FINAL REPORT

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On

Morphological Study of River Hooghly using Remote Sensing Technique

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Preface

Morphology of rivers is a field of science which deals with the change of river plan form and cross sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements. The morphological studies, therefore, play an important role in sustainable river management & restoration structures as well as for mitigating flood risk and geomorphic hazards. From a scientific and rational approach to different river problems and proper planning and design of water resources projects, an understanding of the morphology and behaviour of the river is a pre-requisite.

The morphological studies on various Indian rivers using remote sensing techniques are an important requirement for the Central Water Commission (CWC), Government of India and other State Water Resources Departments. The use of remotely-sensed data in natural resource mapping and as a source of input data for environmental process modeling has been popular in recent years. With the availability of remotely-sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions has made remote sensing as, perhaps, the best sources of data for large scale applications and study.

The Department of Civil Engineering and the School of Water Resources, Indian Institute of Kharagpur were engaged as consultants for preparation of Morphological Studies of the rivers Mahanadi, Mahananda and Hooghly using Remote Sensing Techniques by the CWC. The team focused on the morphological structures, erosion/deposition pattern, cross section profiles, water level information and sand mining areas. Various tables and diagrams are generated based on primary and secondary data with field observed photographs to authenticate the contents of the morphological report.

The present report provides a detailed database of information generated on the Hoogly through the consultancy work, as mentioned above. Please note that the stretch of river studied in this project is a distributary of the river Ganga, offtaking from near Farakka. The upper stretch of this river is known as the river “Bhagirathi”, while the lower stretch that is affected by the tides of the Bay of Bengal, is known as river Hooghly. However, in this report the entire stretch of river is referred to as river Hooghly.

Acknowledgement

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Figure No.	LIST OF FIGURES	Page No

LIST OF TABLES

LIST OF ANNEXURE

CHAPTER 1

INTRODUCTION

1.1 Overview

Water flowing over the land surface is the leading agent of land space alteration. Water flowing downhill inherently contains the energy and the rate of energy is power, which power erodes the surface and makes its own path to follow. Those paths with flowing water are known as a stream or river. River morphology or fluvial geomorphology is used to describe the shapes of river channels and how they change in shape and direction over time. It is dynamic and constantly changing in both space and time.

It is clear that rivers play an important role in landform evolution; the force of water is deeply connected to the dislodging of soil and rock particles and their conveyance. Where the power of water becomes less, it is forced to deposit the particles on its way. When the sediment load being transported by a river is less than sediment transporting capacity of the river and the excess sediment needed to satisfy the capacity of the river will be scoured from the erodible riverbed. Degradation results in channel incision and milder slopes, often this phenomenon is observed downstream of a dam constructed on a river. When the sediment transporting capacity of a river at a point becomes less than the sediment load being carried, as a result of reducing the velocity due to an increase in cross-section or reduction in the slope of the river, the excess sediment gets deposited on the river bed. As a result the riverbed raises, the phenomenon is termed as aggradation. Channel aggradation may also occur in a river reach if due to geological reasons (say, increase of erosion of the catchment) the sediment load being conveyed to the river increases than that can be carried by the river in equilibrium. As a result the river bed rises and forces the channel to carve out its path in a braided fashion. For braided rivers, there is a tendency for a stream to widen and become very shallow with bars subjected to rapid changes in morphology. At high flows braided streams have a low sinuosity and often appear to be straight at low flows, numerous small channels weave through the exposed bars. A river that winds a course not in a straight line, but in a sinusoidal pattern is called a meandering river. It is the continued action of the secondary flow developed on the river bends that cause further erosion

on the outer bank and deposition on the inner bank. The meandering action increases the length of the stream or river and tends to reduce the slope. Channel meandering is a result of an ongoing bed and bank deformation of the flow in a self-formed alluvial channel, thus the meander sinuosity increases with the passage of time. The increase in sinuosity of a meandering river is associated with riverbank retreat. Riverbank retreat or bank erosion is inseparably connected to lateral river migration or river bank shifting.

Sinuosity is the only plan-form parameter used in the initial delineation of the stream. Sinuosity describes how the stream has adjusted its slope in relation to the slope of its valley and is quantitatively described as the ratio of stream length to valley length and also as the ratio of a valley slope to channel slope. The stream and valley lengths are measured from two common points in a direction that is parallel with the line of the valley. The shape of the river in a plan is very important in many design problems concerning the location of bridges, etc. In general, the plan forms of alluvial rivers can be classified as (i) Braided, (ii) Straight and (iii) Meandering. In streams having highly variable discharge and easily erodible banks, sediment gets deposited to form bars and islands that are exposed during periods of low discharge. In such a stream the water flows in a braided pattern around the islands and bars, dividing and reuniting as it flows downstream. Where they do occur, the channel is usually controlled by a linear zone of weakness in the underlying rock, like a fault or joint system. Even in straight channel segments, water flows in a sinuous fashion, with the deepest part of the channel changing from near one bank to near the other. Velocity is highest in the zone overlying the deepest part of the stream. The velocity structure of a stream, and especially in streams flowing over low gradients with easily eroded banks, straight channels will eventually erode into meandering channels. Erosion will take place on the outer parts of the meander bends where the velocity of the stream is highest. Sediment deposition will occur along the inner meander bends where the velocity is low. Such deposition of sediment results in exposed bars, called point bars. Because meandering streams are continually eroding on the outer meander bends and depositing sediment along the inner meander bends.

Remote sensing and GIS techniques help to analyze and visualize those morphological characteristics and changes in the river. It also helps to understand the effect of morphological changes in natural and man-made features on the earth's surface.

1.2 Objectives

The specific objectives of works, as mandated by the Central Water Commission, are as follows:

a) 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 final river drainage maps.

b) To Study shifts of river courses and also changes in its plan form from the base year (say 1970) till 2010, by collecting 4 sets of satellite imageries at 10 year interval in addition to one set of Survey of India toposheets for the base year on a scale of 1:50,000. In case toposheets are available for the older period, say 1950, the base year may be shifted accordingly.

c) Compile changes in land use/land cover and study of its impact on river morphology.

d) Channel evolution analysis to describe the status of the river channel. The analysis of the channel dimension, pattern, and longitudinal profile identifying distinct river reaches i.e., channel in the upper reaches, a channel in a flood plain with bank erosion, etc. This segregation of the reaches is to be determined by using channel evolution analysis.

e) Work out the rate of bank erosion/deposition in term of erosion length & erosion area w.r.t. base year at 50 km interval.

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

g) Evaluate the impacts of major hydraulic structures on the morphological behavior of the river's course and its impacts on river morphology.

h) Evaluate braiding pattern of rivers by using plan-form index (PFI) criteria along with its threshold classifications.

i) Compile information (if any) on flood affected areas in the vicinity of river course prepared by NRSC using Multi-temporal satellite data of IRS WiFS (188m) & Radarsat Scan SAR Wide & Narrow (100 m & 50 m).

j) Plot probability curve (exceedance probability vs. flow rate) and show flow rates corresponding to return period of 1.5 years and 2 years for different CWC H.O. Locations. The observed flows need to be normalized before using for analysis.

k) Relate the morphological changes in the river on the basis of available peak discharges of different years in the time domain considered in this study. Study impact of changes in annual rainfall in the basin on river morphology.

l) Identify critical and other vulnerable reaches, locations. Analysis of respective rate of the river course, shifting and based on it, future prediction of river course behaviors.

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

n) Possible location of river sand mining areas in the river reaches.

CHAPTER 2

REVIEW OF LITERATURE

2. Overview

There are several direct and indirect methods of monitoring the river bank erosion/ deposition, river course shifting and flood delineation. The direct method is taking measurements from the field in terms of linear rates of erosion/deposition, volumes of erosion and channel cross section. The indirect method involves as analyzing the archival sources at various time scales with the sediment records. The archival sources can be conventional survey maps, aerial photos or satellite images. In present days, satellite remote sensing and GIS methods/models took the key role in river morphological/engineering studies and geospatial database creation for various analyses. Multi-temporal high-resolution satellite data are used to analyze the river configuration, shifting of courses, the formation of new channels/oxbow lakes, bank erosion/deposition, and drainage-congested areas and also for mapping the database in various scales according to purpose. The remote sensing information also used in river morphological application studies, like flood control, monitoring work, vulnerable reaches identification, river bank protection planning, river bank beatification, drainage improvement planning etc.

2.1 Application of remote sensing and GIS for river shifting analysis

No study is available on river shifting, erosion and deposition, LULC change, soil loss estimation, and possible sand mining area identification based on different resolution satellite data using remote sensing and GIS techniques in the whole Hooghly river. Some researchers carried out on the cause and process of the changing nature of morphological features during the last few decades. A medium number of researchers studied river shifting analysis, erosion-deposition, LULC change using geospatial techniques in different river basins of India. The monitoring the river course changes using IRS 1A and IB LISS-II satellite images for the periods of 1991-1993 on the Ravi river, Amritsar and Gurdaspur Districts of Punjab is available in Thomas and Sharma (1998). The results show that drastic changes in the river course of 20 years due to human activities. Goswami et al. (1999) analyzed bank erosion of various changes in the

channel of the Subansiri river by different index (e.g., sinuosity) in Assam. The bank line of the river is divided by 10 equal segments for the periods 1920–1970, 1970–1990 and 1920–1990. Lahiri and Sinha (2012) identified syntectonic evidence of changes in the morphodynamics for 90 years using platform index in the Brahmaputra River. In this research, the planform characteristics of the Brahmaputra river depends on subsurface configuration and channel slope from upstream to downstream reaches.

Sinha and Ghosh (2012) analyzed temporal dynamic changes of Lower Ganga Plains using satellite images for habitat dynamics. The results show that the Farakka barrage has moved towards the east, but channel shifting downstream of the Farakka barrage has been erratic. Laha and Bandyopadhyay studied the morphometric change of the Ganga River, upstream of Farakka Barrage up to Rajmahal based on sinuosity and braideness index for the periods of 1955, 1977, 1990, 2001, 2003, 2005 and 2010 using multi-resolution satellite images. This research work mainly focuses prediction on the river's future trend and identification of vulnerable areas. Sarkar et al. (2012) analyzed channel pattern changes and shifting of bank line based on a normalized difference water index (NDWI) using IRS 1A LISS-I, and IRS-P6 LISS-III satellite images for the periods of 1990-2008. This analysis included not only river morphology, stable and unstable reaches of the river banks and changes in the main channel. The results provide a guideline of drainage development programmes and erosion control schemes in the northeastern region of the country. Identification of riverbank erosion and change detection analysis of the Pravara River flowing into the northern part of Ahemadnagar district into Akole using remote sensing data is available in Aher et al. (2012). Mallick (2013) identified bank line shifting and fluvial-geomorphological changes using remote sensing techniques in the part of the moribund deltaic region of district Nadia. The objective of the study is to identify the different pattern of fluvio geomorphic features on the flood plain by GIS platform. The analysis indicates the anthropogenic cause has a greater influence on morphological changes.

Gogoi and Goswami (2013) performed shifting of the bankline due to erosion in the Subansiri river using the satellite imagery (IRS LISS-III of 1995 and Landsat 5 TM of 2010) of 1995 and 2010. It is one of the principal tributaries of the Brahmaputra river. It contributes as much as 11% of the total flow of the river Brahmaputra. The Lower Subansiri has flood and drainage congestion problems. The results show erosion is dominant in the upper, middle a lower channel.

Laha (2015) studied fluvio-geomorphological analysis of the Bhagirathi-Hooghly River reach from 5 km north of the confluence of Ajay River for 5 km south of the Jalangi River using satellite images. This analysis shows that north-south flowing river is characterized by acute meandering (e.g., cut-off meanders, ox-bow lakes, meander scars, abandoned channels). Mongaldip et al. (2015) analyzed bank erosion and shifting based on cross-section data in the Hooghly river at Sundalpurchar and Gosainchar Mouza, Ranaghat-I Block, Nadia. This research mainly focuses on the formation of a mid-channel bar named Mangaldwip. Maurya and Yadav (2016) identified the historical changes in the Ramganga river course using remote sensing and GIS techniques from 1972-2013 for river management and planning framework. The delineation of river course changes by Landsat MSS, TM, ETM+ and LISS-III images from 1972, 1989, 2000, 2005 and 2013. The result shows the shifting trend is the south-west direction in different places. Rai et al. (2018) studied quantitative and qualitative assessment of the floodplain region of the lower Kosi river basin based on morphometric analysis using remote sensing data from the GIS platform. The Landsat data of 2005, 2010 and 2015 are utilized to assess the changes in the dynamic of river basin for watershed prioritization by GIS environment. Moreover, the morphometric parameters can be assessed nature of bedrock, infiltration capability and surface runoff for channel development.

2.2 Impact of land use/land cover change on river morphology

According to Shirira and Yanda (2002), management of riparian ecosystems would be of particular importance in mitigating the effects of land-use/cover change on the southern slopes of Mount Kilimanjaro, north-eastern Tanzania. Establishment of riparian buffer vegetation using appropriate plant species will increase infiltration and water storage in the catchment and reduce sediment loading in the river. The changing proportions of these land-use types within a basin can have dramatic effects on discharge and response to storms, either increasing total yield in a flashier manner or decreasing and smoothing the hydrography in the Hilly Red Soil Region of Southern China (Zheng et al., 2008). Wang et al. (2012) developed an integrated erosion model for land use information and the effects of land use changes on soil erosion in the Lushi basin, China. Land use affects soil erosion through altering soil loss and influencing sediment delivery, which indicates the relative minor land use changes had a significant effect on regional soil erosion rates and sediment transport to rivers. Prokop and Sarkar (2012) employed to delineate

three study areas along river courses on alluvial fans based on a hydrologic and geomorphic approach using topographic maps and satellite images combined for land use transformation in the Sikkimese-Bhutanese Himalayan piedmont over last 150 years. The effect of land use changes on soil erosion is also assessed after the transformation of forest to farmland. Mahapatra et al. (2014) analyzed long-term morphological changes of Narmada estuary based on LULC change using multi-date maps and satellite images spread over a 37-year period. It is a significant change in the LULC and morphological feature for the evolution of river mouth geomorphology. The result shows that continue increasing human activities, like salt pans, industrial and settlements during past three to four decades.

Hazarika et al. (2015) show in an active floodplain that change in the land-use occurred due to the river dynamics of upper Brahmaputra plains. Importance of river dynamics of land-use is a major concern as it directly influences livelihood of the floodplain dwellers. The study shows that increased in settlement and agricultural land, but grassland is decreased. Thus, erosion and deposition area in the river basin affected by agricultural land. Zope and Jothiprakash (2016) performed, the impact of land use–land cover (LULC) change on urban flooding using the HEC-GeoHMS and HEC-HMS models for periods 1966, 2001 and 2009 in the Oshiwara River Basin in Mumbai. The flood plain and hazard maps for various flow condition have been developed by using the hydrological model. Moreover, the developed output can help to prepare flood mitigation and early evacuation management planning framework. Debnath et al. (2017) described the channel migration of the Khowai river of Tripura directly affects the land use, which has a direct impact on the floodplain dwellers. River reveals the endangered condition of the nearby settlements and infrastructures due to high bank erosion. The output results very much helpful for upcoming future mitigate the hazards and minimize human intervention to the natural flow of the river. Finally, remote sensing & GIS technology provides a detailed assessment of spatial and temporal changes in the river under changing climatic condition.

