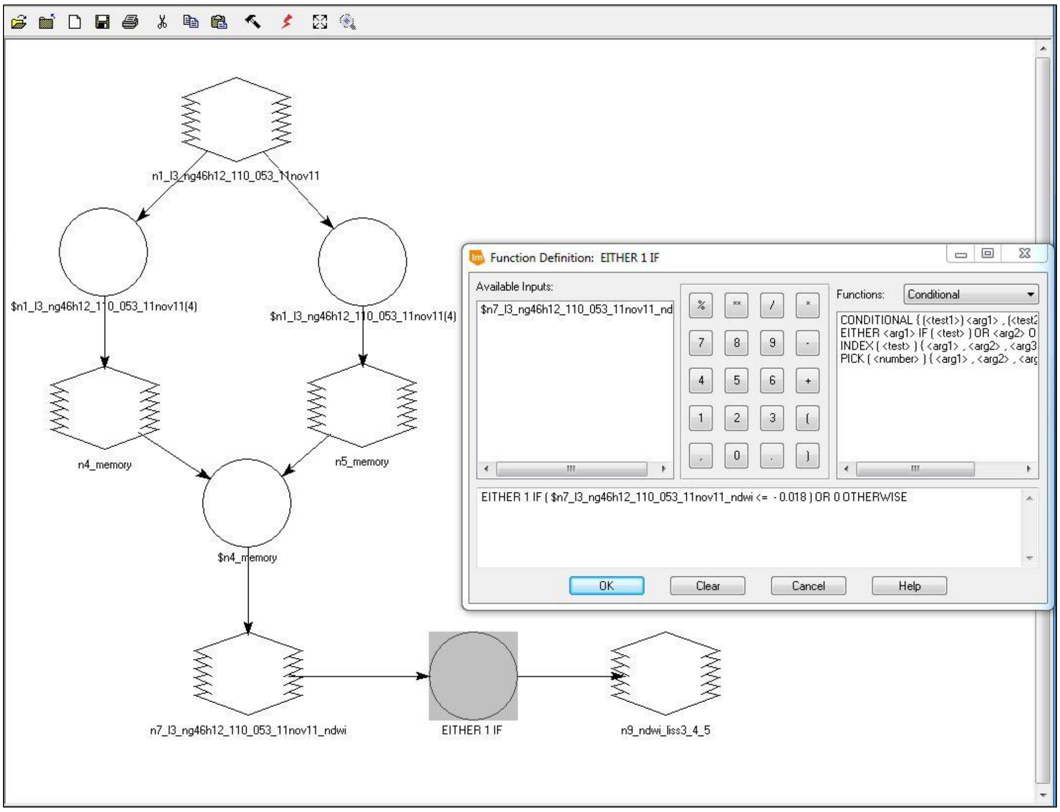
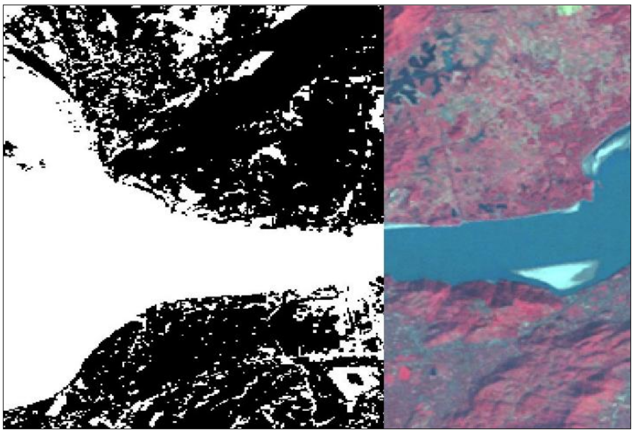


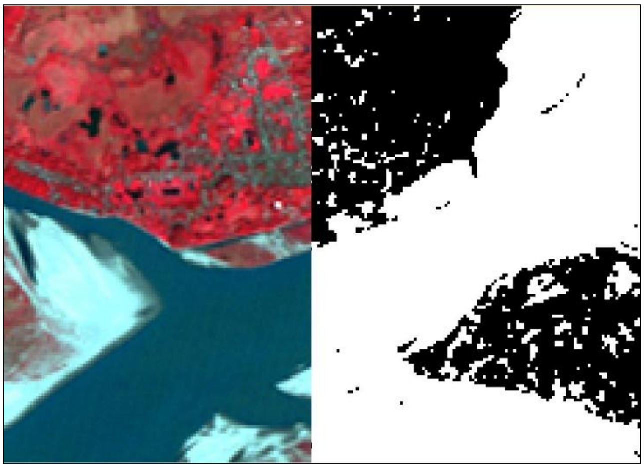
Figure 48: Erdas model used for auto delineation of water bodies

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 (Figure 48a. & 40b.). 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.



a.



b.

Figure 49: 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 Pagladiya has been done for different years using ArcGIS 9.3. The delineated banklines are used to study the channel shifting and analysis of various morphological parameters. Figure 49 shows the digitized Pagladiya banklines for different datasets.

11.1.2.2 Methodology

The entire Pagladiya River system with the confluence of important tributaries from upstream of Bhutan Hills till its confluence with the Brahmaputra was delineated from satellite imagery (Figure 49). The banklines of river Pagladiya 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 49). 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 49 shows the digitized Pagladiya River system. The river Pagladiya originating from the Bhutan hills on entering the plains of Assam get wider. This is due to the sudden change in the energy dissipation as soon as it reaches the plains of Assam. The river after flowing for some area again constricted.

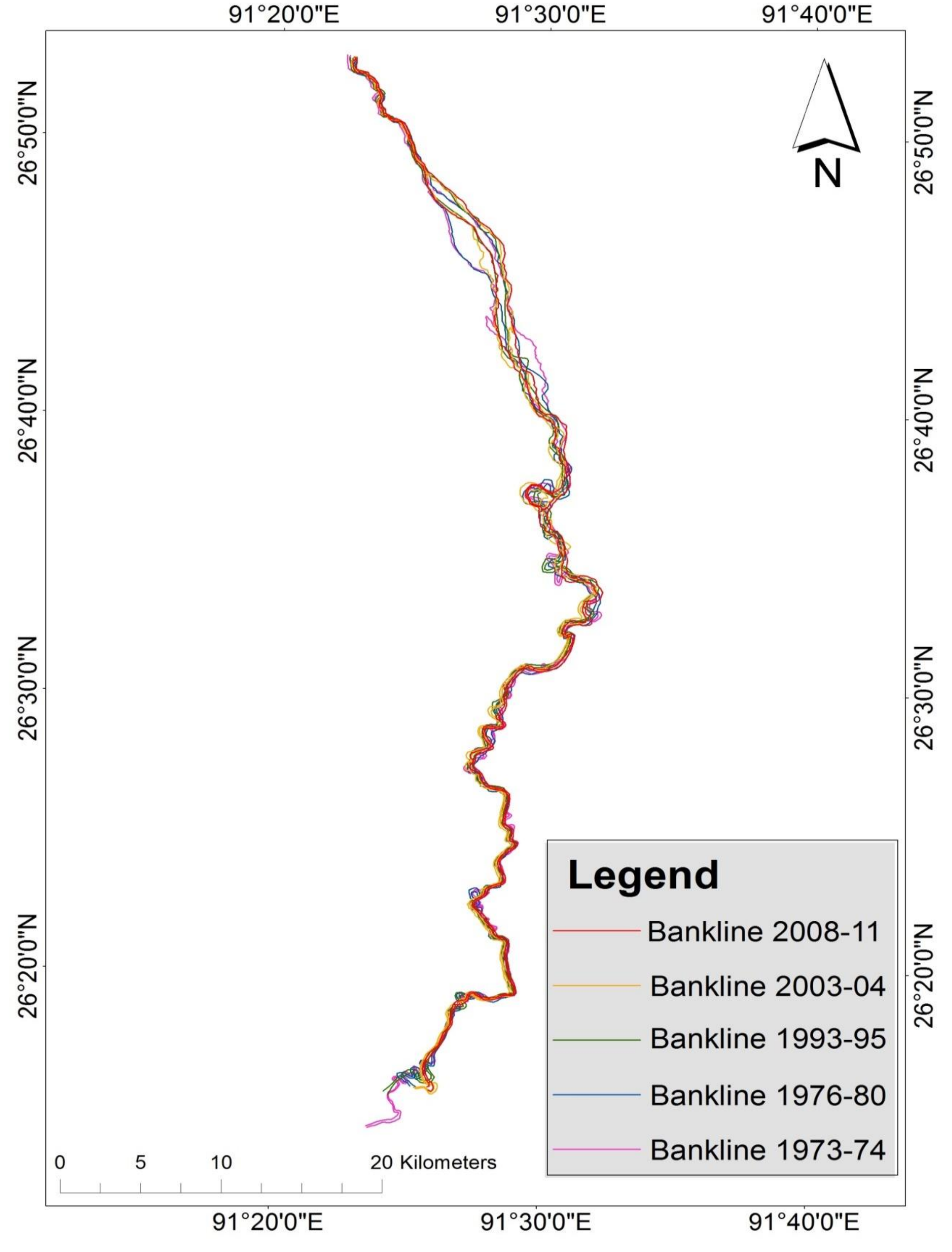


Figure 50: Pagladiya banklines at different time periods

11.2 Bankline Shifting

Riverbank erosion and its effect on channel evolution is an important geomorphological research with relevance to many scientific and engineering fields. Riverbank erosion is a dynamic geomorphological event which effects the river course and floodplain development. It can also affect economically due to the loss of agricultural land adjacent to the river thereby creating a threat to the people dwelling nearby. Bank erosion is defined as wearing of bank materials due to the action of secondary currents of a stream. The erosion phenomenon of a river scientifically is a complex mechanism. Several factors can be attributed for riverbank erosion phenomenon which includes the attack of direct and secondary currents due to the adverse orientation of flow direction, wave action due to boat movement, sudden drawdown due to flood recession, failure due to seepage. The mechanism of erosion is associated with deposition which occurs simultaneously. Floods of very high magnitude may be a contributing factor to channel widening and river bank erosion along with associated changes in the channel pattern (Schumm and Lichty, 1963; Schumm, 1968). The erosion process may be triggered by the channels during the high floods which result in undercutting of the upper bank materials.

11.2.1 Methodology

The digitized banklines for the different datasets were taken. A comparative quantitative analysis was done for two years. The shapefiles for the two years were overlaid. Centerlines for each dataset were created. The centerlines were then divided into 2 km upto its confluence with the Brahmaputra. The bankline shifting is then calculated for the left bank as well as for the right bank. Figure 50 shows the sections taken for the analysis.

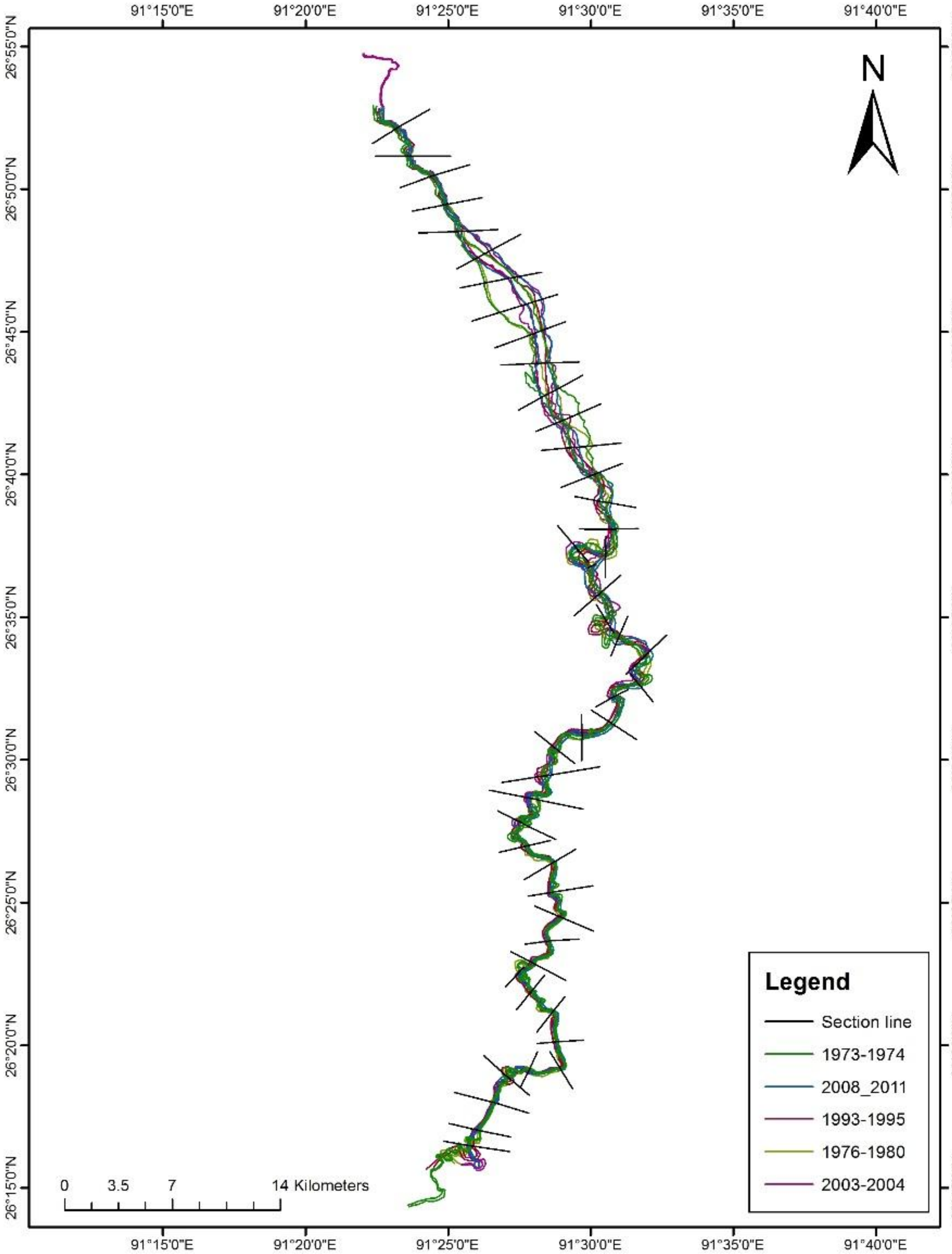


Figure 51: Sections taken for bankline shifting study

11.2.2 Results and Discussions

Figure 51 to 58 shows the shifting of the banklines either eastward or westward on both the banks for the different datasets. During the period of 1973-74 to 1976-80, a maximum shifting of 0.7 km occurred eastward and 0.6km occurred westward along the right bank. Along the left bank maximum shifting of 0.34 km occurred and maximum shifting occurred westward is found to be 1.02 km. For the dataset 1976-80 to 1993-95 a maximum shifting of 1.8 km can be seen eastward and a maximum shifting of 0.38 km occurred westward along the right bank whereas along the right bank it can be seen a maximum shifting of 0.7km and 1 km occurred along the left bank. The quantitative comparative analysis for the datasets 1993-95 and 2003-04 reveals that maximum shift towards east is 0.4km and 0.36km maximum shifting occurred towards west along the right bank. Along the left bank, 0.5 km maximum shift occurred eastward and 0.2km maximum shift occurred westward. For the temporal dataset 2008-04 and 2008-11 the river is found to be shifting towards east along both the banks. A maximum of 0.37 km shift eastwards and 0.35 westward occurred along the right bank. Along the left bank 0.4 km shift eastwards and 0.2 km westward occurred.

