REMOTE SENSING BASED STUDY OF RIVER AVULSION OF BRAHMAPUTRA NEAR DIBRUGARH

A DISSERTATION

Submitted in partial fulfillment of the
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled: **"Remote Sensing based study of River Avulsion of Brahmaputra near Dibrugarh"** in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Water Resources Development, submitted in Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2006 to June 2007, under the supervision and guidance of Dr. Nayan Sharma.

The matter embodied in this Dissertation has not been submitted by me for the award of any other degree.

Date : June 29 , 2007.

Place : Roorkee

(Ajay Kumar)

Certified that the above declaration given by the candidate is correct to the best of my knowledge.

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ABSTRACT

The Brahmaputra River is known for tremendous morphological changes over the years. The huge sediment load of the Brahmaputra River is mainly responsible for its changing morphology. In the past various studies have been conducted to understand the morphological changes like meandering, braiding etc. of the Brahmaputra River. But no or little attention has been given to the avulsion phenomenon. Therefore, in the present study avulsion of the Lohit and Dibang Rivers, tributaries of the Brahmaputra River, has been emphasized. The multi-temporal satellite data for the years 1990, 1997, 2000 and 2002 of IRS 1A, LISS I and IRS 1C/1D, LISS III has been used for the observation of morphological changes. The avulsion of these rivers had taken place on upstream of Dibru-Saikhowa Reserve Forest, near Dholla Township in Tinsukia district of Assam. It has been observed from the study that during the 7 years (1995 to 2002) almost entire discharge of Lohit and Dibang River has transferred to the Dibru River through Dangori River, a tributary of the Dibru River. From the results it is indicated that the width of avulsed channel increased upto 2 to 3 times in a period of 5 years. The Dibru-Saikhowa Reserve Forest has lost its appreciable area in a period of only 5 years doe to the erosion along the banks, at the mouth and confluence of the avulsed channel with the main Brahmaputra River.

Various river training measures have been taken by Govt. of Assam to tackle this serious problem of avulsion. After observing the scenario after the

implementation of the river training works it has been found that RCC porcupines have been proved very effective in diverting the flow of Dibang and Lohit River to their original courses.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Rivers are the natural channels which carry a sufficient quantity of water drained by the catchment as run-off. They take off from mountains, flow through plains and finally join the sea or ocean. The discharge in a river increases as it flows from the mountain to the because of increase in the catchment area and various streams and tributaries join It.

Rivers have been playing an important role in the development of the early civilizations because these rivers provide water for various purposes such as drinking, irrigation, navigation etc. Rivers are not just the channels of water but these are the life lines of the habitations developed along side of the river banks.

In addition of water, the rivers also carry sediments or silt which is washed down from the catchment area and also eroded from the bed and banks of the rivers. The amount of sediments in a river depends upon the topography and geology of its catchment. The sediments or silt play an important role in the behaviour of the rivers in the alluvial soils. Alluvial rivers, whose bed and banks are composed of sediment being transported by the river, are generally divided into three major types based on planform. These are straight, meandering, and braided, with other subsets continuously evolving. Of these the meandering pattern is the most common. Because these dynamic streams migrate laterally across their floodplains, features such as avulsions, cut-offs, and oxbow lakes frequently develop. Channel migration can occur gradually, as a river erodes one bank and deposits sediment along the other or it may occur during a single flood event as an abrupt shift of the channel to a new location. Avulsion is also responsible for the migration of a river. Avulsion may be defined as the sudden removal of land from one parcel to another, when a body of water such as river, stream etc. abruptly changes its channel. Channel avulsion is a common and widespread phenomenon and many examples have been reported in the literature from diverse locations. The Mississippi River in the USA (Smith et. al. 1997), Thomson River in Australia (Brizga and Finlayson 1990), Okavango River, South Africa, Yellow River in China (Zhao-Yinwang et. Al. 2003) and in India rivers of the Northern Gangetic Plain such as Kosi (Wells and Dorr 1987), Gandak (Sinha and Friend 1994) and Brahmaputra River in north east India (Sarma 2005) are well known for frequent channel shifts due to avulsion.

1.2 AVULSION IN BRAHMAPUTRA RIVER

The river Brahmaputra is one of the biggest rivers in the world. The Brahmaputra River characterized by high seasonal variability in flow and heavy sediment load transported by it. Avulsion is the inevitable result of the river aggradations due to deposition of the sediments. The Brahmaputra River showed formation of new channels as a result of avulsion. Majuli, the largest river island, formed as a result of diversion of the Brahmaputra River in 1750. Avulsion caused the straightening of the Brahmaputra River from Pandu to Hazo around 1532. Also, in 1995 an important change has been noticed in the present course of Lohit in the west of Saikhowaghat.

The rivers Dihang, Dibang and Lohit join near Kobo, 5 Km. downstream of the Pasighat town, and thereafter the river is known as the Brahmaputra River. The entire reach of the Brahmaputra River from Pasighat to Dhubri in Assam comprises of alluvial soil. During high floods, the river spills over the banks, in various reaches, inundating the vast area comprising of cultivable and homestead land. Except at few places the river is braided and unstable in its entire reach. The instability of the river is because of the high sediment load, steep slope and transverse land gradient. Also, the entire area is located in a highly seismic zone and periodically receives earthquake shocks from moderate to severe intensity. This factor also contributes to the unstable character of the river.

The combined flow of the Dibang and Lohit Rivers was originally falling into the Dihang River at about 25 Km. down stream of Saikhowa Reserve forest. From 1995, as a result of avulsion 90% of the discharge from Dibang and Lohit Rivers travels through Dibru River and falls into Brahmaputra at North Balijan instead at Kobo. As a result extreme dangerous situation has threatened the agricultural land and paddy fields of the poor farmers and tea gardens in the districts of Tinsukia and Dibrugarh. Thousands of hectares of rich cultivable land of 49 villages have already been eroded away. An approximate 48,000 people of the area are facing very serious situation due to heavy erosion of the agricultural and homestead land. The areas threatened by erosion have hospitals, schools, public and private institutions. Thousands of labour and staff will become jobless if the tea-gardens of the above areas area eroded away by the avulsion of the

Lohit and Dibang Rivers. If timely measures are not taken, the avulsion of the Lohit and Dibang River will erode away tea gardens tend to unemployment for thousand of labour and staff.

For tackling this serious problem of avulsion, the Government of Assam prepared the schemes of implementation of river training works for diverting the flow from Lohit and Dibang River to their original courses. The Flood Control Department of Assam has also requested the advice of CWC and CWPRS, Pune to tackle this serious problem of avulsion.

1.3 ROLE OF REMOTE SENSING

Remote Sensing (RS) and Geographical Information System (GIS) play a rapidly increasing role in the field of river engineering. The remote sensing data provides synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum. The space borne multi-spectral data enable generating timely, reliable and cost effective information on various natural resources, namely surface water, land-use and land-cover, soil and environmental hazards. Conventional measurements of plan form characteristics of alluvial rivers are a time consuming, laborious and expensive procedure. Their main disadvantage is that they provide information only at a particular point and instant of time. On the other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. This is one of the greatest advantages of using RS data for hydrological modelling and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. However, the use of RS technology involves huge amount of spatial and temporal database management, and requires an efficient system to handle the database. The GIS technology provides suitable alternatives for efficient management of large and complex databases.

Changes in the river channel alignment and size, development of bars, islands take place during floods, time dependant changes can be monitored in the specific river reach using remote sensing and GIS. Depending on the resolution of the imageries, accurate and dependable predictions can be made covering long reaches. The change detection monitoring (CDM) of the river channel includes the aspects namely location, size and alignment. For rivers with multiple channel system or braided rivers, these could be the important aspects resulting in bank erosion. CDM can also be important for planning and management for the development of inland navigation system, locating riverine ports and other structures, design of anti-erosion works, etc. Which are generally affected by the development of islands, bars in the channel, changes in the orientation of channel, avulsion etc. Thus, monitoring of temporal changes in the river channel with the help of satellite imageries would highlight on these aspects.

With the advancement in RS & processing technique, it is possible to deduce other information, about existence of paleo-channels, low lying areas, reaches under active erosion, damages due to over bank flows, breaches in the embankments and damages to the existing hydraulics structures. In spite of the fact that normally the changes in a braided channel are sudden and unpredictable, efforts have been made from time to time with the help of satellite imageries for identification of any cyclic behaviour observed in the past. Efforts are also made to identify physical limits of such changes, if any, observed earlier. About river studies co-relating these observations with other information can give fairly good idea of the river behaviour in a specific reach and likely behaviour in the immediate future.

In the present study, avulsion of river Brahmaputra near Dibrugarh has been studied. Until 1995, the Lohit and Dibang Rivers were joining the river Dihang near Kobo to form Brahmaputra River. In the year 1995, an avulsion near Saikhowaghat forced part of the flow of the river Lohit to join the river Dangori. This flow joined the Dibru and through it joined the Brahmaputra River at the mouth of the Dibru River near Balijan.

1.4 OBJECTIVES OF THE STUDY

Keeping in view the above problem of avulsion of Lohit and Dibang River in mind, the objective of the present work is to study the morphological changes in combine flow of Lohit and Dibang River during the period 1997-2002. Satellite imageries of the study area are available for year 1990, 1997, 2000 and 2002. So river morphology for these years has been compared among themselves to observe the changes.

Considering the importance of the river training works needed for diverting the flow of Lohit and Dibang River to their original course, the morphological changes at the mouth of the avulsed channel have been studied by using the satellite imageries for the given years. The morphological changes along the avulsed channel have also been observed after the river training works installed by various agencies to tackle this serious problem of avulsion.

The main objectives of the study are enumerated as follows:

1) Change detection of river morphology of channel formed due to avulsion with the help of satellite data.

2) To analyse the present scenario after the implementation of river training works.

1.5 ORGANIZATION OF THESIS

The chapters are organised in the following way:

Chapter 1: Description of introductory aspects of the topic studied, underlying objectives and the layout of the thesis

Chapter 2: Presentation of a comprehensive review of literature

Chapter 3: Description of the study area and data collection

Chapter 4: Description of the methodology adopted

Chapter 5: Presentation of the Results and discussions

Chapter 6: Presentation of conclusion and scope of future work

CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

Avulsion can be defined as the abandonment of one channel and development of another in a new location on the flood plain, as contrasted with migration of channels by progressive bank erosion on the outside of bends and deposition on the inside of the bends. Allen (1965) defined avulsion as the abandonment of a part or the whole of a channel belt by a stream in favour of a new course.

Avulsion causes a meander or entire segments of rivers to become abandoned and new ones to form. Also, avulsions are important in the development of floodplains and may be accompanied by a transformation in channel pattern and are difficult to predict. Avulsion formation leads to various problems encountered in the field of water resources and river engineering. When avulsion takes place a new channel formed below the point of avulsion. If the channel avulses into an existing, smaller channel, then there will be a large increase in discharge and sediment load, and the bridges downstream of this channel will be inadequate and presumably destroyed. A bridge on the abandoned channel below the site of avulsion will appear to be significantly over designed. If, through avulsion, the river takes a shorter course to the sea, the gradient will become steeper, and scour above the point of avulsion is certain unless a bedrock control prevents upstream degradation. A bridge located above the point of avulsion will still span the channel, but it may be subjected to degradation and nick point migration. This is the only one example many other problem relating to the variation in the discharge and change in the direction of flow can occurred in various projects and structure constructed on the abandoned channel. Also, the diversion of flow from main channel into the new channel with less capacity will lead to the erosion of useful land, flooding etc. of the adjoining area along the new channel.

Various researchers classified avulsion differently on the basis of their studies.

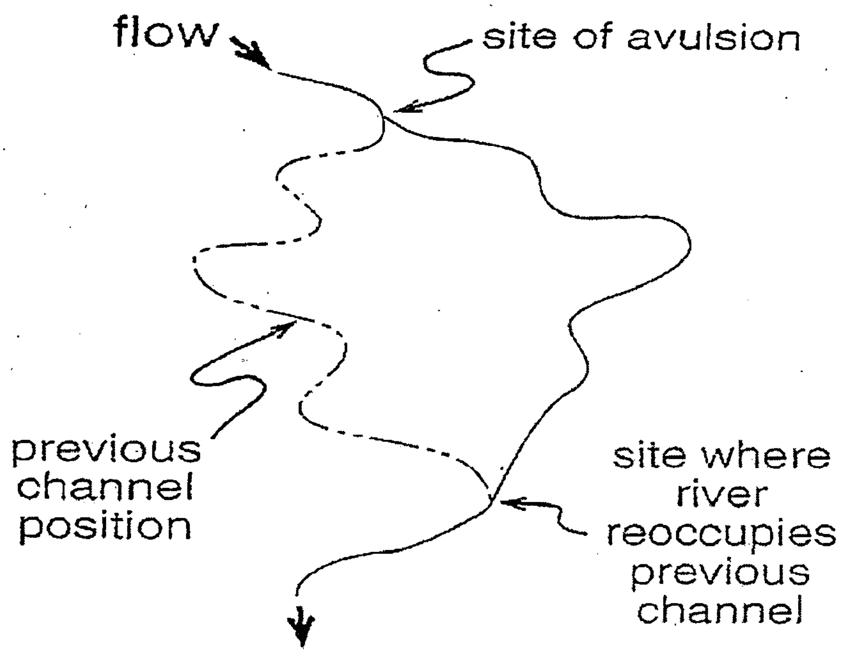
Leeder (1978) classified the avulsion on the basis of the location of the occurrence of the avulsion as follows:

> ***A. Nodal Avulsion:*** If over time more than two avulsions occur at approximately the same location, then this is called a nodal avulsion.
>
> ***B. Random avulsions*** can occur at any point along an active channel belt.

Heller and Chris (1996) classified the avulsion on the basis of the downstream distance the river remains outside its previous course after it leaves the channel as follows:

> ***A. Local Avulsion:*** Where an avulsion occurs in one part of a river system, but after a short distance downstream of the avulsion river rejoins its old channel.
>
> ***B. Regional Avulsion:*** Where any avulsion upstream affects the location of the channel belt everywhere downstream.

A. LOCAL AVULSION



B. REGIONAL AVULSION

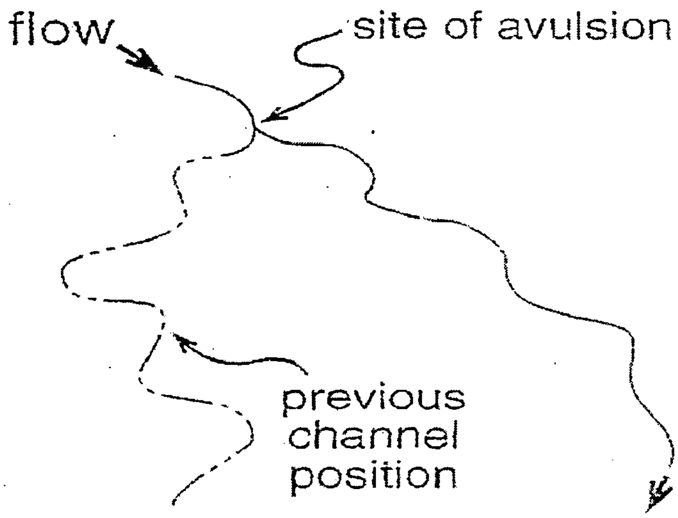


Figure 2.1: Types of Avulsion, A. Local Avulsion, B. Regional Avulsion

2.2 FACTORS AFFECTING AVULSION

Morphological behaviour of a river depends on an interactive process between flow and soil. The condition of flow and properties of soil are major factors affecting morphology of a river. Any factors that affect flow condition and soil properties affect avulsion as a result for being a part of the river morphology. A lot of investigation and research have been done to identify influential factors. A relatively complete list of these factors is as follows:

- Soil properties (soil erosion function)
- Flow condition (discharge, velocity, water depth)
- Meander geometry (width, depth, radius of curvature, sinuosity)
- Stream pattern (straight, meandering, braided)
- Free surface slope
- Channel roughness (Manning's "n", friction factor "f")
- Sediment load
- Vegetation
- Debris Problem
- Channel relocation
- Human activities on the floodplain of river

2.3 CAUSES OF AVULSION

High intensity rainfalls, distinct rainfall seasonality, highly erodable soil, increase in the population leading to sparse vegetation cover due to increased deforestation and irrational land use practices have aggravated the environmental degradation in the catchment areas in different parts of the world. Man's interference has also been responsible for altering the natural processes. As a consequence of the increased deterioration of the environment of the catchment, there has been a sharp rise in the amount of sediment load being transferred to and deposited in the channels, with no appreciable change in the discharge of the rivers, resulting in the silting up of the rivers. Channel aggradations causes reduction of the channel gradient and reduced water carrying capacity of the channel, hence reduction in the velocity and sediment transporting capacity of the stream, which further enhances the silting up of the channel. The above sequence of events results in the abandonment of the existing course by the stream to seek a new course where it would get a greater hydraulic advantage. The stream initially becomes quite stable in its new path, as it is flowing along a topographically low area. However, with time the process of aggradations will proceed along this route also, making it vulnerable to avulsion. Eventually it will become a topographic high and a new avulsion will become progressively more likely. These alternate periods of stability and instability may last from a few tens of years to a few hundred years. The location and timing of avulsions are highly unpredictable.

Avulsions are the inevitable result of river aggradations and are therefore closely related to the sediment load that a stream carries. Avulsions are frequent events, and characteristic recurrence intervals in natural rivers are ten to thousands of years, although this interval may depend upon sedimentation rate.

The study of avulsion can be best done by direct observation, Field (2001) studied channel avulsion on alluvial fans in southern Arizona and found that channel avulsions invariably occur where the bank heights are low and also often where the channel bends. The action of the aggrading floods has been found to be critical in the avulsion process, since the greatest amount of overland flow is generated where bank heights are lowest. On the basis of the observation made by various researchers occurrence of avulsion depends upon following factors:

1. The amount of sediment transport partitioning at the bifurcation.
2. The ability of bifurcated channels to change their capacities.
3. Superelevation of the channel or the channel belt above the floodplain.
4. The associated increase in cross-valley slope relative to either the down-channel or the down-valley slope.

2.3.1 The amount of sediment transport partitioning at the bifurcation:

Any given configuration of bifurcated channels is stable as long as the sediment moving through the upstream trunk channel is partitioned between the two bifurcated downstream channels in exact proportion to their sediment-carrying capacities. If it is not, then both the channels adjust themselves by changing their discharges, slopes and/or cross sections, and consequently changing their discharge carrying capacities. The process of adjustments and modifications to the bifurcated downstream channels will proceed until either their discharge carrying capacities equal their sediment loads, at which time the channel system will be stable i.e. achieved equilibrium, or until one channel closes completely.