CHAPTER 3

STUDY AREA AND DATA USED

3. Overview

The watershed lies in both the regions of West Bengal and Jharkhand states of India. In Bhagalpur, the Ganga River begins to flow south-southeast and at Pakur, it begins its attrition with the branching away of its first distributary, the Bhagirathi-Hooghly, which goes on to become the Hooghly River. The Hooghly River (Figure 1), flowing mostly in a southerly direction, is the portion of the river which is affected by the tidal flow. Just before the border with Bangladesh, the Farakka Barrage controls the flow of the Ganges, diverting some of the water into a feeder canal linked to the Hooghly for the purpose of keeping it relatively silt-free. The Hooghly River is formed by the confluence of the Bhagirathi River and Jalangi River in Nabadwip, and Hooghly has a number of tributaries of its own. The largest is the Damodar River. Other important tributaries are Mayurakshi River, Ajoy River and Kangsabati River. The Hooghly River empties into the Bay of Bengal near Sagar Island. For the purpose of this study, the Hooghly river is divided into 14 reaches, starting from the Farakka Barrage (Reach 1). Each reach distance is around 34 kms, approximately.

A few other points may be noted for the river Hoogly which are important from hydraulic and morphological points of view. The lower portion of this river, in its estuary, experiences a phenomenon called the “tidal bore”, which occurs only on specific high tide dates and at specific streteches of the river , going up almost up to the port of Kolkata (formerly Calcutta) – the only river port of the country. The salinity of the river due to the influence of the tidal fluctuations of the sea is also significant mostly on the stretch of the river downstream of Kolkata and the drinking water supply of the city is obtained from the river itself. In its upper reaches, where the river goes by the name of “Bhagirathi”, the river flows around in meanders at several places and remnants of ox-bow lakes may be seen from the satellite imageries. However, there is no formation of braiding anywhere in the the entire river system of Bhagirathi-Hooghly.

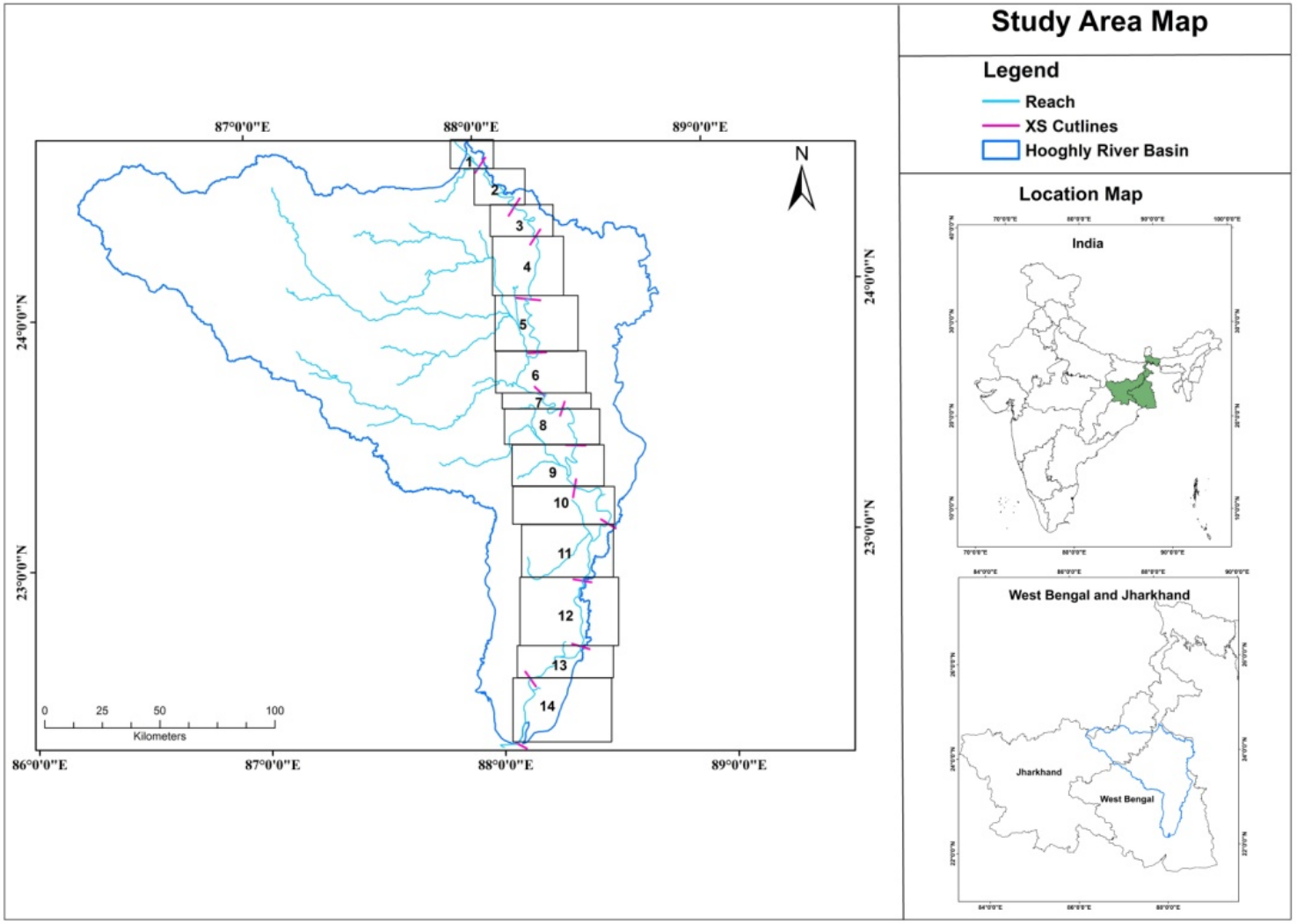


Figure 1: Study area map of Hooghly river basin

3.1. Soil:

The texture of the soil, which is classified into 5 types, namely coarse -loamy, fine, fine loamy, loamy and very fine textures (Figure 2). Hooghly river basin maximum area covers by the fine and fine loamy.

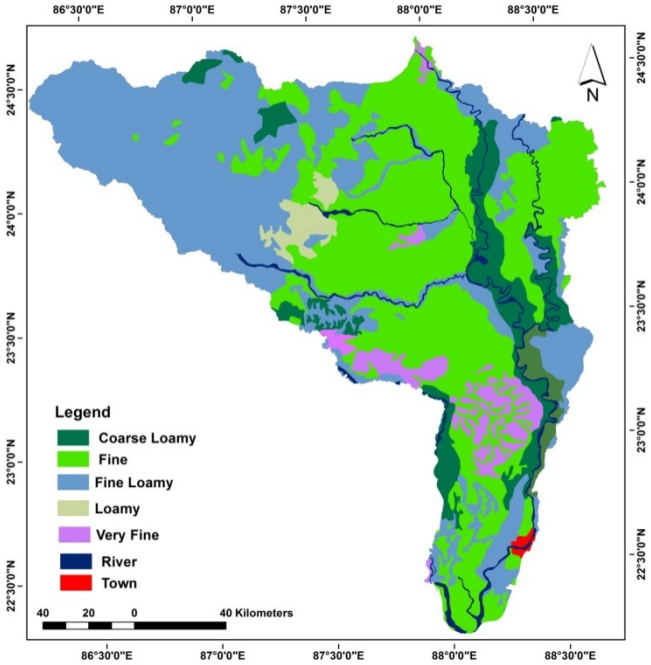


Figure 2: Soil map of Hooghly river basin

3.2. Rainfall:

The average annual variations in the basin based on daily rainfall data (0.25 ×0.25) for the period 1960-2010, collected from IMD, is shown in following the Figure 3. The major part of the basin area receives rainfall from 1000-2000 mm. More than 90% of the total annual rainfall occurs during the monsoon.

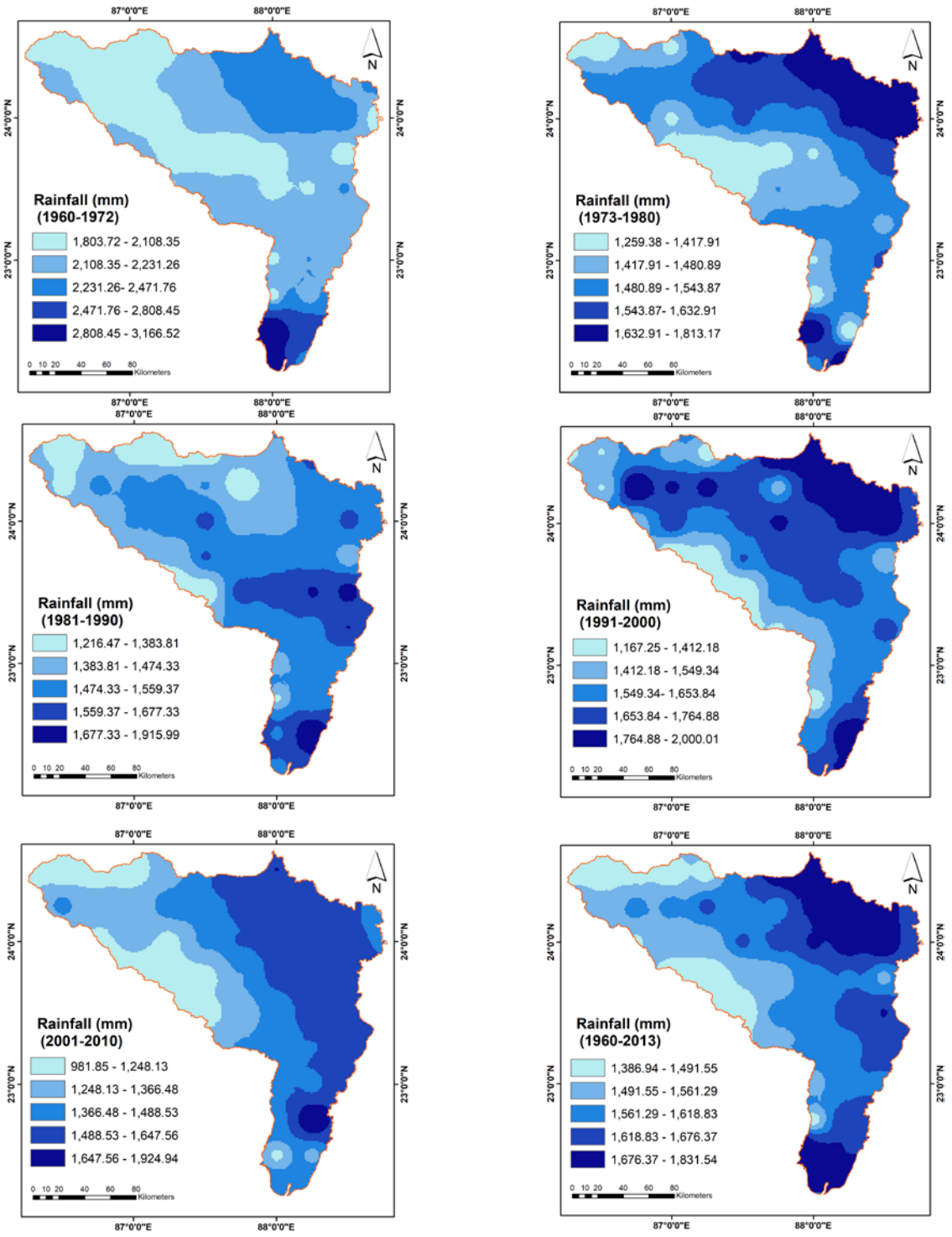


Figure 3: Rainfall map of Hooghly river basin(172, 1980.1990m, 2000 and 2010)

3.3. Geology:

The narrow part of the Hooghly basin, in between the two plateaus, is called the Holocene Garo Rajmahal gap. Because of the proximity of a major subduction fault on the north and a transform fault on the east, the Hooghly basin and its adjacent areas are tectonically very active. The Hooghly river basin geological map prepared from a Geological Survey of India (GSI) shown in following Figure 4. The Hooghly basin area can be divided into eleven geological classes: a) Holocene (45.26%),b) Pleistocene (Lower) (8.70%), c) Proterozoic (4.02%),d) Jurossic- Cretaceous (1.02%), e) Proterozoic (0.79%),f) Pleistocene (Lower) (3.84%), g) Pleistocene (Middele to to Upper) (19.46%) , h) Kolhan series/Limestone (16.05%), i) BHQ/BHJ/Metased Mentary (0.33%), j) Lower Gondwana system/Carbona (0.45%)and , k) Rajmahal Trap (0.03%).