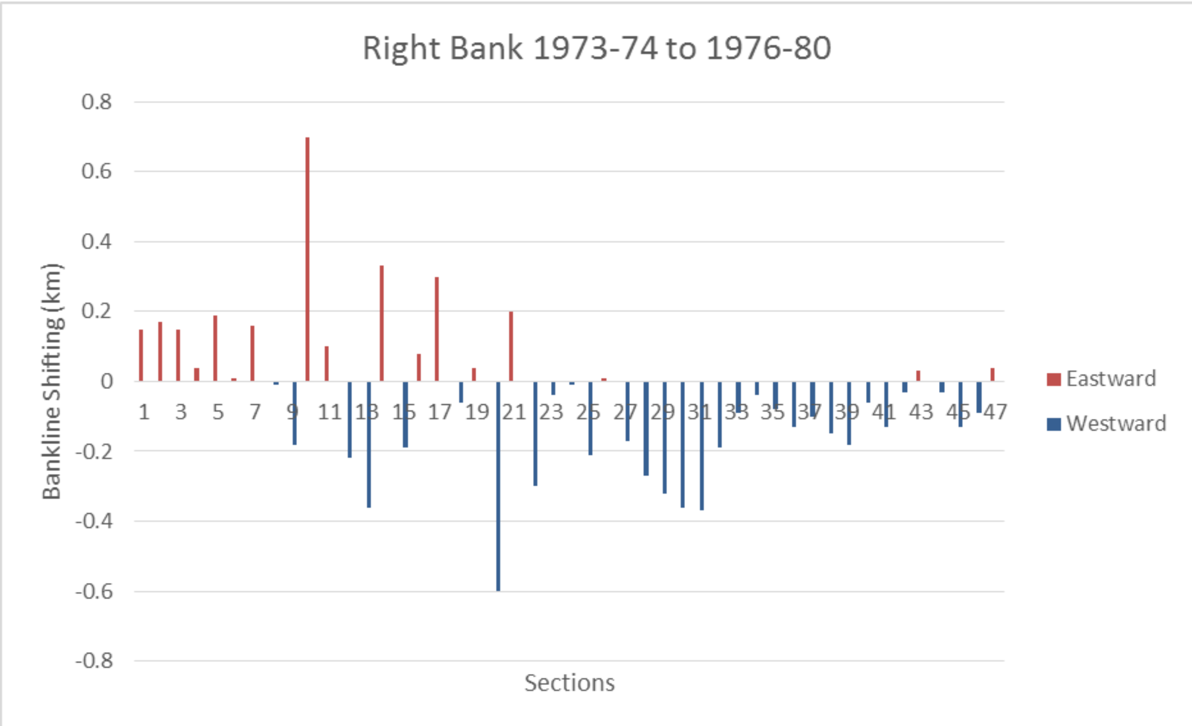


Figure 52: Right bank shifting 1973-74 to 1976-80

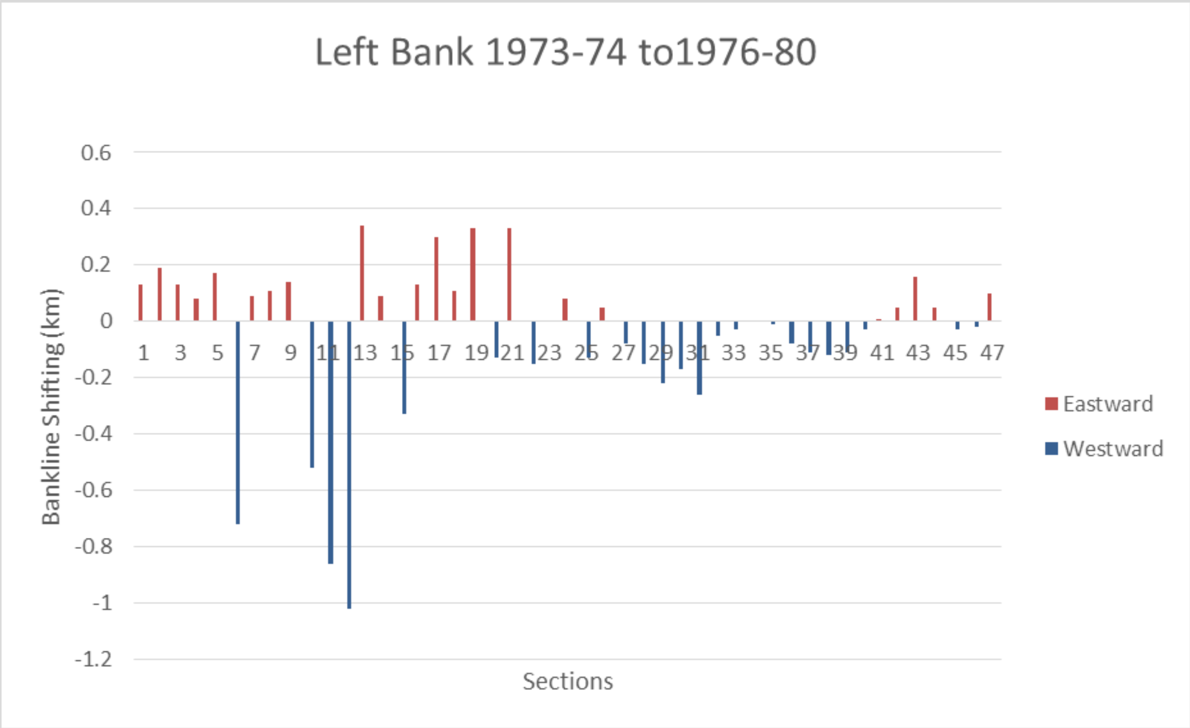


Figure 53: Left bank shifting from 1973-74 to 1976-80

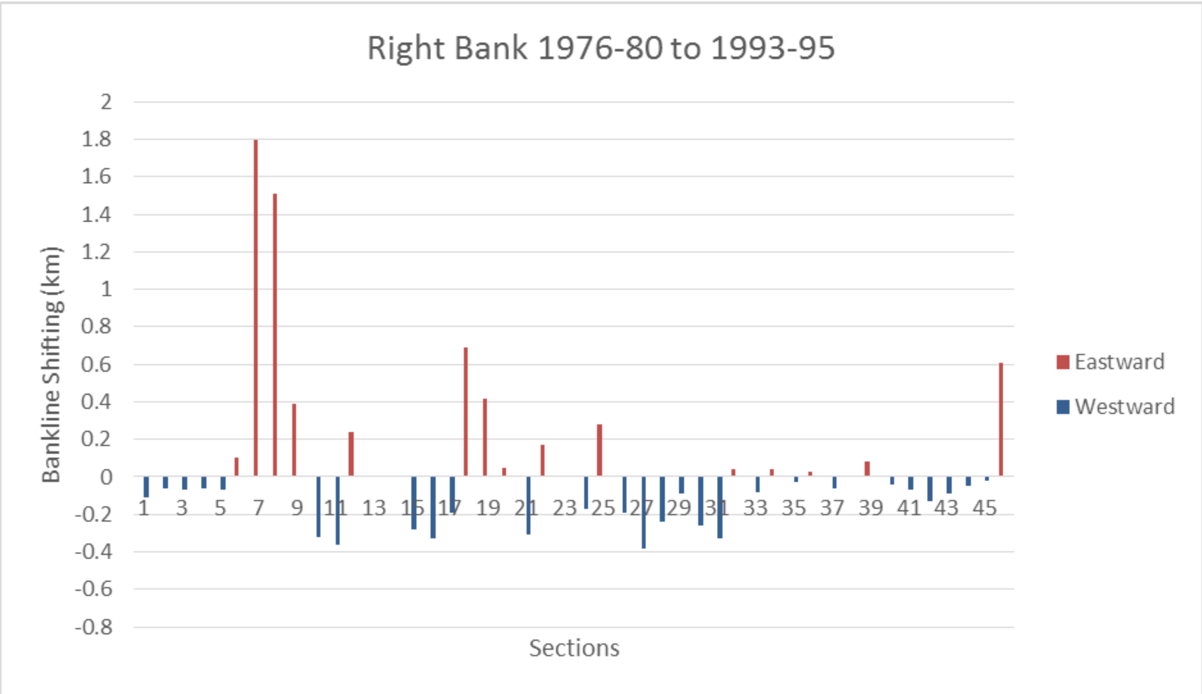


Figure 54 : Right bank shifting 1976-80 to 1993-95

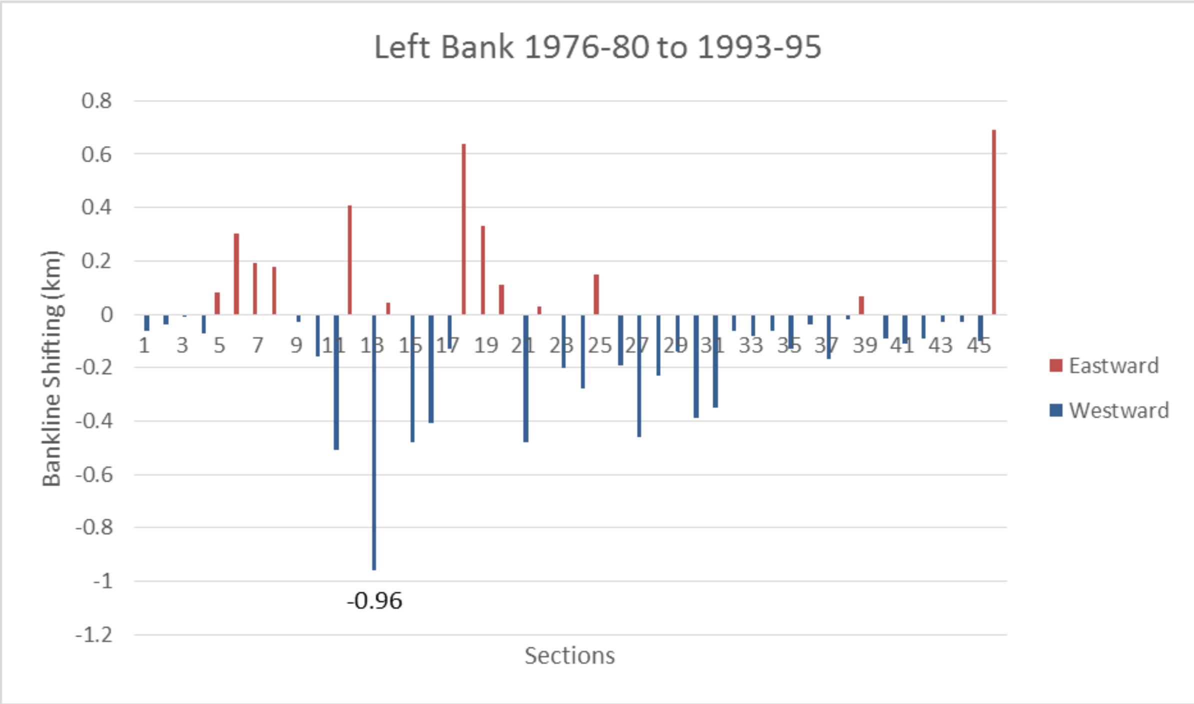


Figure 55: Left Bank Shift1976-80 to 1993-95

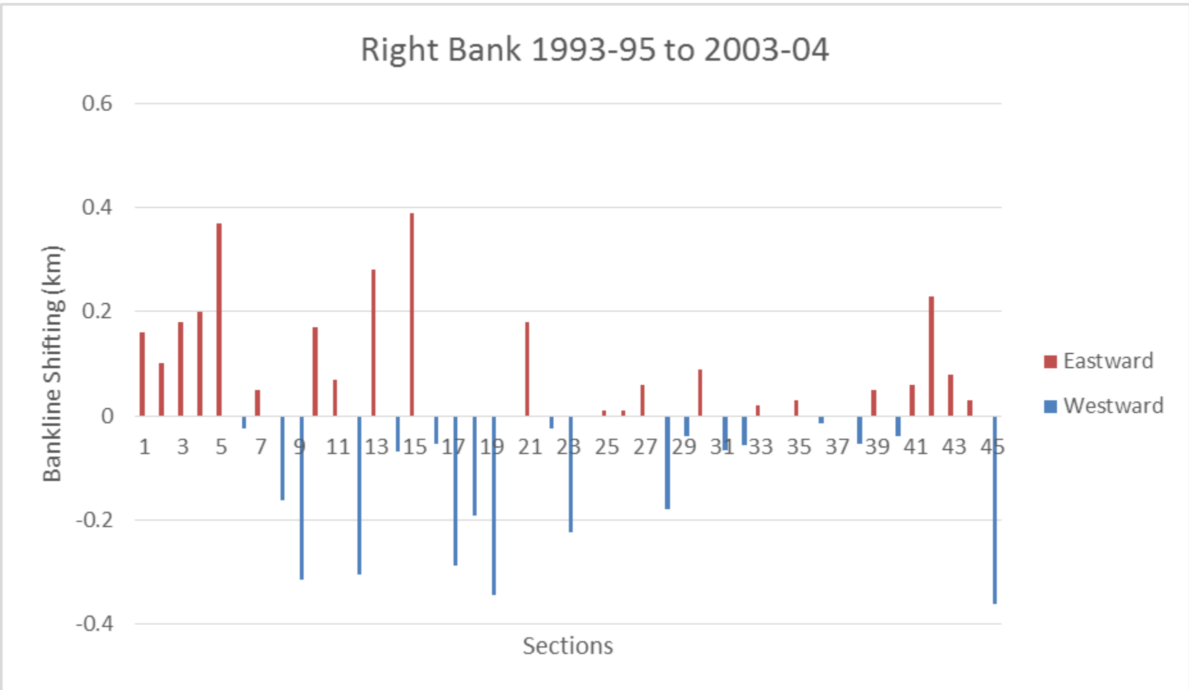


Figure 56: Right bank shift from 1993-95 to 2003-04

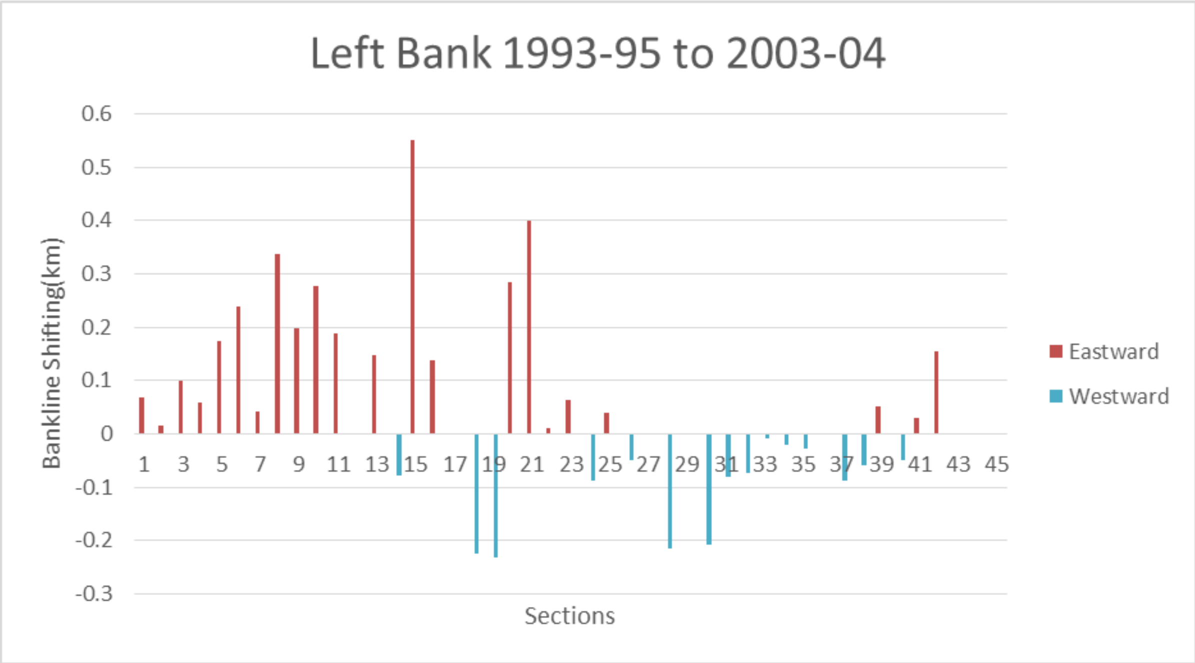


Figure 57: Left Bank shift from 1993-95 to 2003-04

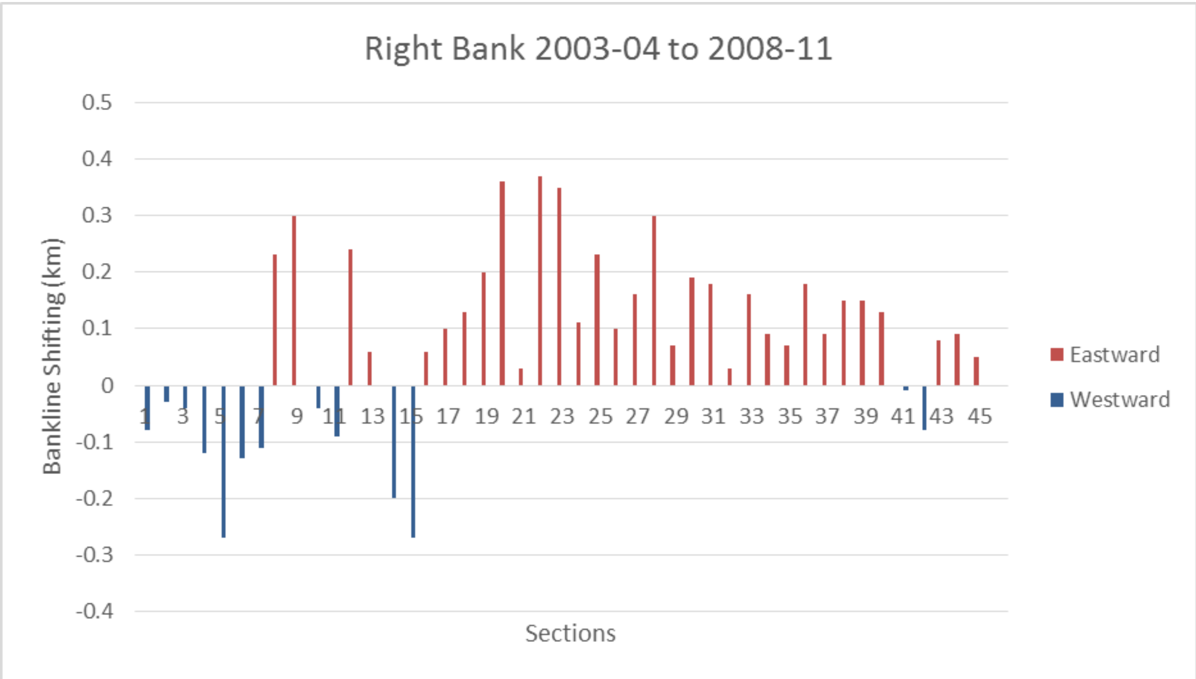


Figure 58: Right bank shift 2003-04 to 2008-11

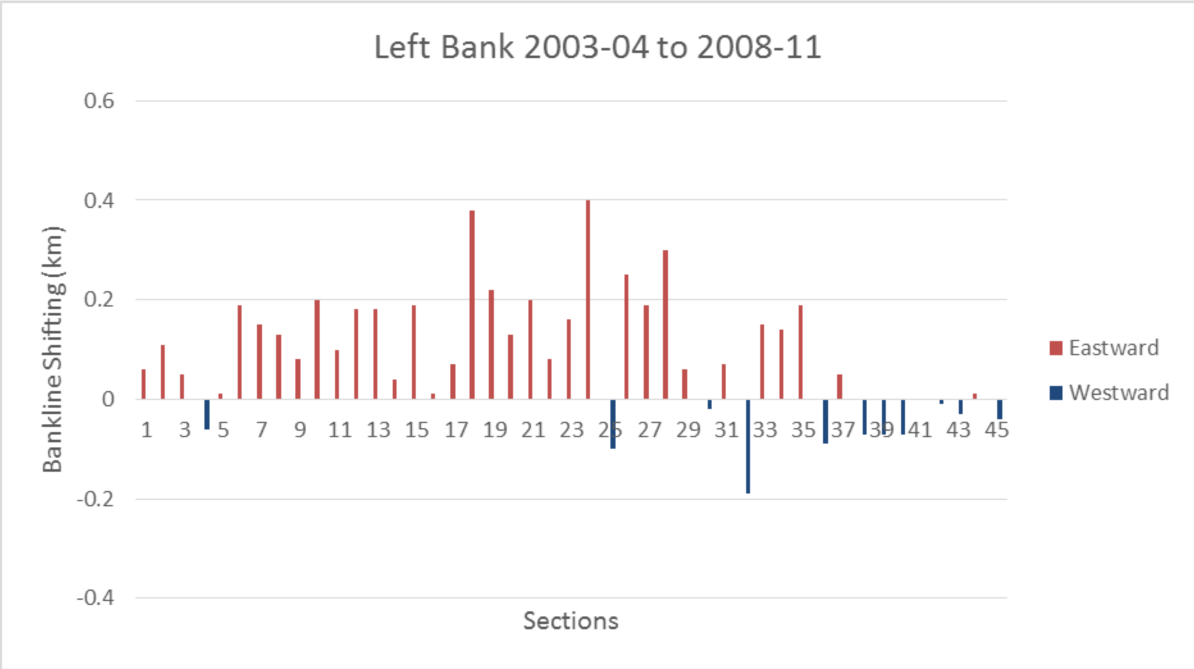


Figure 59: Left bank shift from 2003-04 to 2008-11

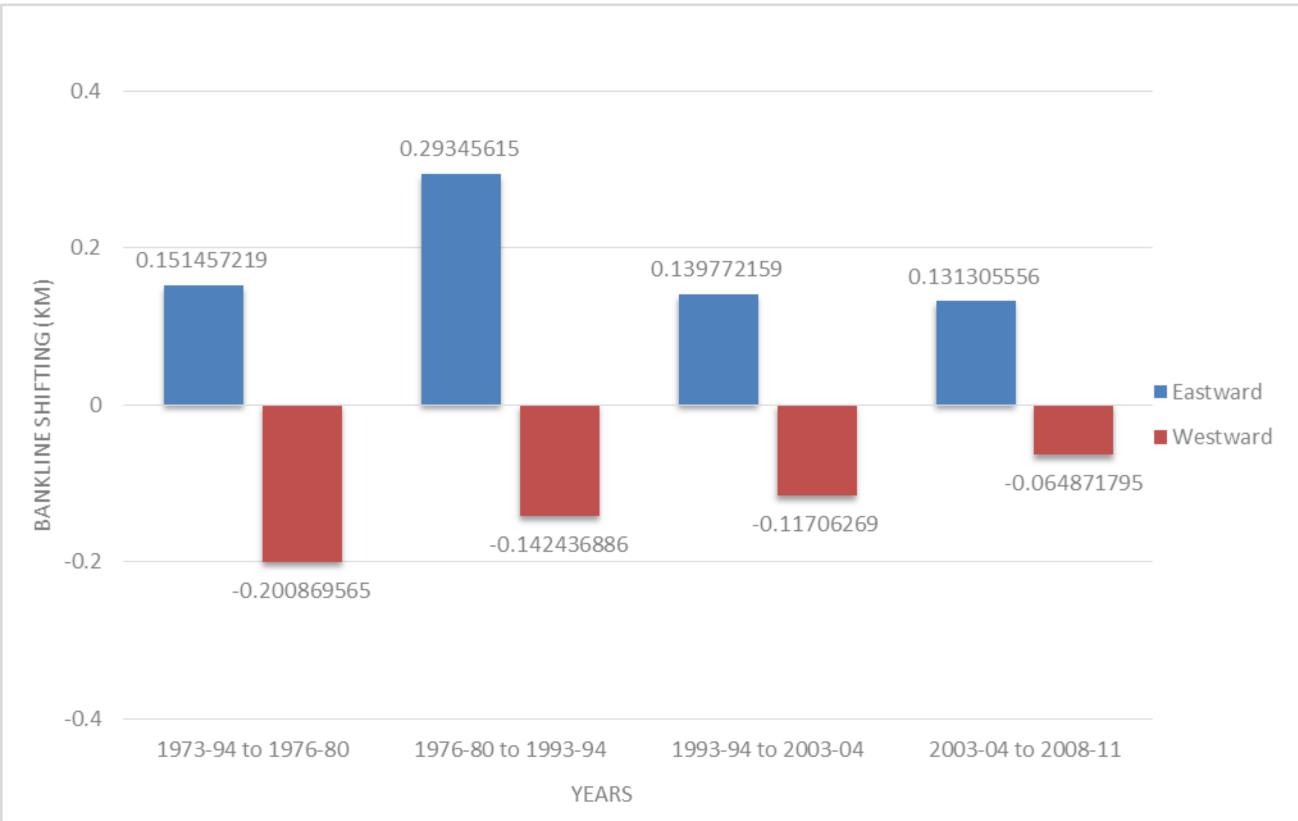


Figure 60: Average bankline shifting eastward and westward

Figure 59 shows the average shifting of the river eastward and westward considering both the banks. From the analysis, it can be ascertained that the bankline of the River Pagladiya is shifting towards eastward direction along both the banks. Thus the course of the river is migrating towards east direction. This can be evaluated with the previous researches as mentioned in section 2.1.

11.3 Planform 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,

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

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

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

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

11.3.1 Methodology