2.3.2 The ability of bifurcated channels to change their capacities:

The ability of channels to change their capacities is determined by stream power and cohesion of banks. Low stream power results in inability of the system to erode its banks sufficiently to create space for lateral storage of the surplus of bed load in bars. Therefore the material is stored on the channel beds which are aggrading. Bed aggradations limits channel flow and sediment transport capacity and leads to the formation of new channels onto the flood plain. This process played an important role in the Columbia River (Canada) and the abandoned Schoonrewoerd channel belt (The Netherlands).

2.3.3 Superelevation of the channel or the channel belt above the floodplain:

Alluvial rivers carry a large amount of sediments during floods or otherwise depending upon the topography and geology of the catchment. It is a well known fact that every stream has a certain sediment transport capacity, sediments more than this amount settles on the stream bed and sediments less than this amount compensated by the erosion of stream bed and banks. River avulsion is a direct consequence of channelization and sedimentation. Sediment deposition rates tend to be higher near the axes, so that continued deposition raises the channel above the surroundings. This superelevation in the channel bed makes the channel increasingly susceptible to flow diversion into lower lying areas.

2.3.4 The associated increase in cross-valley slope relative to either the down-channel or the down-valley slope:

Various researchers have revealed that the rivers are sensitive to the changes in gradient. Jones and Schumm (1999) studied the Geomorphic and sedimentary response of rivers to tectonic deformation and found that the cross valley slope due to tilting will commonly force rivers to avulse towards the lower/down tilted side of the river. The avulsion will occur or not depends partly upon the ratio between the avulsion course slope to the existing channel slope (Jones and Schumm, 1999) or the cross-valley slope to the down-valley slope (Mackey & Bridge, 1995). The critical slope ratio for avulsion was estimated by various authors as follows:

S.No.	*Authors*	*Critical Slope Ratio*
1	Slingerland and Smith (1998)	5
2	Tornqvist And Bridge (2002)	3 to 5

Real slope ratios have been determined for different river systems and at different locations along the Mississippi River by several authors (Guccione et al., 1999; Peakall et al., 2000; Aslan et al., 2005). The slope ratios are highly variable and range from 1 to 110.

2.4 FREQUENCY OF AVULSION

Sediment-laden rivers undergo periodic shifts and the frequency of avulsion depends upon the sediment load carried by the stream. More the sediment load more will be the frequency of the avulsion. For example, because of the heavy sediment load carried by the Yellow River, the frequency of avulsion for this river is very high. On an average the channel has changed once in every 10 years. As a comparison, the frequency of avulsions in the Rhine–Meuse River is much lower because the river carries a much lower sediment load. Stouthamer (2001) studied the avulsions in the Holocene Rhine–Meuse delta. Five avulsions occurred in the Rhine–Meuse delta from about 6500 yr BP to 1950 yr BP, when the Rhine-Meuse delta was aggraded. The frequency of avulsion is therefore about 1/800 years.

2.5 CONCEPT OF STREAM POWER

In the light of the previous discussion it is clear that, avulsions are the inevitable result of river aggradations and therefore closely related to the sediment load carried by the stream. The mechanism of the sediment transport has a great importance in the morphological behaviour of the river. The behaviour of the sediment load transported and hence river morphology depends on the energy of the moving water and the force it exerts within and upon the channel.

As the water mass of the river is set in motion flowing downhill under the influence of gravity its gravitational potential energy is converted to kinetic energy. This in turn is transformed to mechanical energy in maintaining river flow and in transporting sediment. During these transformations most of the river's energy is dissipated as unavailable heat energy in friction and resistance to flow. In other words the energy is expended in doing work on the system, and the rate at which this energy is expended is the power of the river or stream **i.e. *Stream Power.***

Stream power is simply the rate of energy expenditure in doing work (overcoming the resistance to flow and transporting the sediments), or the amount of energy expended per unit time. Streams may be regarded as sediment transporting machines, and their behaviour analysed in terms of the availability of stream power to do work.

As stated above stream energy is dissipated in maintaining fluid flow against flow resistance and in doing work by transporting the sediment load:

1. Where stream power is more than sufficient to transport an imposed sediment load, scour of alluvium on the bed, or of bedrock, will occur.
2. Where stream power is insufficient, load transport will decrease and the bed of the stream will aggraded i.e. deposition at the stream bed take place.

Stream Power is a measure of the amount of energy expended per unit time at the channel bed in overcoming friction and transporting sediment. The gross power (W) of a stream is given in Joules per second per metre length of bed, by

$$W = \rho g Q S = \gamma Q S$$

Where, ρ = water density (1000 Kg m^{-3}),

γ= specific weight of water (9810 N m^{-3}),

g = acceleration due to gravity (9.81 ms^{-2}),

Q = discharge (m^3s^{-1}), and

S = slope.

The energy available in the stream or river channel, after friction has been overcome, is used in eroding the channel margin and transporting mineral debris.

Available Stream Power and the Threshold of Critical Stream Power:

Sediment transport is highly sensitive to changes in stream power. This occurs because stream energy is a function of stream velocity, and varies as the cube of velocity, so that slight changes in velocity can significantly affect the work done in the channel. However, it should be noted that only 3-4% of the work or energy of the stream is expended in sediment transport. Some 97% is transformed into frictional heat by the impacts between water molecules. The ratio of the power expended on transport/erosion to the total available power determines the efficiency of the stream. Where stream power is more than sufficient to transport an imposed sediment load, scour of alluvium on the bed, or of the bedrock, will occur. Where stream power is insufficient, load transport will decrease and the bed of the stream will aggrades.

A critical power threshold separates modes of erosion and deposition in stream systems. The threshold of critical power is defined as when the ratio of available stream power to the critical stream power equals to unity.

Available stream power / Critical stream power = 1.0

The critical power is the power needed to transport the average sediment load. It changes with variations in sediment load and size and with hydraulic roughness, and expresses those factors which determine stream competence and capacity.

The available stream power is the power available to transport the sediment load and reflects those variables which, if increased, favour transportation of sediment (discharge, slope).

2.6 RIVER TRAINING WORKS

Alluvial rivers are well known for their sediment load and frequently changing course. Most of the rivers in this class are notorious for overflows and breaching their banks, resulting in the floods. River training works are required to stabilize the river channel along a certain alignment and with a certain cross-section so that the river does not cause the damage to the land and property adjacent to its bank.

Brahmaputra River also falls in the same category and well known for its unstable and frequently changing morphology. As discussed earlier, Dibang and Lohit River, two tributaries of Brahmaputra River changed their course due to avulsion on the upstream of Dibru-Saikhowa Reserve Forest. This change in the course of these two rivers has caused damage to the life, land and property along the new course of flow because of the low flow carrying capacity of the new channel. The Flood Control department of Assam is trying to divert the flow of Dibang and Lohit Rivers to their original course by implementing various structural and non structural river training measures, with the suggestion from the CWPRS, Pune. The Brahmaputra Board has tried various river training works including tie bund, retirement bund, spurs, pilot channel, porcupine etc.

Porcupines are triangular structure made of three poles joined together at the top and braced near the bottom. The geometry of the porcupine is such that it will remain the same in any the position of the porcupine just like a pyramid having three slanting faces. Bamboo porcupines filled with the boulders have been used for training the river flow in the central and eastern Uttar Pradesh and Bihar. But the concept of permeable RCC porcupine is latest and recently used in river training in Brahmaputra River in Assam with a modified design. RCC porcupines, used in Brahmaputra River are made of 3 metre long straight, rectangular RCC members having 10cm X 10cm cross-section and reinforcement as shown in the Figure 2.2. Two holes are provided at a suitable distance from both ends of the member to facilitate the fastening of members with each other to give the shape of pyramid to the arrangement of the straight members. All the porcupines used for training the river are joined together with a steel cable wire and anchored at the bank to withstand the forces due to water current. In latest development it has been decided to use RCC porcupine with greater height and hence bigger cross section

RCC porcupines induce sedimentation by breaking and dissipation of erosive vortex current. It works well in sediment carrying river with good amount of suspended sediments.

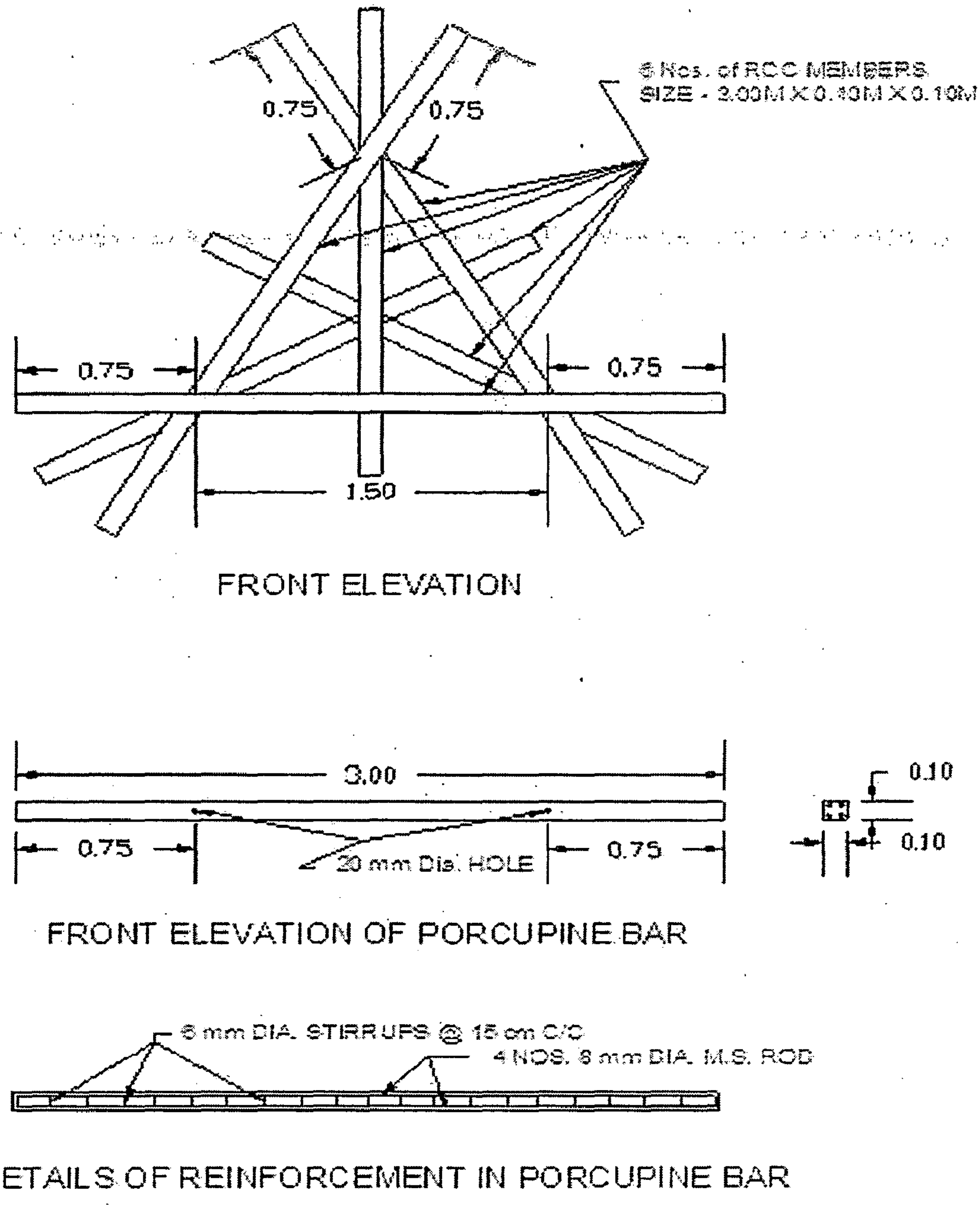


Figure 2.2: Typical cross-sectional details of RCC Porcupine

(Figure Not to scale, All unspecified dimensions are in m)

2.7 RIVER MORPHOLOGY USING REMOTE SENSING DATA

Remote Sensing (RS) and Geographical Information System (GIS) play a rapidly increasing role in the field of water resources development. Remotely sensed based information is of great value since many hydrologically relevant data can be derived from it. One of the greatest advantages of using RS data for hydrological modelling and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. However, the use of RS technology involves large amount of spatial data management, and requires an efficient system to handle such data. The GIS technology provides suitable alternatives for efficient management of large and complex databases. The remote sensing data provides synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum. The space borne multi-spectral data enable generating timely, reliable and cost effective information on various natural resources, namely surface water, land-use and land-cover, soil and environmental hazards.

2.7.1 Application of Remote Sensing to River Engineering

Changes in the river channel alignment and size, development of bars, islands take place during floods, time dependant changes can be monitored in the specific river reach using remote sensing. Depending on the resolution of the imageries, accurate and dependable predictions can be made covering long reaches.

Changes in the river channel monitoring include the aspects, like changes in the location, size and alignment. In case of rivers with multiple channel system or braided rivers, these could be the important aspects resulting in bank erosion. This can also be important while considering the development of inland navigation system, locating riverine ports and other structures, design of anti-erosion works, etc. These aspects are generally affected by the development of islands, bars in the channel, changes in the orientation of channel etc. Monitoring of temporal changes in the river channel with the help of satellite imageries would highlight on these aspects.

Other information, like existence of paleo channels, low lying areas, reaches under active erosion, damages due to over bank flows, breaches in the embankments, damages to the existing hydraulics structures can be identified using satellite imageries. In spite of the fact that normally the changes in a braided channel are sudden and unpredictable, efforts have been made with the help of satellite imageries to identify any cyclic behaviour observed in the past. Efforts are also made to identify physical limits of such changes, if any, observed earlier. Co-relating these observations with other information can give fairly good idea of the river behaviour in a specific reach and likely behaviour in the immediate future.

2.7.2 Earlier Works

The study on river morphology with the use of remote sensing data is a relatively new development, and has been in practice for not more than the last 20 to 25 years in India. Murthy (1990) has studied the flood plain of Brahmaputra

River using satellite imageries. Hussain (1992) has carried out morphological studies of river Brahmaputra with the help of satellite imageries. Morphological studies of the river Brahmaputra has been undertaken by Brahmaputra Board, Government of India in 1993. Best and Bristow (1993) studied the braiding pattern of Brahmaputra in Bangladesh using satellite data. Oak (1998) worked on the prediction of bank erosion of bank of the Brahmaputra river on Gumi-Alikash reach (down stream of Pandu). Some erosion studies using satellite imageries in the vicinity of Majuli Island and Kaziranga National Park had been studied by Space Application Centre, Ahmedabad.

Deepali Mitra et. al. (2003) studied Channel avulsions of the Sarda River system with the help of synoptic coverage and temporal data provided by remote sensing in conjunction with topographical maps and field investigations. Their study revealed that channel avulsions take place over a period of 10–100 years. Avulsion and floods are strongly associated with each other as floods trigger the process of avulsion. The unidirectional lateral migration of Sarda River is related to tectonic tilting of the area, probably during early Holocene.

Sankhua R.N. (2005) has covered the entire Brahmaputra in his Ph.D. thesis while developing the ANN based spatio-temporal morphological model for the River Brahmaputra. Main emphasis of his study was the morphological behaviour of the Brahmaputra River and he has generated some data with the help of RS & GIS necessary for the development of the spatio-temporal morphological model of the Brahmaputra River. He has given just the introduction of the avulsions occurred at various places along the Brahmaputra River.

Singh M.K. (2003) and **Shreshtha R.N. (2005)** both have studied the morphological behaviour of the Brahmaputra River with the help of the Satellite images. In their studies, they emphasised on the morphological behaviour of the main channel of the Brahmaputra River in a particular reach but have not given proper attention to the avulsion.

In the context of the literature review above, it is very clear that not enough attempts have been made to observe the avulsion in the Brahmaputra River. Hence in the present study this topic has been discussed in detail.

CHAPTER 3

STUDY AREA AND DATA COLLECTION

3.1 STUDY AREA

The Brahmaputra River characterized by high seasonal variability in flow, sediment transport and configuration is a unique river system of the world that rains such diverse environments as the cold, dry plateau in Tibet formed of highly erodible deposited soil, the steep rain-drenched slopes of the Himalayas, the land lock alluvial plains in Assam and vast deltaic flat in Bangladesh. The Brahmaputra system originates in a great glacier mass in the Kailash range of Himalayas south of Lake Gunkyud in South West Tibet, the Siang or Dihang in Arunachal Pradesh, and the Jamuna in Bangladesh, is one of the biggest river of the world. Its total length of 2897 km is divided among three countries as below:

Tibet (China)	-	1625 km
India	-	918 km
Bangladesh	-	354 km

In India, 278 km length of the river comes in Arunachal Pradesh and 640 km in Assam. With all its tributaries and vastness, it is considered to be a mighty river of the world having immense potential for damage during floods. Furthermore, it is also one of the most braided rivers of the world. Its width at Pandu (near Guwahati) is just 1.2 km. and while a few kilometres downstream of Pandu, the river width becomes as large as about 18 km. The total catchment's area is 5,80,000 sq. km. out of which only 60,000 sq. km. is in alluvial zone. Its origin point (near Mansarovar lake) is at an altitude of 5300 m whereas its level at Pasighat (Arunanchal Pradesh) is just 155 m and at Kobo it is 120 m while at Guwahati it is 50.5 m and at Dhubri it is 28.4 m. Thus, the river slope in the mountainous reach is 4-17 m/km, while at Pasighat, it is 27 cm/km and at Guwahati it is just 10 cm/Km.

The study area (Figure 3.1) where avulsion has occurred is Hatighuli situated in Tinsukia district at a distance of about 5 Km. from Dholla Township in the state of Assam. The combine flow of Dibang and Lohit River was originally out falling into Dihang River at about 25 Km. down stream of Saikhowa Reserve forest. Avulsion has been taken place on the upstream of the Saikhowa Reserve Forest. Before avulsion, the Saikhowa Reserve Forest was situated in south bank of the Brahmaputra and Lohit Rivers. After the avulsion of the Lohit River in the Dangori River, a tributary of The Dibru River, the Saikhowa Reserve forest become an island surrounded by the Brahmaputra and avulsed channel. The point of avulsion is situated upstream of the Saikhowa Reserve forest and downstream of the confluence of the Lohit and Dibang Rivers. After avulsion 90% of the discharge of the Lohit and Dibang River join the Brahmaputra River through the Dibru River.