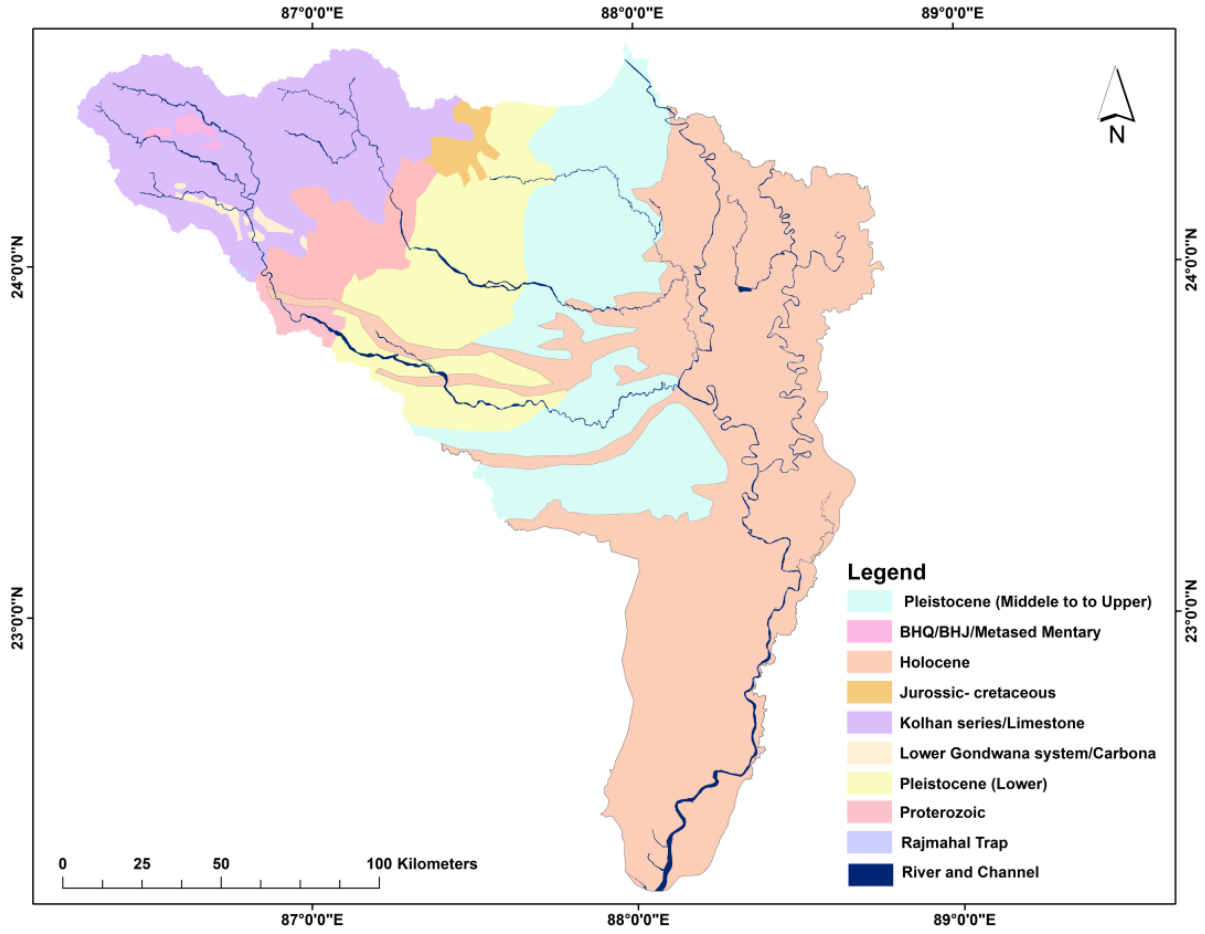


Figure 4: Geology map

3.4. Data Used:

Table 1: Data information of Hooghly river basin for morphological Study

Toposheets					
Data		**Data sources**	**Year**	**Scale**	**Remarks**
Toposheeets for Hooghly river Basin		SOI, Dehradun	1970 onwards	1: 50,000	Available data is not cover the whole study area
Remote Sensing Data for study shifting of river					
Data		**Data sources**	**Year**	**Resolution**	**Remarks**
Landsat MSS		USGS	1972 and 1980	60 m	Only main river
IRS LISS-I		NRSC, Hyderabad	1990	72.5 m	Only main river
IRS LISS-II		NRSC, Hyderabad.	2000	36.25 m	Only main river
IRS LISS-III		NRSC, Hyderabad.	2010	23.50 m	Only main river
Remote Sensing Data for land use/land cover mapping					
Data		**Data sources**	**Year**	**Resolution**	**Remarks**
Landsat MSS		USGS	1972 and 1980	60 m	Full basin
Landsat TM		USGS	1990 and 2000	30 m	Full basin
Bhuvan land use and land cover		Bhuvan	2010	1:250,000	Full basin
Hydro-meteorological Data					
Name of the station	Data Types	Data Sources	Year	-	-
Bazarsau	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1958-2015	-	-
Berharmpore	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1968-2015	-	-
HR Farakha Feeder	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1975-2015	-	-
Kalna EBB	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1956-2015	-	-
Kalna Flow	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1957-2014	-	-
Katwa	Rainfall	IMD	1970-2010	-	-
	Hydrological Data	CWC	1991-2015	-	-

CHAPTER 4

METHODOLOGY

4. Overview

The present study, Survey of India toposheets and satellite data has been used to delineate the course of the Hooghly River. Satellite data for the year 1990, 2000 and 2010 have been collected from NRSC, Hyderabad and Satellite data for the year 1972 and 1980 have been collected from USGS website (https://earthexplorer.usgs.gov). All the digital maps were georeferenced with the same projection and then the shifting course of the river, erosion-deposition of river banks, etc. have been studied in GIS environment by using the ArcGIS software. The data of IRS satellite of LISS-I, LISS-II, and LISS-III sensors for different dates pertaining to the years 1990, 2000 and 2010 were obtained from the NRSC. Collected data were processed and analyzed using the ERDAS software. Image mosaic, and color balancing were performed to join individual scans to generate the full basin of the river course in which Hooghly basin area was extracted. Bank lines of the year 1972, 1980, 1990, 2000 and 2010 were digitized from satellite imageries by on-screen digitization methods in ArcGIS.

On-screen visualization of Google Earth helps to generate GIS layer including riverbank line, major hydraulic structures, embankment, railway bridges, airport, city, town, important monuments. Rainfall Map of 1972, 1980, 1990, 2000 and 2010 are generated using collected data from the India Meteorological Department. Soil map and Geology map have been digitized form available Soil map and Geology map. Land Use/Land Cover (LU/LC) map of 1972, 1980, 1990 and 2000 was prepared using satellite imageries. The Landsat MSS satellite image was used for 1972 and 1980. LISS I and LISS-II satellite imageries were used for 1990 and 2000 respectively. The river was divided into 14 reaches approximately by 34 km distance to prepare the detailed study (Figure 5).

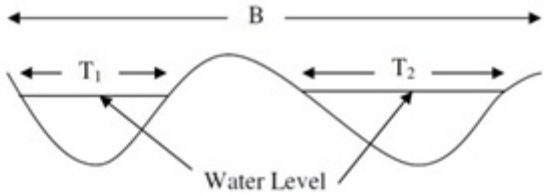
Digital Elevation Model (DEM) of 2000 was collected from USGS Earth Explorer and Google earth was used to prepare the DEM of 2010. Longitudinal profiles for each reach were drawn using that DEM. The slope was calculated for each reach. Channel evolution analysis was done comparing two DEMs of 2000 and 2010.Overlay operation performed to calculate the shifting of

the river bank, measure shifting distances, and erosion and deposition areas in specific locations. The area considered as erosion where the bank goes to the inner side of the river respected to the previous year and the area considered as deposition where the bank goes to the outer side of the river. Critical zones are extracted based on the maximum erosion of a particular location. We have identified a possible sand mining area based on maximum deposition year by year in river reaches. We have also calculated average depth using cross-section data of 1km distance in the upstream to downstream.

4.1. Plan form index (PFI) describes the river property as its braiding, meandering or straight. PFI was calculated from the following equation.

$$Plan\ Form\ Index\ (PFI) = \frac{\frac{T}{B} \times 100}{N}$$

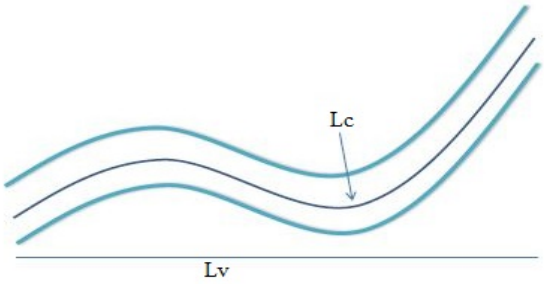
Where, $T=T_1 + T_2$= Flow top width, B= Overall flow width, N= Number of braided channels



4.2. Sinuosity index (SI) is computed by using the length of the channel and length of the valley. It is the ratio between those two lengths.

$$Sinuosity = \frac{L_c}{L_v}$$

Where, L_c = Length of the channel, L_v = Length of the valley



Hydrologic data like discharge, gauge, stage, water depth, etc. have been collected from CWC, Bhubaneswar. Plot probability curve generated based on the relation between exceedance probability and discharge relation. Recurrence interval has been calculated.

4.3. Soil loss: is an important factor for morphological study. Land use/ Land cover change, Soil type, rainfall, surface slope, etc. are influencing the total soil loss and sediment in the river. Soil loss has been estimated using RUSLE method. The RUSLE method is expressed as:

$$A = R \times K \times LS \times C \times P$$

where A is the computed spatial average of soil loss over a period selected for R, usually on yearly basis R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; LS is the slope length steepness factor (dimensionless); C is the cover management factor (dimensionless, ranging between 0 and 1.5); and P is the erosion control (conservation support) practices factor (dimensionless, ranging between 0 and 1).

The critical zone has been identified, considering the long-term effects of erosion, LULC change, shifting which is the most affected and changed zone in total length. In any reach, most eroded zones are considered as a critical zone. Identification of possible sand mining area also has been identified in the whole river basin. Finally, it is justified by field investigation.

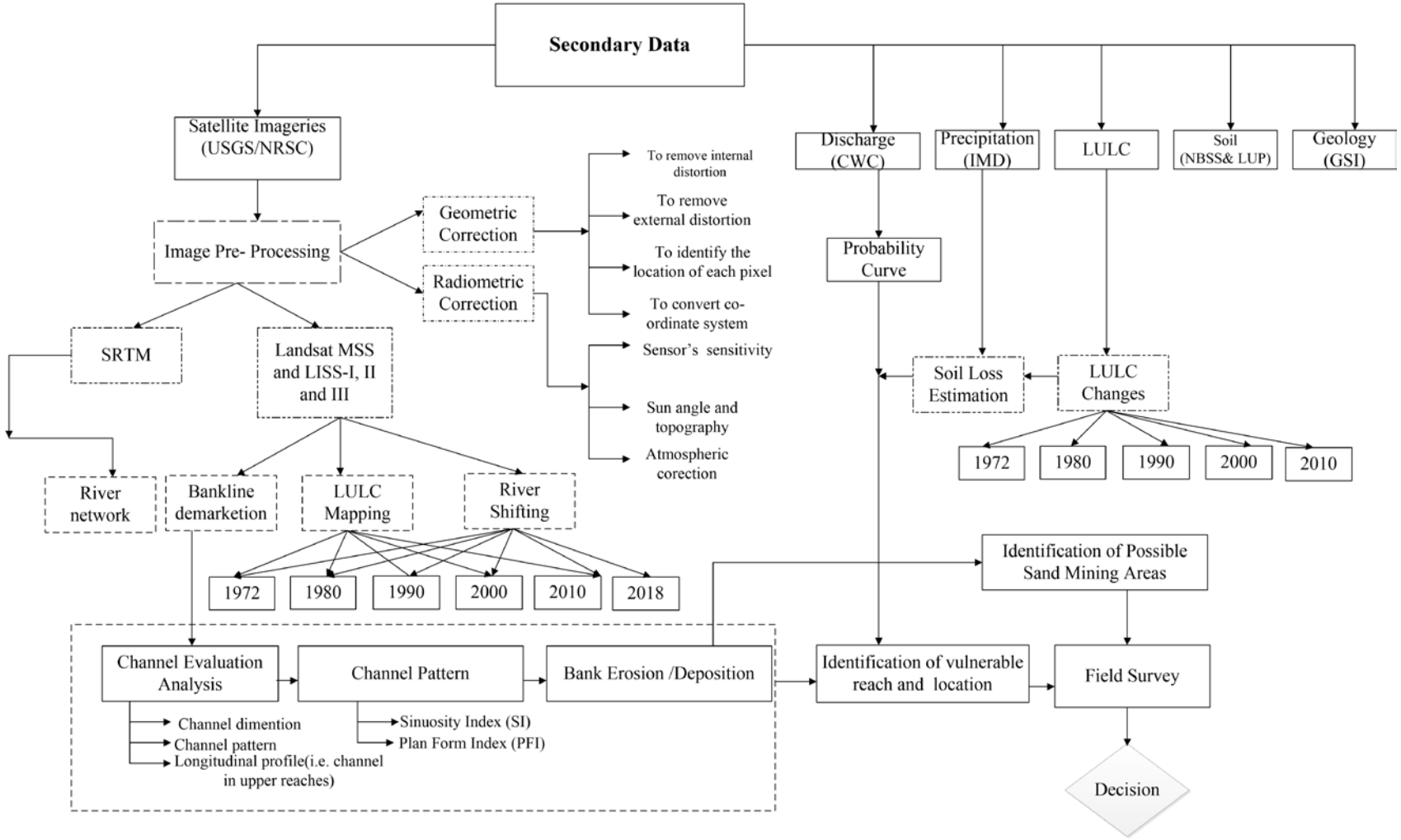


Figure 5: Overall methodology adopted for the study

CHAPTER 5

ANALYSIS AND RESULTS

5.1. River drainage map in GIS by integrating available secondary maps:

The drainage map was prepared by using remote sensing and GIS technique. The position of city, town, local place, major hydraulic structure, Railway Bridge, the airport was identified from Google Earth. Compile complete drainage map was prepared by incorporation of those things with the Hooghly River basin area (Figure 6).

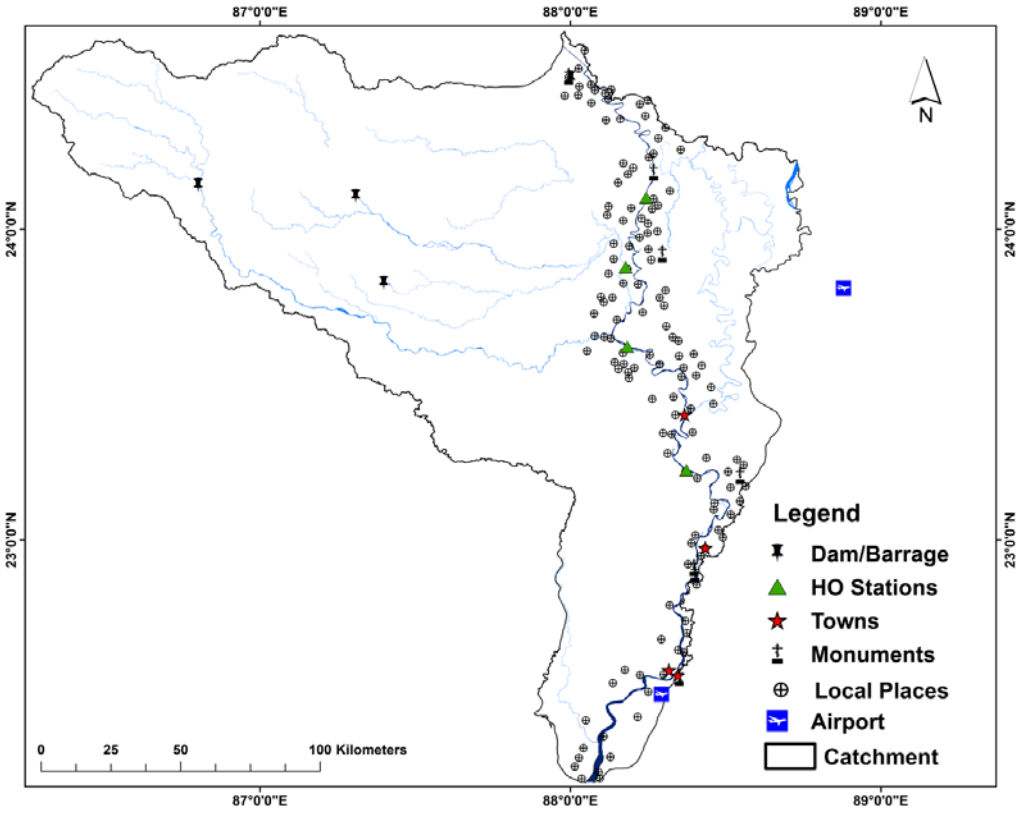


Figure 6: Compile complete river drainage map in GIS by integrating available secondary maps

5.2. Shifting of River Bank:

Digitization of the shifting of both the banks (left and right) of River Hooghly has been carried out using satellite imageries of 5 years, separated roughly by gaps of 10 years (1972, 1980, 1990, 2000 and 2010). In order to carry out the detailed analysis for river shifting and morphological parameters, the total length of Hooghly River has been subdivided into 14 reaches at an interval of approximately 34 km each (Figure 7). The left and right bank shifts for the different years (1972, 1980, 1990, 2000 and 2010) for river Hooghly are illustrated in Figure 8.1 to 8.14 by overlaying each image in a single map. Also, the the shift in the distance of the centre-line of the Hooghly River is presented in Table 2. The left and right bank lines for the years 1972, 1980, 1990 and 2000, using the year 2010 as the baseline, is shown in Figures 9.1 to 9.7.