In this study, the Plan Form Indices were computed for every 10 km reach starting from upstream Bhutan Hills till its confluence with river Brahmaputra at Nalbari (Figure 60). A sample calculation of PFIs are shown in Figure 61. The cross section indicating highest braiding within each reach was selected on the basis of visual analysis and corresponding PFIs were computed. These exercises had been performed for all the datasets and were tabulated as Annexure III.

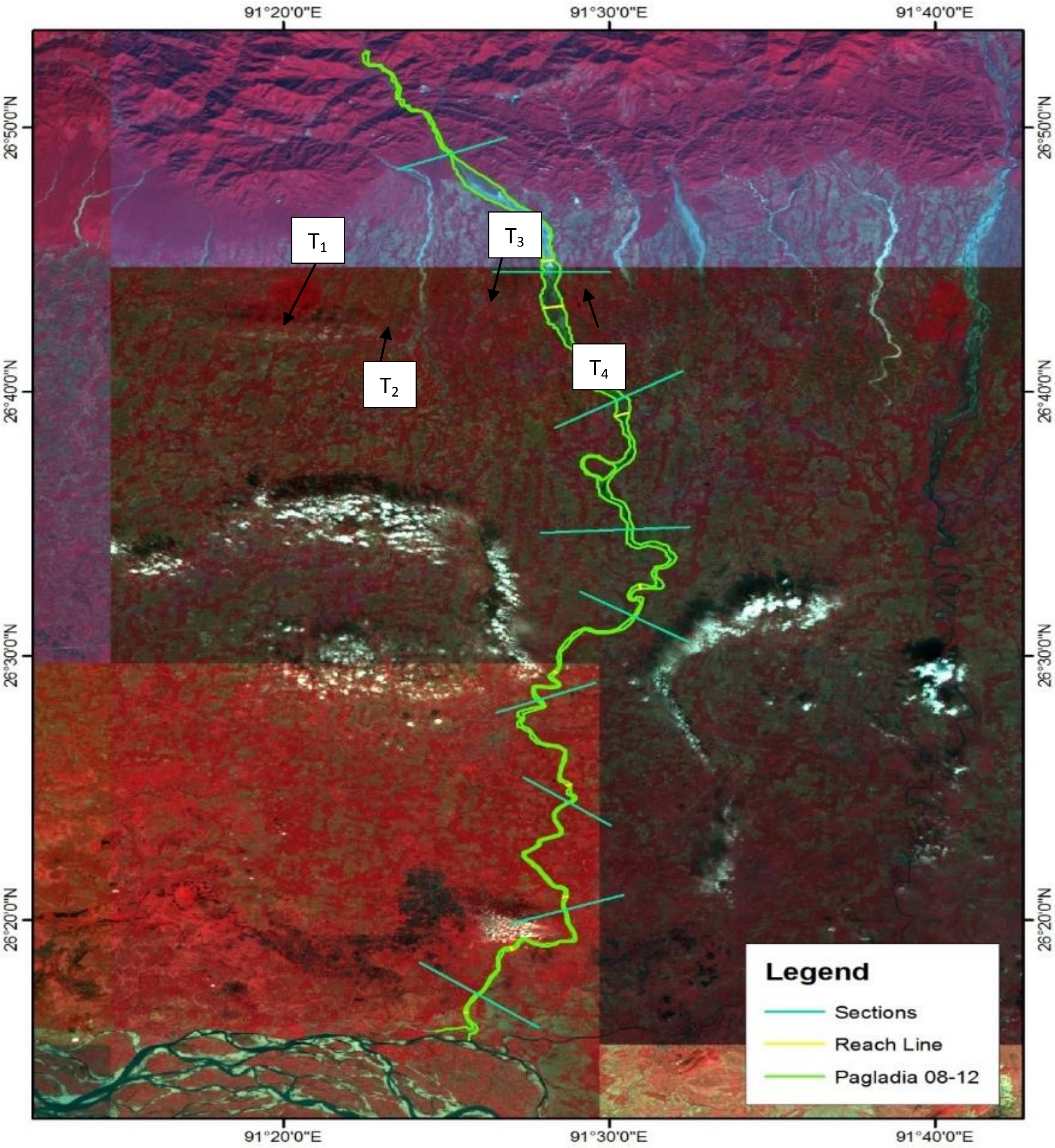


Figure 61:Sections of Pagladiya

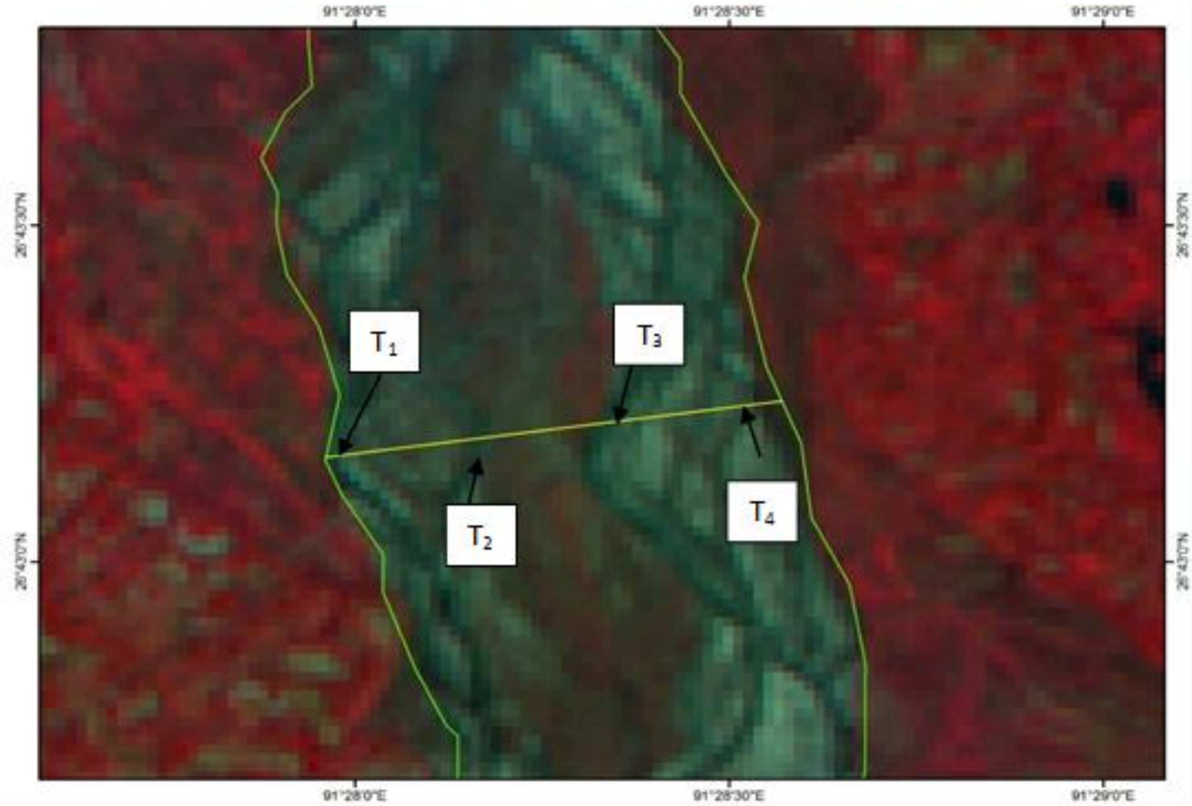


Figure 62 : PFI calculation at a reach of Pagladiya River (2008-2011)

T = T1+T2+T3+T4

= 0.251 km

B = 1.043 km

N = 4

$$PFI = \frac{0.251 \times 100}{1.043 \times 4}$$

= 6.02> 4

Moderately Braided

The computed PFI values were plotted against the reach number and are shown in Figure 62. to 66.

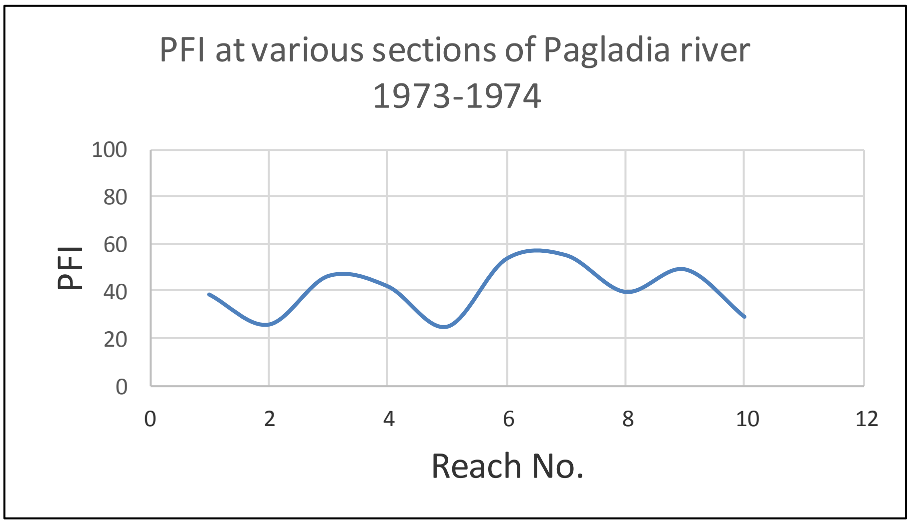


Figure 63: PFI at various sections in 1973-74

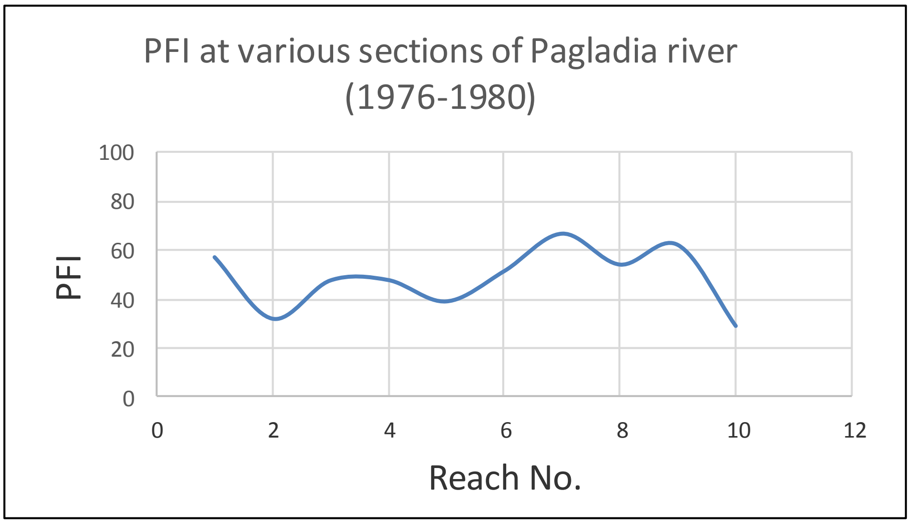


Figure 64: PFI at various sections in 1976-80

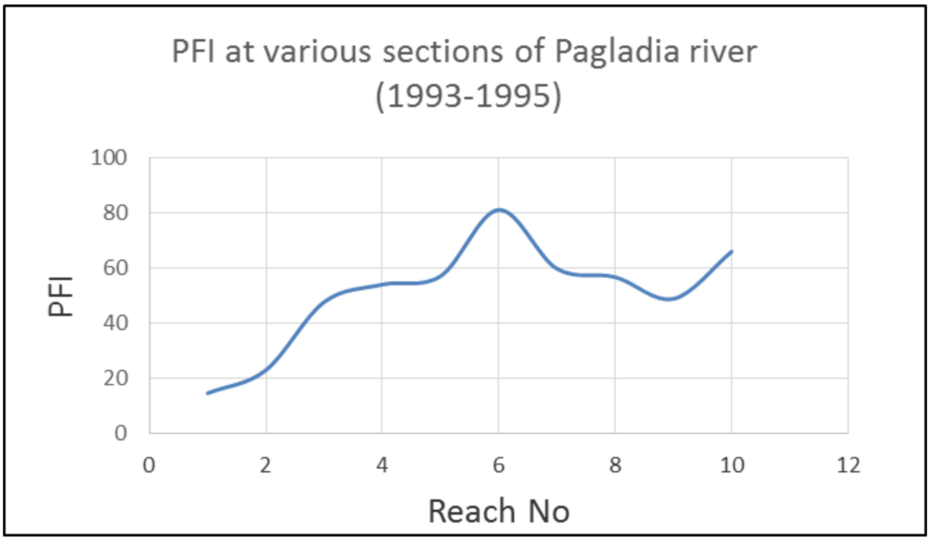


Figure 65: PFI at various sections in 1993-95

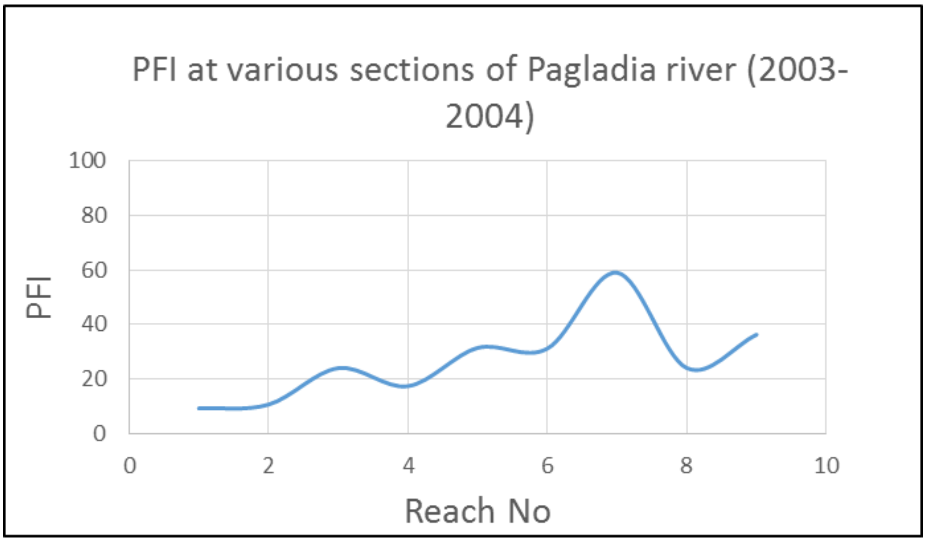


Figure 66: PFI at various sections in 2003-04

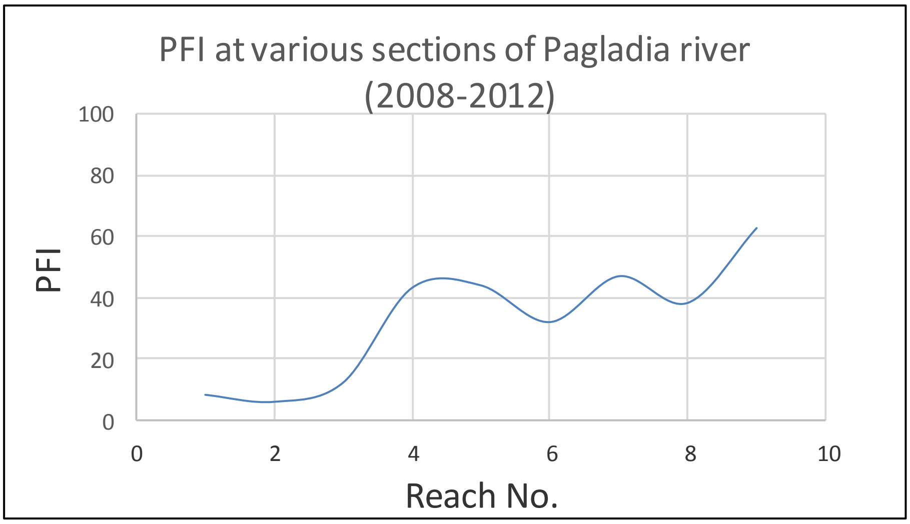


Figure 67: PFI at various sections in 2008-2012

From the analysis, it can be seen that the river is low braided as the PFIs are greater than 19. However, from Figure 64, 65 and 66 i.e. from 1993-95 onwards the values of PFIs of reach 1 are lower than 19 which show that the reach is moderately braided. This shows that the upper region of Pagladiya River when it enters the plain of Assam is moderately braided.