3.1.1 Geology

The Brahmaputra basin in Assam is confined by the eastern Himalayas on the north and east, the Patkai and Naga Hills on the northeast and Mikir Hills and Shillong Plateau on the south. The oldest (Precambrian) rocks are exposed in

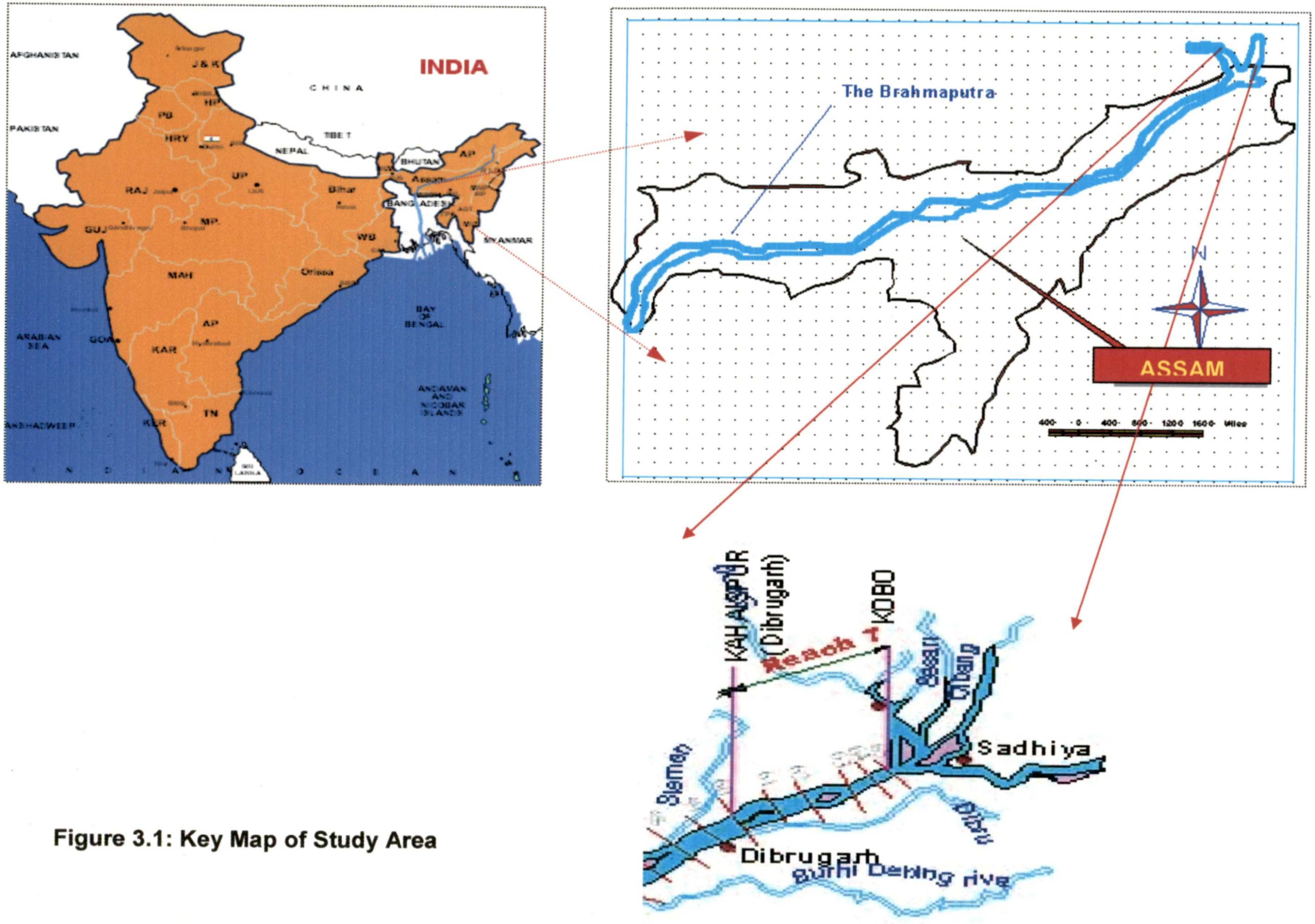


Figure 3.1: Key Map of Study Area

the Shillong Plateau and Mikir Hills, which are made up of high-grade metamorphites, gneiss, schists and granites overlain by metasediments. On the northern side, the alluvial plain of Assam abuts against Siwalik ridges of the Himalayas, which are in turn overlain by highly tectonized Paleozoic sediments. n the eastern side of Assam Valley, the alluvial deposits abut directly against metasediments, which are successively followed eastward by gneisses, high grade schists, some sediments, low grade schists, ultra basic rock and diorite, granodiorite complex of Mishimi Massif. On the southeastern side of the alluvial plain the Tertiary rock sequences occur in Patkai and Naga Hills and consists of dark grey shales, sandstones and shales with coal seams, thin conglomerates, ferruginous sandstones and mottled clays, soft sandstones, clays and conglomerates, thick pebble beds, thin clays and sand. The Quaternary sediments, overlying unconformably the Tertiary deposits, are described as Older Alluvium or High Level Terraces, consist of indurated yellowish or reddish clays with sand, shingle, gravel and boulder deposits. The Recent sediments in the Brahmaputra valley were deposited as alluvial fan and floodplain sediments of the Brahmaputra and its several tributaries.

3.1.2 Slope of the river

The slope of the river is steep when it crosses the Himalayas as shown in the longitudinal profile of the river (Fig.3.2). The amount of slope of the river at different reaches are 1.63 m/km in Tibet, 4.3m/km to 16.8 m/km across the Himalayas, 0.62 m/km in plains up to Kobo, 0.27 m/km from Kobo to Dibrugarh, 0.17 m/km from Dibrugarh to Nimatighat (near Bessamora), 0.15 m/km from

Nimatighat to Tezpur, 0.14 m/km from Tezpur to Pandu (near Guwahati), 0.11 m/km from Pandu to Jogighopa 0.094 m/km from Jogighopa to Dhubri and 0.079 m/km from Dhubri to the mouth. A sudden decrease in slope in front of the Himalayas near Pasighat results in a large amount of sediment deposition, which chokes up the channel and gives rise to development of prominent braiding pattern.

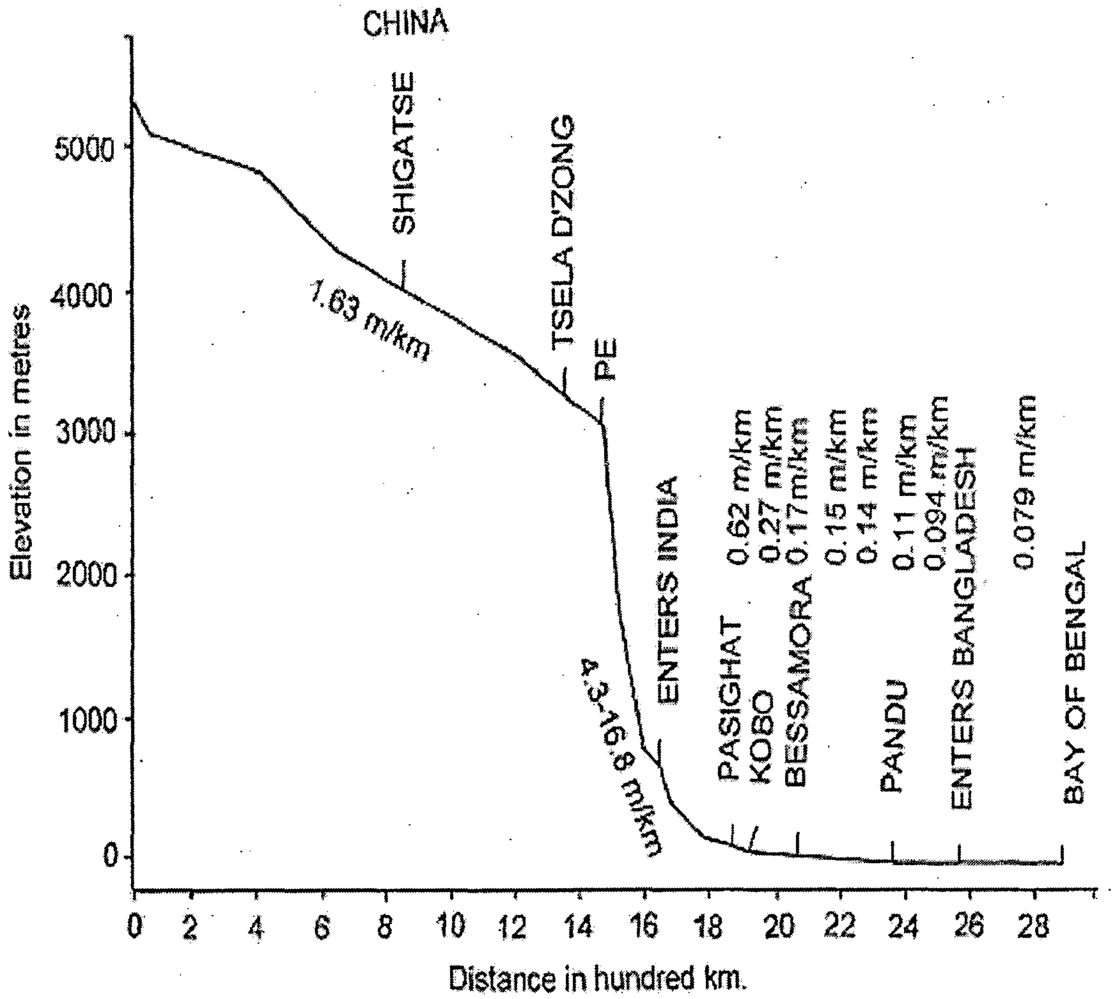


Figure 3.2: The longitudinal profile of the Brahmaputra River (modified after WAPCOS, 1993)

3.1.3 General climatic features

The annual rainfall in the basin area of the Brahmaputra River under study in Assam varies from 100 cm to 400 cm and the normal annual isohyetal map of this part of the basin is given in Fig. 3.3. Most of the annual rainfall occurs in the monsoon months from June to September, with the eastern parts experiencing pre-monsoon thundershowers from March to May. To the south of the Brahmaputra River, the central portion is situated in a rain shadow area of the southern hills, e.g. at Lanka. In the rest of the plains area, annual rainfall gradually increases to 300 cm. The annual mean basin rainfall, excluding Tibet and Bhutan, is nearly 230 cm and rainfall increases gradually from west to east. The Burhi Dihing River basin receives an annual rainfall varying from 210 cm to 388 cm.

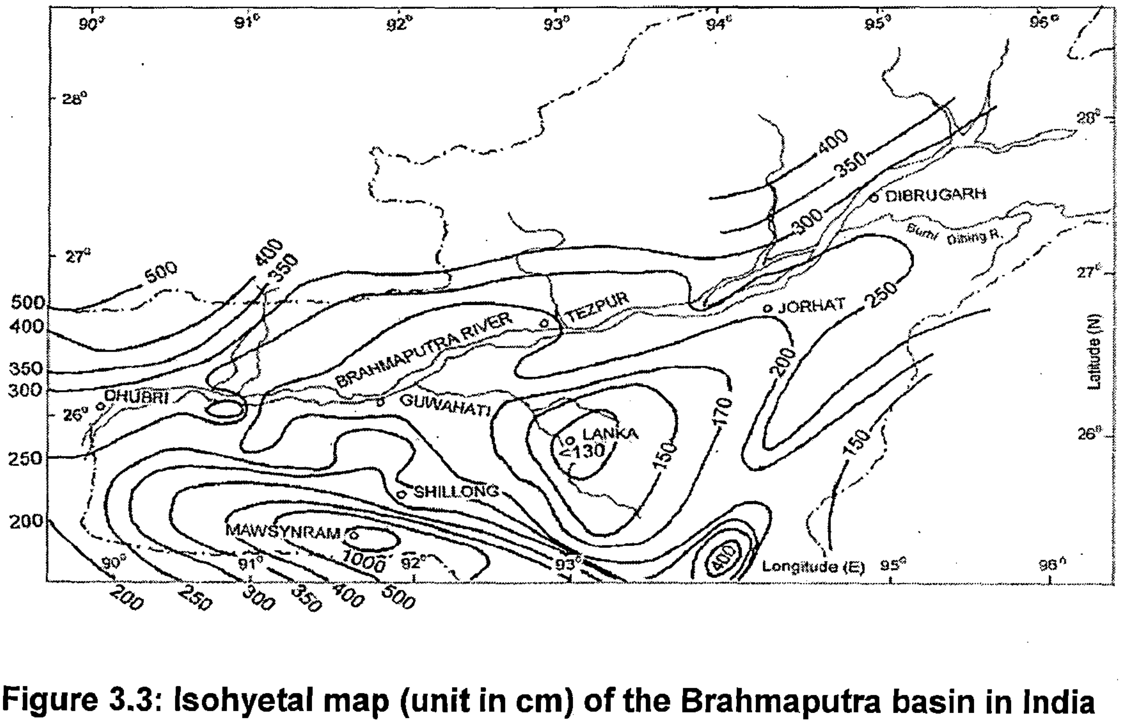


Figure 3.3: Isohyetal map (unit in cm) of the Brahmaputra basin in India (modified after WAPCOS, 1993)

The monsoon commences over Assam around the first week of June and ceases around in the second week of October. The highest rainfall occurs in June/July and gradually decreases thereafter. In the Brahmaputra valley, 66–85% of annual rainfall occurs during the monsoon and 20–30% occurs during the pre-monsoon season. A small percentage of annual rainfall then occurs in the winter season (less than 1% in December, up to 2%in January, up to 4% in February and up to 6% in March). The first spell of rain with high intensity occurs generally in the month of April. This is closely related to the occurrence of the first flash flood in the otherwise smooth hydrographs of the tributary rivers, e.g. Burhi Dihing River in 1976.

3.2 DIGITAL SATELLITE IMAGES

The digital satellite data were procured from National Remote Sensing Agency (NRSA) Hyderabad for the years 1990, 1997, 2000 and 2002. The details of digital satellite data procured are shown in Table 3.1. The satellite images presented in Table 3.1 were used to synthesise a map of cumulative stream bank erosion of the Brahmaputra for the period 1990 - 2002. Satellite scenes covering the study area were identified from the satellite pass index map of IRS. Dates of satellite passes over the area were selected from the orbital calendars available for the years under consideration. However, it could not be possible to procure the satellite data of monsoon period due to the presence of cloud cover for the period under study. In all, the digital satellite data comprising of 8 scenes of IRS Linear Imaging Self Scanner (LISS) I and LISS III for the years 1990, 1997, 2000 and 2002 were analysed. These sensors provide multi-spectral data in 4 bands, two in visible (0.52 -0.59μm) and (0.62-0.68μm), one in near infrared (NIR 0.77-0.86μm) and one in shortwave infrared (SWIR 1.55-1.70 μm) regions of the electromagnetic spectrum. The spatial resolution of LISS-I is 72.5 m and that of the LISS-III is 23.5 m.

Table 3.1: Details of Satellite Data

S.NO.	SATELLITE	SENSOR	PATH/ORBIT	ROW/SECTOR	YEAR
1	IRS 1A	LISS I	13	48	1990
2	IRS 1A	LISS I	14	48	1990
3	IRS 1C	LISS III	113	52	1997
4	IRS 1C	LISS III	114	52	1997
5	IRS 1C	LISS III	113	52	2000
6	IRS 1C	LISS III	114	52	2000
7	IRS 1D	LISS III	113	52	2002
8	IRS 1D	LISS III	114	52	2002

CHAPTER 4

METHODOLOGY

4.1 GENERAL

The remote sensing technique is used to collect, analyze and convert remotely sensed data into useful information in order to assist in inventory, mapping and monitoring the earth resources. Useful information has been extracted from the satellite images and analysed with the help of ERDAS IMAGINE 8.5.

4.2 REMOTE-SENSING TECHNIQUE AND ITS IMPLEMENTATION

Notwithstanding significant advances in river engineering, the task of predicting the process of channel adjustment to the hydraulic transients of imposed water and sediment discharge is fraught with uncertainties. To understand this process, there are analytical approach which employs the use of equations such as sediment transport, flow resistance and bank stability. Extremal hypotheses are approaches, which describe on the basis of assumption that a channel acquires equilibrium or stability when some of specified function of variables has an extreme (maximum / minimum) value subject to given constraints.

In order to study the river plan-form and morphological changes of a river, information at a regular interval of time for whole length of the river may be required. Ground based observations and other methods may not be sufficient to model the plan-form and morphological changes. These may be uneconomical and time consuming if these methods have to be adopted on a repetitive basis. With advancement of remote sensing technique as an analysis tool, it is now possible to acquire information related to river morphology.

4.2.1 Remote Sensing Technique

Remote sensing is a science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation. (Lillesand and Kaifer, 1982).

Photographic interpretation involves the study of photographic images. While remote sensing which is relatively a new technique, includes not only the analysis of photographs but also the use of data gathered from a wide range of remote sensing sensors and scanners on board the satellites. Remote sensing images, obtained from orbiting satellites are capable of providing quantitative as well as qualitative information about objects.

Remote sensing activity started in the decade of fifties. The usefulness of images for mapping and other applications increased in 1960, with the launching of the first US meteorological satellite TIROS-1. The launching of the first Earth Resources Technology Satellite (ERTS) by USA in July 1972, marked the beginning of space development activities, including the use of remote sensing images for various natural resources applications.

4.2.2 Remote sensing data

There are two types of remote sensing data used for various applications:-

(i) Aerial remote sensing data

The platform used for these data is normally an aircraft, and data products are black & white and coloured photographs.

(ii) Satellite remote sensing data

The platform used for these data is a satellite, and the data products are black &white images, false colour composites (FCCs), computer compatible tapes (CCTs) , compact discs (CDs), etc.

4.2.3 Remote sensing components

Remote sensing works with the help of a sensor which records reflected electromagnetic energy from the objects to be characterized. Various objects are identified with the help of variation in the reflected electromagnetic energy. Remote sensing system may have the following components: -

i. Source of electromagnetic energy

ii. Medium (atmosphere) which interacts with this energy

iii. Ground objects

iv. Sensor to detect and record the changes in electromagnetic energy.