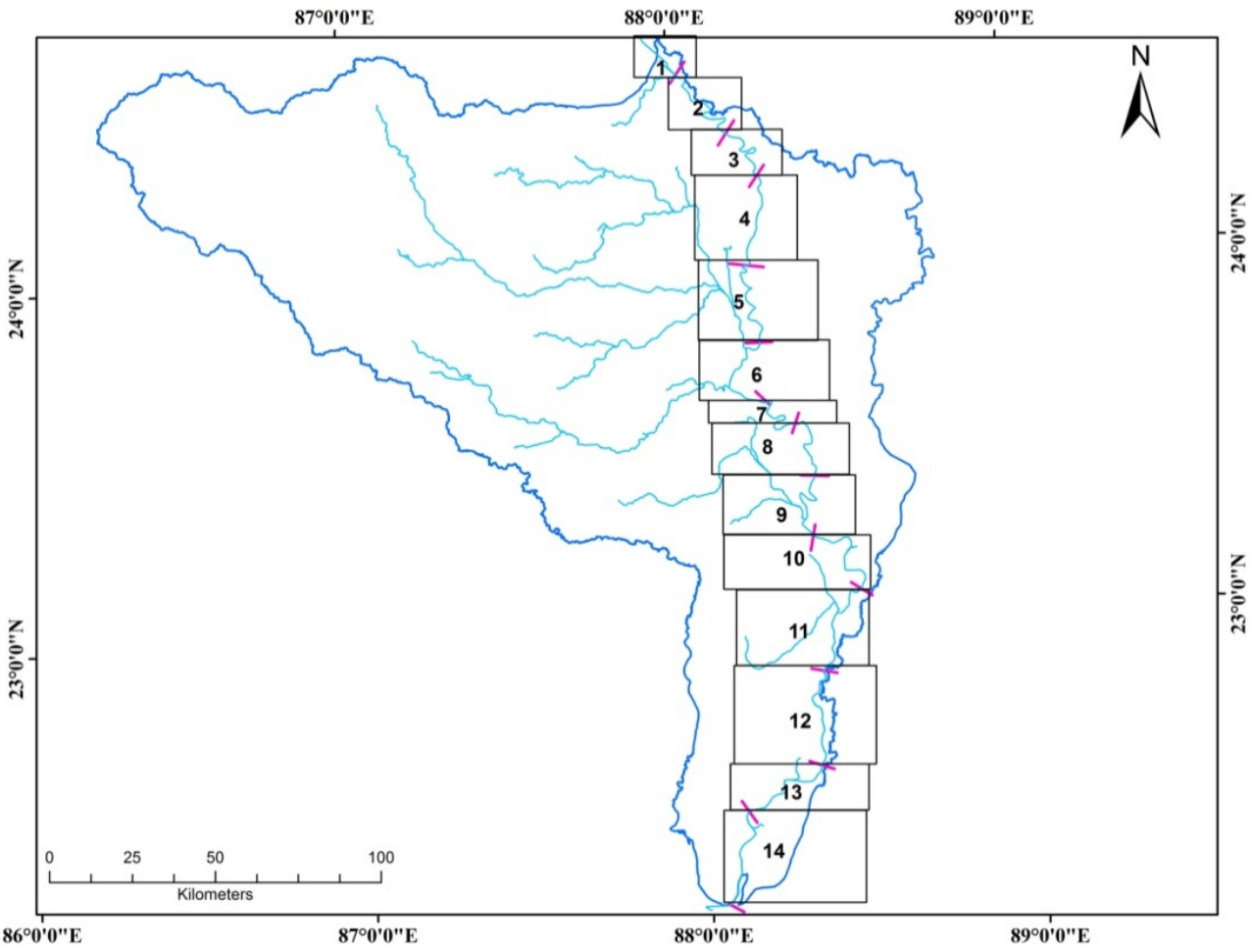


Figure 7: The division of the Hooghly river into reaches for the purpose of the present study