Chapter 12
IMPACT OF HYDRAULIC STRUCTURES

There was a proposal for a multipurpose project over Pagladiya River. The project was proposed to achieve three purposes namely flood control, irrigation and power generation. However, the project was not undertaken and as a result no impact has been observed.

There are no major hydraulic structures available in the Pagladiya Basin. But the presence of bridge may affect the downstream flow to a great extent. A number of road bridges including two railway bridges are located various sections of the Pagladiya basin (Fig.67). The span of the bridge is enough for the length of the river. Therefore, major impact on downstream of the bridge has been observed. A total of 7 bridges are located over the river as shown in the Fig. 68-74.

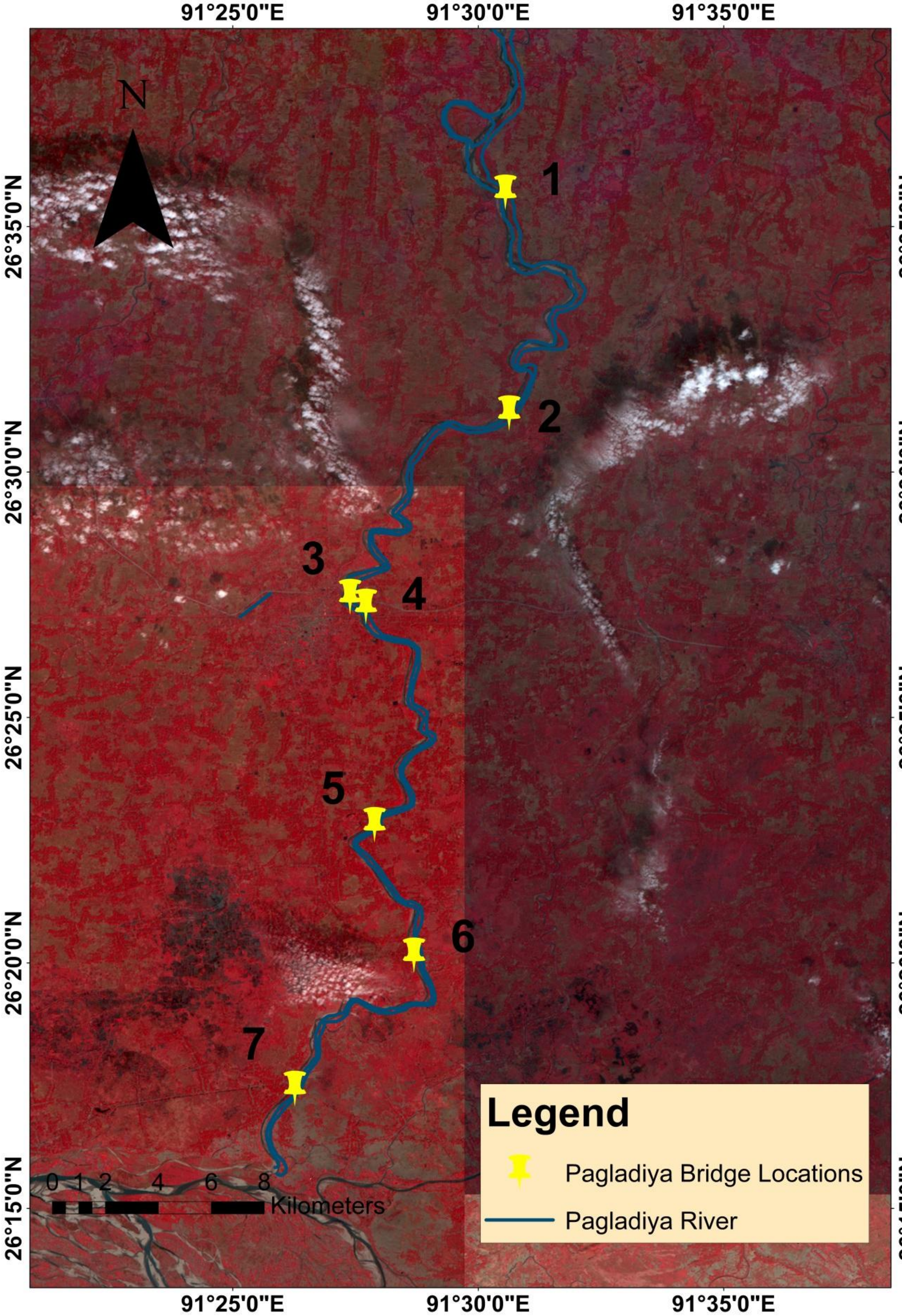


Figure 68: Bridge at Pagladiya basin

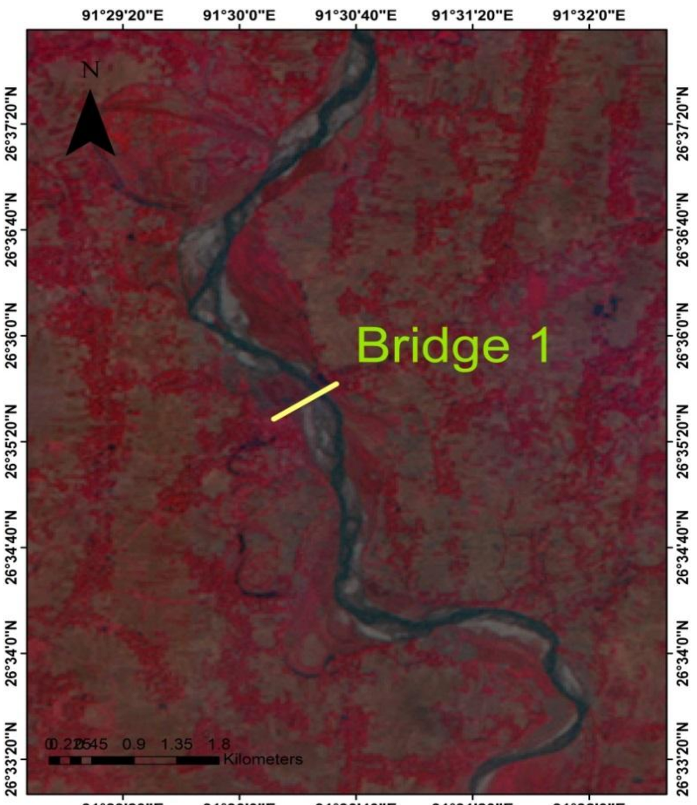


Figure 69:Bridge near Hahkata

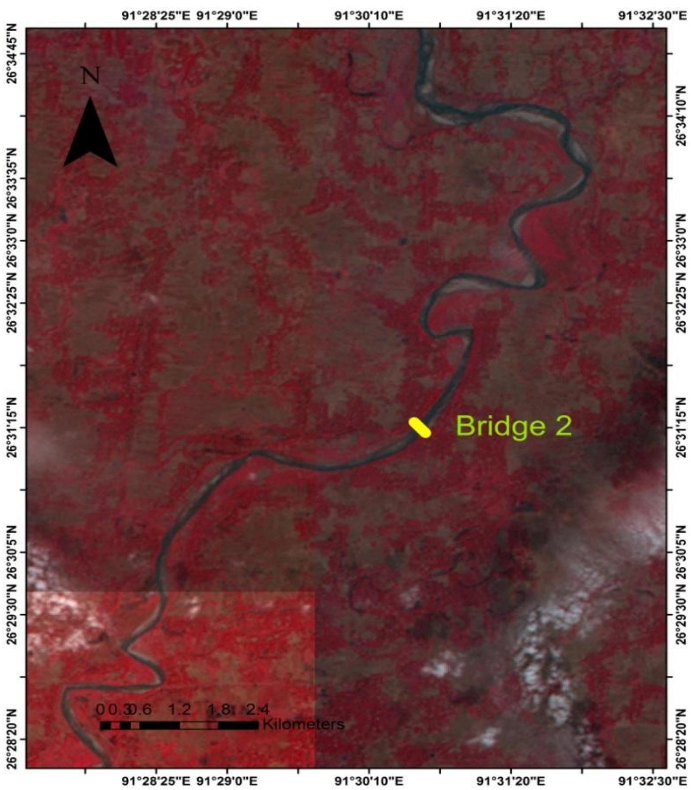


Figure 70:Bridge near Sagarkuchi

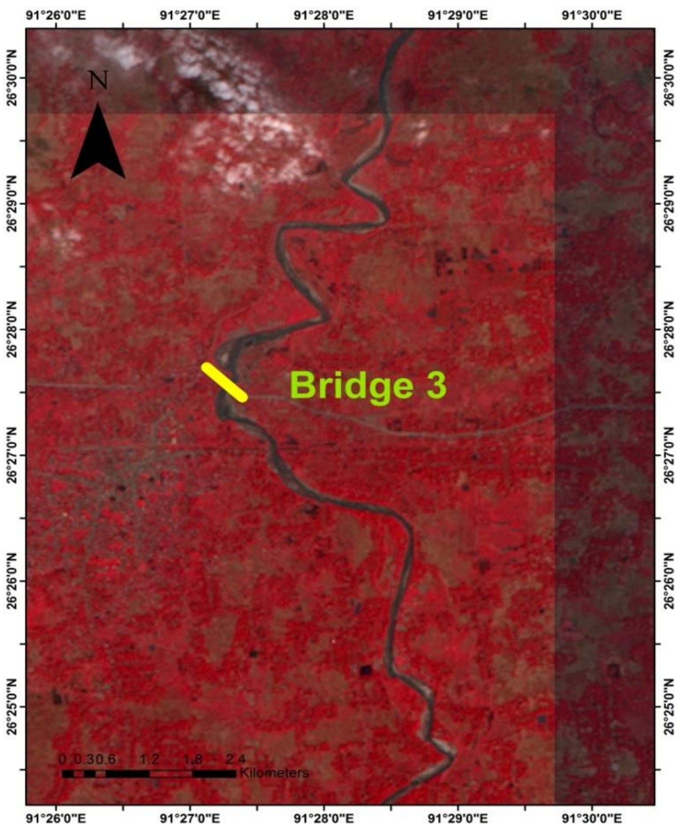


Figure 71: Bridge near Doulgobindapur

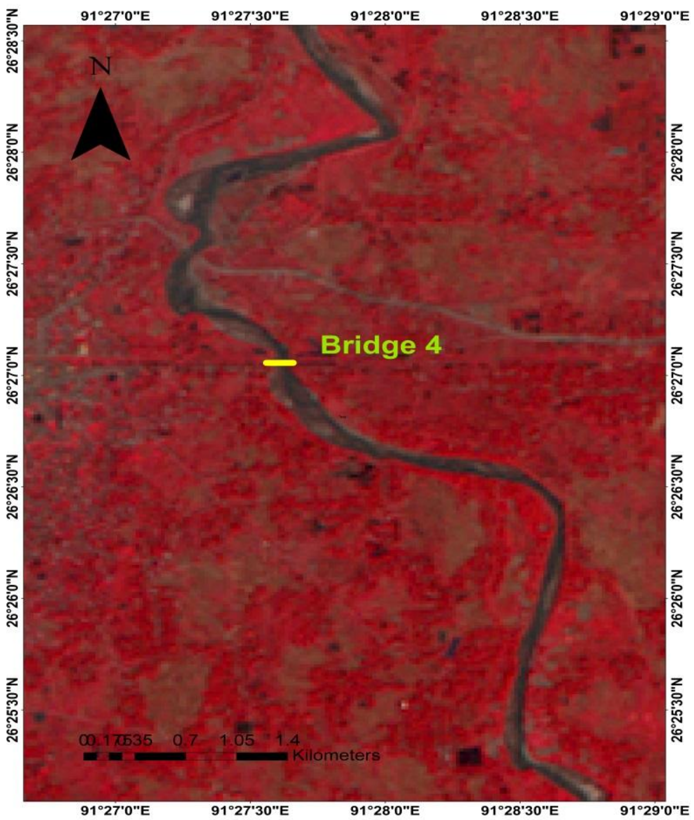


Figure 72: Railway Bridge near Doulgobindapur

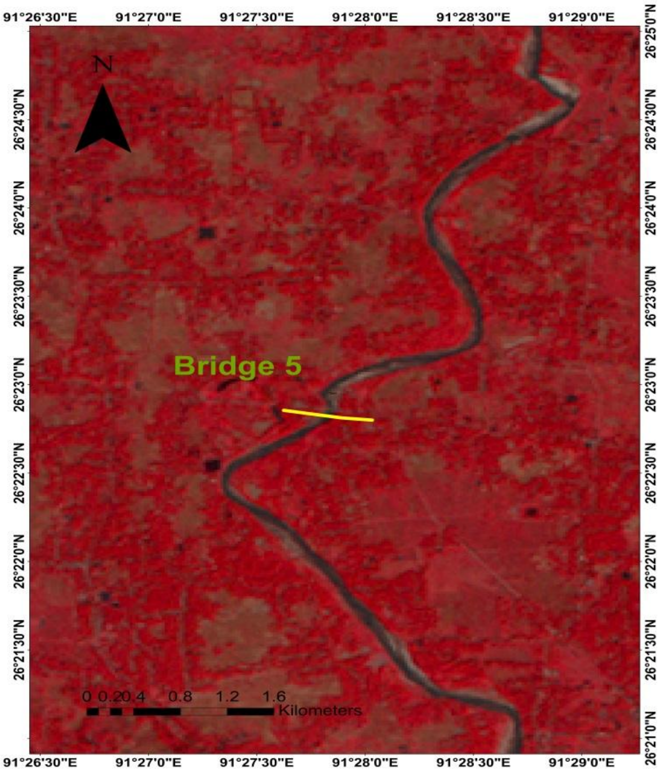


Figure 74:Bridge near Marowa

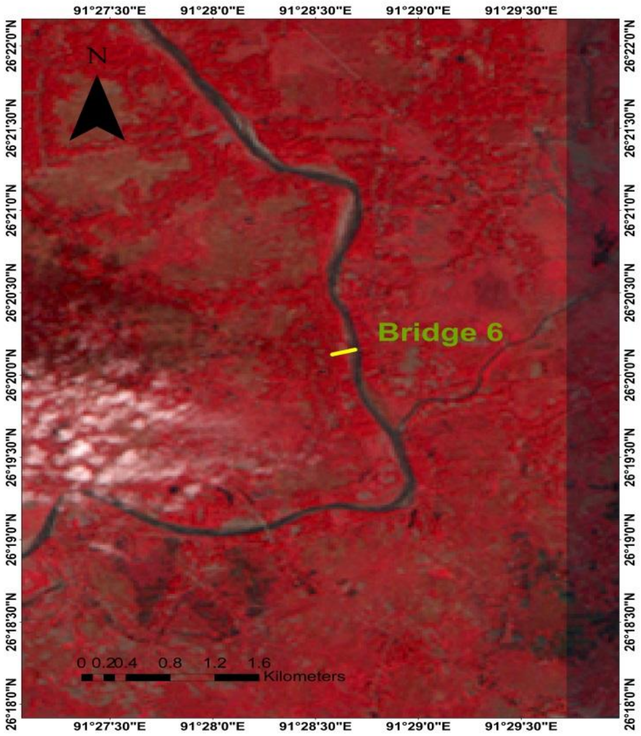


Figure 73: Bridge near Ulabari

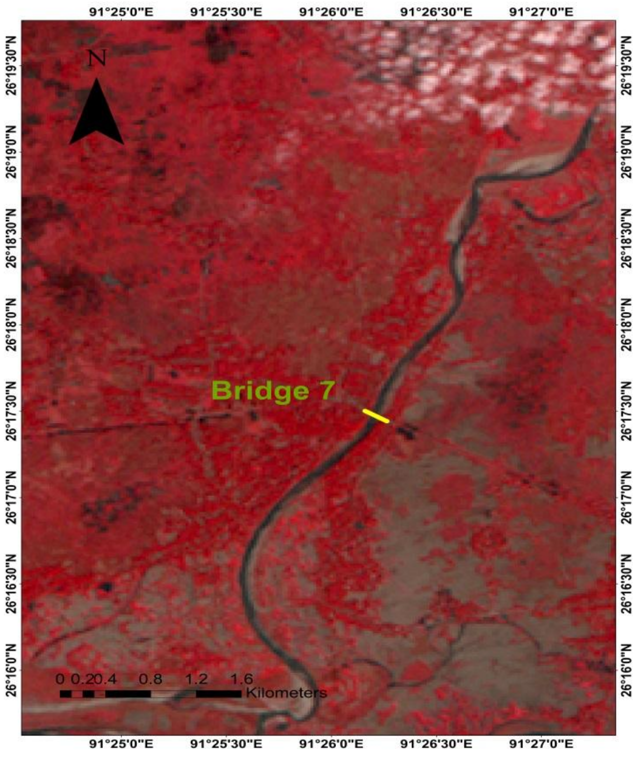


Figure 75: Bridge near Adabari

Chapter 13
FLOOD AFFECTED AREAS

12.1 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

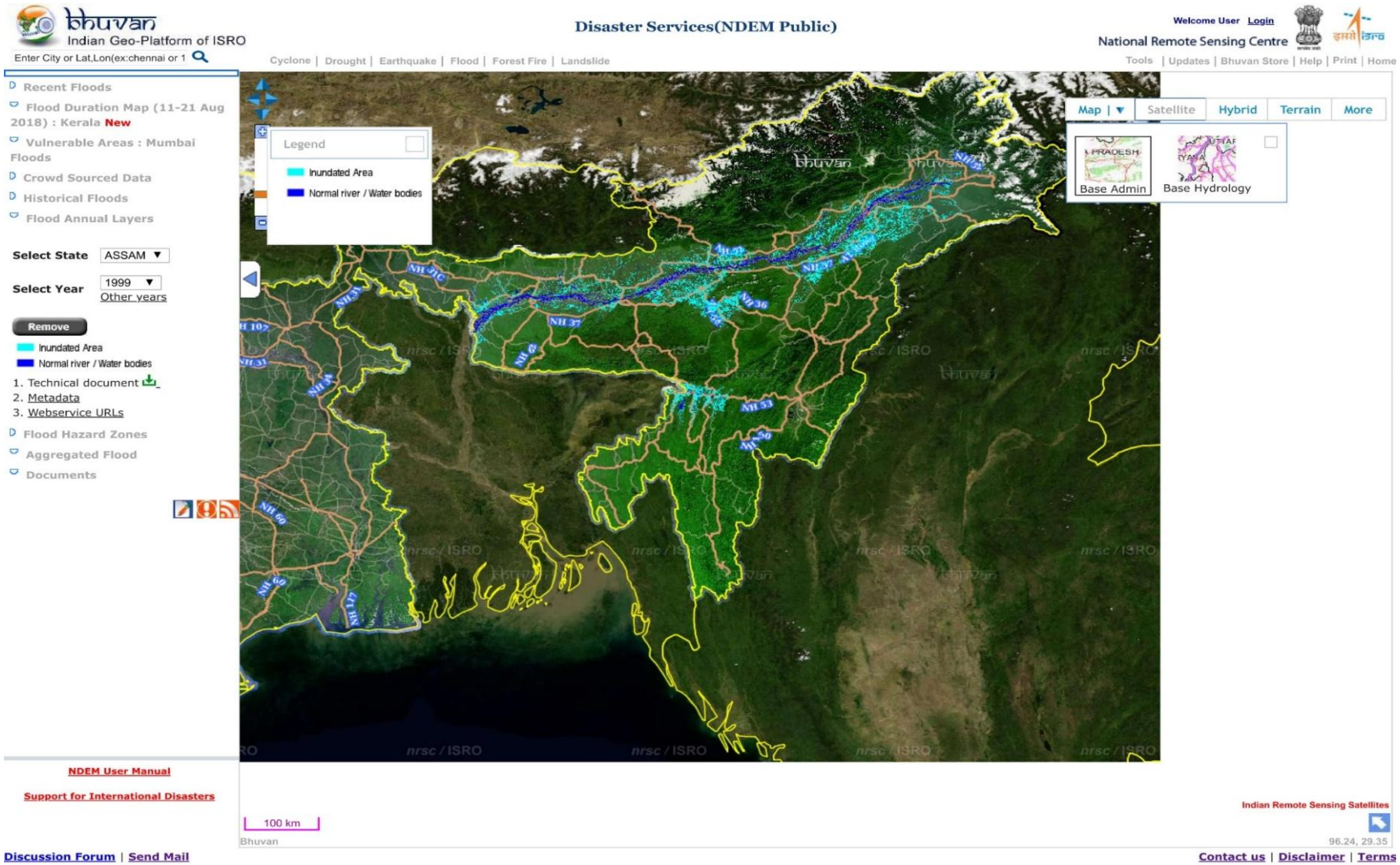


Figure 76:Flood layer of Assam in 1999

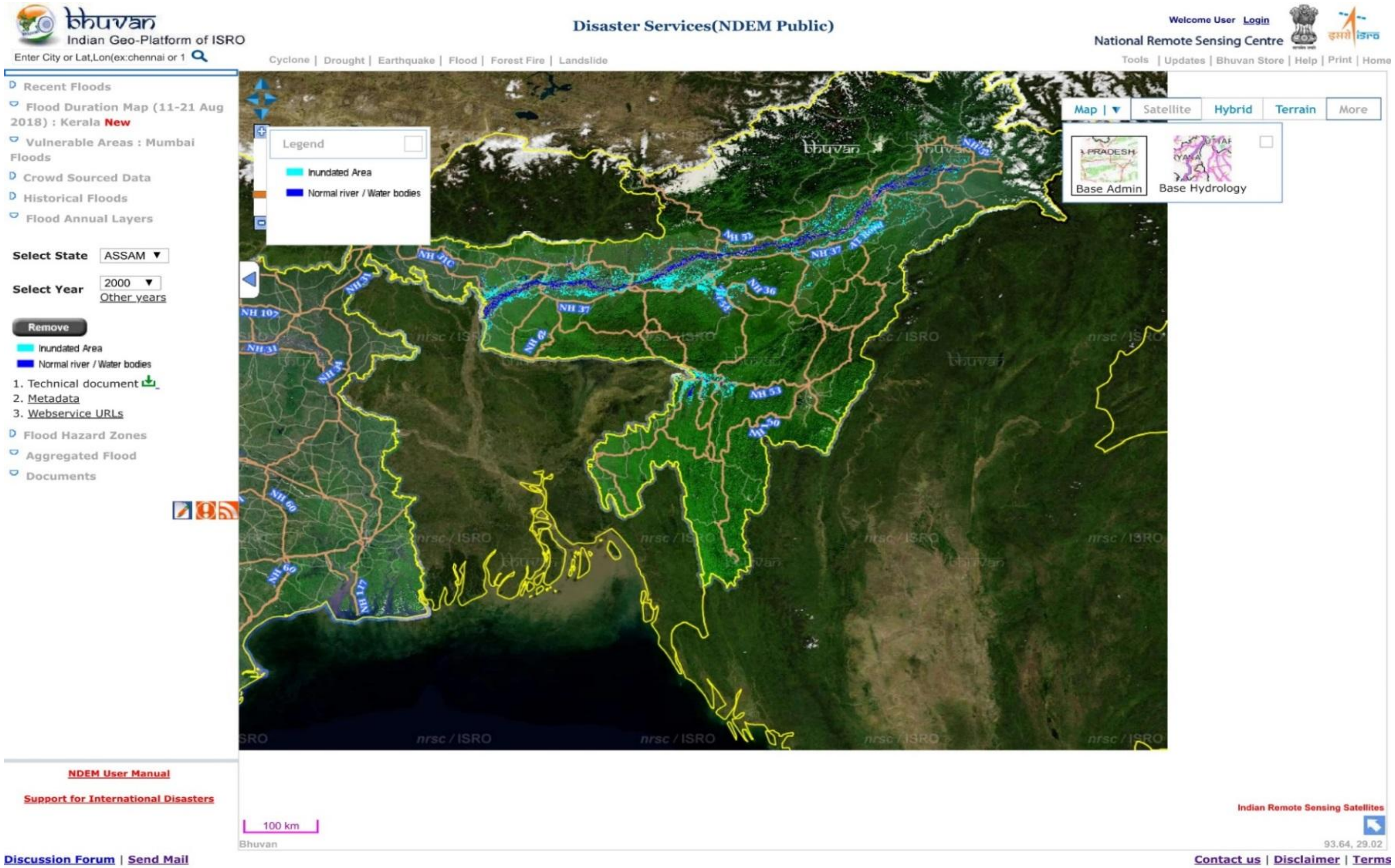

bhuvan
Indian Geo-Platform of ISRO
Enter City or Lat,Lon(ex:chennai or 1
Disaster Services(NDEM Public)
Welcome User Login
National Remote Sensing Centre
Cyclone | Drought | Earthquake | Flood | Forest Fire | Landslide
Tools | Updates | Bhuvan Store | Help | Print | Home
Recent Floods
Flood Duration Map (11-21 Aug 2018) : Kerala New
Vulnerable Areas : Mumbai Floods
Crowd Sourced Data
Historical Floods
Flood Annual Layers
Select State ASSAM
Select Year 2000
Other years
Remove
Inundated Area
Normal river / Water bodies
1. Technical document
2. Metadata
3. Webservice URLs
Flood Hazard Zones
Aggregated Flood
Documents
Legend
Inundated Area
Normal river / Water bodies
Map | Satellite Hybrid Terrain More
Base Admin
Base Hydrology
NDEM User Manual
Support for International Disasters
Indian Remote Sensing Satellites
100 km
Bhuvan
93.64, 29.02
Discussion Forum | Send Mail
Contact us | Disclaimer | Terms