Remote sensing satellite

Remote sensing started with the launching of the first Earth Resources Technology Satellite (ERTS), now known as LANDSAT-1, by the USA in 1972. Since then, with the advancement in sensor technology, a number of remote sensing ERTS have been launched, such as

LANDSAT series 1,2,3,4,5,6 and 7. French satellite SPOT 1,2 and 3, Indian satellites IRS 1A /1B /1C /1D , IRS-P2 /P3 /P4 /P6 and Indian meteorological and communication satellites INSAT 1A /1B / 1C / 1D & 2A /2B /2C /2D / 2E

India started the use of remote sensing techniques with the launch of Bhasker 1 & 2 in 1979 &1981 respectively. In 1989, the first Indian Remote Sensing (IRS) satellite was launched under the Indian space programme. Indian remote sensing satellites in the IRS series, designated as IRS 1A, IRS 1B, IRS P2, IRS 1C, IRS P3, IRS 1D, IRS P4 and IRS P6 were launched during the year 1989, 1991, 1994, 1995, 1996, 1998, 1999 and 2004 respectively.

The National Remote Sensing Agency (NRSA) Hyderabad, under the Department of Space (DOS), is mainly responsible for acquisition, processing and dissemination of satellite data. The Space Application Centre (SAC), Ahmedabad, and the Indian Space Research organization (ISRO), Bangalore, are mainly responsible for the design and launching of sensors and platforms, including satellite launch vehicles.

The data from Indian remote sensing satellites are received in the form of digital signals at Sadhnagar ground receiving station, Hyderabad. These data are corrected, pre-processed and analysed on computers and is converted into different forms such as films, paper prints, FCC, CCTs , CDs etc and is supplied to the users for various application.

4.2.4 Application of remote sensing data

Remote sensing data provide a permanent record of topographical features of the area. The profusion of information contained in a photograph is much greater than that afforded by any other cartographic device. The camera or sensor often reveals the ground information that would have been ordinarily missed by a human eye.

Developments in space technology have greatly enhanced the capabilities of resources, survey and mapping. Remote sensing has found many applications in the study of earth's resources, mainly because of its synoptic and repetitive coverage to gather real time information.

Data acquired by remote sensing are now accepted as a useful source for mapping and making inventories of natural resources. These data have been used in the field of forest mapping, snow hydrology, reservoir sedimentation, flood estimation, river morphology, watershed conservation, soil mapping, land use / land cover mapping, crop yield forecasting etc.

4.2.5 Stages Involved In Remote Sensing Technique

The basic stages involved in this process are data collection, data analysis and data representation.

(i) **Data collection:** It involves energy sources, propagation of energy through the atmosphere, energy interactions with earth surface features, airborne or space borne sensors to record reflected or radiation energy from features and data products in pictorial, graphical or numerical form.

(ii) **Data analysis:** It involves examining the data and deduces its significance. This may be performed by one of the following methods:

a) Visual interpretation

b) Digital interpretation

c) Hybrid method

Visual interpretation is interpretation of an image by a skilled or trained analyst whereas digital interpretation is done by a computer. Hybrid method is a mixed form of above two methods of data analysis. Since visual and digital methods are complementary in nature, consideration must be given to obtain best results by combination.

(iii) **Data representation:** It is done in graphical, tabular or numerical forms depending upon the purpose for which the end result is needed.

(iv) **Image processing systems:** After the spatial data are received, these need a system for manipulation, and this system is known as image processing. Thus remote sensing and image processing are two powerful tools for many research and applications areas. Image processing application software normally resides as an executable command module on the hard disk of a system. This software should be interactive, prompting the user for specified inputs to make the software helpful to the users. There are many software available for image processing. If the data to be analyzed are enormous, digital interpretation techniques may prove to be faster.

This study has been carried using ERDAS IMAGINE 8.5.

4.2.6 Analysis Using Remote Sensing Technique

The satellite data of the year 1990, 1997, 2000 and 2002 have been procured from NRSA, Hyderabad. The list of detailed remote sensing data collected is given in Table 3.1. The following procedure has been adopted for analysis using remote sensing technique.

Remote sensing data have been used to extract information regarding the avulsion and shift in banks of the avulsed channel. For this ERDAS-IMAGINE 8.5 has been used as follows:-

Data decoding

ERDAS IMAGINE 8.5 has in-built routines to read IRS LISS data directly. However, it requires input regarding the header file length. For IRS LISS-I the length of header file is 540 bytes while for LISS III it is 0 bytes. The images are displayed using the Image Viewer.

Data registration

As the Earth and Satellite are both dynamic systems, hence as the data are collected some geometric disturbance creeps in. This affects the scale and leads to errors in measurement. To get accurate measurements, the image has to be registered to the actual earth. This process is known as data registration.

Data registration consists of two basic processes of geocoding and data resampling.

For geocoding, the image is to be correlated to salient ground features such as roads, bridges, river junctions or by defining the exact latitude and longitude values of the four corner points of the image. In case of river Brahmaputra, there are very few salient ground points which can be clearly identified on the satellite image. ERDAS-IMAGINE 8.5 has the capability to geocode satellite data to the ground by defining the latitude and longitude values of the 4 corner points of the image using Polyconic projection system. These values of the 4 corners points are available in the Leader file available with each data set. With help of this input each image is geocoded, using the WARP function in ERDAS IMAGINE 8.5.

After geocoding is performed, resampling or intensity interpolation of the geocoded image is carried out using Bi-linear interpolation. This is performed by RESAMPLE function of ERDAS IMAGINE 8.5.

Mosaicking

As the study area is covered in many imageries, hence all these images have to be joined together to form one complete image. This will help in adopting a single base line for making measurement. The joining of all the imageries of the study area for one year has been carried out by the MOSAIC function of ERDAS IMAGINE 8.5.

Digitisation

After all the images of one year have been mosaicked to form one single image, to find the position of bank line, onscreen digitization of the bank line has to be carried out. Each bank line, the position of live channels and riverine feature are digitised and stored with the GIS module of ERDAS IMAGINE 8.5.

The information digitized are in the form of small arcs and hence have to be converted into shape files for continuous and smooth shape, before any computations can be carried out.

4.3 COMPUTATION FOR MIGRATION OF CHANNEL BOUNDARY AND CHANGE IN THE WIDTH OF CHANNEL

For computing the variation in width of the channel a sufficient number of sections selected randomly at suitable distance along the avulsed channel. It is a deliberate attempt to select the sections randomly in order to cover the morphological changes in the avulsed channel completely. At these sections width of the avulsed channel for the given years has been computed with the help of the measure tool from the utility menu of the viewer of ERDAS IMAGINE 8.5 (Figure 4.1 & Table 5.1).

The baseline at 27.5^0 N Latitude has been selected from which all the offset measurements ($\mathbf{Z_L}$ and $\mathbf{Z_R}$) to baseline location on the digitized maps have been carried out. Offsets have been measured at specified sections (Figure 4.2 & Table 5.2).

While comparing the boundary migration for any two years (both left & right boundary) -ve sign indicates boundary migration towards south and +ve sign indicates boundary migration towards north. For left bank –ve migration shows deposition while +ve migration shows erosion whereas for right boundary +ve migration shows deposition and –ve migration shows erosion.

A flow chart showing the methodology adopted is shown in Fig. 4.3. The procedure with available data is performed as mentioned above. The detailed results and discussions are given in Chapter 5.

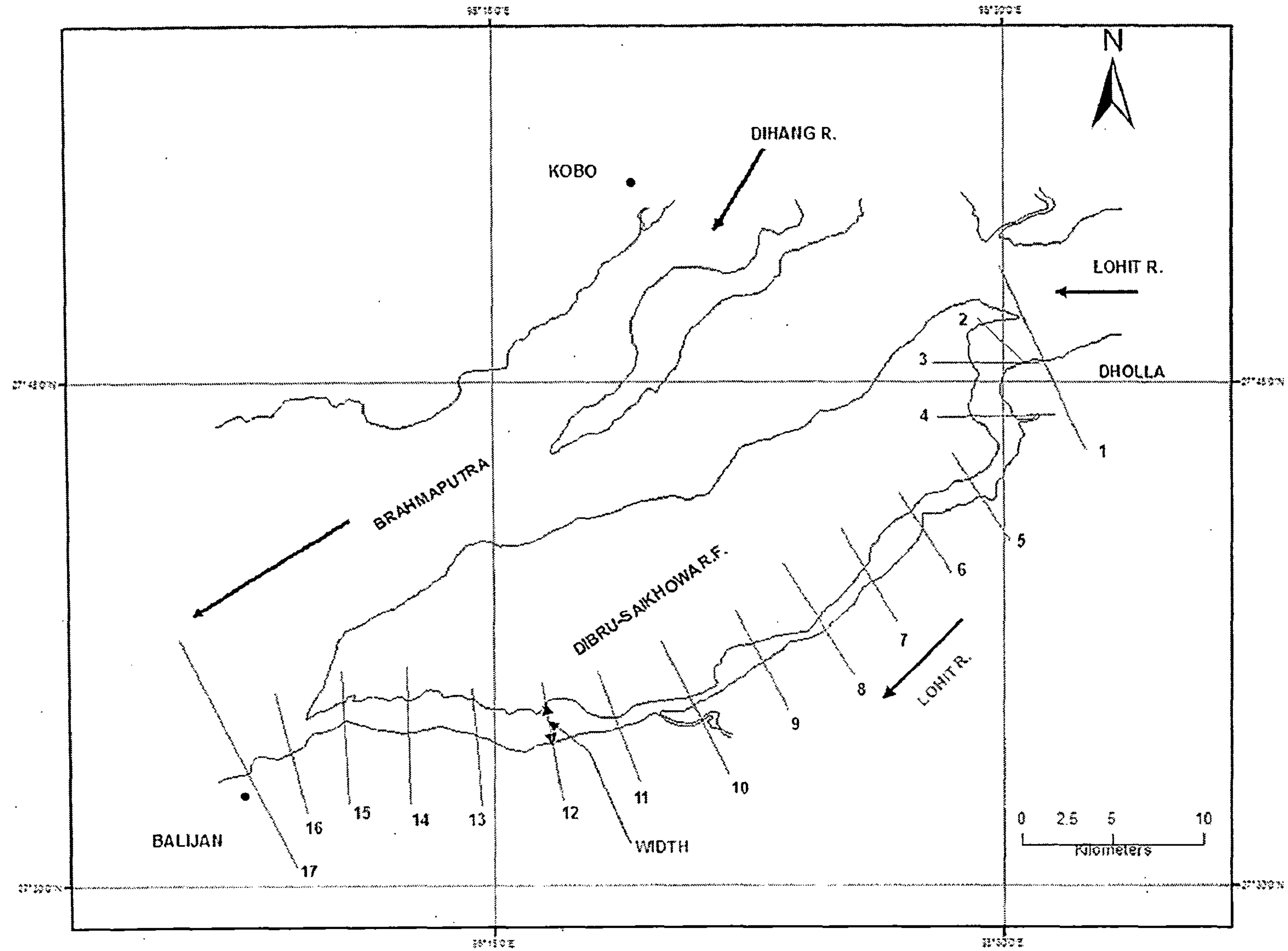


Figure 4.1: Sections for Computation of Width

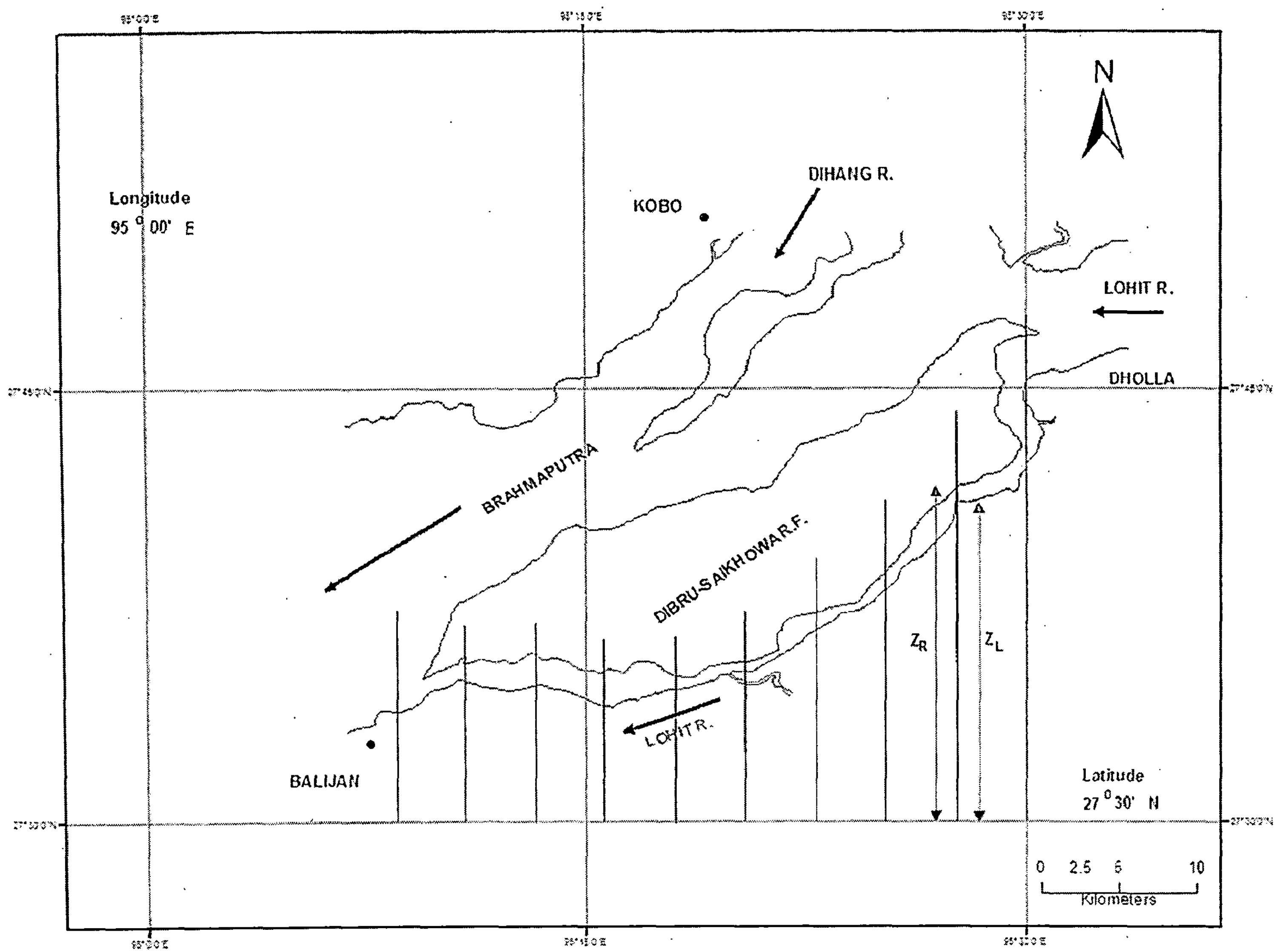


Figure 4.2: Computation of Z_L and Z_R

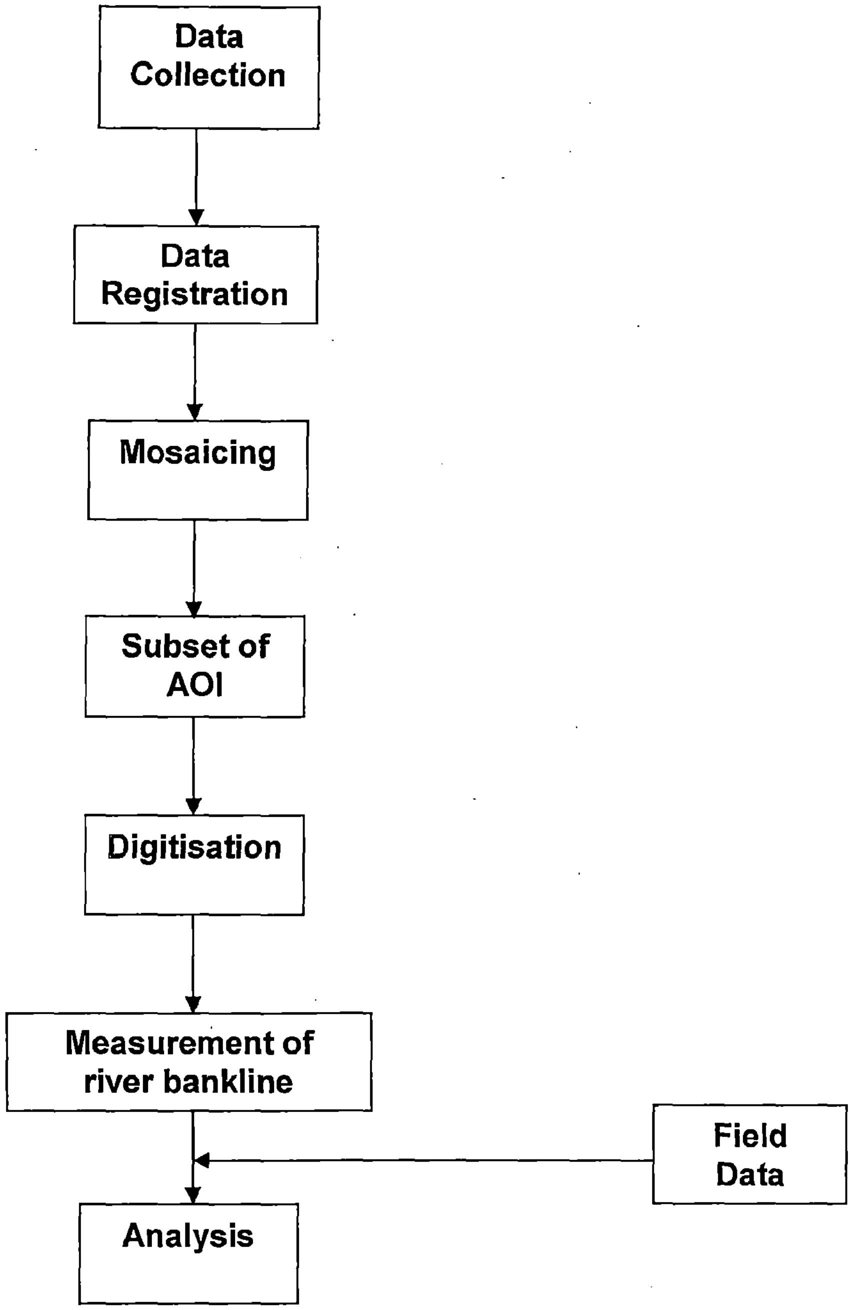


Figure 4.3: Flow chart of the methodology

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 GENERAL

The problem of avulsion of Brahmaputra at Dholla-Hatighuli area started in 1989 due to breach in Saikhowa bund, which caused the diversion of flow of Lohit River into Ananta Nallah. Although this breach was patched up in1990, the breach increased in width of about 1 km during floods from 1993 onwards. The breach in 1998 became about 1.3 km wide and subsequently migrated into Balu Nallah. Since then entire flow of Lohit River has been flowing through this Balu Nallah.