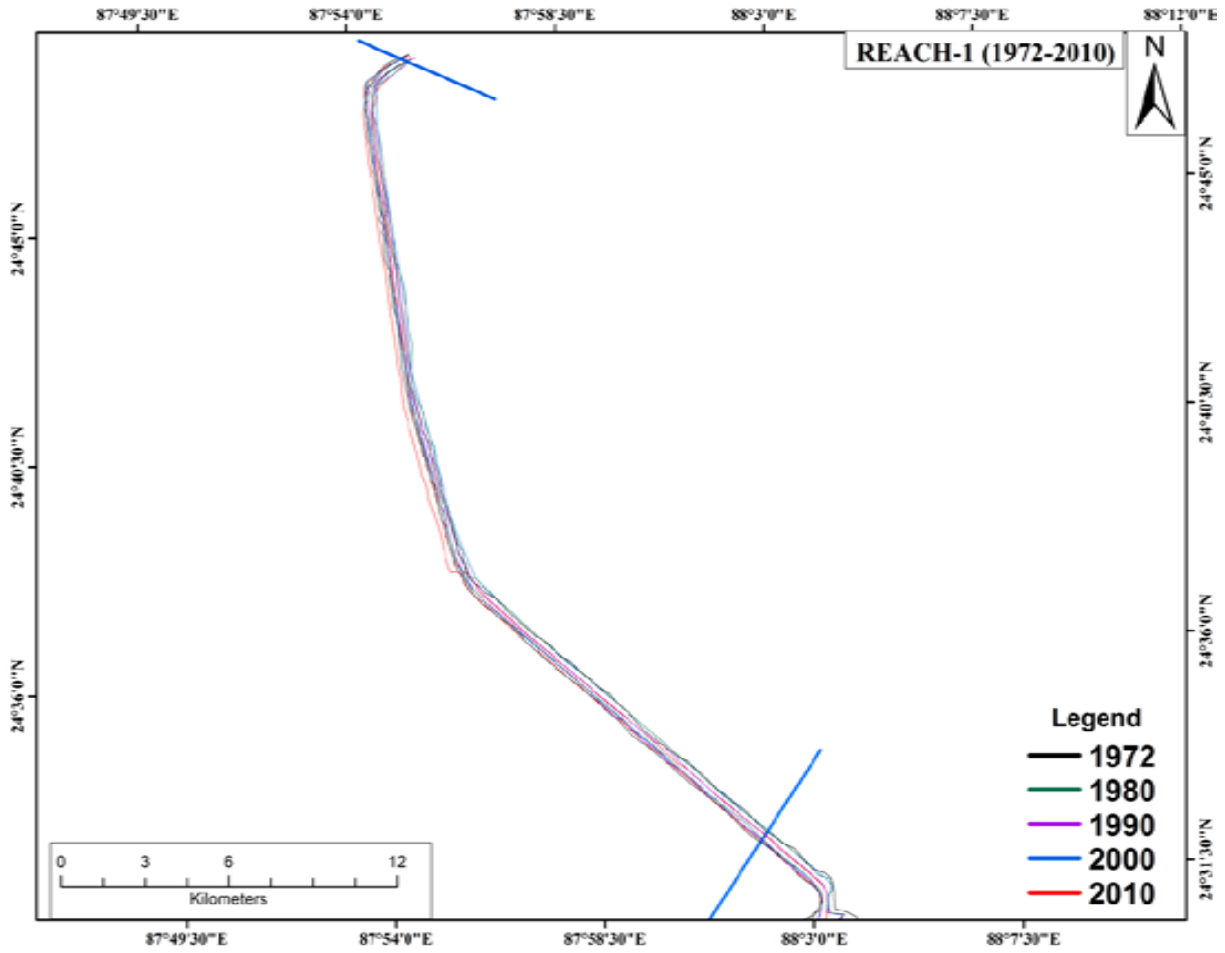


Figure 8.1.: Map of Superimposed Courses of Reach 1 during 1972-2010

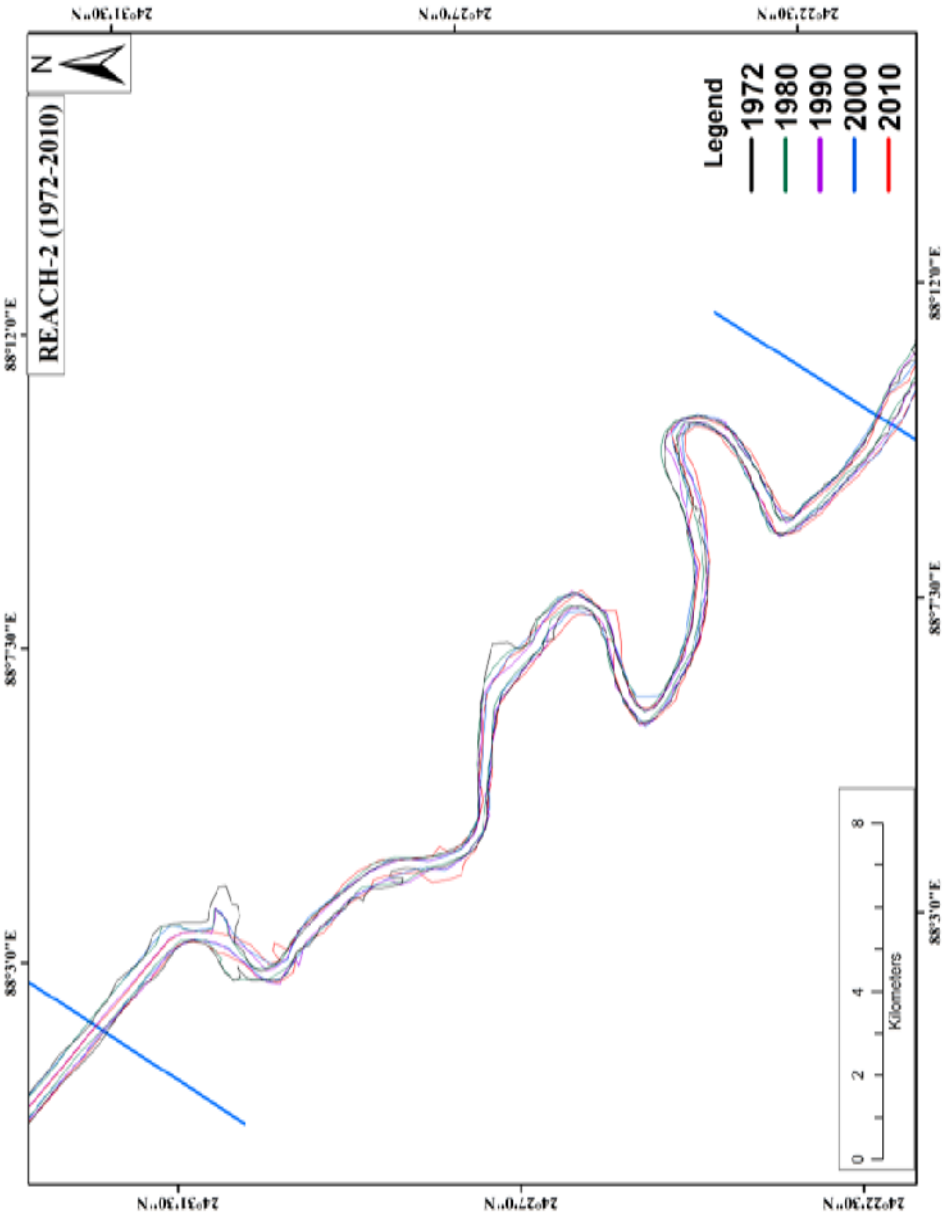


Figure 8.2: Map of Superimposed Courses of Reach 2 during 1972-2010

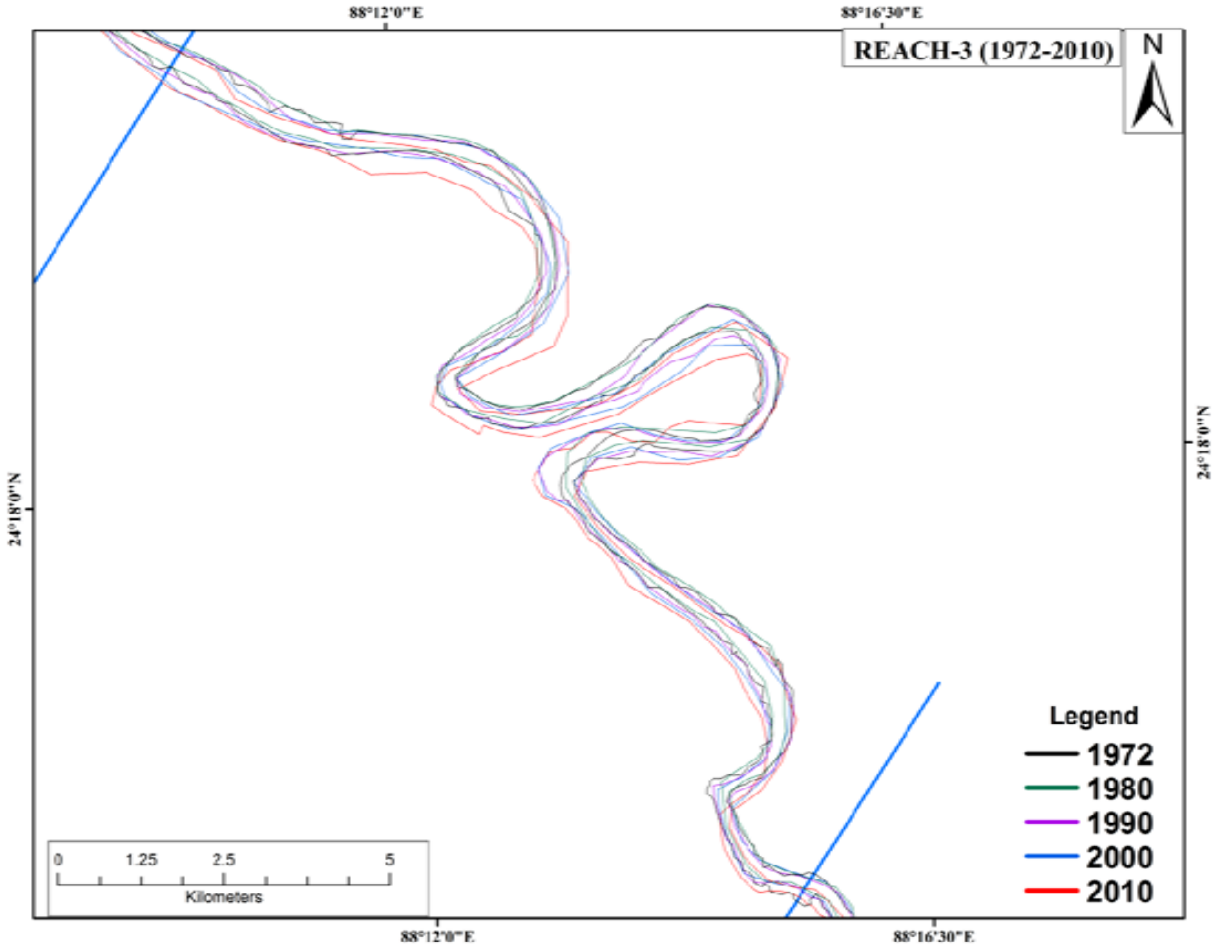


Figure 8.3: Map of Superimposed Courses of Reach 3 during 1972-2010

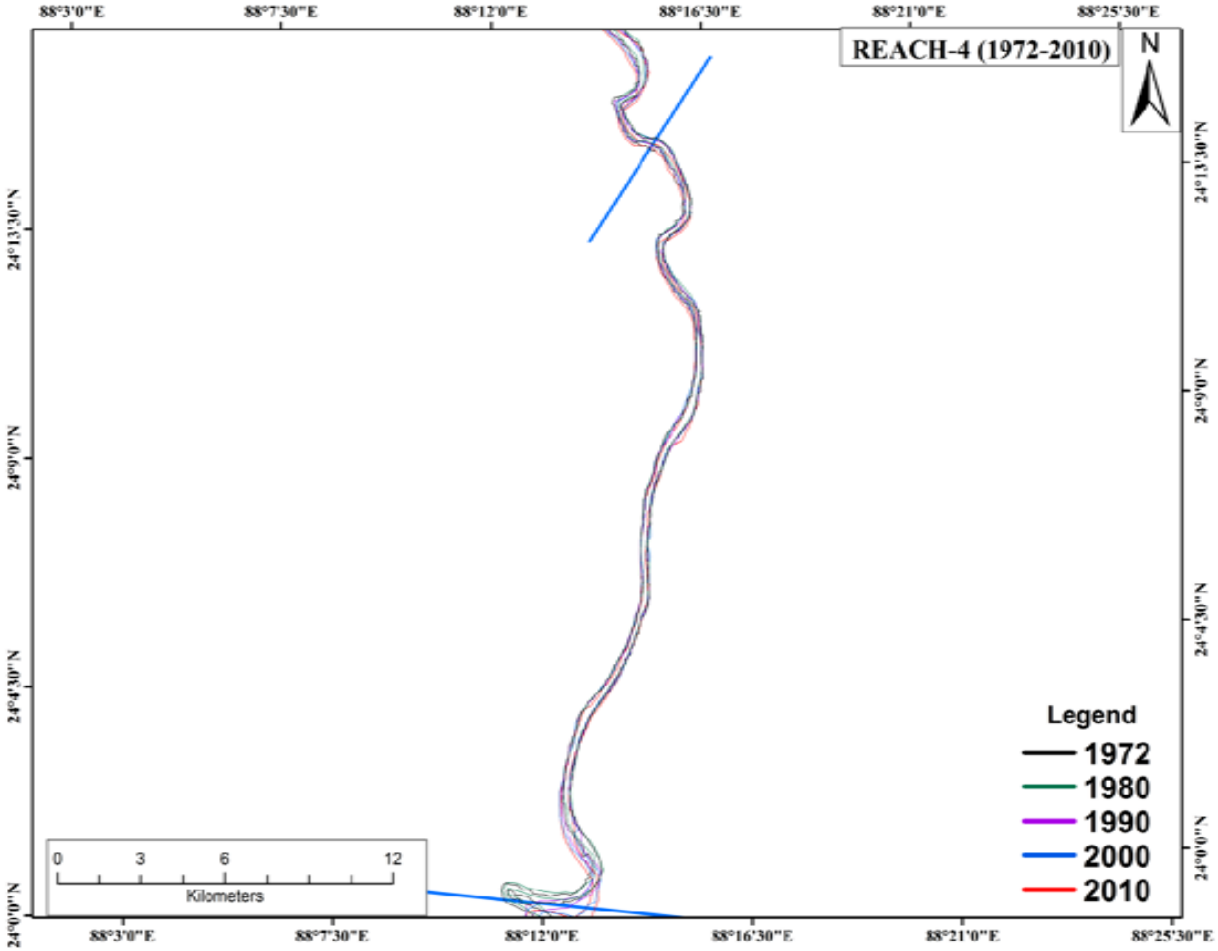


Figure 8.4: Map of Superimposed Courses of Reach 4 during 1972-2010

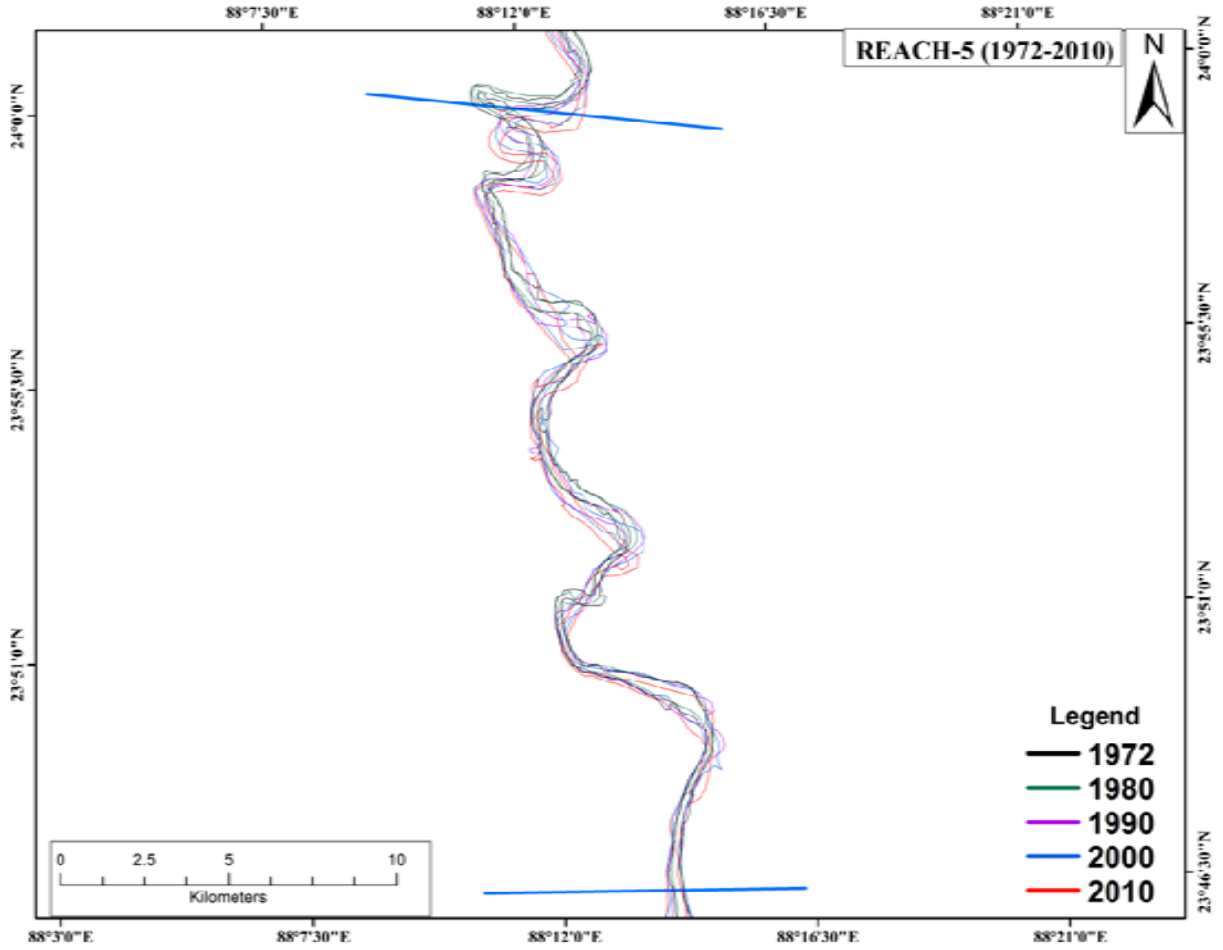


Figure 8.5: Map of Superimposed Courses of Reach 5 during 1972-2010

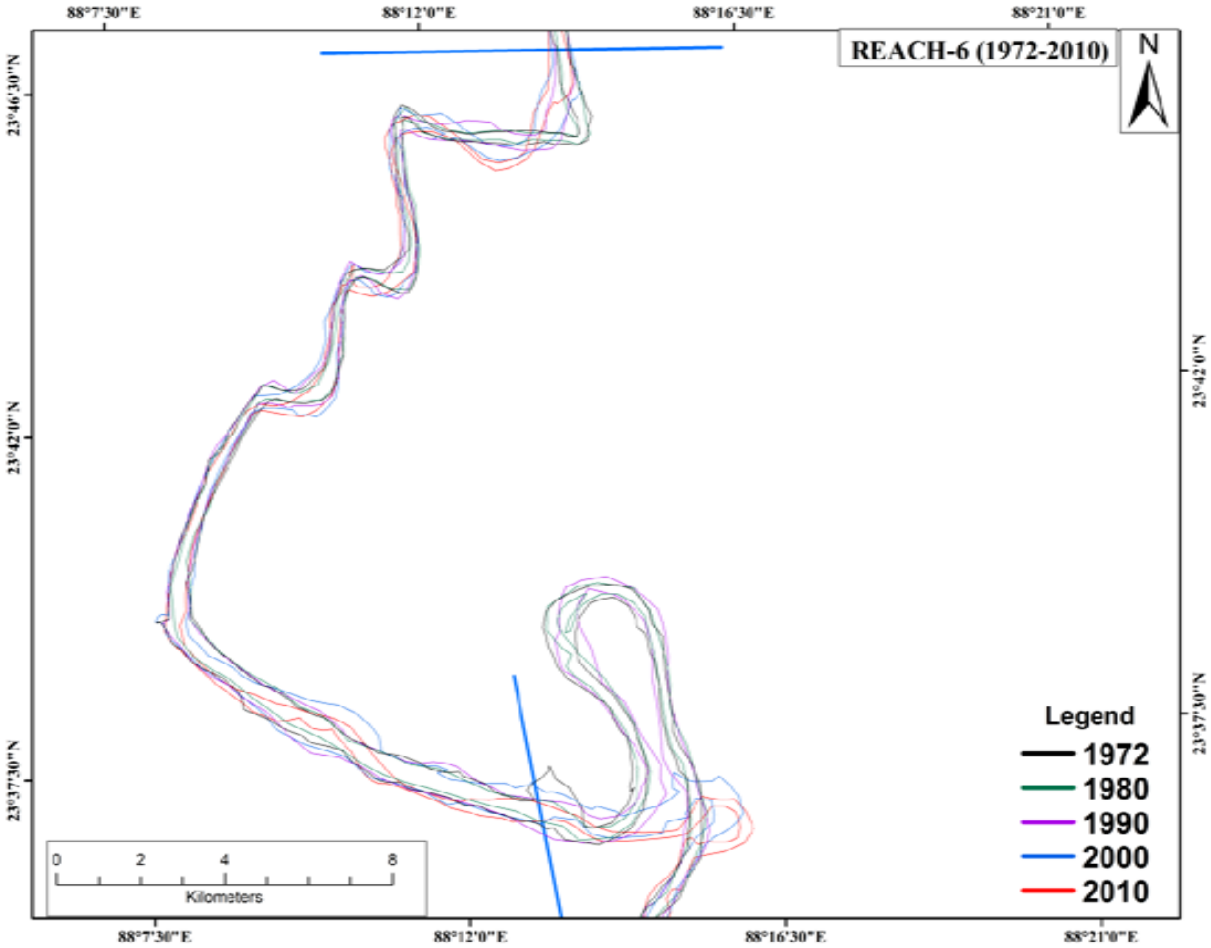


Figure 8.6: Map of Superimposed Courses of Reach 6 during 1972-2010

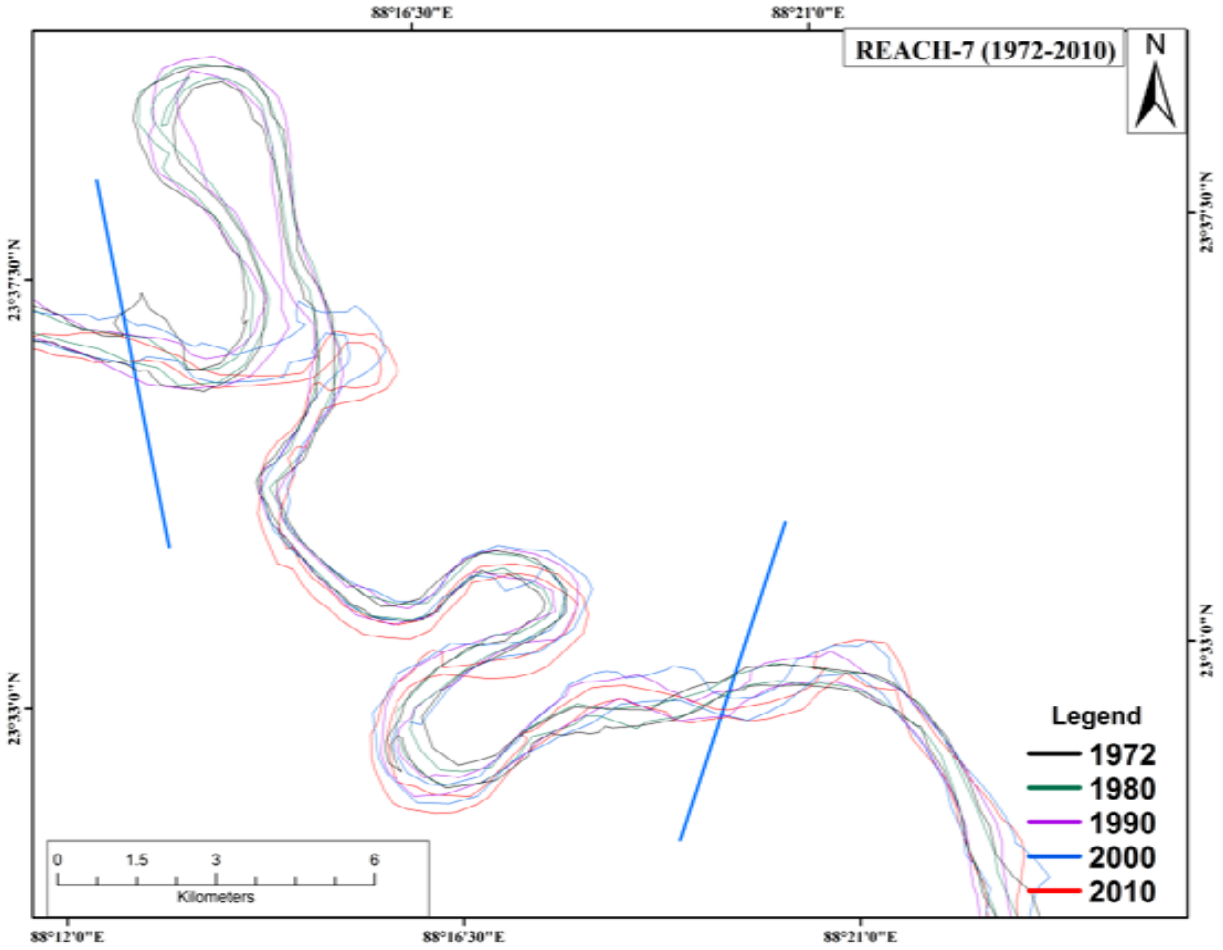


Figure 8.7: Map of Superimposed Courses of Reach 7 during 1972-2010

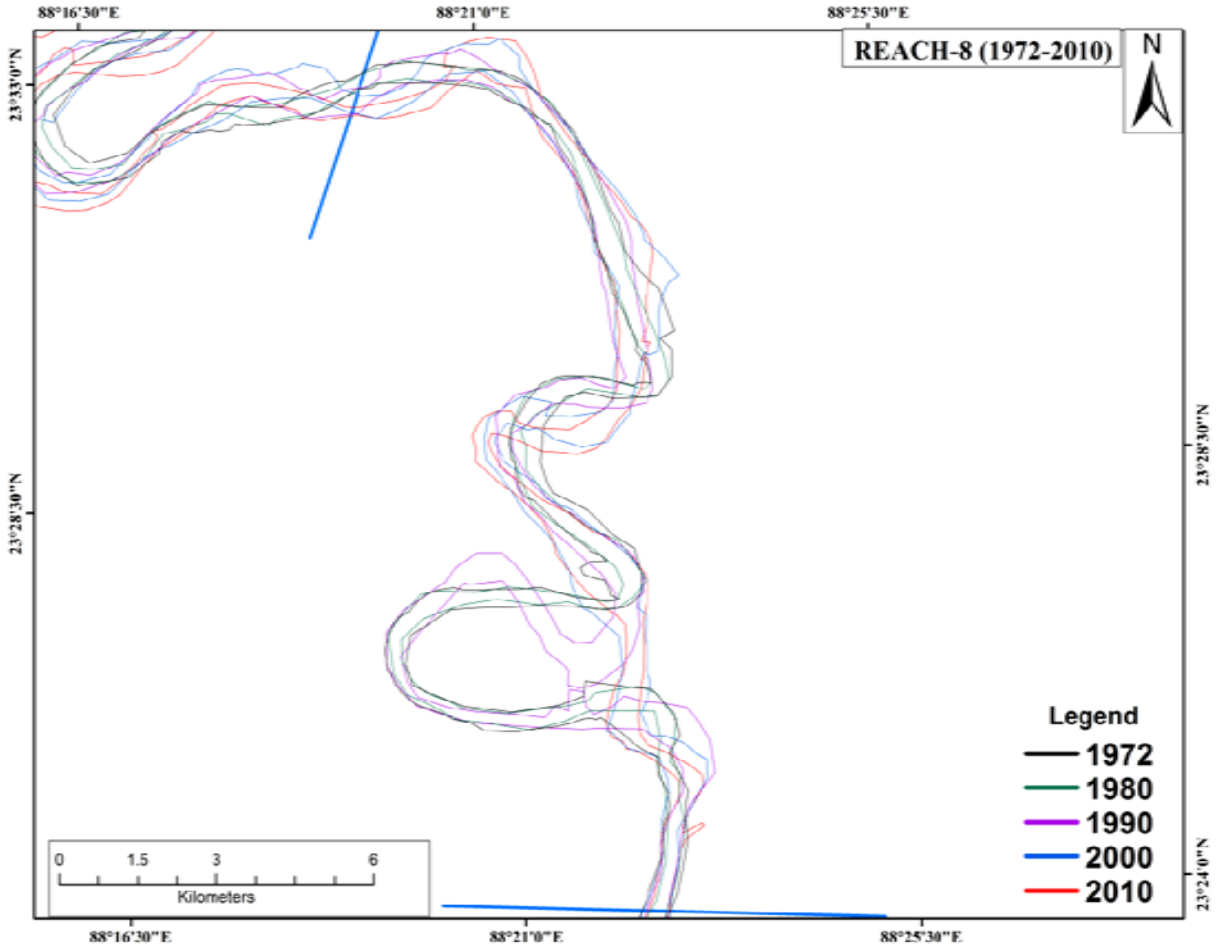


Figure 8.8: Map of Superimposed Courses of Reach 8 during 1972-2010

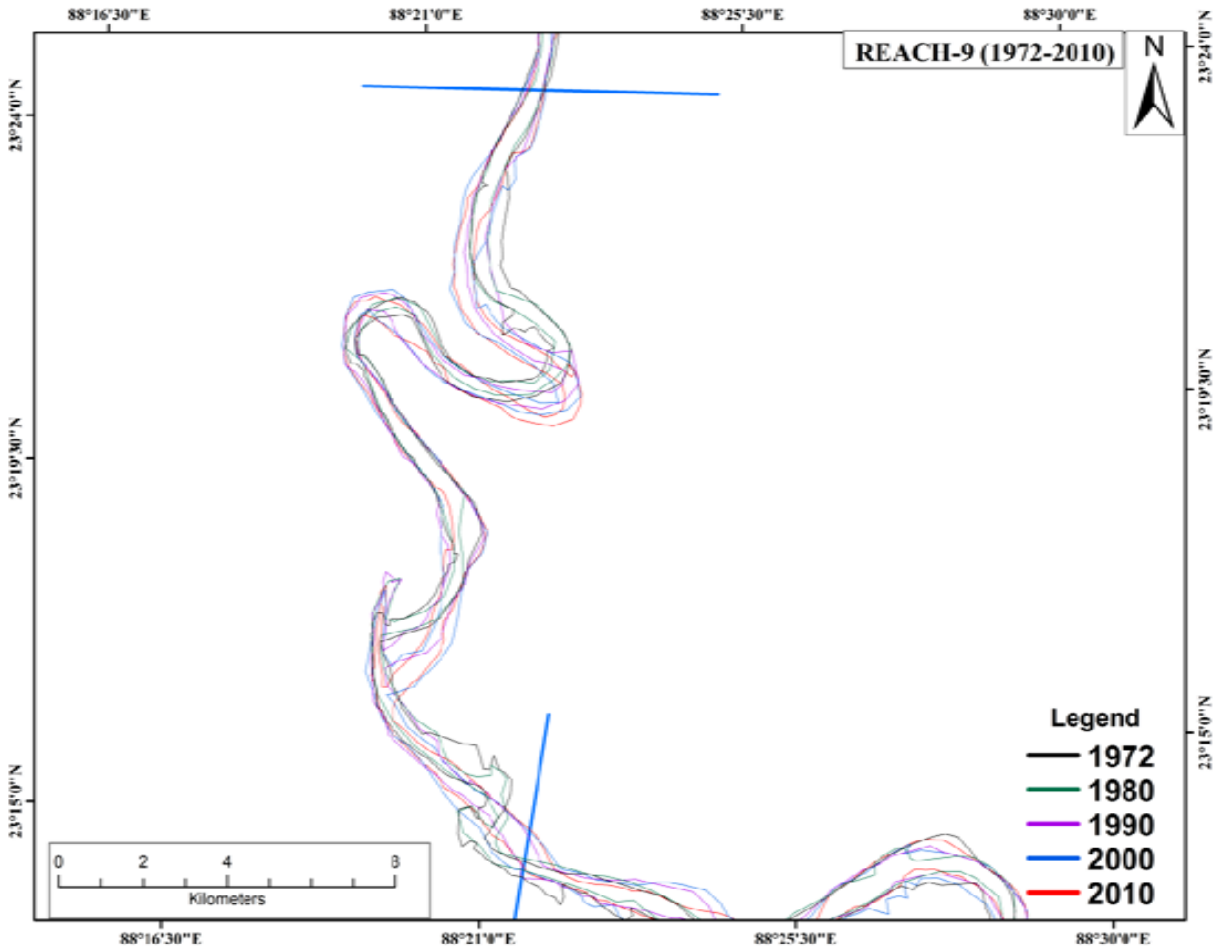


Figure 8.9: Map of Superimposed Courses of Reach 9 during 1972-2010

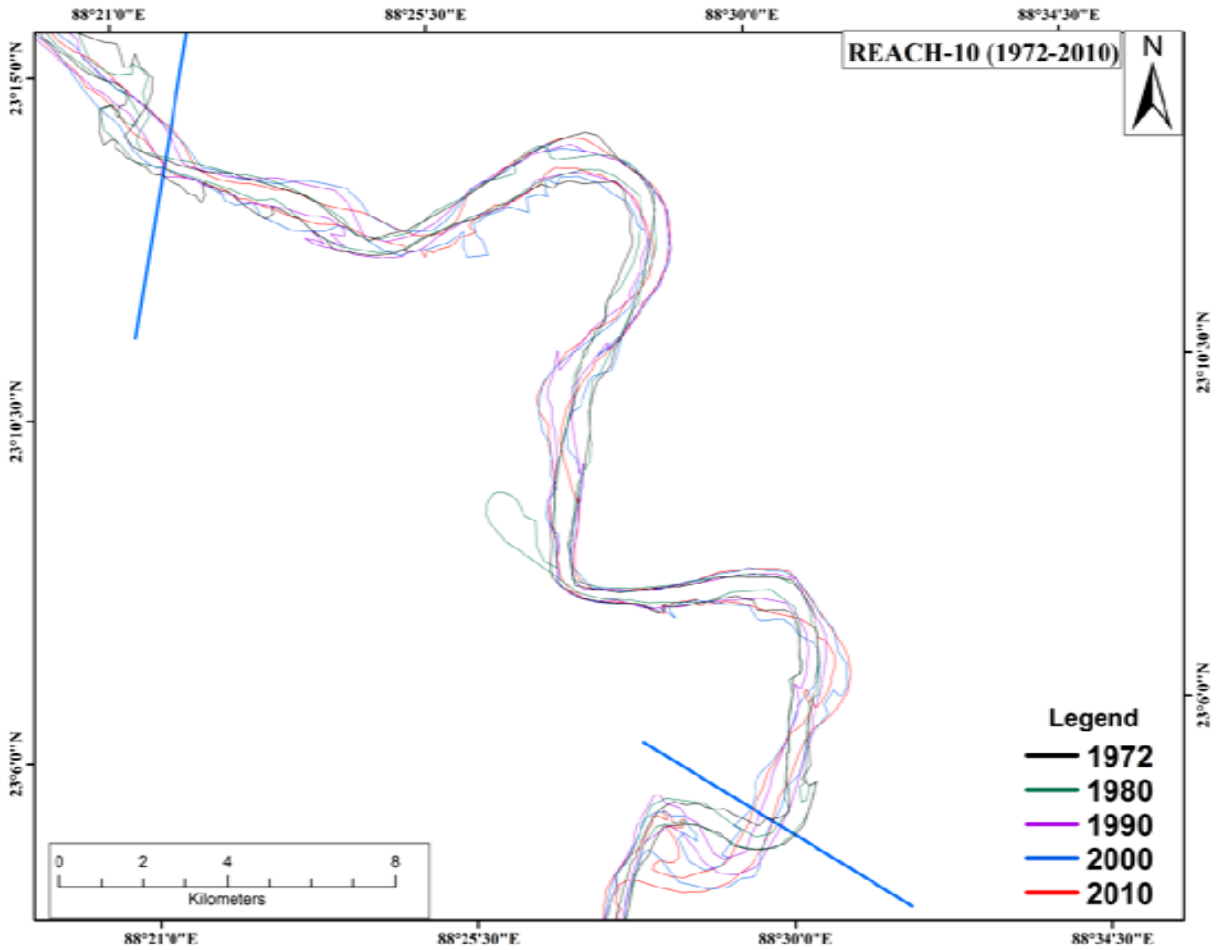


Figure 8.10: Map of Superimposed Courses of Reach 10 during 1972-2010

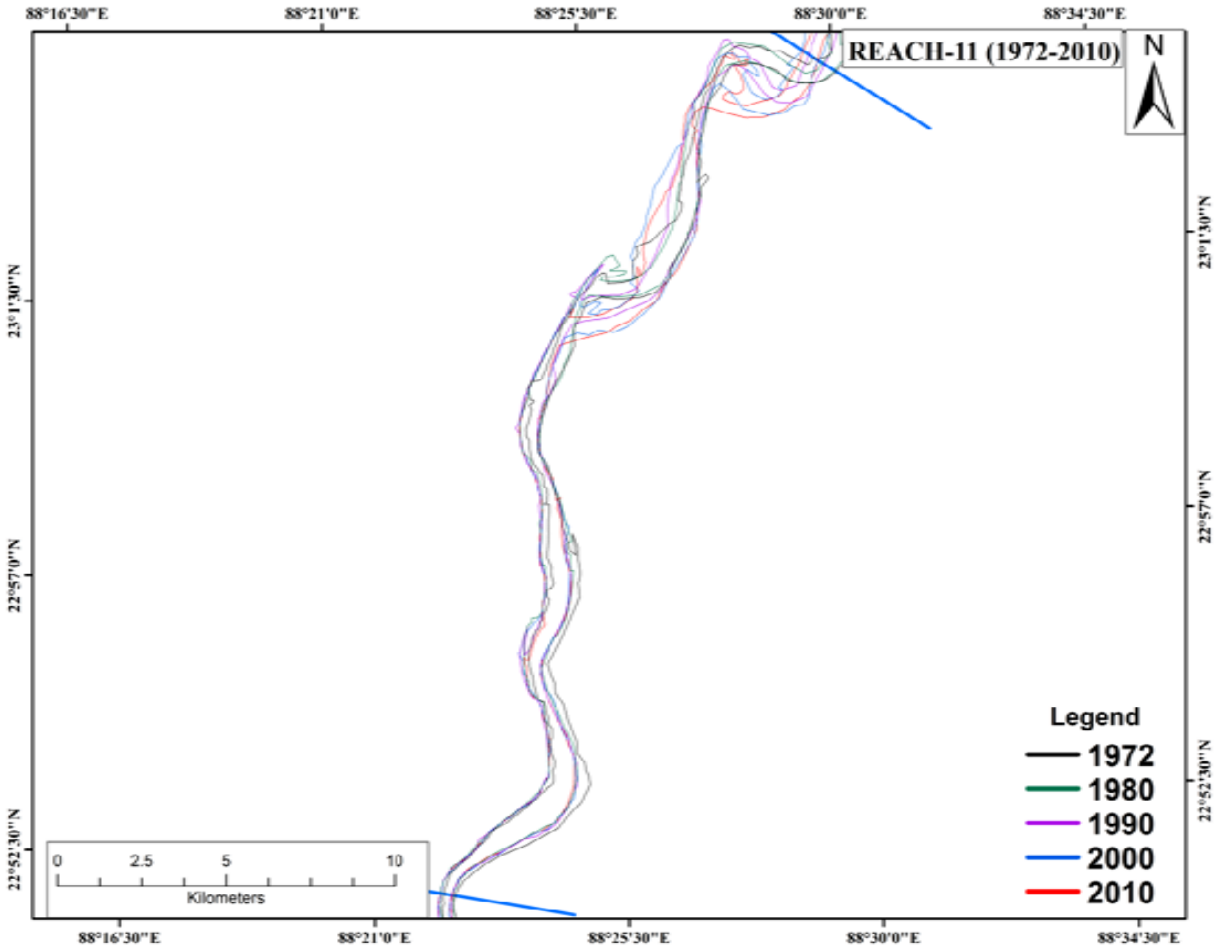


Figure 8.11: Map of Superimposed Courses of Reach 11 during 1972-2010

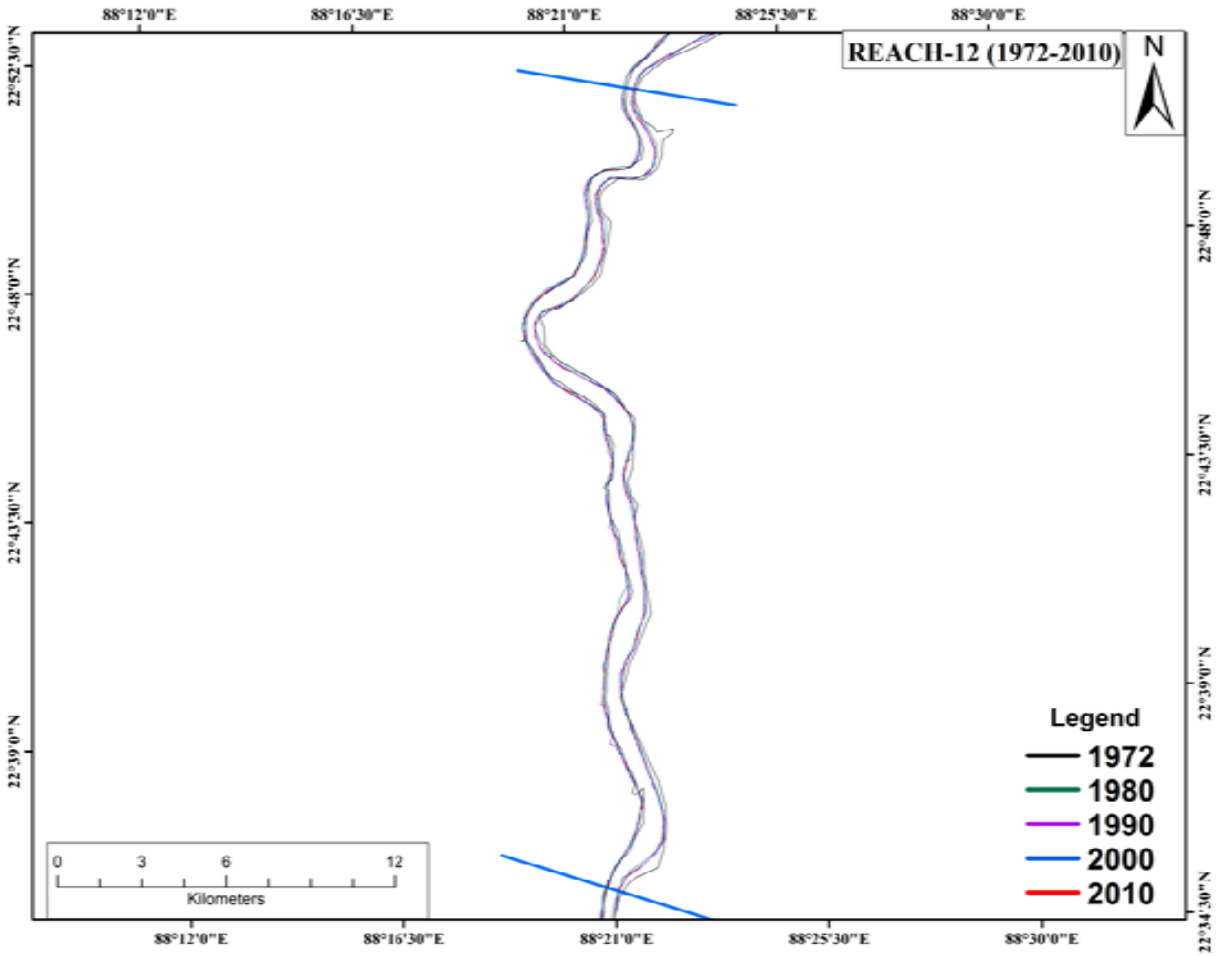


Figure 8.12: Map of Superimposed Courses of Reach 12 during 1972-2010

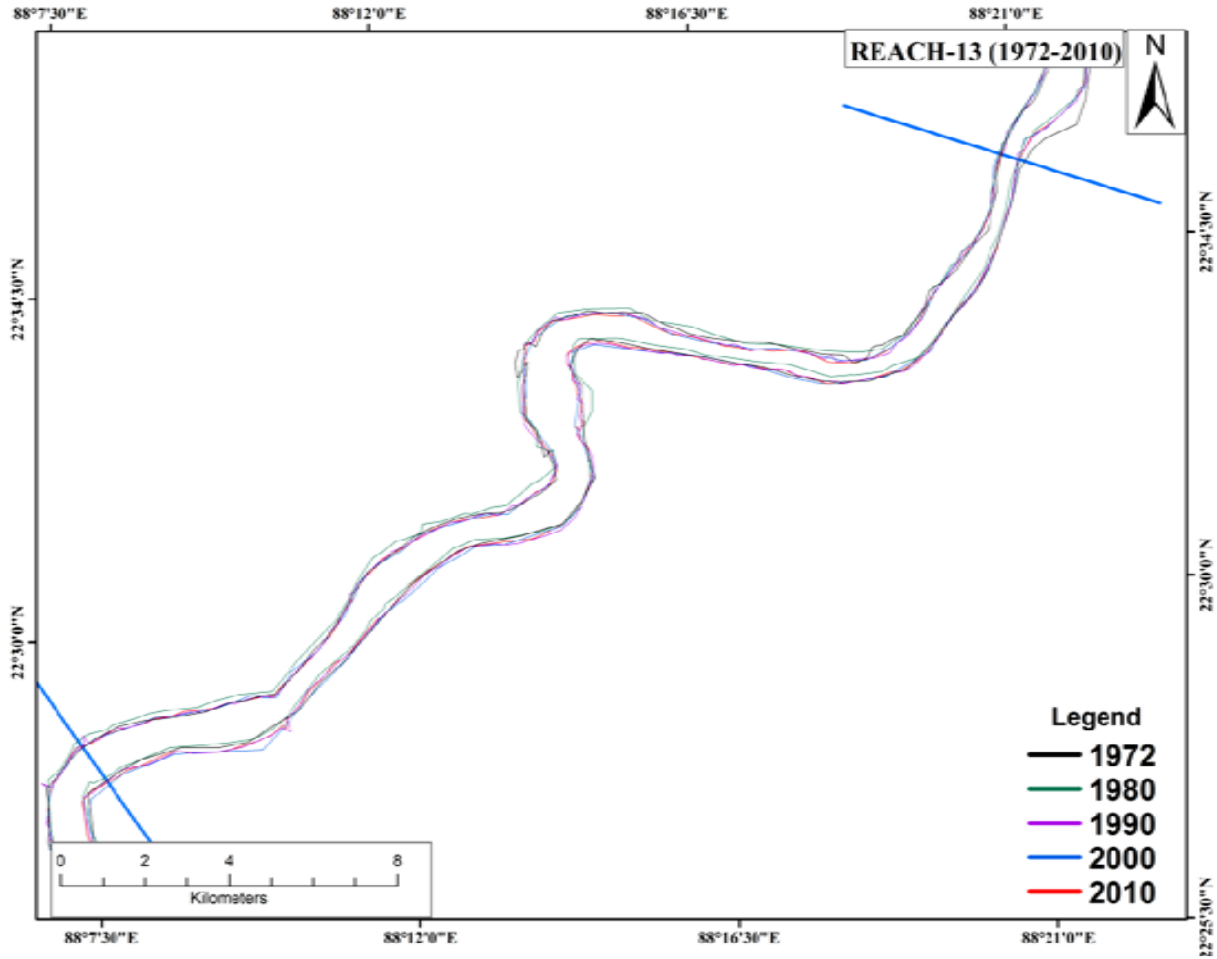


Figure 8.13: Map of Superimposed Courses of Reach 13during 1972-2010

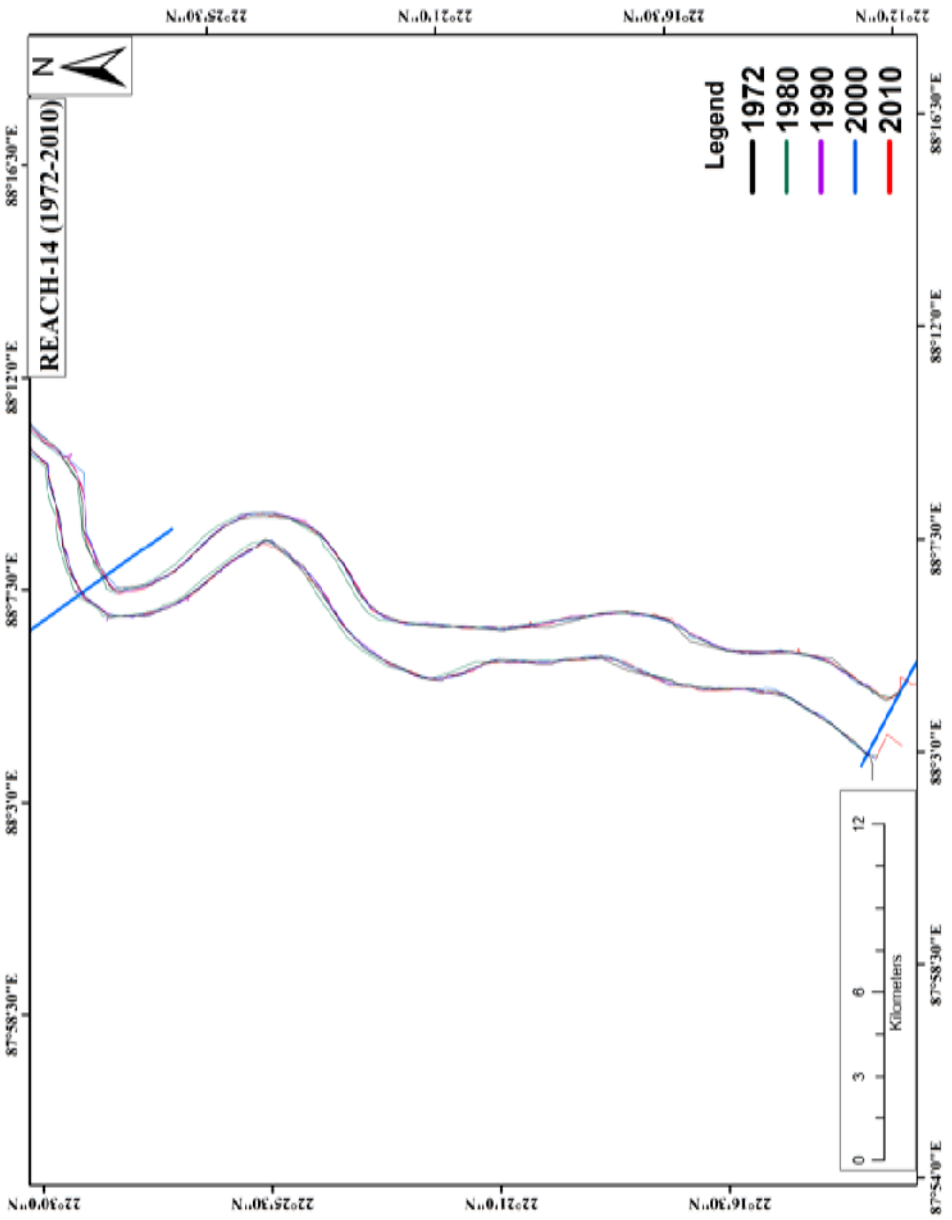


Figure 8.14: Map of Superimposed Courses of Reach 14 during 1972-2010

Table 2: Shift in the course of the Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