Figure 77:Flood layer of Assam in 2000

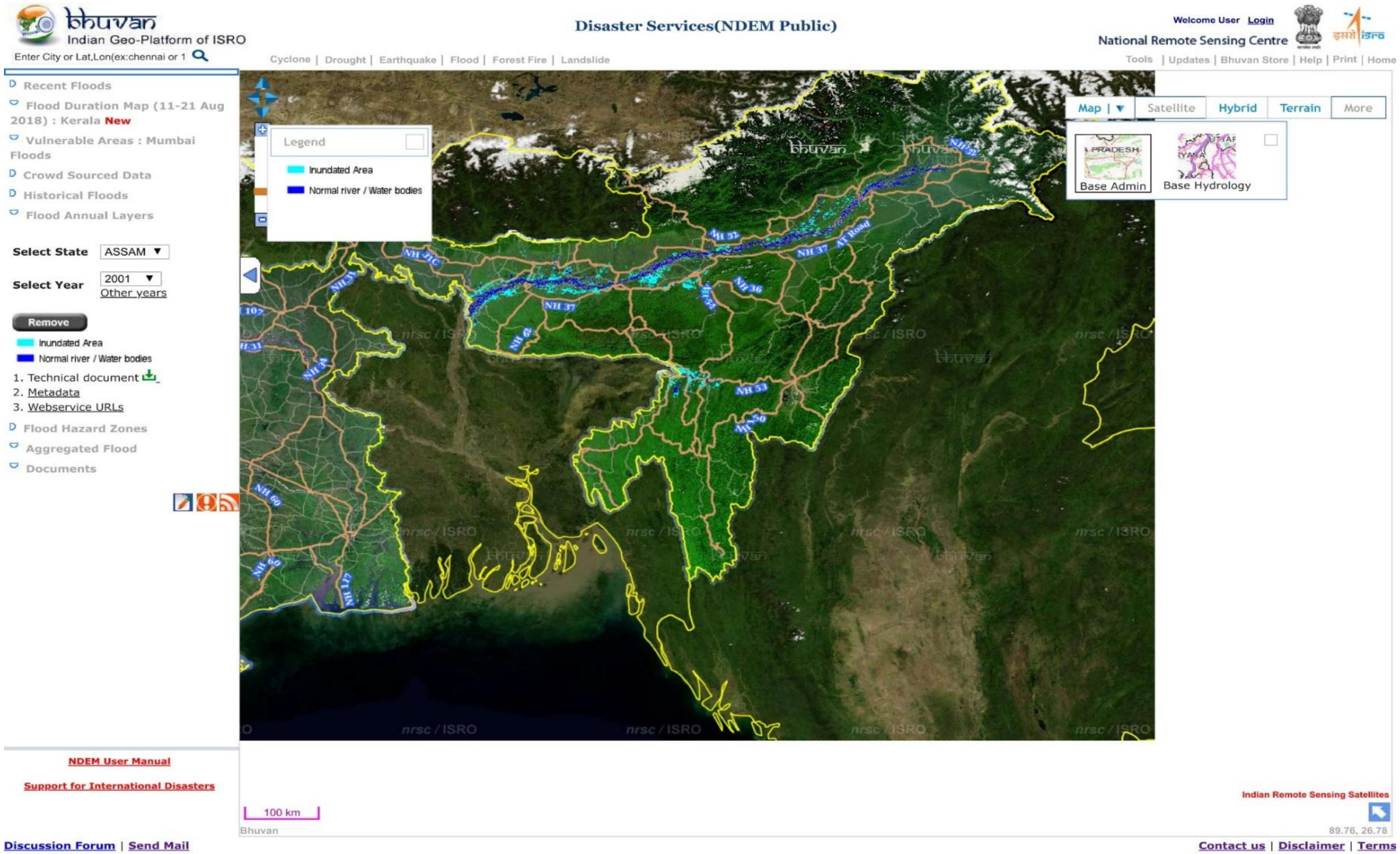


Figure 78: Flood layer of Assam in 2001

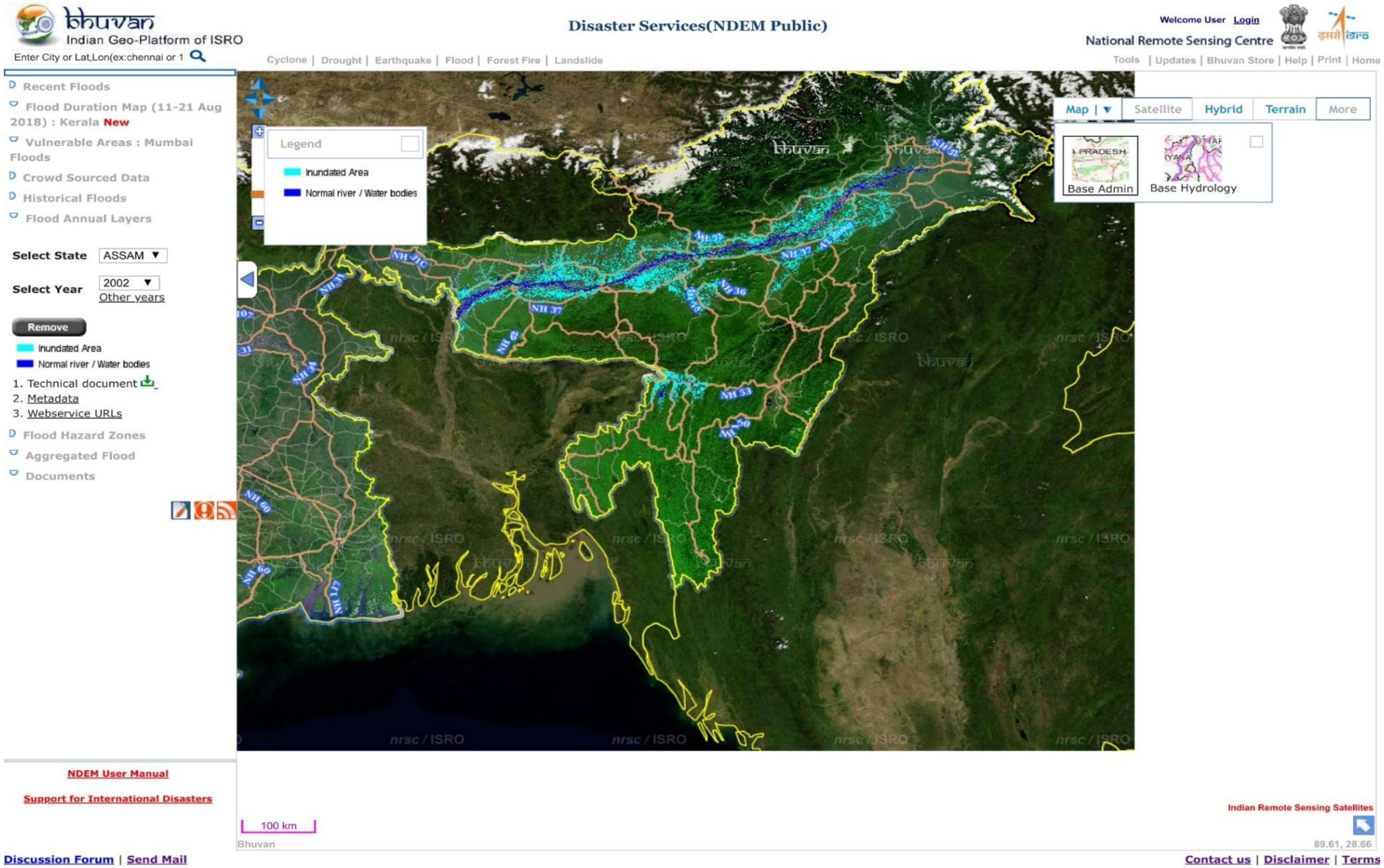


Figure 79: Flood layer of Assam in 2002

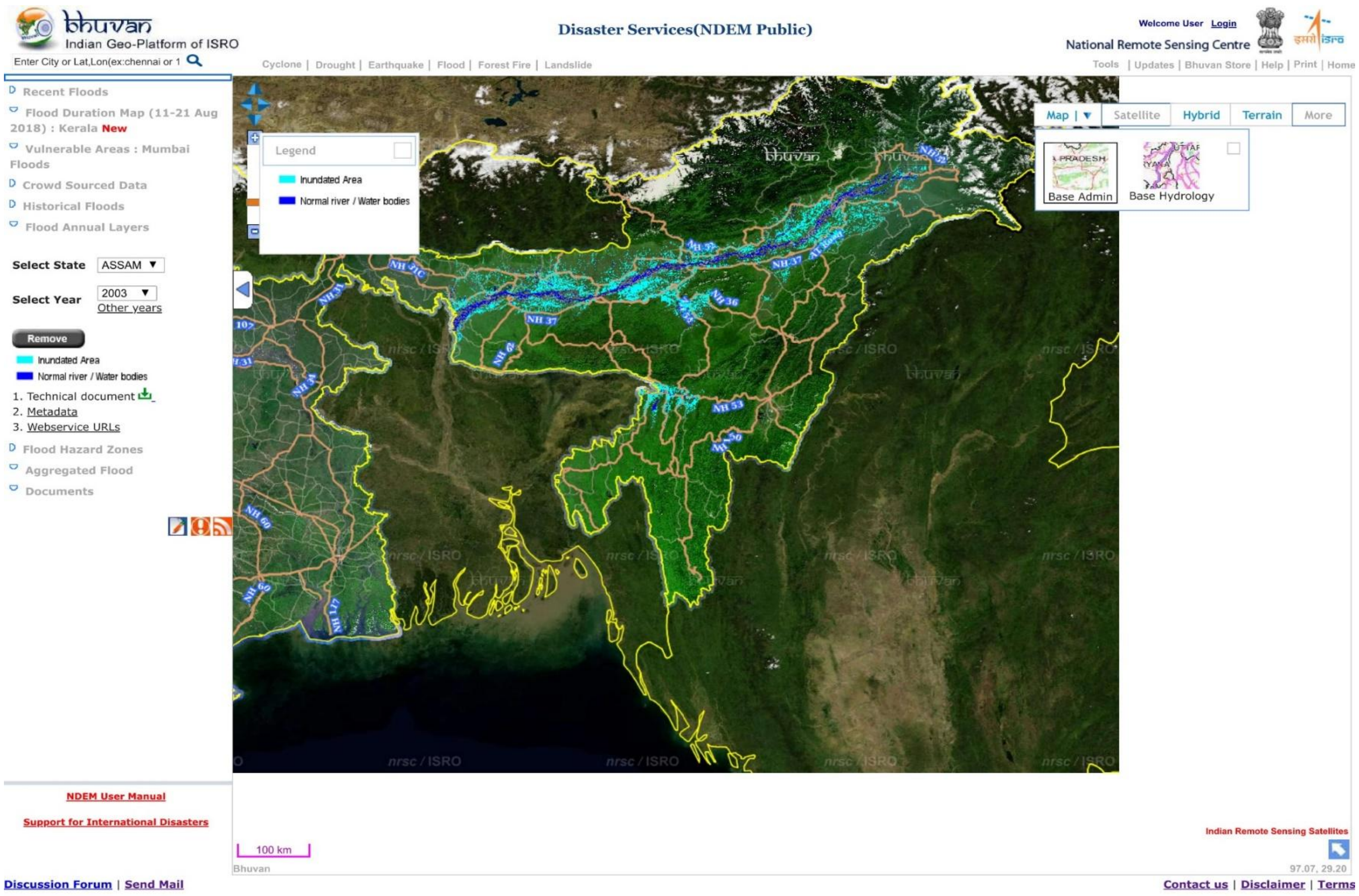


Figure 80: Flood layer of Assam in 2003

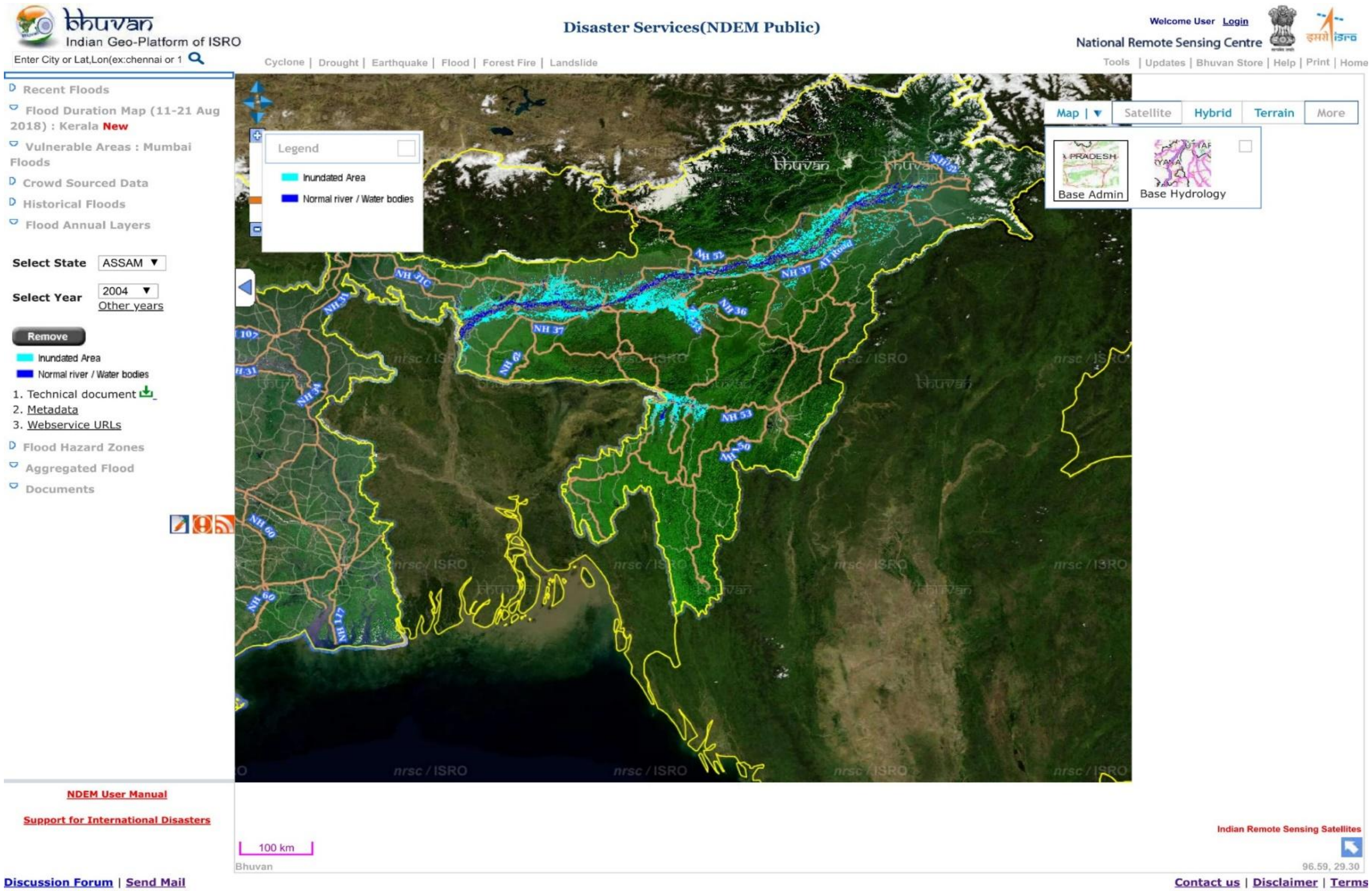


Figure 81: Flood layer of Assam in 2004

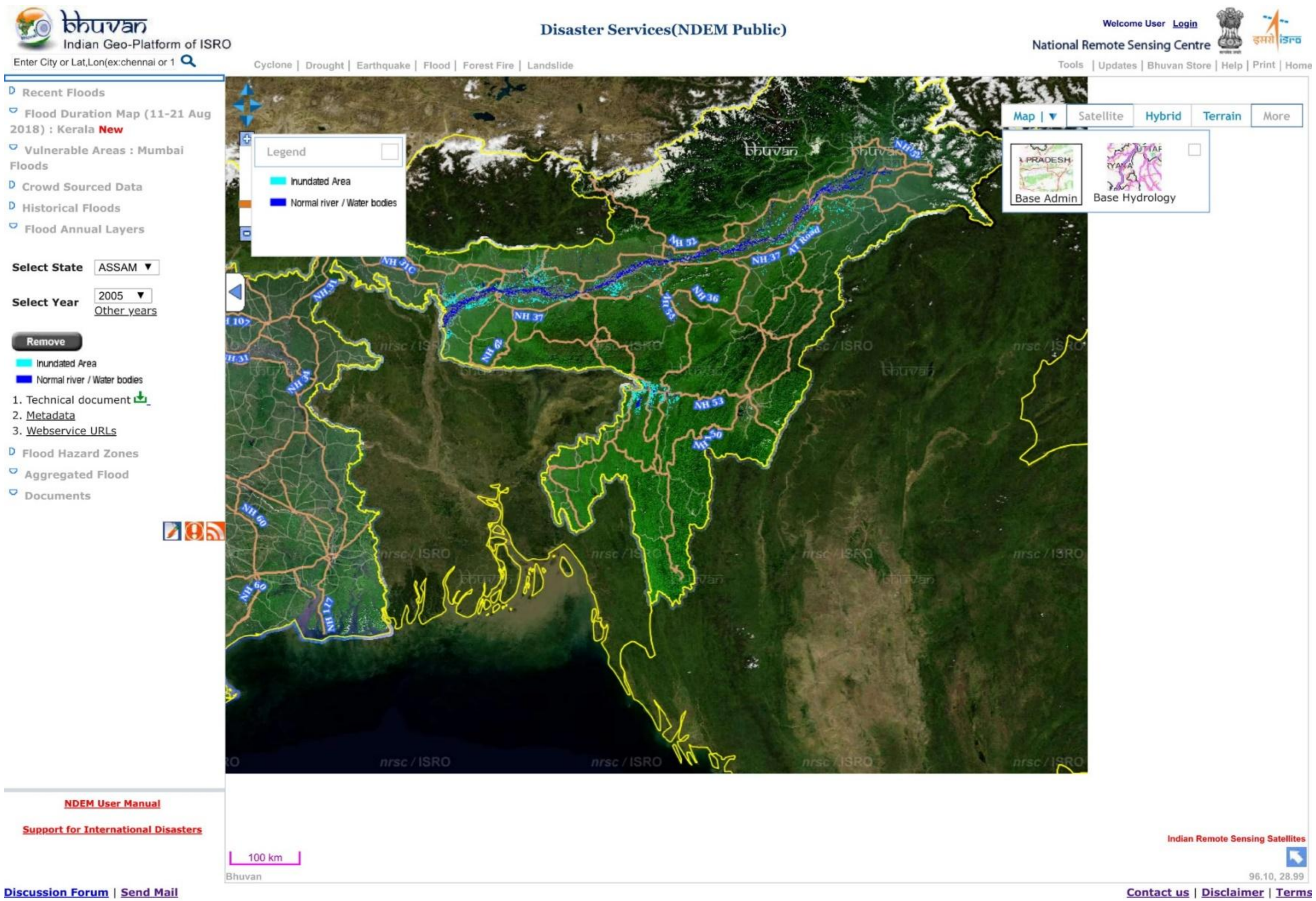


Figure 82: Flood layer of Assam in 2005

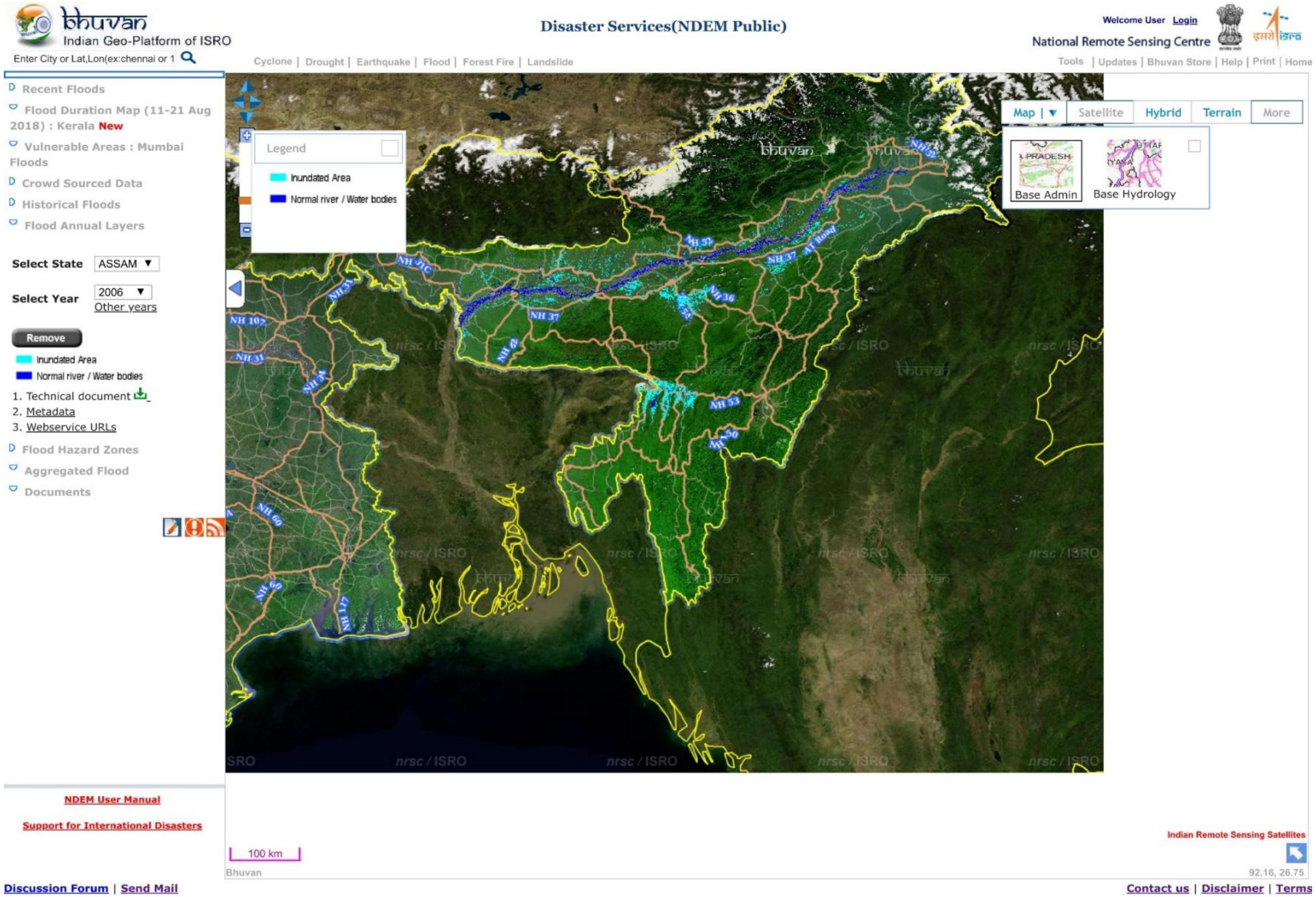


Figure 83: Flood layer of Assam in 2006

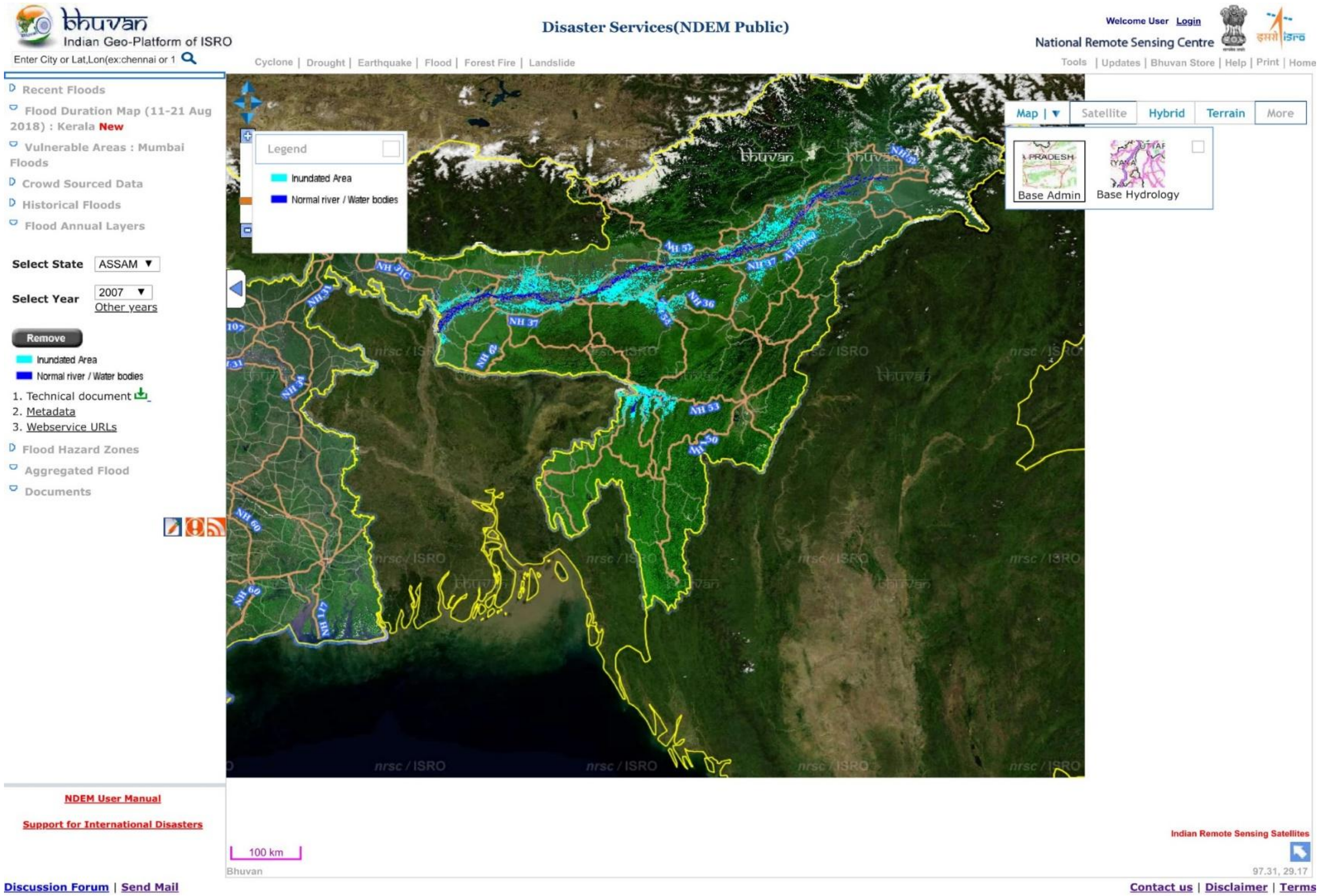


Figure 84: Flood layer of Assam in 2007

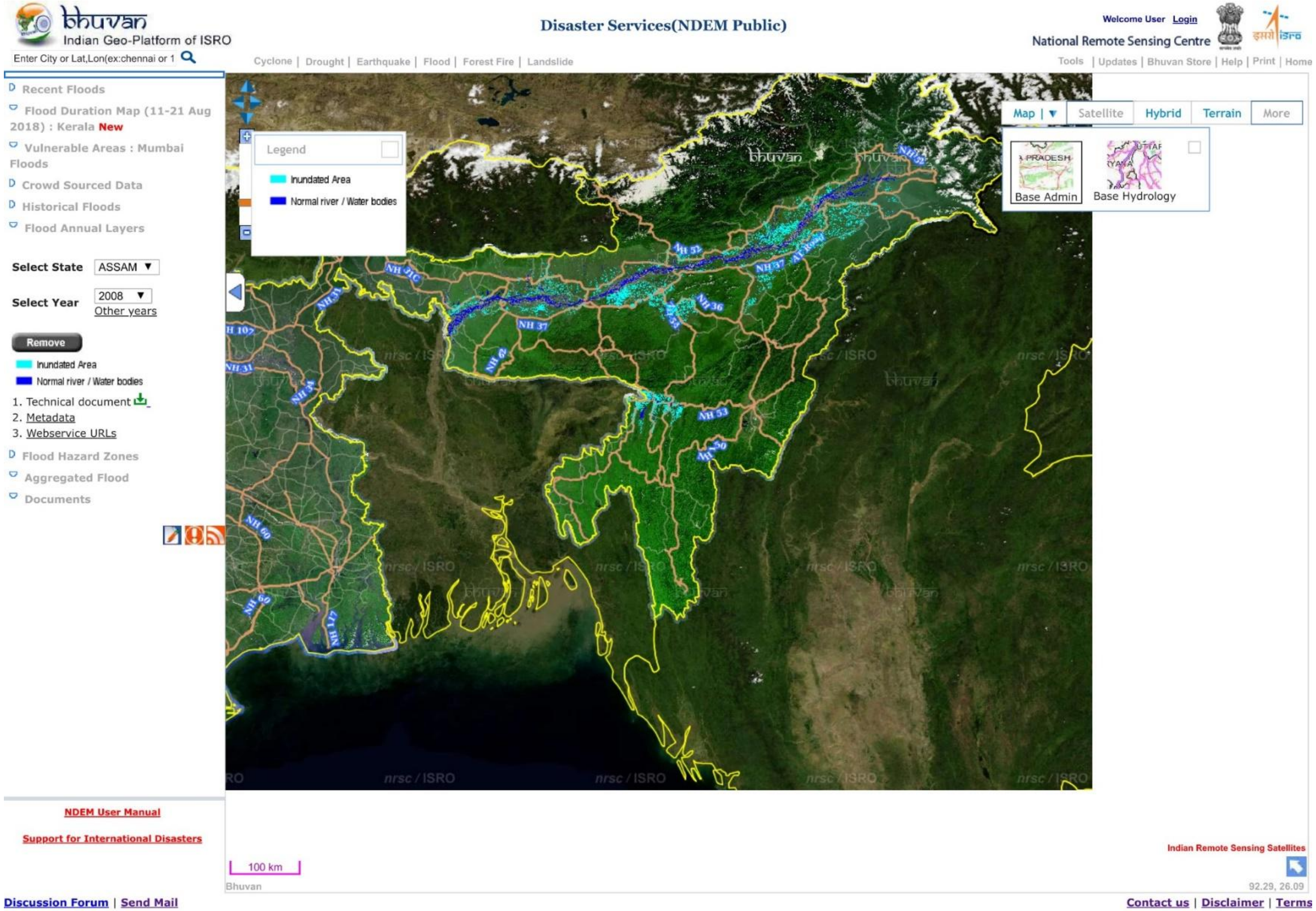


Figure 85: Flood layer of Assam in 2008

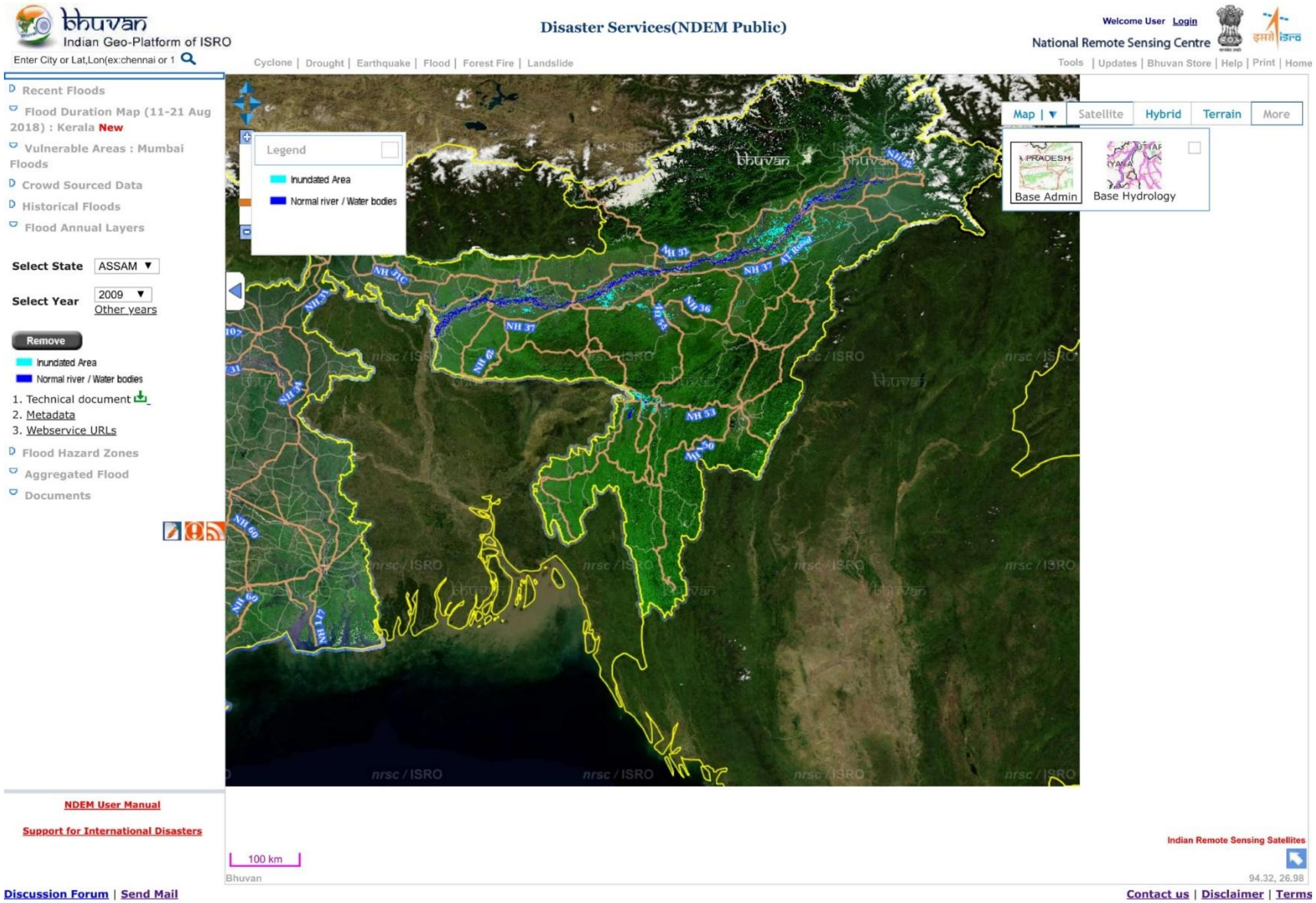


Figure 86: Flood layer of Assam in 2009

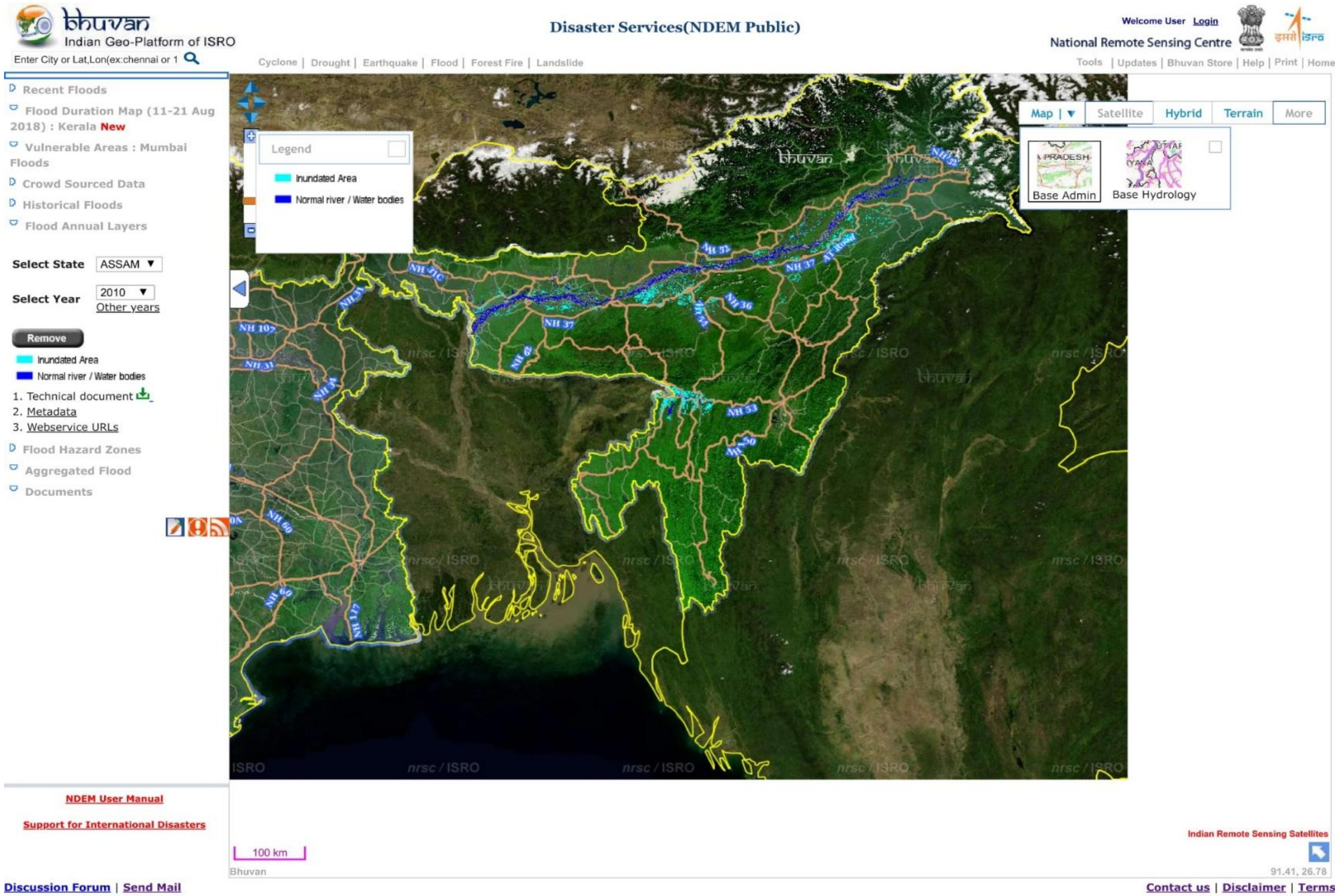


Figure 87: Flood layer of Assam in 2010

Chapter 14
DISSEMINATION WORKSHOP

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

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

18.1 Session 1

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

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

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

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

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

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

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

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

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

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

Figure 88: Prof. Arup Kr. Sarma welcomes the dignitaries and the participants

Figure 89: Felicitation of the dignitaries

Figure 90: Inaugural Address by Prof. Gautam Biswas, Director, IIT Guwahati

Figure 91: Lighting of the lamp

Figure 92: Presentation By Mr Ravi Shankar, CWC

Figure 93: Presentation by Prof. Arup Kr Sarma, PI

18.2 Session 2

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

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

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

1. Bathymetric survey was conducted by IIT Guwahati from Tezpur to Guwahati.
2. Flood estimation report of Brahmaputra was prepared by CWC.

3. Morphological study and cross-section of Barak river was carried out.
4. Studies for rivers like Ghagra and Gandak were done previously.
5. CWC carries out cross sectional survey on Brahmaputra at 64 cross sections at an interval of 10 km from Tinsukia to Dhubri each year. Cross sectional survey is also carried out in Subansiri and Pagladiya each year.
6. NESAC has operational flood early warning system for some rivers of Assam.
7. Some pilot studies are going on at university levels.
8. Various organizations such as ISRO/DOS, Gauhati University, IIT Roorkee, Dibrugarh University, Brahmaputra Board are doing some Remote Sensing based studies in some reaches of these rivers.
9. At Rohmoria reach of Brahmaputra River (u/s), change in morphology was studied little bit and also the effect of porcupine screen on river cross section was studied.
10. IIT Guwahati and Brahmaputra Board are involved in the development of a hydrodynamic and morphological numerical model.
11. As a part of a mathematical model study of Brahmaputra, IIT Guwahati in collaboration with Brahmaputra Board has taken up a model study near Majuli.
12. Study of Kaziranga reach was jointly carried out by Brahmaputra Board, SAC Ahmedabad and NRSA.
13. Researchers from Gauhati University and Dibrugarh University are carrying out some academic research on Brahmaputra.
14. A PhD thesis on ‘Bed form morphology, spatio-temporal variability and erosional vulnerability of Brahmaputra river within Assam’ was carried out at Gauhati University.

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

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

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

20. Based on river morphology, anti-erosion schemes are evaluated, whether those schemes were properly designed/executed, the percentage of success/achievements of the schemes can be found.

21. Prioritizing embankment strengthen.

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

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

Q4: Suggestions, if any

Response to Q4:

1. The suggestions provided are as follows:
2. More recent data can be used for predicting the future scenario.
3. More morphological case studies of the rivers mentioned above can be taken up for prediction of erosion and morphological action of river.