The present study was undertaken on upstream of the Dibru-saikhowa Reserve Forest near Dholla Township in Tinsukia District of Assam to see the phenomenon of avulsion using the multi-temporal satellite data from IRS LISS I & LISS III satellite. The combination of the satellite and digitized vector images has been used to evaluate the variation in the width of the avulsed channel. The records and drawings from Brahmaputra board, Govt. of India have also been studied to observe the changes in the river morphology after the implementation of the river training works.

5.2 AVULSION DETECTION USING RS & GIS

(a) Before the implementation of river training works

The problem of avulsion of Brahmaputra at Dholla-Hatighuli area started in year 1989 due to breach in Saikhowa bund, which caused the diversion of flow of river Lohit into Ananta Nallah. This breach patched up in 1990. The traces of this avulsion are visible in the satellite imagery of year 1990 (Figure 5.1).

As it is visible in the satellite imagery of 1990, there was no sign of the active avulsion and whole of the combined discharge of the Lohit and Dibang Rivers join the Dihang River near Kobo, 45 Km. downstream of Pasighat town, from where the combined flow is known as the Brahmaputra River. Till 1995, there has not been much change in the river morphology near Kobo.

In the year 1995, an avulsion on the upstream of the Dibru-Saikhowa Reserve Forest took place. This avulsion of the Lohit River can easily be seen in the satellite imagery of year 1997 (Figure 5.2) of the Brahmaputra River near Dholla township in Tinsukia district of Assam.

After avulsion a part of flow of the Lohit River joined the river Dangari, a tributary of the Dibru River flowing along the eastern and southern boundary of the Dibru-saikhowa R.F. This flow joins the Dibru River and through it joins the Brahmaputra River near Balijan instead near Kobo in the past. From the satellite images of year 1997 length and average width of avulsed channel computed as 54 Km and 695 metres respectively.

The avulsion occurs when the magnitude of the triggering mechanism such as stream power, slope ratio, superelevation etc exceeds the geomorphic thresholds. The avulsion on the upstream of the Dibru-Saikhowa R.F. occurred because of the insufficient stream power with respect to the sediment load carried by the flow of Lohit and Dibang River which caused the deposition of the sediments at the river bed thus the aggradation of the river bed. Finally there was increase in the bed slope of the potential avulsion course as compared to the bed slope of the existing channel, thereby increasing the discharge in the left anabranch significantly.

It was also opined that when the channel roughness exceeded the floodplain roughness, thus creating a preferential flow path with lesser resistance to the flow across the floodplain and setting the stage for the channel avulsion.

In 1995, not more than 50% of the discharge of the Lohit River was passing through the anabranch i.e. the avulsed channel.

With the passage of time, more and more discharge from the Lohit and Dibang River began to flow through the newly avulsed channel. This is because of the steeper slope of the potential avulsion channel as compared to the parent channel and less resistance to the flow as stated above. Subsequently a new channel named Balu Nallah has become active. During the year 2000 the entire combined flow was flowing through the Balu Nallah which is visible in the satellite imagery of the area of the year 2000 (Figure 5.3). The increase in the width of the avulsed channel is clearly shown in the figures 5.6 to 5.8 and Table 5.1. The length and average width of the avulsed channel computed from satellite image as 52 Km and 1100 m respectively in year 2000 as compared to 54 Km and 695 m in year 1997.

In year 2002, total discharge of the Lohit and Dibang River transferred to the avulsed channel. This increased discharge caused bank erosion at the entry & along the length of avulsed channel which leads to a decrease in length of channel from 52 Km to 51 Km and an increase in the average width of channel from 1100 m in year 2000 to 1480 m in year 2002 (Table 5.0 & 5.1). The entry of the avulsed channel got widened and moved southwards because of this bank erosion at the entry of the channel, the left bank at the mouth of avulsed channel moved approximately 4 Km southwards (table 5.2).

Table 5.0: Variation in the Length of the Avulsed Channel

Item	Year		
	1997	2000	2002
Length of the Avulsed Channel (Km)	54	52	51

Spatial and temporal variation in the length and width of the channel is represented in the Tables 5.1 & 5.2 and Figure 5.9.

It has been observed that the erosion in the avulsed channel is prominent at places where the disturbance in the flow is excessive i.e. at the entry of Lohit and Dibang River into the Dangori tributary of the Dibru River, at the confluence of Dangori with the Dibru River and at the confluence of the avuklsed channel with the Brahmaputra River (Table 5.2 & Figure 5.10).

Table 5.1: Width of Avulsed Channel Measured from Satellite Images

Section No.	Longitude (°)	Width (m)			Change in Width(m)		Remarks
		1997	2000	2002	1997 to 2000	2000 to 2002	
1	95.51	660	1825	2701	1165	876	
2	95.50	738	1431	2863	693	1432	
3	95.49	717	1124	2361	407	1237	
4	95.50	571	1125	1980	554	855	
5	95.49	881	1009	1139	128	130	
6	95.46	747	861	1055	114	194	
7	95.43	861	871	874	10	3	
8	95.41	333	425	744	92	319	
9	95.38	252	998	1124	746	126	
10	95.35	409	752	521	343	-231	Braided Portion
11	95.31	291	599	619	308	20	
12	95.28	655	2110	2215	1455	105	
13	95.24	1877	1914	1986	37	72	Braided Portion
14	95.21	776	1764	1769	988	5	
15	95.18	987	1116	1082	129	-34	Braided Portion
16	95.15	360	809	647	449	-162	Braided Portion
17	95.14	351	-	-	-	-	
Average Width		694.69	1170.8	1480			

Table 5.2: Offset of Bankline of Avulsed Channel from a common Latitude of 27.5°

S.No.	Sec. No.	Longitude (°)	1997		2000		2002		Shift in Bank (m)			
			Z_L	Z_R	Z_L	Z_R	Z_L	Z_R	1997-2000		2000- 2002	
									Left	Right	Left	Right
1	**1 (a)**	95.50	29798	30932	29653	31279	27816	31170	145	347	1837	-109
2	**1 (b)**	95.50	26531	24810	23094	26872	22548	26948	3437	2062	546	76
3	**1 (c)**	95.50	22688	24372								
4	**2**	95.46	19201	20632	19208	20750	19227	21132	-7	118	-19	382
5	**3**	95.42	14666	15477	14733	15654	14719	15738	-67	177	14	84
6	**4**	95.38	12167	12496	12171	13323	12200	13382	-4	827	-29	59
7	**5**	95.34	9954	10283	9466	10089	9506	10174	488	-194	-40	85
8	**6**	95.30	8325	9082	8298	9141	8317	9183	27	59	-19	42
9	**7**	95.26	7258	9400	8220	9316	7293	9478	-962	-84	927	162
10	**8**	95.22	8502	10138	8780	9973	8514	10547	-278	-165	266	574
11	**9**	95.18	8962	9902	8899	9904	8723	9969	63	2	176	65
12	**10**	95.14	7595	7949	7419	-	6774	-				

Note: Z_L, Z_R and Width are in metres
-ve sign shows the deposition

Change in the morphology of Dibru-Saikhowa Reserve Forest

Comparative study of satellite imageries of the area for the given years has shown that there is a continuous decrease in the area and length of the Dibru-Saikhowa reserve forest. These variations have been clearly visible in the table 5.3. Figure 5.11 & 5.12 show these observations graphically.

Table 5.3: Variation in the Dimensions of the Dibru-Saikhowa R.F.

S.No.	Item	Year			Variation (Decrease)		
		1997	2000	2002	From 1997 to 2000	From 2000 to 2002	From 1997 to 2002
1	Max Length (Km)	43.13	41.42	40.98	1.71	0.44	2.15
2	Area (Km^2)	316.38	299.76	289.63	16.62	10.13	26.75

Length has been measured along azimuth 60^0 appx.

It has also been observed that this decrease in the area is the result of the bank erosion by the avulsed Lohit River as the width of the avulsed Lohit River goes on increasing from 1997 to 2002. The increase in the width of the avulsed channel endangered the habitations, tea gardens, cultivable land along its length.

The decreasing length is the result of erosion of the reserve forest land at the entry of Lohit River near Dholla and at the confluence of Lohit River in Brahmaputra River near Balijan (Figure 5.2, 5.3 & 5.4).