0	1	87°55'20.387"E 24°48'8.262"N	+80.06	21.17	32.26	-111.03	+25.33	+91.21	-116.01	-5.97	-191.16	+111.03	+43.00	+91.89
2	1		-27.58	-71.45	-184.89	+100.15	-70.49	-106.77	+88.80	-34.38	-119.06	-36.71	-46.29	-37.66
4	1		-125.05	-117.57	-71.01	-167.50	+105.29	-253.43	-279.28	-280.08	-162.84	-204.38	+231.09	-238.15
6	1		-140.39	-146.95	-88.37	-226.58	-145.83	-208.50	-345.99	-278.32	-184.83	-211.53	-161.45	-233.49
8	1		-80.92	-151.00	-127.81	-175.27	-134.99	-168.11	-263.03	-227.16	-177.60	-172.94	-238.43	-237.08
10	1		-183.90	-141.96	-100.11	-187.15	-157.16	-282.30	-285.30	-244.93	-202.52	-219.50	-230.49	-276.83
12	1		-117.29	-147.20	-67.65	-222.14	-156.53	-191.60	-262.37	-218.28	-212.94	-260.10	-263.46	-203.88
14	1		-238.75	-214.75	-186.31	-298.89	-208.95	-365.18	-345.66	-288.68	-321.28	-336.05	-401.71	-397.73
16	1		-226.21	-232.74	+206.47	-321.42	-212.70	-367.03	-349.91	-328.63	-297.71	-329.50	-361.29	-376.07
18	1		-223.87	-259.51	-306.66	-319.64	-250.14	-338.90	-297.99	-324.23	-297.15	-332.47	-361.93	-615.35
20	1		-43.13	-52.16	-33.66	-134.28	-43.54	-132.13	-154.63	-57.97	-148.50	-189.23	-147.23	-239.78
22	1		-59.88	-119.84	-161.03	-91.61	-108.18	-235.45	-126.37	-109.28	-81.09	-78.91	-173.33	-119.70
24	1		+55.81	-121.04	-203.45	111.23	-121.79	-188.67	-111.22	-134.36	-115.33	-93.92	-175.50	-217.54
26	1		+2.17	-138.09	-243.73	-113.10	-135.52	-233.75	-127.78	-147.89	-78.41	-215.36	-134.52	-191.45
28	1		-106.89	-67.74	-110.99	-109.48	-10.44	-192.58	-47.00	-44.63	-49.25	-97.66	-143.48	-220.93
30	1		+56.10	-94.95	-193.55	-93.43	+102.54	-228.13	-25.60	-96.24	-85.52	-87.53	+93.62	-209.79