4. Incorporation of sand bar and sediment load study.
5. Community awareness programme in educational institutes and departments can be held.
6. For better understanding of the river course/shifting, morpho-tectonic/ tectonic studies can be incorporated as a part of the study.
7. Space technology/high resolution satellite data may be utilized for site specific study.
8. Identification of hotspots for scientific sediment mining.
9. A study on effect of climate change on river morphology can be made.
10. Utilizing flood discharge in hydro power generation.
11. Sediment transport model can be made.
12. Prediction of future cutoffs, ox-bow lakes.
13. Collaboration between different organizations.

14. SOI topo sheet can be used for data before 1950, 1:1 mile scale data is available.
15. The data can be provided in public domain for further research studies.
16. Morphological studies can be conducted using latest technology, eg. Drones.
17. Ground control point maybe established to observe neotectonic activity.
18. Morphological survey is very important by manual method.
19. Presently Mikir Gaon area in Morigaon district is one of the most erosion prone areas along Brahmaputra. Special emphasis in this reach for delineation of bankline, its causes and appropriate approach to be given in the study.
20. Construction of solid spurs in erosion prone reaches often become counterproductive. This is because of river changing its flow direction after erosion and making the spurs attractive which were otherwise constructed as deflecting.
21. Awareness programs can be planned for various departments and technocrats for hydrological study like Arc GIS/working on toposheet.
22. Study of bank materials as well as bed materials and find the relative silting and scouring.
23. To determine the actual course of erosion, specific site wise.
24. Model study before implementation/execution.
25. Use of aerial photography, ultrasonic sound velocity method to find the change in depth of flow after execution of anti-erosion measures.
26. To study the change in morphology, w.r.t. the bed level before 1950 earthquake.
27. Field verification is essential along with remote sensing techniques to validate the findings.
28. River modelling can be done to find out the vulnerable reach along with remote sensing techniques.
29. For modelling purpose, high resolution DEM data can be used to get better results.

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

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

The facilitators of the group discussion

Group 1

Group 2

Group 3


Group 4

Group 5


Group 6

Group 7


Group 8

Group 9

Concluding the GD

Certificate distribution

Chapter 15
MANAGEMENT STRATEGIES

15.1 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

15.2 Immediate short-term measure

- ✓ Removal of bed sediments through dredging may be applied to divert the main flow from hitting the river bank.
- ✓ Model study carried out at Department of Civil Engineering, IIT Guwahati, in 2011 for the Morigaon reach of the Brahmaputra suggested that dredging of sand deposition along with the construction of spurs is an effective measure to push the river away from the bank.

SUMMARY AND CONCLUSIONS

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

- ✓ The drainage map of Pagladiya has been prepared showing all the major tributaries of the river. The major tributaries of the river are Darunga and Matunga.

- ✓ The watershed of Pagladiya is delineated using 90m resolution SRTM DEM. The areas and the perimeters are found to be 639.31 km^2 212.85 km respectively. The watershed delineated and the areas and perimeters are used as input for morphometric analysis. From the morphometric analysis of the Pagladiya catchment, it has been observed that the bifurcation ratio is lowest in the upstream region of the watershed where two tributaries of the Pagladiya river viz. Daranga and Mutanga Rivers flow through.

- ✓ From the morphometric analysis of the Pagladiya catchment, it has been observed that the bifurcation ratio is lowest in the upstream region of the watershed where two tributaries of the Pagladiya river viz. Daranga and Mutanga Rivers flow through. The bifurcation ratio is highest for the stream order 2 which occupies the downstream part. From these differences in the values, it can be inferred that the upstream portion of the Pagladiya watershed should be more prone to flooding as it exhibits a low value of R_b. However actual flooding depends on the status of embankment and many other factors. The drainage density of the catchment is found to be low i.e. 0.249 km/km^2 which infer that the catchment is prone to flash floods in case of intense rainfall and has 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 in nature.