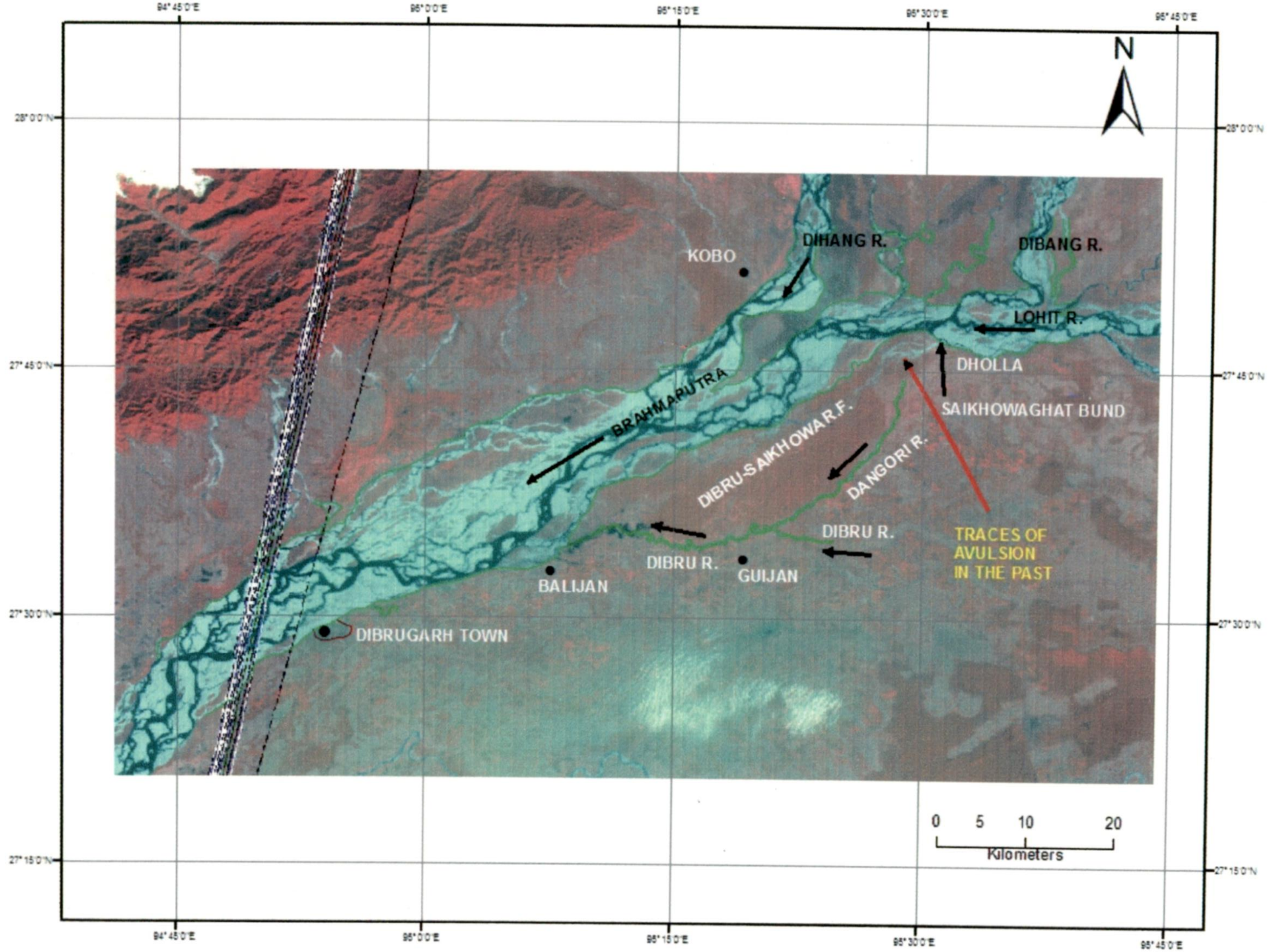


Figure 5.1: Satellite Image of area, Year 1990

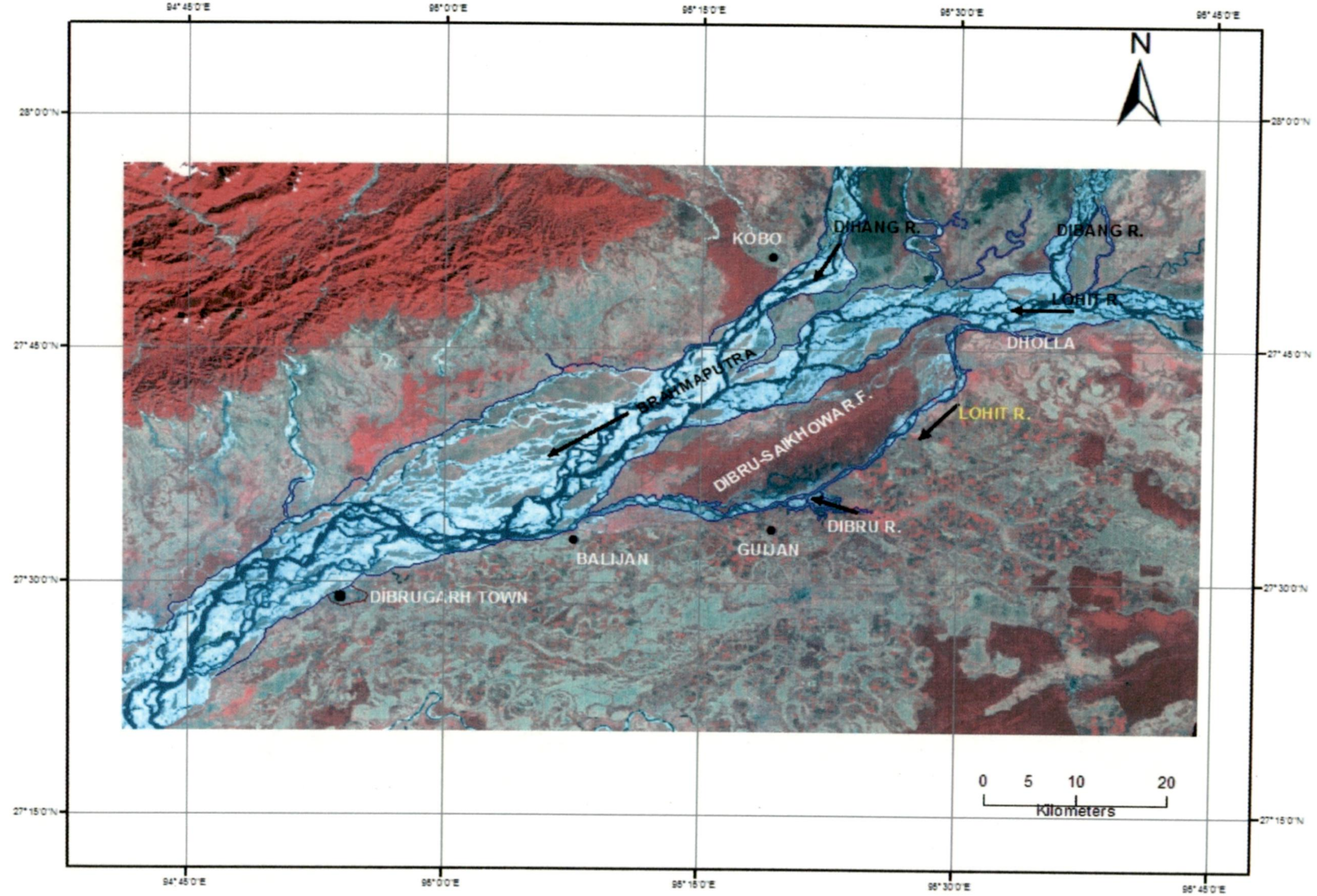


Figure 5.2: Satellite Image of area, Year 1997

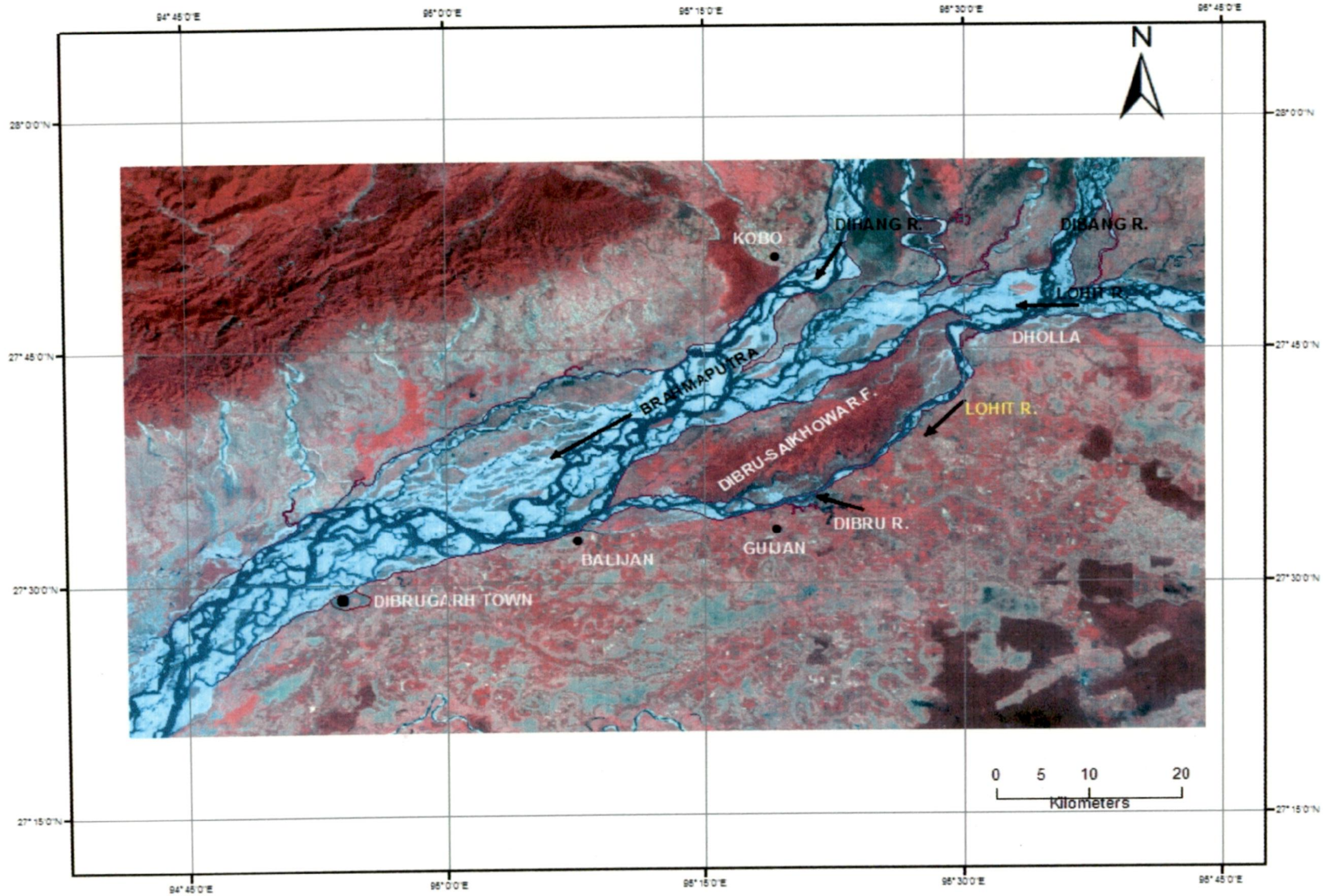


Figure 5.3: Satellite Image of area, Year 2000

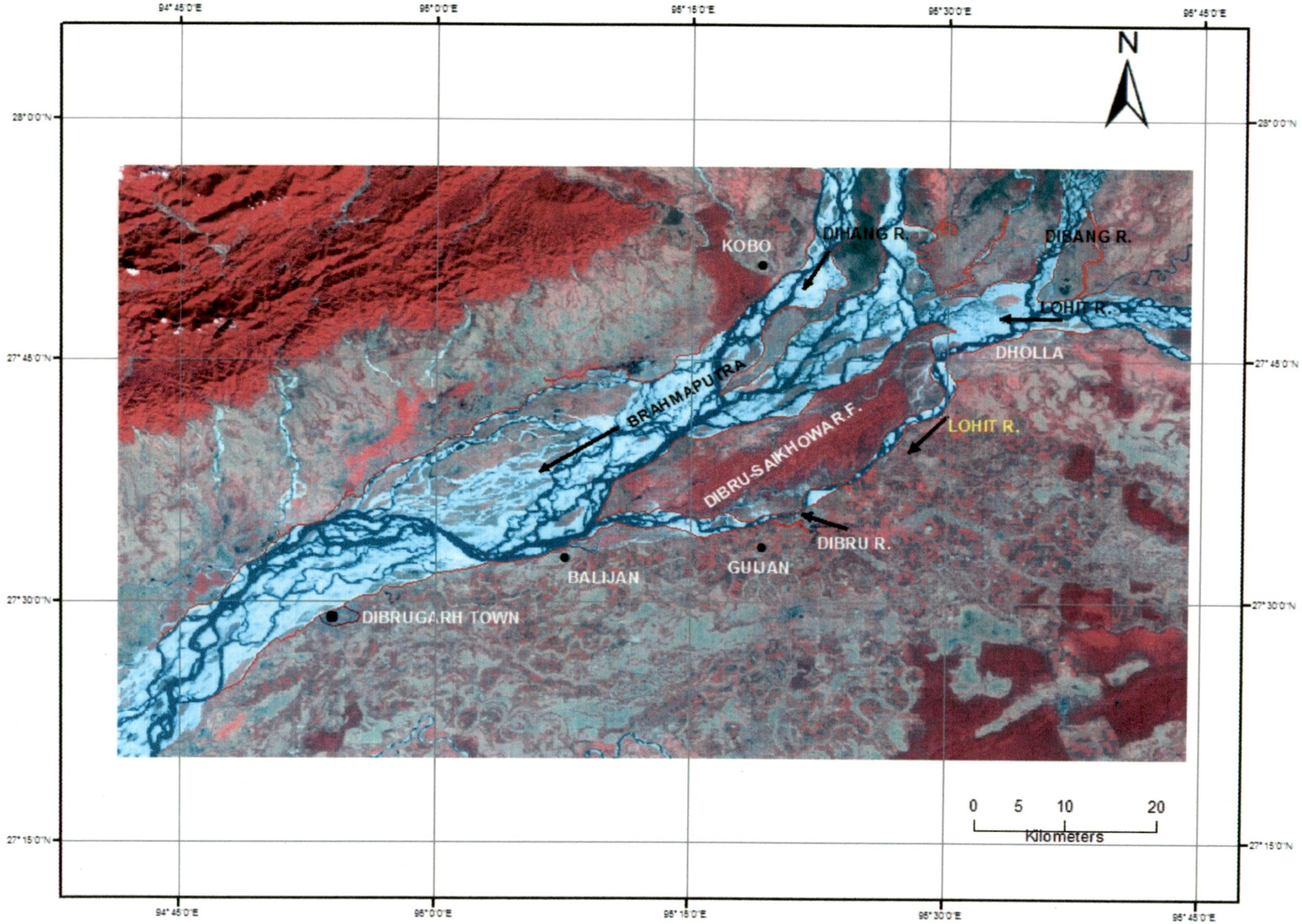


Figure 5.4: Satellite Image of area, Year 2002

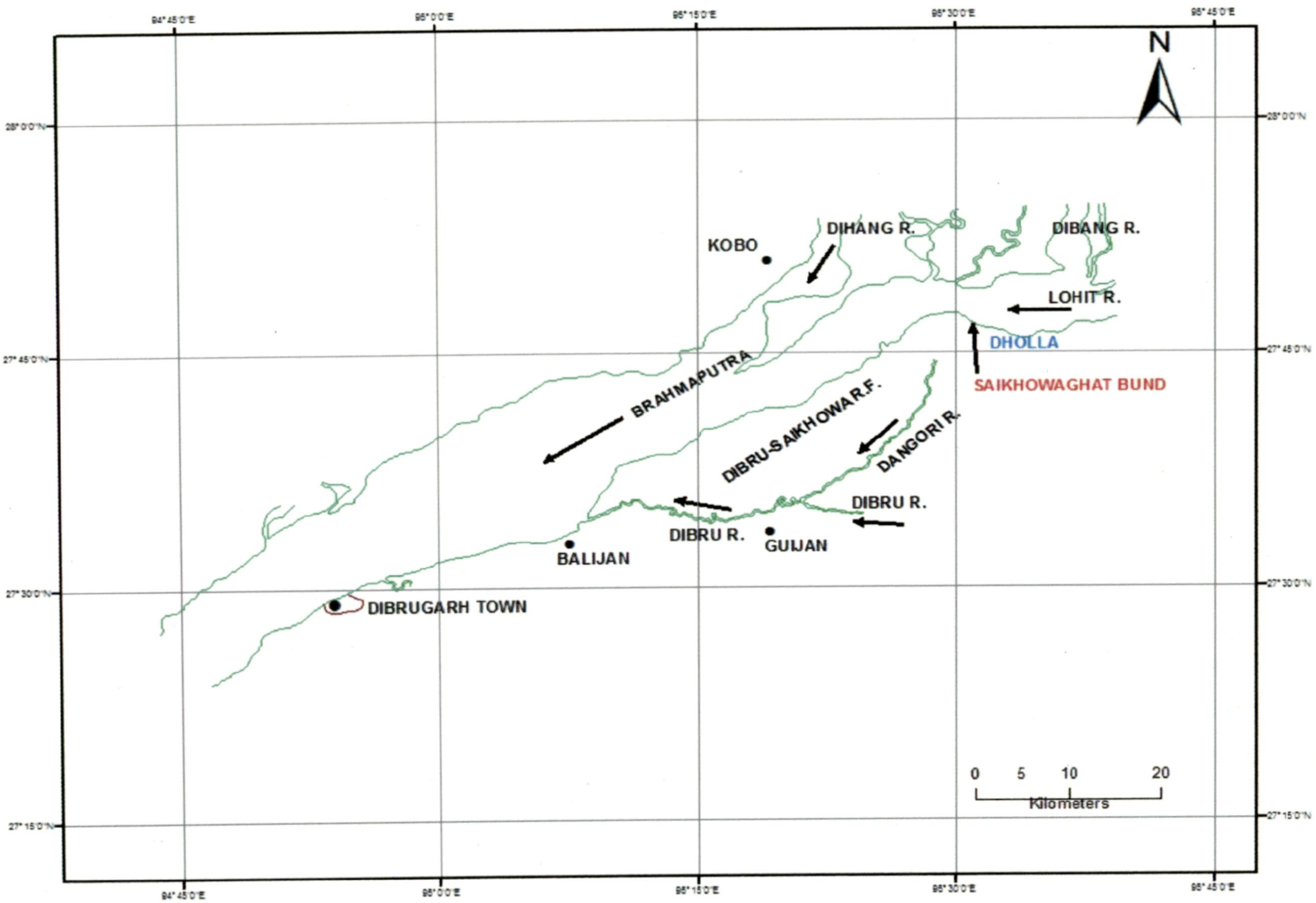


Figure 5.5: Bankline Representation Year 1990

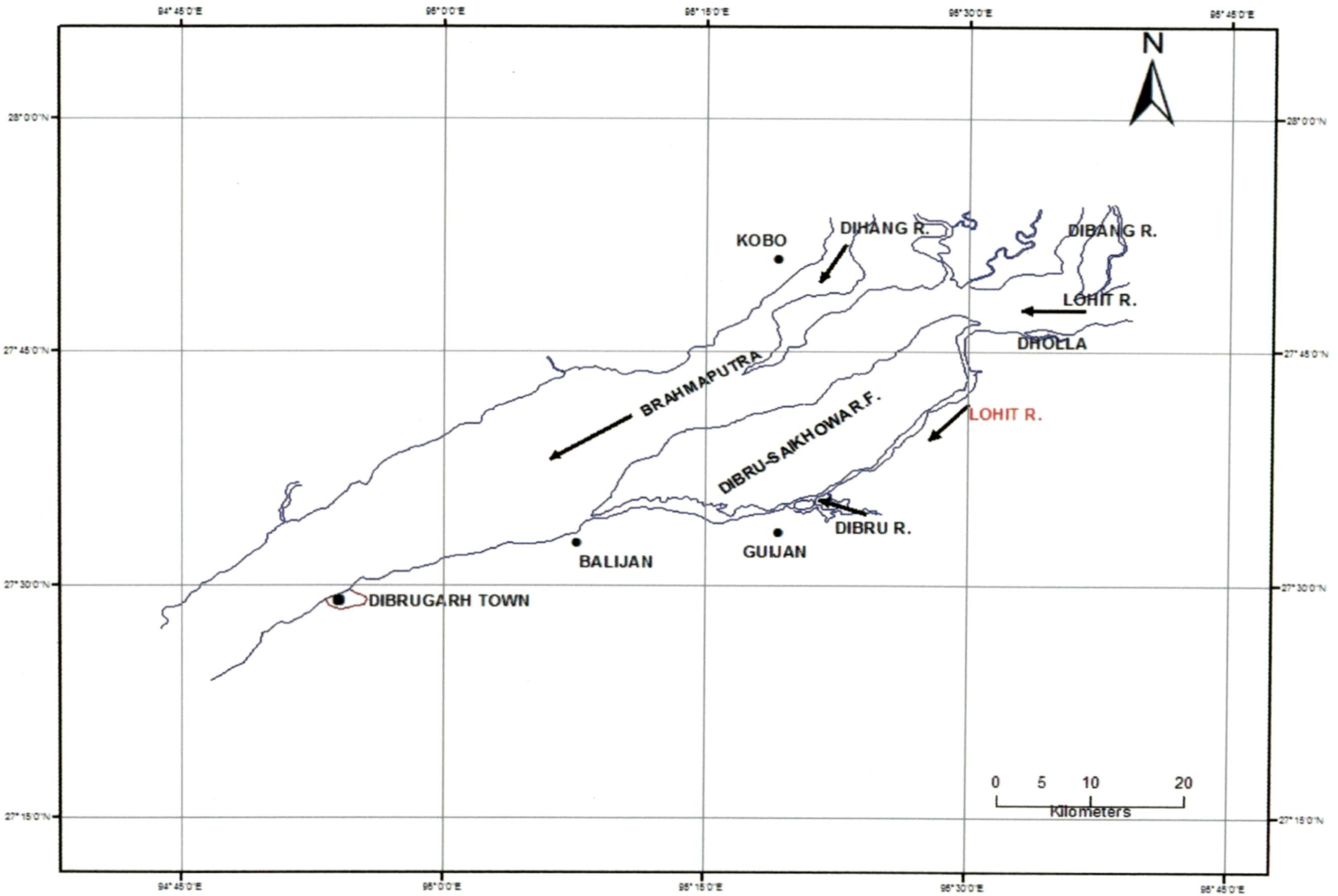


Figure 5.6: Bankline Representation Year 1997

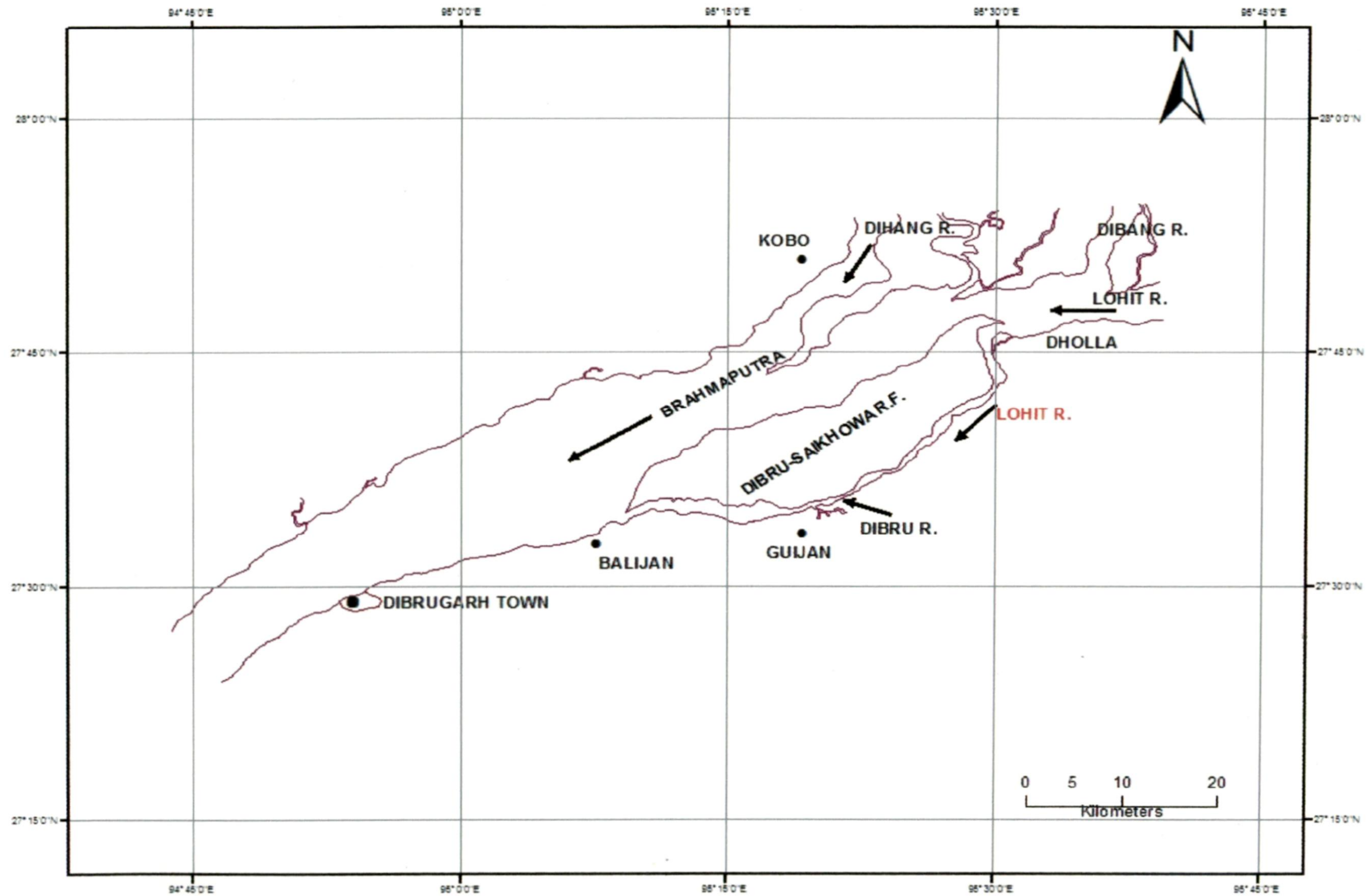


Figure 5.7: Bankline Representation Year 2000

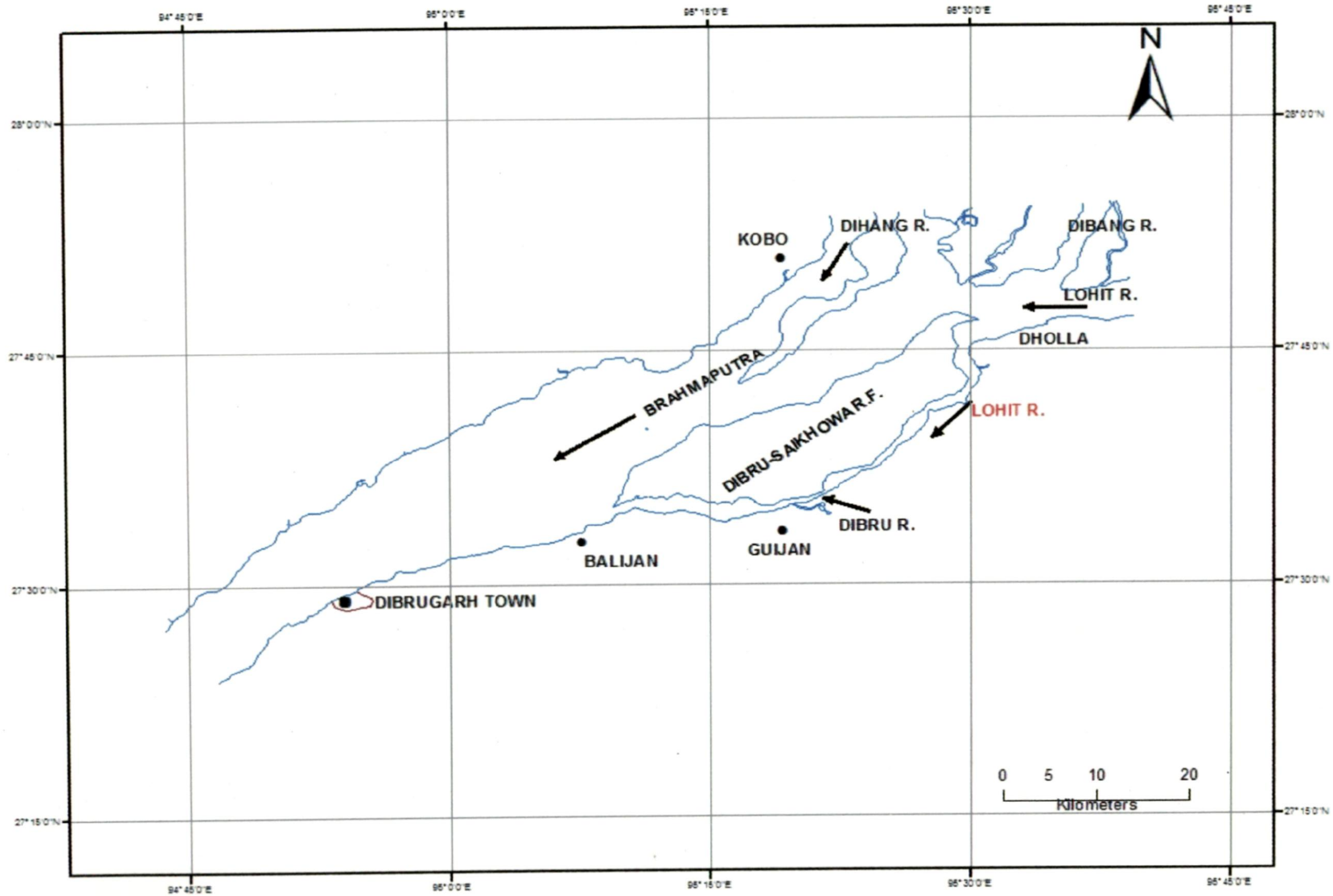


Figure 5.8: Bankline Representation Year 2002

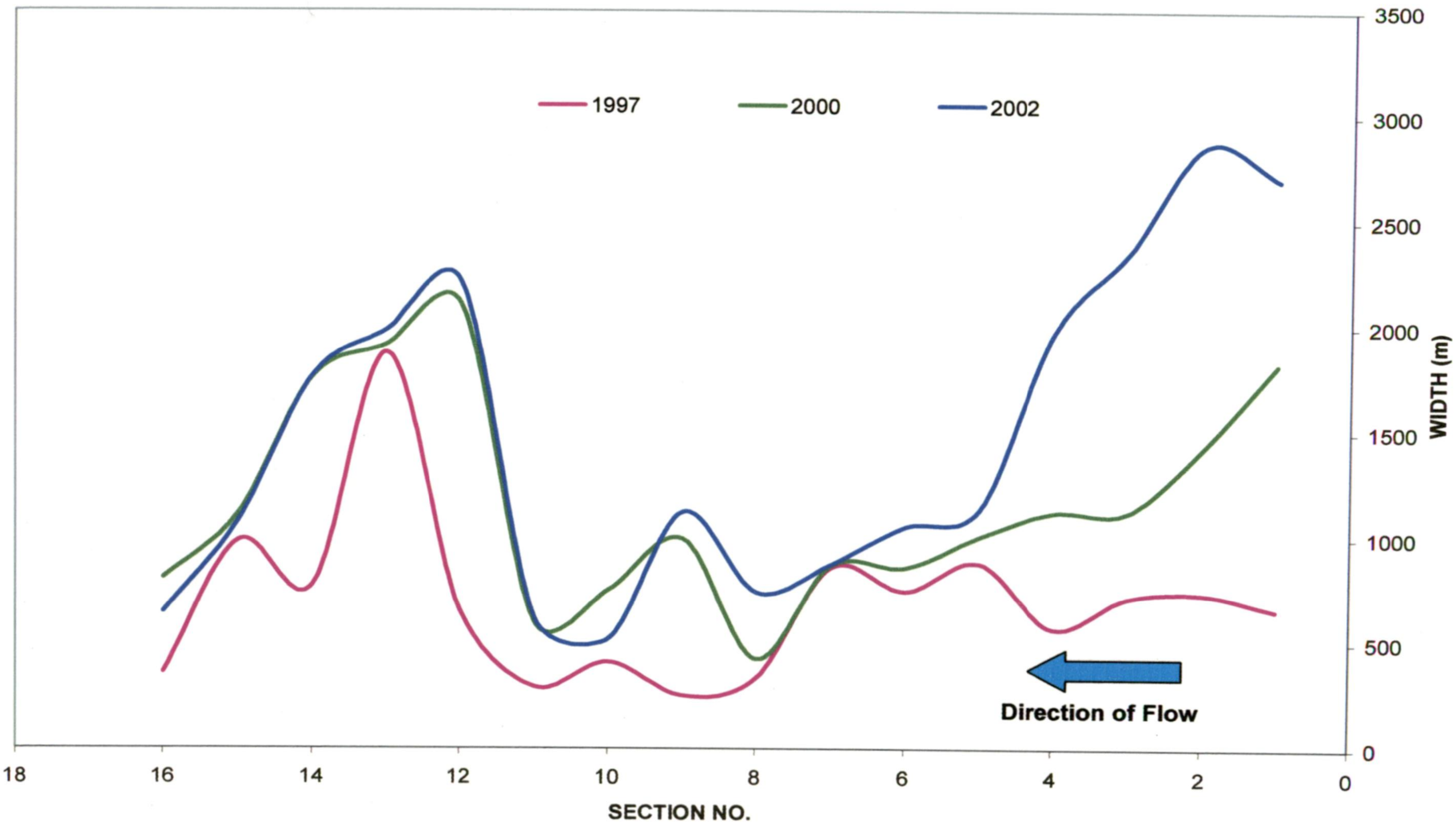


Figure 5.9: Variation of Width

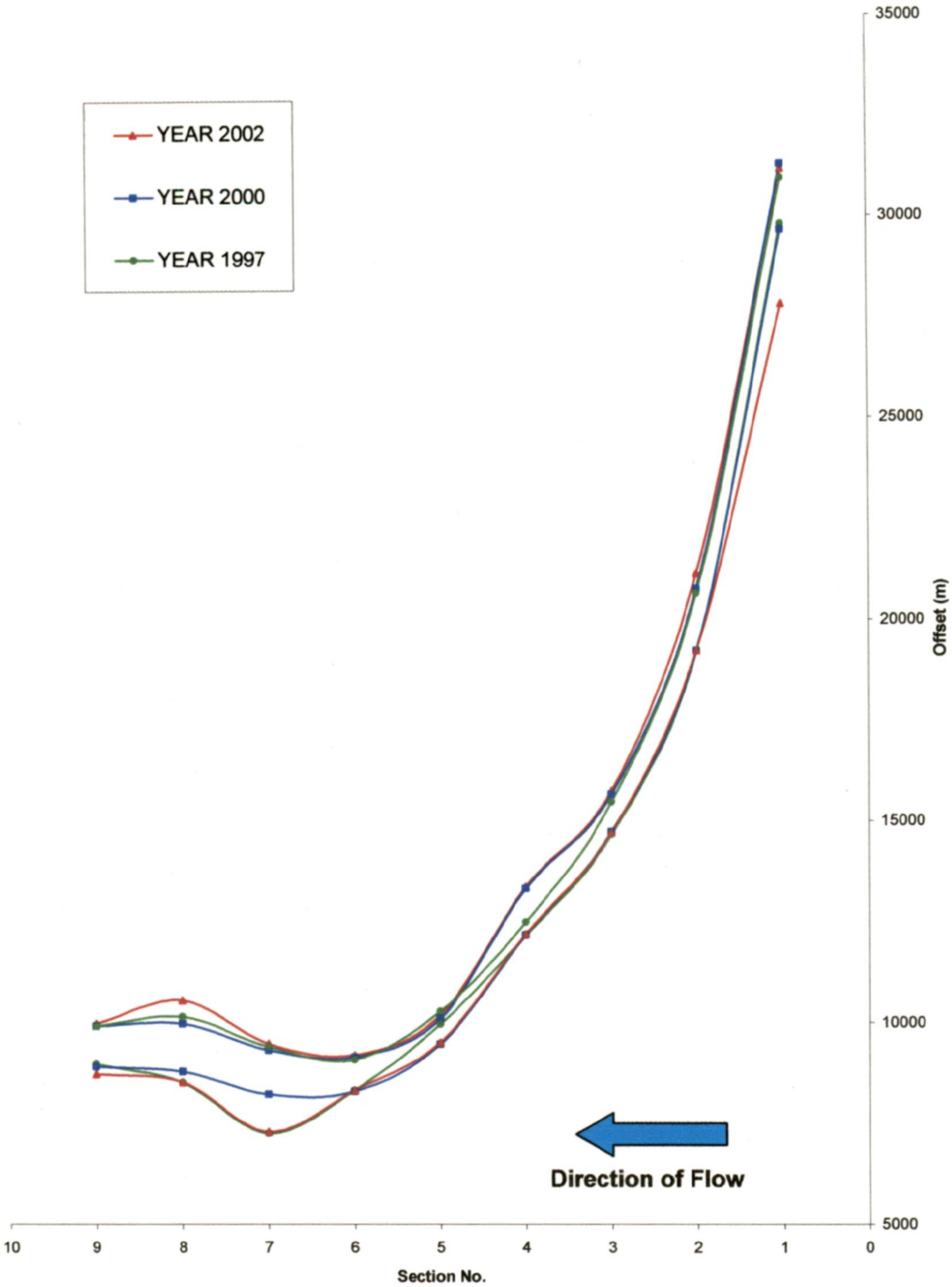


Figure 5.10: Shift in the Bankline of the channel from 1997 to 2002

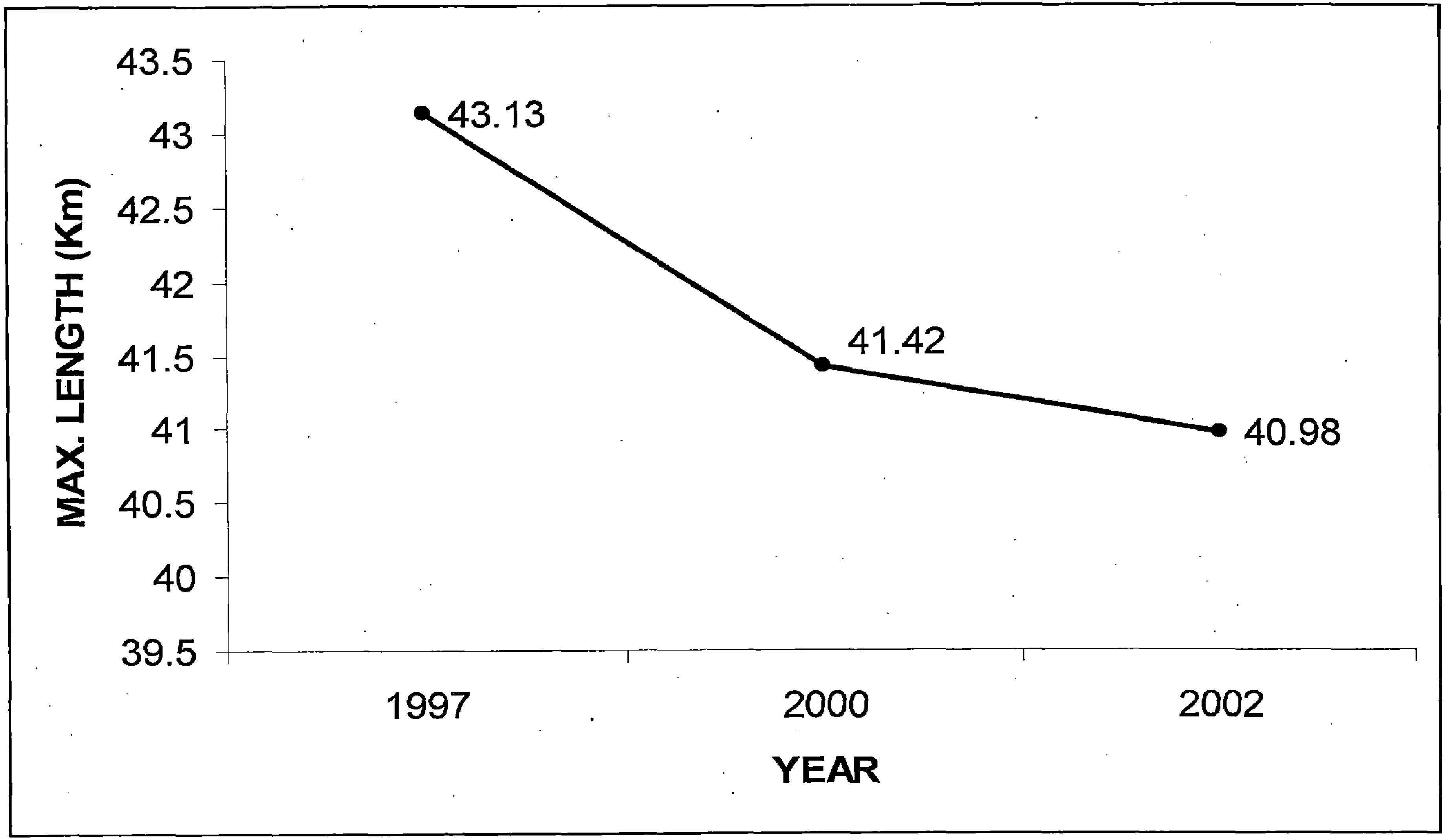


Figure 5.11: Variation of Length of Dibru-saikhowa R.F. w.r.t. time

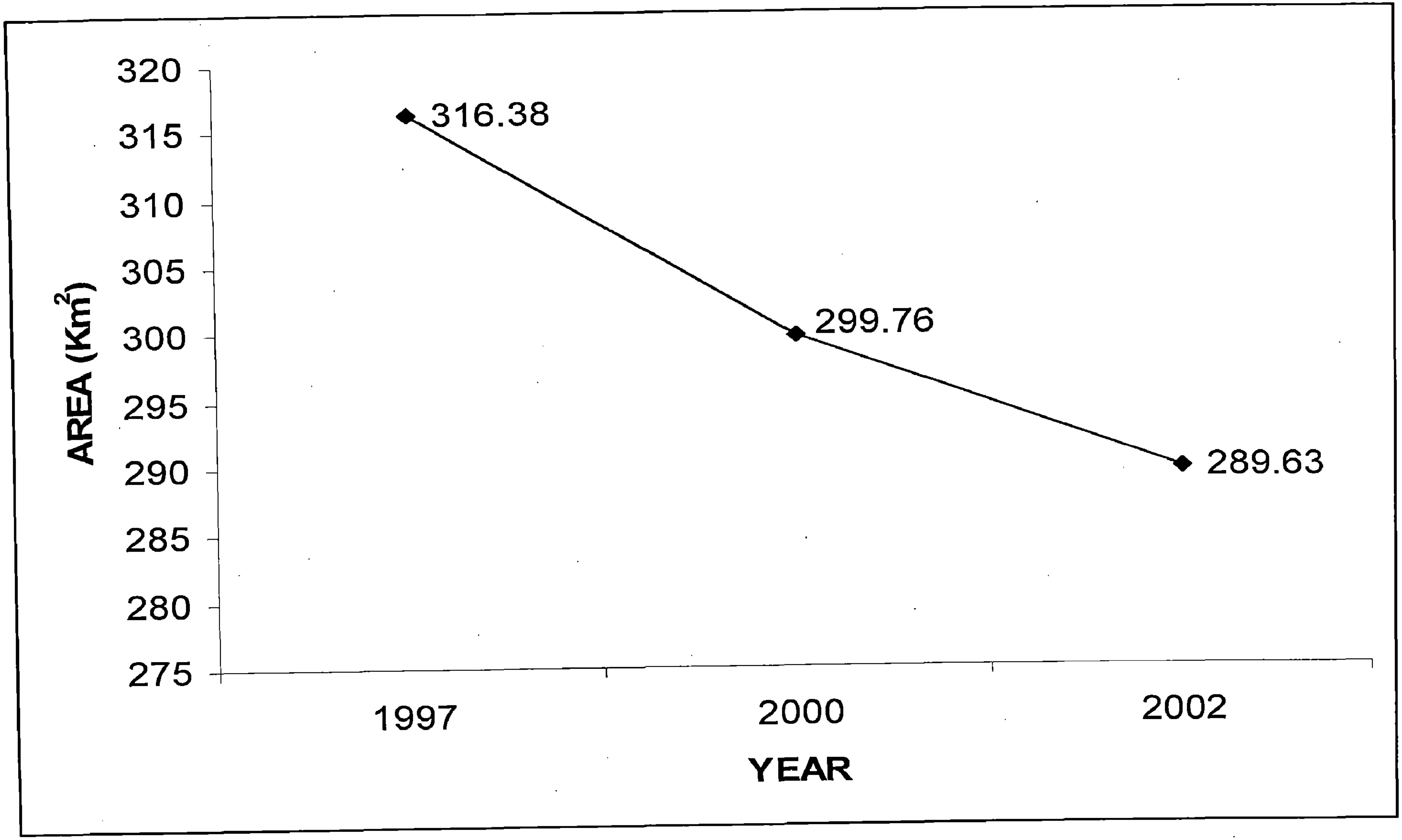


Figure 5.12: Variation in the area of Dibru- Saikhowa R.F. w.r.t. time

(b) After the implementation of river training works