Table 2 (continued)**:** Shift in the course of the Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
32	1		+34.51	-178.42	-225.89	-100.56	+136.33	-167.74	-35.05	-65.53	-42.22	-124.64	+211.29	-200.21
34	1	88°1'58.927"E 24°32'30.152"N	+78.17	-54.01	-141.21	+98.06	+70.34	-205.91	+71.73	-51.25	-47.46	-93.14	+188.46	-255.03
36	2		-48.75	190.75	+212.371	-129.99	+164.29	+206.60	-40.99	-68.78	-44.16	-87.23	+250.00	+358.70
38	2		-65.41	-212.99	+466.486	-119.28	-214.86	+215.71	-150.67	+96.40	+323.24	-108.58	-212.88	+244.74
40	2		-61.25	-113.46	+143.078	-184.94	-80.06	+198.64	-57.55	-119.77	+241.52	-126.14	-77.66	-131.05
42	2		-112.48	-74.92	-30.739	-108.93	-73.48	-69.92	-150.28	+153.97	-149.26	-102.01	-95.91	-143.63
44	2		-265.28	-39.59	-70.5992	-196.11	-66.42	+13.42	-104.63	+89.74	+116.32	-108.60	-124.16	+115.48
46	2		-99.19	-100.32	+6.87373	-286.70	+99.17	+78.22	-123.71	-116.21	+65.89	-120.10	+141.72	+89.75
48	2		-70.12	-60.03	+30.3986	-113.72	-56.06	+69.79	-76.68	+51.29	+47.54	-114.85	-75.25	+92.53
50	2		-87.34	-155.85	+142.98	-143.90	-148.76	+200.05	-58.02	+37.07	+119.90	-159.99	-97.78	+142.29
52	2		-109.78	-150.38	+147.27	-256.56	+170.70	+68.44	-33.43	+156.21	+135.81	-260.81	+161.88	+192.82
54	2		-64.88	-43.43	+24.2631	+129.17	+65.14	+52.66	+224.72	+30.36	+115.78	100.55	-99.41	+112.42
56	2		-35.78	-38.77	-37.0569	-81.89	-40.94	-33.94	-59.29	+46.37	-97.86	-150.72	-120.68	-122.58
58	2		-54.45	-44.47	-20.3157	-143.22	-106.58	-49.23	-152.41	+104.71	-41.98	-86.27	-65.42	-101.66
60	2		+61.62	-77.87	+29.8985	+157.17	+75.14	+80.41	+87.90	+69.96	+39.83	+115.00	+200.68	+138.44
62	2		-162.36	-218.09	+120.407	-245.42	-261.67	+137.04	-75.81	+79.88	+54.49	-79.26	-90.05	+193.32