- ✓ From the estimation of LULC change over 1973-74 to 2011-12, it has been observed that there is a decrease in dense forest & agricultural area while there is an increase in the built-up area (Fig.23). Also, the area occupied by the river has been reduced over the years. Further, there is an increase in the sandbar/dry riverbed area as well as area under water bodies/marshy land. From this analysis, it can be inferred that the increase in the built-up area in the downstream portion and reduction of forest cover in the upper catchment of Pagladiya have resulted in siltation in the river. This siltation has further triggered the northward shifting of the confluence point of Pagladiya and Brahmaputra. The landuse change indicates that agriculture and forest lands are converted to build up areas. This will increase the flow in the river. As such, a detailed study on such flow scenarios can be carried out by hydrological modelling and river flow simulation.

- ✓ The banklines has been digitized manually for all the years viz. 1973-74, 1976-80, 1993-95, 2003-04, and 2008-11. The digitized banklines are then used in channel evolution process, bankline shifting, channel dimension, planform index *etc.*
- ✓ Channel Evolution study indicated the changes in the river channel over the time. As per the latest imagery, the river at the upstream is found to be constricted as compared to the previous year's datasets. In some of the reaches, it has been observed that some of the meander has straightened in due course of time.
- ✓ The longitudinal profile of Pagladiya River has been plotted taking section at 10 km interval. From the plot of longitudinal profile of Pagladiya River, it can be observed that the elevation at the Bhutan foothill is around 652 ft. Gradually, on entering Assam, the elevation get reduces and finally reached to 45 ft above MSL at the confluence point with the Brahmaputra river.
- ✓ The confluence point of the river with the Brahmaputra has been identified as the vulnerable reach of main stem Pagladiya. A shift of 4.6 km shift has been observed.

- ✓ From the computation of sinuosity, it can be seen that though the river is changing its course in some years, the sinousity value within a reach is remaining more or less same from the base year 1973-74 till 2008-11. No major change has been seen as it is taking the similar path. It can be observed that Reach 5 and 9 have high sinuosity indices for all the datasets. In these reaches, the topographic sinuosity index is more predominate than hydraulic sinuosity index. Reach 3, 4, 8 have higher channel index which means significant deviation can be observed from its straight course.
- ✓ The quantification of erosion-deposition analysis of Pagladiya River is not feasible as significant shifting in the river course has been observed in many reaches. Decadal bankline shifting has been calculated for both the banks. For finer study, section lines are taken at 2 km intervals from the foothill of Bhutan in Assam border to the confluence point of the river with Brahmaputra. This study reveals that the average maximum shifting of the river is taking place in eastward direction.
- ✓ The meandering parameters like meander lengths, meander widths, bankfull widths and meander width ratios are calculated. Maximum meandering length of 4 km has been observed in the year 2003-04 and minimum length of 0.54 km observed in 1973-74. The maximum meandering width of 2.31 km in 2003-04 at reach 6 and minimum of 0.34 km has been observed at reach 7 in 1976-80. The maximum bankfull width have been observed as 437.82m at reach 4 in 2003-04 whereas minimum bankfull width has been observed as 92.8 m at reach 9.
- ✓ The Planform Index (PFI) has been calculated. It can be seen that the river is low braided as the PFI values are greater than 19. However, from 1993-95 onwards, the values of PFIs of reach 1 are lower than 19 which show that the reach is moderately braided. This shows that the upper region of Pagladiya River when it enters the plain of Assam is moderately braided.
- ✓ There are no major hydraulic structures present in the basin. Although presence of bridges may have some impact. There are 7 bridges along the main stem Pagladiya including railway bridges. The span of the bridges is sufficient within the waterway. As such, no major downstream impact of flow has been be observed.