The Flood Control Department, Government of Assam has requested the advice of CWPRS, Pune to tackle this serious problem of avulsion. The CWPRS, Pune has conducted a morphological study of the river for Saikhowaghat - Ananta Nallah reach and suggested phase wise measures for permanent solution of the problem at this reach.

On the suggestions given by CWPRS, Pune, the Flood control Department, Government of Assam had prepared a four phase plan to tackle the problem.

Phase I : Works to channelise the flow in rivers Lohit, Dibang, Ananta Nallah and Balu Nallah in Dholla Hatighuli area during Year 2002.

1. Construction and excavation of a pilot channel along the dead channel ob Dibang River for a length of 6500 metre.
2. Construction of permeable R.C.C. porcupine screens to divert the flow through proposed length of pilot channel.
3. Construction of Tie bund for a length of 2000 metres for anchoring the permeable screens with earth and sand fill cement bags. (X, Figure 5.14)
4. Construction of retirement bund at Dholla Hatighuli. (X, Figure 5.14)

After the completion of the Phase-1 works (Sr. No. 1, 2 & 3) as mentioned above, major flow of river Dibang have diverted to its original course and the flood affected villages in the Dholla – Hatighuli area were protected. The flow through Balu Nallah has been reduced and erosion along the southern bank of Balu Nallah has been minimised (Figure 5.13).

On the recommendations of an expert team consisting of the Brahmaputra Board, CWC, CWPRS and Flood Control Department, Government of Assam officials, following further measures has been taken up under Phase I (B) and Phase II for diversion of balance flow of Dibang River and diversion of Lohit River to its original course. The works recommended by the Expert team were taken up in 2004 under the Phase-I (B) and Phase-II.

The following works were proposed under phase-I (B):

(i) Permeable RCC Porcupines (31,560 Nos.) @ 3m c/c spacing for a length of 1500 m for closing of newly formed channel at the end of RCC screen.

(ii) Permeable bamboo crib (816 Nos.) for protection of left bank of the river Lohit.

(iii) Raising & filling of deeper bed portion frorn chainage 2410m to 2710m for a crest width of 15 m to stop overflow.

(iv) Repair of existing Tie Bund for a length of 2110 m with crest width of 3.0 m and side slope of 1:1 on both sides at the damaged portion.

(v) RCC Porcupines (31140 Nos.) for protection of left of the river Lohit @ 3m c/c spacing for a length of 2500 m.

(vi) Construction of Permeable PVC pipe of 16 cm diameter at 2.5 m c/c spacing spurs (2 Nos. @ 50 m c/c spacing) on the left bank of river Lohit for a length of 25 m each making a length of 50 m.

These works were completed in July 2004. As a result of these works the balance flow of the Dibang River has completely diverted towards the north side and also observed siltation in the left bank of Lohit River in the Dhollaghat area (Figure 5.14).

Phase II: Works to divert the flow of Lohit River towards further north to meet Dibang River

(i) Construction of RCC porcupine screens across Balu Nallah and Ananta Nallah in two strips, 4 Nos. of rows in the u/s and 3 Nos. of rows in the d/s. In addition, 4 rows of bamboo cribs between the RCC porcupines have also been proposed in the deepest portion of the Balu Nallah for a length of 500 m of the screen to induce more siltation. (E & F, Figure 5.14)

(ii) A pilot channel of 30 m bed width with bell mouth transition from a width of 100 m at the beginning to a width of 30 m in a distance of 100 m to guide the flow. (G, Figure 5.14)

The works of construction of the RCC porcupine screens under Phase- II was completed in July, 2004 and the work of pilot channel was left incomplete.

As a result of all above works, considerable amount of flow of river Lohit has been diverted towards the north of Saikhowa forest. In the reach from Sisini to d/s of Dhollaghat, the deeper channel of the river has been shifted towards

North and siltation has taken place near the Dhollaghat area. The flood channel off-taking from Sisini has almost silted up (Figure 5.14).

It has been observed that for Dibang River the river training works executed in the form of porcupine has already been proved successful. Further works executed before, floods of year 2004 has also further improved sedimentation in the old channel and is almost closed. Some tendency of development of channel observed close to the porcupine screen. It was indicated that screens may be constructed at the off take of the channel so as to induce sedimentation in the off take channel. It was reported that a minor channel has developed at the u/s end of the Tie bund during high flood. The new channel may be closed by further rows of RCC porcupine screen in the newly developed channel.

But for Lohit River, the training measures in the form of pilot channel and porcupine screen provided in the river Lohit for diverting the channel away from the bank had only a limited success due to very small difference in the water levels at both ends of the pilot channel. To divert the Lohit River flow completely following river training works are proposed under the Phase III.

Phase III:

A. Works for diversion of Lohit River

1. Construction of 7 rows of RCC porcupines screens across the Lohit River for a length of 5500 metres. (C, Figure 5.15).

2. Construction of 3 rows of RCC porcupines along the pilot channel for a length of 4000 metres. (D, Figure 5.15).

3. Construction of 3 rows of 3 metres RCC porcupines along the left bank of Lohit River from tying point of the RCC screen across the Lohit for a length for a length of 2000 metres and a screen of length 600 metres at off take of the spill channel at the Sisini for the protection of the left bank of Lohit River. (K, L, Figure 5.15).

4. Construction/Improvement of existing pilot channel by excavation at the entry and the exit portion and improvement of the channel in middle portion wherever necessary to guide the flow of Lohit River to meet the new channel of Dibang near Dibru-Saikhowa R.F.

B. *Works along the left bank of Dibang River at Bahbari*

1. Construction of 4 rows of 3 metre RCC porcupine in the vulnerable portion at the down stream of the Tie Bund (across the off take of old Dibang River) for a length of 1200m. (A, Figure 5.15).

2. Construction of 3 rows of 3 metre RCC porcupine for a length of 150m at upstream of the existing Tie Bund to close the spill channel. (B, Figure 5.15).

Apart from the works of Phase III, it has also been decided to use porcupines of length 4 to 5 metres and larger cross section for better performance.

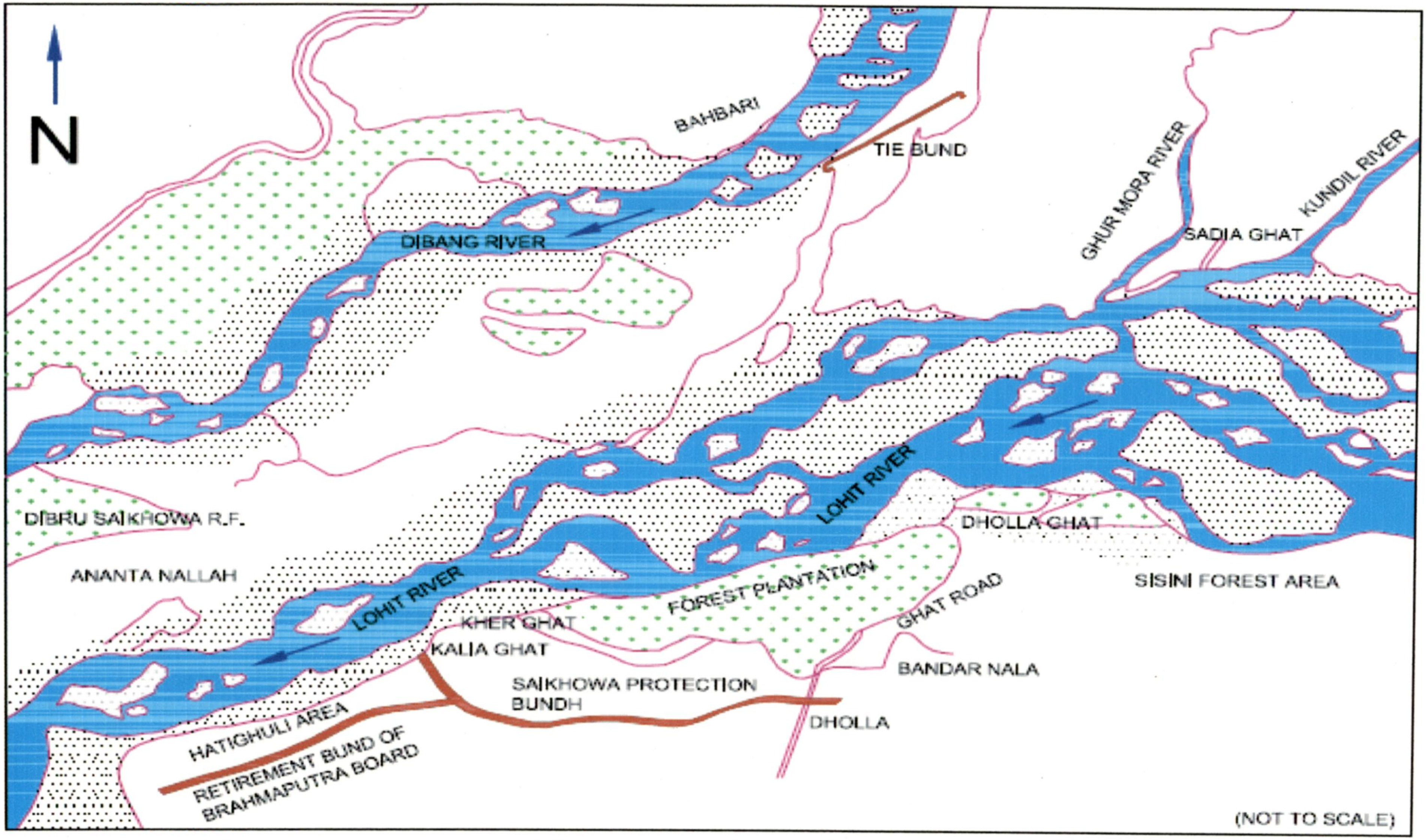


Figure 5.13: Avulsion of Brahmaputra at Dholla Hatighuli Area (Source: Brahmaputra Board)

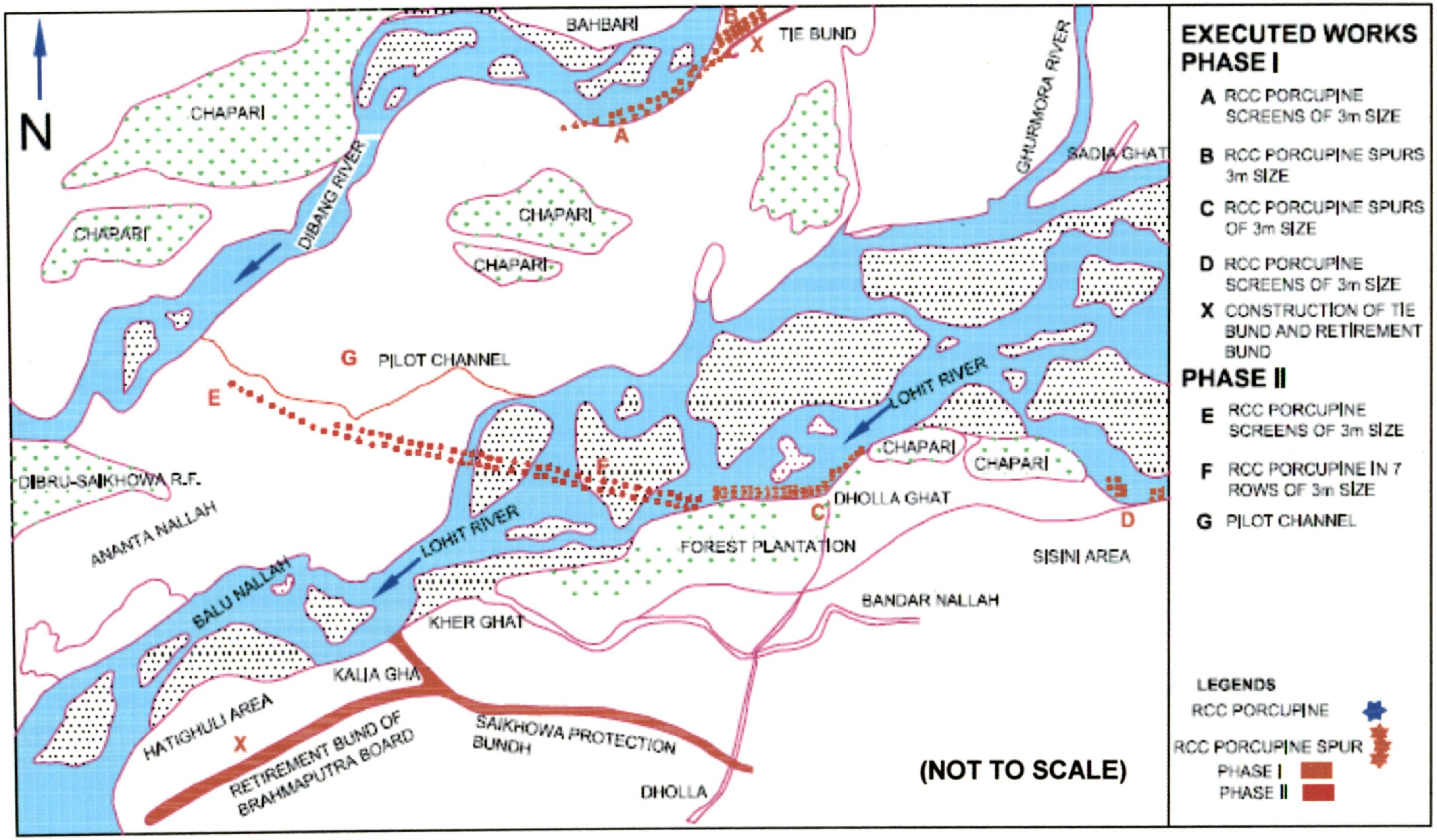


Figure 5.14: Layout Map of Executed Works under Phase I & Ii (Source: Brahmaputra Board)

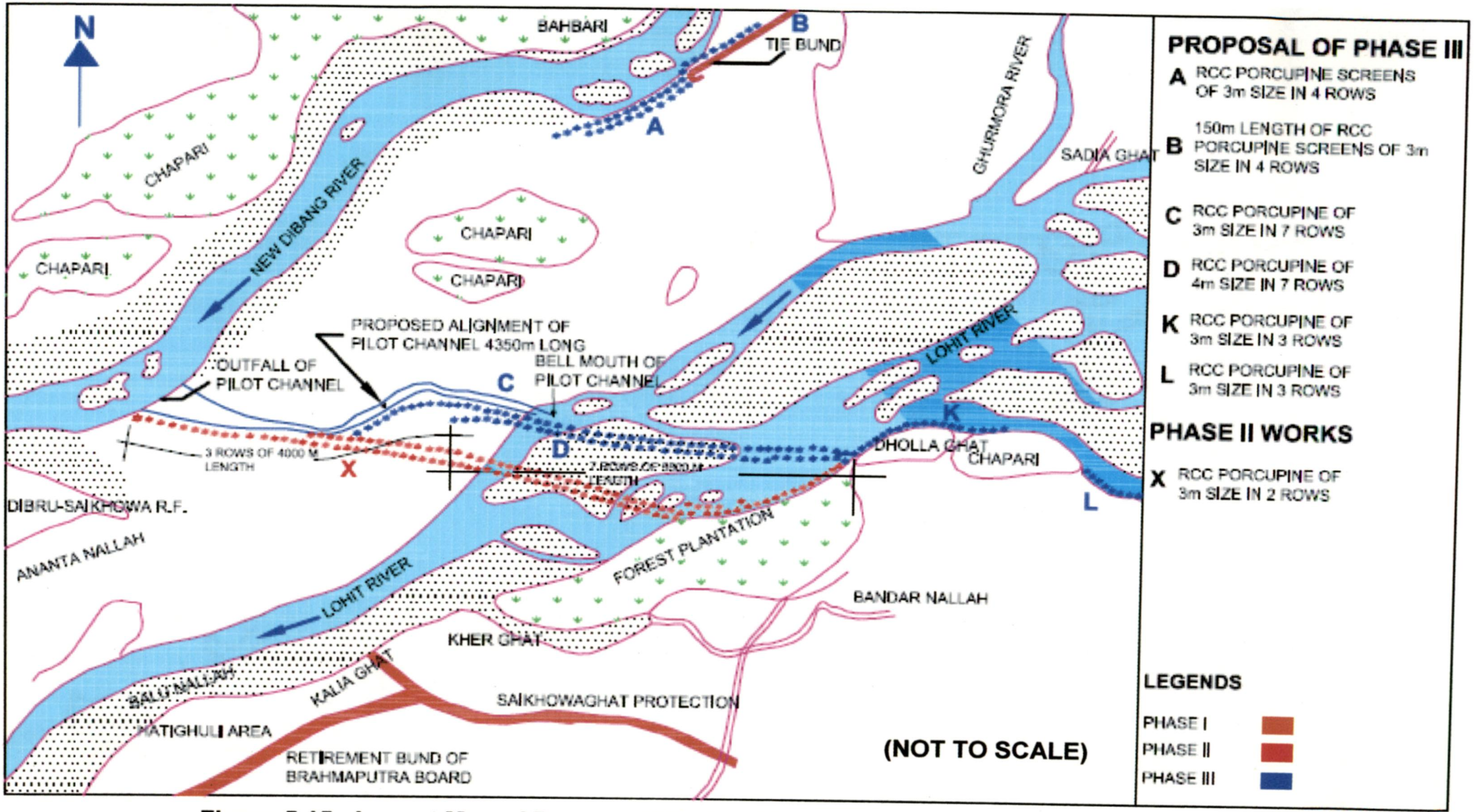


Figure 5.15: Layout Map of Proposed Works of Phase III (Source: Brahmaputra Board)

CHAPTER 6

CONCLUSION & FUTURE SCOPE OF WORK

6.1 CONCLUSION

The understanding of the various phenomenons associated with the morphological behaviour of the large braided stream like Brahmaputra is very necessary in order to establish some reliable relationship among different variables involved. The present study has been performed for better understanding of the avulsion in the Brahmaputra River.

On the basis of present study the following conclusions have emerged:

1. Following an avulsion, the new flow path of avulsed channel followed the pre-existing course of a small tributary of a main channel. In this study Dangori tributary of the Dibru River served the same purpose.
2. The increase in the discharge due to diversion of flow from the parent channel resulted in 2 to 3 times increase in the width of avulsed channel in 5 years (1997 to 2002).
3. It opined that increase in the cross slope of the Lohit River, which may be responsible for transfer of flow towards the Saikhowa Bund thus causing avulsion, may be due to tectonic activities in the area.
4. Bank erosion along the avulsed channel took place where turbulence is excessive mainly at the confluence of the two streams.

5. The area of Dibru-Saikhowa Reserve Forest has evidently decreased by 26.75 Km^2 over a period of 5 years from 316.38 Km^2 in 1997 to 289.63 Km^2 in 2002.
6. The maximum length of the Dibru-Saikhowa R.F. has decreased by 2.15 Km in 5 years.
7. The progressively upstream shifting of avulsion site nearly 4 km southwards at Dholla confirms to the study conducted by Mackey and Bridge (1995).
8. River training measures (construction of tie bund, retirement bund, pilot channel, porcupine screens etc.) proved effective in diverting the flow of Dibang River to its original course.
9. Porcupines screen of 3 metre height not proved very effective in diverting the flow of Lohit River to its original course because of its high discharge.

6.2 FUTURE SCOPE OF WORK

Keeping in view the serious problems due to avulsion and for their mitigation, various river training works namely construction of porcupines, pilot channel, spurs etc for the diversion of flow of Lohit and Dibang Rivers back to their original course have been implemented. In this context, the performance of RCC porcupines of height 4.5 m to 5.0 m can be evaluated by physical modelling. Also, some numerical model can be developed by using hydraulic and hydrographic data for the threshold of different causes triggering the avulsion.

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Zhao-Yinwang, Shixiong Hu, Yongsheng Wu and Xuejun Shao (2003), "Delta processes and management strategies in China", Intl. Journal of River Basin Management Vol. 1, No. 2 (2003), pp. 173–184. © 2003 IAHR & INBO.