- ✓ Flood Inundation map between 1999 and 2010 of Brahmaputra Basin in Assam has been downloaded from BHUVAN website. The rivers of 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 SOI Toposheets used in the project

Sl. No.	Toposheet No.	Year	Scale
1	78N/2	1973-74	1:50000
2	78N/3	1973-74	1:50000
3	78N/4	1973-74	1:50000
4	78N/6	1973-74	1:50000
5	78N/7	1973-74	1:50000
6	78N/8	1973-74	1:50000
7	78N/10	1973-74	1:50000
8	78N/11	1973-74	1:50000
9	78N/12	1973-74	1:50000
10	78n/14	1973-74	1:50000
11	78N/15	1973-74	1:50000
12	78N/16	1973-74	1:50000

Table 9:List of Satellite Data used in the project:

Sl. No.	**Satellite**	**Sensor**	**Path**	**Row**	**Date of acquisition**
1.	Landsat 2	MSS	147	041	1977-02-08
2.			147	042	1977-02-08
3.	IRS 1B	LISS 1	16	049	1994-11-20
4.	IRS P6	LISS3	110	052	2004-05-03
5.			110	053	2004-05-03
6	Resourcesat -1	LISS3	110	053	2008-12-08
7			110	053	2009-11-09
8			110	053	2009-11-09
9			110	053	2009-11-09

ANNEXURE II

Table 10: Hydrological data for Pagladiya River collected from CWC

Sl No.	Pagladiya River stations	Type of data	Frequency	Period of data
1.	N.T. Road Crossing	Gauge	Daily	Jan 1998 to May 2015
2.	Matunga	Gauge	Daily	May 2000 to May 2015

ANNEXURE III

Table 11: PFI calculated at the corresponding reach lines for the year 1973-1974

Reach No.	PFI	Threshold Indicator
1	38.52	Low Braided
2	25.75	Low Braided
3	46.32	Low Braided
4	42.01	Low Braided
5	24.86	Low Braided
6	53.65	Low Braided
7	55.17	Low Braided
8	39.60	Low Braided
9	49.18	Low Braided
10	29.06	Low Braided

Table 12: PFI calculated at the corresponding reach lines for the year 1976-1981

Reach No.	PFI	Threshold Indicator
1	57.178	Low Braided
2	32.028	Low Braided
3	47.692	Low Braided
4	47.847	Low Braided
5	39.106	Low Braided
6	51.471	Low Braided
7	66.820	Low Braided
8	54.167	Low Braided
9	62.195	Low Braided
10	29.070	Low Braided

Table 13:PFI calculated at the corresponding reach lines for the year 1993-1995

Reach No.	PFI	Threshold Indicator
1	14.71	Moderately Braided
2	23.10	Low Braided
3	47.82	Low Braided
4	54.16	Low Braided
5	57.22	Low Braided
6	81.30	Low Braided
7	59.90	Low Braided
8	56.87	Low Braided
9	48.97	Low Braided
10	66.11	Low Braided

Table 14:PFI calculated at the corresponding reach lines for the year 2003-2004

Reach No.	PFI	Threshold Indicator
1	9.19	Moderately Braided
2	10.60	Moderately Braided
3	23.99	Low Braided
4	17.38	Moderately Braided
5	31.41	Low Braided
6	31.18	Low Braided
7	59.05	Low Braided
8	24.00	Low Braided
9	36.27	Low Braided

Table 15:PFI calculated at the corresponding reach lines for the year 2008-2011

Reach No.	PFI	Threshold Indicator
1	8.30	Moderately Braided
2	6.02	Moderately Braided
3	12.29	Moderately Braided
4	43.30	Low Braided
5	44.12	Low Braided
6	32.11	Low Braided
7	47.12	Low Braided
8	38.39	Low Braided
9	62.88	Low Braided

ANNEXURE IV

Table 16:Sinousity Indices of Year 1973-1974

Reach	CL	VL	Air	CI	VI	HSI(%)	TSI(%)	SSI
2	10.08	10	9.463	1.07	1.06	12.97	87.03	1.01
3	10.64	10	6.7	1.59	1.49	16.24	83.76	1.06
4	10.08	10	6.4	1.58	1.56	2.17	97.83	1.01
5	11.01	10	6.85	1.61	1.46	24.28	75.72	1.10
6	10.66	10	6.87	1.55	1.46	17.41	82.59	1.07
7	10.51	10	6.47	1.62	1.55	12.62	87.38	1.05
8	10.35	10	6.39	1.62	1.56	8.84	91.16	1.04
9	11.01	10	6.4	1.72	1.56	21.91	78.09	1.10
10	10.5	10	6.15	1.71	1.63	11.49	88.51	1.05

Table 17:Sinousity Indices of Year 1976-1980

Reach No.	CL	VL	Air	CI	VI	HSI(%)	TSI(%)	SSI
1	10.5	10	9.77	1.07	1.02	68.49	31.51	1.05
2	10.25	10	9.37	1.09	1.07	28.41	71.59	1.03
3	10.41	10	6.31	1.65	1.58	10.00	90.00	1.04
4	10.3	10	6.5	1.58	1.54	7.89	92.11	1.03
5	11.3	10	7.12	1.59	1.40	31.10	68.90	1.13
6	10.62	10	6.03	1.76	1.66	13.51	86.49	1.06
7	10.7	10	6.28	1.70	1.59	15.84	84.16	1.07
8	10.22	10	6.01	1.70	1.66	5.23	94.77	1.02
9	10.97	10	5.9	1.86	1.69	19.13	80.87	1.10
10	8.6	7.6	4.8	1.79	1.58	26.32	73.68	1.13

Table 18:Sinousity Indices of Year 1993-1995

Reach No.	CL	VL	Air	CI	VI	HSI(%)	TSI(%)	SSI
1	10.1	10	9.74	1.04	1.03	27.78	72.22	1.01
2	10.12	10	9.39	1.08	1.06	16.44	83.56	1.01
3	10.02	10	7.23	1.39	1.38	0.72	99.28	1.002
4	10.32	10	6.8	1.52	1.47	9.09	90.91	1.03
5	11.05	10	6.4	1.73	1.56	22.58	77.42	1.11
6	10.53	10	7.3	1.44	1.37	16.41	83.59	1.05
7	10.61	10	7.65	1.39	1.31	20.61	79.39	1.06
8	10.31	10	6.29	1.64	1.59	7.71	92.29	1.03
9	10.99	10	6.3	1.74	1.59	21.11	78.89	1.10
10	10.2	10	6.2	1.65	1.61	5	95	1.02

Table 19:Sinousity Indices of Year 2003-2004

Reach No.	CL	VL	Air	CI	VI	HSI(%)	TSI(%)	SSI
1	10.15	10	9.58	1.06	1.04	26.32	73.68	1.02
2	10.23	10	9.46	1.08	1.06	29.87	70.13	1.02
3	10.19	10	6.35	1.60	1.57	4.95	95.05	1.02
4	10.39	10	6.7	1.55	1.49	10.57	89.43	1.04
5	11.02	10	6.4	1.72	1.56	22.08	77.92	1.10
6	10.54	10	6.58	1.60	1.52	13.64	86.36	1.05
7	10.45	10	6.33	1.65	1.58	10.92	89.08	1.05
8	10.25	10	5.49	1.87	1.82	5.25	94.75	1.03
9	11	10	6.19	1.78	1.62	20.79	79.21	1.10
10	7.38	7.17	4.92	1.5	1.46	8.54	91.46	1.03

Table 20:Sinousity Indices of Year 2008-2011

Reach No.	CL	VL	Air	CI	VI	HSI(%)	TSI(%)	SSI
1	10.4	10	9.7	1.07	1.03	57.14	42.86	1.04
2	10.32	10	9.37	1.10	1.07	33.68	66.32	1.03
3	10.22	10	6.47	1.58	1.55	5.87	94.13	1.02
4	10.47	10	6.1	1.72	1.64	10.76	89.24	1.05
5	11.04	10	6.44	1.71	1.55	22.61	77.39	1.10
6	10.52	10	6.25	1.68	1.60	12.18	87.82	1.05
7	10.66	10	6.34	1.68	1.58	15.28	84.72	1.07
8	10.19	10	5.5	1.85	1.82	4.05	95.95	1.02
9	11.05	10	6.39	1.73	1.56	22.53	77.47	1.11
10	5.19	5.05	4.53	1.15	1.11	21.21	78.79	1.03

ANNEXURE V

Table 21: Percentage probability of stage at NT Road Crossing Site, Pagladiya river

Daily W/L(m) (col. 1)	**No. of days in each class interval (col. 2)**											**Total no. of days (col. 3)**	**Cumulative total (col. 4)**	**Pp (%) (col. 5)**
	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015			
6.5- 6	1	0	0	0	0	0	0	0	0	0	0	1	1	0.024882
6 - 5.5	1	2	0	1	0	0	0	0	0	0	0	4	5	0.124409
5.5- 5	2	0	1	4	2	0	0	0	2	0	0	11	16	0.398109
5 - 4.5	3	2	1	2	6	1	0	0	3	0	1	19	35	0.870863
4.5- 4	9	11	5	8	9	2	3	0	7	2	0	56	91	2.264245
4 - 3.5	15	43	14	35	36	32	40	8	16	2	10	251	342	8.509579
3.5- 3	53	114	57	142	144	115	142	66	59	9	52	953	1295	32.22195
3 - 2.5	155	138	287	173	169	215	180	267	142	246	175	2147	3442	85.64319
2.5- 2	127	55	0	0	0	0	0	24	137	106	127	576	4018	99.97512

ANNEXURE VI

Table 22:Percentage probability of mean daily discharge at NT Road Crossing Site, Pagladiya river

Daily mean discharge (cumecs)	No. of days in each class interval							Total no. of days	Cumulative total	Pp
	1998	1999	2000	2001	2002	2003	2004			
873-940	0	0	0	0	0	0	1	1	1	0.039108
806-873	0	0	0	0	0	0	0	0	1	0.039108
739-806	0	0	0	0	0	0	0	0	1	0.039108
672-739	0	0	0	0	0	0	0	0	1	0.039108
605-672	0	0	0	0	0	0	0	0	1	0.039108
538-605	0	0	0	0	0	0	0	0	1	0.039108
471-538	0	0	1	0	1	0	0	2	3	0.117325
404-471	1	0	1	0	2	0	0	4	7	0.273758
337-404	0	0	0	0	0	0	2	2	9	0.351975
270-337	0	0	1	0	1	0	2	4	13	0.508408
203-270	2	2	0	1	0	1	0	6	19	0.743058
136-203	7	4	2	2	5	2	4	26	45	1.759875
69-136	38	48	24	32	20	25	16	203	248	9.698866
2-69	317	311	337	330	336	337	340	2308	2556	99.96089

ANNEXURE VII

DISSEMINATION WORSHOP ON

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

3rd MAY, 2019, IIT GUWAHATI

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53	Dept. of Civil Engg. IIT Ghy	Gaurav Talukdar	PhD	gaurav t@ iitg.ac.in	84729 79101	
54.	Dept of Civil Engg IIT Ghy	Amit Kalita	JRF	amit_kalita@ iitg.ac.in	863818 2995	Amit
55.	Dept. of Civil Engg, IIT Ghy.	KHYATI MANJURI CHAUDHURY	Asstt Project Engineer.	khyati@iitg.ac.in	9401380409	Khyati
56.	Dept. of Civil Engg, IIT Ghy	Dipsikha Devi	PhD Scholar	ddevi@iitg.ac.in	9864561841	Dipsikha
57.	Dept of Civil Engg, IIT Ghy	BHASWATEE BAISHYA		bhaswatee11@iitg.ac.in	9706783935	
58.	"	APOORVA SINGH	MTECH	singh174104117@iitg.ac.in	99845 99091	

Annexure VIII

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
10		
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Figure 94: 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:	
10		
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12		
13		
14		

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

Name: Adarsh Shukla

Organisation: Central Water Commission

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

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

Name: Gilbert Hinge

Organisation: IIT Guwahati

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

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

Name: Ashutosh Sharma

Organisation: IIT Guwahati

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

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

Name: Ayush Garg

Organisation: Central Water Commission

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

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

Name: SONU RAJAK

Organisation: CWC.

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

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

Name: VSD PRAKASH

Organisation: C.W.C.

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

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

Name: Pranjal Pratim Sharma

Organisation: Assistant Executive Engineer, Irrigation.

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

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

Name: Dr. Juran Ali Ahmed

Organisation: W R Deptt. Assam,

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

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

Name: Karuna Dutta

Organisation: Irrigation

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

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

Name: Maneesh Kumar Gupta

Organisation: CWC

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

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

Name: Ravi Shankar Singh, JE

Organisation: HDC, 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
10		
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12		
13		
14		

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
10		
11		
12		
13		
14		

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:	
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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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12		
13		
14		

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

Name: Kankana Narayan Das

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
11		
12		
13		
14		

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		
11		
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13		
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3/5

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

Name: Parismita Saikia

Organisation: Gauhati University

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

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
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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
11		
12		
13		
14		

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

Name: Ajay Kumar Sinha

Organisation: CWC

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

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:	
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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

Name: ATUL SARMA

Organisation: Brahmaputra Board

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

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

Name: Dr. Ratanali 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:	
10		
11		
12		
13		
14		

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
10		
11		
12		
13		
14		

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

Name: Subhankar Das

Organisation: C.W.C.

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

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

Name: AKASH BHARADWAJ

Organisation: C.W.C

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

ANNEXURE IX

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

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

Group No: 1

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

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

~~No~~. yes.
~~First Experience~~.
1. Bathymetric survey from Gty to Tezpur
2. flood Estimation report (Brahmaputra Sub zone 2(b)
3. morphological study & cross-section of Barak River & its ~~tributary~~

2. How result of this study can help different organizations

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

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

Yes.

For example-

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

4. Suggestions, if any

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

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

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

Group No: 2

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

We are not aware of such study done earlier.

2. How result of this study can help different organizations

* The Present Study has been done taking SRTM 90m resolution Data as well as satellite data.
* The various data collected through morphology survey help railway Dept, PWD Dept etc, flood control.
* It also help Irrigation Dept in study & Implementation of micro-macro projects.
* The present study also helps dept. like Inland Navigation

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

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

4. Suggestions, if any

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

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

GRoup 3.

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

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

Group No: 3.

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

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

→ c/s data
- studies by Brahmaputra Board

2. How result of this study can help different organizations

- State Govt, Central Govt.
- local authorities

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

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

Yes, it may be recommended for

1) Godavari

2) Jhelum.

3) Barak

4)

4. Suggestions, if any

(a) Identification of hotspots for scientific sediment mining.

(b) Effect of CC on River Morphology.

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

(d) Future cut-offs

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

(f) Sediment Transport Model

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

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

Group No: 4

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

Yes,
① CWC is doing morphological study on Brahmaputra river from Dhubri to Sadiya at 62 no. of cross section and also Subansiri & Pagladia every year.
② NESAC has operational flood early warning system for the state of Assam
③ many pilot study at University levels.

2. How result of this study can help different organizations

① Flood management. – Water Resource department
② It can serve as sedimate geospatial data base for related studies.
③ Water assessment of the river.
④ Helpful in inland water transportation, construction of bridges, planning of hydropower plant, disaster management.
⑤ Protection measures like river island, embankments can be improved.
⑥ Identification of the most likely eroded areas & premanagement & planning against further erosion by State Government.
⑦ To understand river meandering process.

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

Yes

Lohit, Beki, Jiabharali, Kolong, Kopili

4. Suggestions, if any

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

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

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

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

(5) SRTM 10m resolution is also freely available that can be 90m effectively ~~used~~ utilize in the present study

Group-5

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

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

Group No:

Sl. No	Name	Department/ Organization	Signature
1	Rekhraj Meena	CWC	[signature]
2	Dr. Ratamali Machahary	Applied Geology, Dibrugarh University	[signature]
3	Adarsh Shukla	CWC	[signature]
4	Porismita Saikia	Gauhati University	[signature]
5	Apoorva Singh	IIT Guwahati	[signature]
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

YES →

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

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

*

2. How result of this study can help different organizations

→ Academic based data for further studies.

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

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

* Have done morphological survey along Brahmaputra from Neamatighat to Dibrugarh. ~~[illegible]~~ [illegible] CWC.

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

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

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

4. Suggestions, if any

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

→ Provide data in public domain for further research studies.

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

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

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

Group No: 6

Sl. No	Name	Department/ Organization	Signature
1	UTPAL SARMA	ARSAC / ASTEC	Utpa
2	KUNTALA BHUSAN	NESAC, UMIAM	[signature]
3	RANJIT DEKA	BRAMAPUTRA BOARD	[signature]
4	SUNIL VERMA	CWC	Sunil
5	Ravi Shanker Singh	CWC	Rsingh
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1. Are you aware of such study done elsewhere for these rivers: If any, please provide information

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

2. How result of this study can help different organizations

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

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

YES

All tributaries of the Brahmaputra.

4. Suggestions, if any

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

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

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

Group No: 07

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

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

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

10 km interval — 32 sec^n — 62 sec^n UBD

2. How result of this study can help different organizations

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

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

1. Jia Bharali – flood prone

2. Beki –

3. Aie –

4. Suggestions, if any

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

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

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

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

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

Group No: 8

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

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

2. How result of this study can help different organizations

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

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

- Jiabharali
- Burhidihing & Dishoo
- Dhanshiri river.

4. Suggestions, if any

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

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

3) Model study before implementation/execution.

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

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

(G-9)

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

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

Group No:

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

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

2. How result of this study can help different organizations

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

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

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

Yes, this type of study can also be implemented in some other rivers like Beki, ~~Pagladiya~~ Manas, etc. Dibru river, Jia Bharali.

4. Suggestions, if any

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

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

For modelling purpose high resolution DEM ~~can~~ will give better result.

Sense of belongingness of the area is necessary

Study to see the relation betn morphological changes and seismic activity