Table 2 (continued)**:** Shift in the course of the Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
64	2		-231.42	-204.46	-161.584	-202.47	-200.54	-230.40	-110.72	+165.58	-167.39	-65.98	-85.38	-160.70
66	2		-120.42	-86.33	-25.0314	-131.31	-138.69	-73.13	-166.11	+106.99	+51.10	-94.83	-111.19	-131.51
68	2	88°8'54.977"E 24°23'6.385"N	-85.84	-130.61	-114.286	-149.86	-102.31	-170.36	-124.19	+106.25	-72.44	-139.43	-67.83	-118.30
70	3		-76.71	-74.03	+62.0041	+281.74	+144.45	+68.10	+73.16	+55.58	-55.05	+107.57	+138.73	+118.72
72	3		+160.28	+123.80	+71.2188	+290.52	+119.98	+100.84	-94.49	+227.74	+53.60	+60.11	+166.44	+72.24
74	3		-29.99	-75.90	-134.23	-150.38	-188.60	-171.02	-164.79	+51.76	-90.32	-119.92	-91.79	-154.63
76	3		-322.13	+236.06	-151.969	-382.68	-245.67	-219.98	-35.31	-353.25	-139.89	-227.84	-271.41	-173.64
78	3		167.61	+49.72	+9.38664	+191.67	+98.76	+86.19	-265.40	-125.10	-89.22	+178.09	-184.64	+296.63
80	3		-362.45	+394.44	+469.159	-293.98	+391.00	+442.20	-189.39	-309.49	-391.08	-261.60	+233.99	+136.56
82	3		-244.74	-190.83	-117.474	-234.62	-173.87	-112.18	-318.28	-139.17	-75.42	-216.85	-216.23	-105.53
84	3		-233.04	-294.64	-289.076	-353.74	-299.25	-338.74	-199.36	-143.89	-115.39	-110.07	-143.89	-79.97
86	3		-475.12	-449.58	-423.842	-484.68	-422.27	-440.43	-232.00	-356.93	-422.50	-270.34	-219.00	-121.39
88	3		+88.78	29.96	+29.0886	+44.63	-78.77	-70.80	+257.34	-123.94	-64.95	101.28	-78.04	-127.03
90	3		-181.18	-123.89	-213.779	-135.87	+121.51	-313.97	-108.33	-92.26	-206.72	-307.88	-122.31	-121.93
92	3		-125.36	-98.56	-52.1753	-308.50	-97.21	-186.74	-331.09	-164.54	-74.12	-85.31	-99.31	-133.23
94	3		+219.42	+155.03	+115.553	+327.21	+152.05	+136.25	+134.14	-122.59	-94.92	+104.75	-116.60	-143.50

Table2 (continued)**:** Shift in the course of the Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
96	3		-197.77	-116.48	-38.1621	-326.68	-87.00	-94.42	-119.00	-108.13	-81.87	-178.83	-179.36	-75.89
98	3		+224.64	-261.65	-104.986	-318.05	+182.06	-149.31	-179.57	-125.73	-89.13	-187.12	-127.51	-244.74
100	3		+233.02	-144.83	-180.188	-273.88	+89.26	-234.28	-150.51	-159.85	-162.49	-209.73	-196.03	-131.60
102	3	88°15'51.694"E 24°13'53.3"N	+149.61	-114.50	+75.1973	-203.98	+95.46	+79.15	-164.13	-138.28	-154.79	-153.95	-152.24	-124.85
104	4		+197.11	-122.89	+95.0575	-168.37	+128.66	+112.11	-137.75	-106.42	-127.60	-164.14	-133.77	-154.81
106	4		+78.73	-120.88	+97.525	-153.94	+125.16	+127.58	-110.92	-120.88	-78.29	-134.82	-120.88	-161.63
108	4		+82.33	-115.45	+95.3694	-163.26	+115.47	+111.18	-127.31	-157.86	-124.40	-119.79	-123.70	-178.86
110	4		+17.92	-25.43	+12.4581	-62.40	+79.62	+67.98	-99.65	-156.03	-138.38	-157.05	-134.37	-103.78
112	4		+31.84	-52.10	+42.7364	-55.48	+55.60	+102.81	-34.50	-84.48	-96.13	-104.05	-102.12	-242.79
114	4		-52.53	-56.56	+33.6088	-56.36	-73.98	+38.21	-86.63	-69.70	-127.91	-76.30	-116.66	-123.27
116	4		-37.96	-25.97	-75.3494	-35.86	-31.91	-71.09	-69.32	-159.95	-133.63	-108.76	-145.15	-124.86
118	4		+41.93	+27.40	+20.497	+29.71	+24.25	+58.80	-41.79	+25.28	107.50	+68.62	-85.18	-128.93
120	4		+27.57	+14.84	+23.087	+47.48	+14.10	+43.54	-3.33	+76.13	+83.36	-85.53	-72.91	-95.01
122	4		+64.93	+91.45	+60.1625	+98.36	+88.63	+106.95	-50.81	+133.78	+84.95	-78.43	-76.68	-83.94
124	4		+120.09	+64.77	+27.3228	+45.19	+40.24	+68.41	+93.96	+03.60	+108.92	-152.01	-101.20	-83.60
126	4		-52.68	-40.92	-106.572	-19.50	-54.93	-78.67	-89.32	-207.43	-81.71	-252.74	-204.28	-220.17

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
128	4		-369.47	+313.16	+248.959	-431.01	306.83	+239.97	-47.49	+254.41	+208.60	-112.65	-84.41	-105.87
130	4		-238.81	-117.40	-24.23	-119.68	-113.37	-89.26	-234.71	-221.54	-115.65	-225.20	-95.32	-185.82
132	4		-916.25	+882.59	-816.85	+915.38	+881.06	-868.27	+59.40	699.97	-578.99	-536.05	-410.40	-260.40
134	4		-1579.29	-1594.32	-1602.46	-1586.64	-1506.63	-1544.07	-752.06	-639.89	-597.78	-309.23	-208.93	-155.23
136	4	88°12'33.285"E 23°58'48.034"N	-868.74	-1269.80	-668.98	-413.75	-1106.87	-994.80	-634.14	-622.39	-118.79	-204.34	-183.97	-219.29
138	5		-596.22	-524.13	-471.52	-561.03	-528.40	-450.06	-482.12	-307.66	-223.88	-224.26	-304.62	-137.02
140	5		-241.80	-301.84	-338.13	-206.81	-296.11	-407.33	-232.16	+126.15	-114.20	-176.61	-129.51	-192.53
142	5		-55.21	+163.59	+197.80	+234.48	+152.43	-259.80	+100.88	+82.37	-84.39	+169.29	+132.05	+96.19
144	5		-1058.79	-1062.99	-980.56	-1144.22	-979.70	-1045.81	-137.02	-414.92	-261.12	-120.62	-88.34	-226.15
146	5		-750.03	-779.32	-222.61	-779.19	+793.99	-134.66	-469.78	+848.42	-110.23	-827.86	+1012.10	-303.33
148	5		-39.75	-123.77	+109.46	-169.34	+131.70	-149.44	-727.81	+211.84	-147.01	-31.50	+326.98	-247.16
150	5		-153.82	-77.89	-143.47	-195.05	-76.39	-167.53	-211.08	+77.89	-259.04	-389.62	-77.89	-276.38
152	5		-503.29	-454.11	-397.68	-475.42	-482.37	-407.21	-154.18	+177.06	-115.66	-178.02	-171.17	-670.03
154	5		-325.81	-371.35	-213.79	-428.60	+320.22	-346.53	-191.56	-462.98	-740.51	-163.16	+530.43	-236.71
156	5		+79.83	+107.47	+47.57	+228.12	+111.02	-145.01	-432.87	-205.24	-92.45	+321.57	+142.32	-109.41
158	5		-162.21	236.97	+122.00	-245.96	+152.80	-117.50	-130.33	-205.75	-235.00	-171.15	+91.10	+202.60

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972			1980			1990			2000		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
160	5		-83.82	-78.09	-149.18	-223.75	-135.06	-314.93	-233.80	-174.08	-278.88	-136.49	-112.73	-162.82
162	5		-129.61	-167.74	-237.85	+110.23	-92.96	-327.19	-144.63	-83.33	-210.26	+157.04	-167.74	-134.04
164	5		+368.13	+115.87	+79.7244	+477.36	+147.96	-72.64	-120.39	-170.01	-144.54	+212.84	+111.66	+318.35
166	5		+251.23	+331.18	+404.406	+202.17	+332.12	-340.00	-332.78	-181.16	-332.63	+287.22	+292.54	+71.56
168	5		+37.24	+106.36	+94.9494	+99.26	+55.08	-122.87	-219.00	-125.02	-104.16	+294.89	+153.67	+148.50
170	5	88°14'8.177"E 23°46'19.03"N	+261.64	+226.25	+98.0012	+321.71	+221.90	-149.96	-24.26	-143.21	-62.12	+151.20	+97.04	+174.66
172	6		+246.69	+178.37	+62.0671	-285.03	+216.54	-166.64	-154.07	-193.80	-211.42	-124.39	+126.10	+139.14
174	6		-394.50	-382.08	-273.633	-414.76	-329.60	-336.24	-159.81	-364.20	-298.52	-203.65	-211.97	-120.56
176	6		+239.97	-148.10	-129.475	-281.73	-138.81	-124.76	-804.25	-148.10	-131.15	-304.37	-148.10	-108.12
178	6		+112.99	+93.31	+60.1965	+223.46	86.83	+121.24	-206.38	-183.14	-140.38	-158.28	-184.37	-133.15
180	6		-324.32	-166.60	-48.89	-284.67	-188.78	-108.21	-68.20	-117.41	-263.99	-224.30	-72.46	-75.77
182	6		+39.63	-114.35	-119.13	-217.62	-63.86	-160.02	-239.05	-106.40	-48.02	-297.12	-77.82	-147.72
184	6		-124.72	-158.54	-114.92	-79.13	-155.49	-58.32	-76.32	-135.99	-73.86	-175.68	-114.45	-99.40
186	6		-69.09	-75.73	-101.75	-36.82	-58.05	-87.03	-212.54	-100.54	-56.34	-279.88	-159.20	-97.73
188	6		-13.34	-51.05	-20.00	-63.40	-56.06	+119.25	-95.20	-166.55	-85.23	-127.80	-187.68	-149.73
190	6		-31.02	-66.66	-46.05	-84.49	-46.45	-529.85	-58.82	-108.04	-82.07	-86.65	-108.69	-269.36

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
192	6		-45.80	-245.88	-516.91	-135.97	-242.03	-387.62	-15.01	-254.26	-488.32	-83.07	-89.49	-297.60
194	6		-80.37	-194.50	-270.96	-251.49	-183.16	-175.81	-32.11	-214.21	-314.96	-126.90	-186.87	-340.22
196	6		-439.36	-293.89	-178.04	-319.12	-270.15	-469.68	-152.31	-381.25	-123.17	-136.03	-254.61	-484.19
198	6		+67.87	-324.40	-581.04	-166.60	-301.01	-340.64	-694.38	-253.67	-496.62	-578.99	-323.24	-401.78
200	6		-154.79	-322.91	-464.83	-323.34	-257.43	-140.63	-63.30	-284.91	-456.71	-64.25	-257.89	-367.46
202	6		-208.09	-59.11	-684.99	-100.26	-41.84	-413.97	-197.87	-127.45	-158.15	-168.98	-188.45	-437.09
204	6	88°14'22.106"E 23°36'22.145"N	-308.90	-427.64	-596.06	-405.04	-451.61	-5980.91	-416.02	-326.56	-511.48	-125.72	-288.69	-434.94
206	7		+5291.42	+5600.49	+5459.19	+5900.15	+5494.97	-6434.05	+171.62	-5857.92	-5551.35	-96.84	-381.03	-448.16
208	7		+6365.64	+6490.74	+6871.64	+6246.24	+6616.52	-62.57	+5814.45	-6180.74	-6535.90	-375.55	-646.29	-125.21
210	7		-43.56	-70.53	-61.4605	-78.70	-90.14	-107.40	-6265.66	-51.06	-85.28	-704.40	-132.68	-108.47
212	7		+322.20	-197.84	-149.905	-236.80	-215.23	-365.10	-61.91	-170.45	-207.24	-57.45	-201.68	-460.77
214	7		+320.08	+423.90	+369.693	+348.60	-419.16	-235.30	-242.97	-332.48	+288.84	-223.02	-414.96	-315.71
216	7		-197.33	-289.41	-362.408	-309.39	-284.64	-171.17	-285.92	-195.17	-292.27	-338.59	-297.87	-307.13
218	7		-116.65	+167.27	+203.269	-173.60	-137.64	-528.88	-214.47	-179.73	+262.85	-195.15	-126.48	-151.90
220	7		-602.12	-539.07	-432.803	-479.13	-528.69	-552.21	-102.18	+356.46	+352.58	-265.27	-260.29	-428.91
222	7		-343.32	+443.17	+475.191	-469.03	-412.53	-464.71	-379.60	+487.67	+540.19	-231.35	-346.52	-631.58

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
224	7		+781.54	-308.52	-588.564	-348.57	-356.04	-722.25	-454.49	+193.06	-422.52	-310.18	-82.33	-233.76
226	7		-86.22	+966.19	-919.684	-731.39	-924.76	-207.27	-114.48	-369.77	-319.49	-170.10	-309.53	-209.42
228	7		+111.85	+248.37	+401.068	+171.90	-276.58	-94.47	-304.89	+223.46	+251.66	-321.12	-180.06	-110.35
230	7		-320.95	-170.52	-86.8852	-47.99	-168.70	-414.24	-174.05	-115.86	-120.80	-173.11	-67.82	-318.20
232	7		+682.50	-301.19	-379.021	-441.03	-391.14	-672.28	-143.48	+63.42	-203.31	-163.70	-220.84	-162.64
234	7		+222.39	+637.96	+811.253	+707.35	-539.60	-217.69	-57.47	+407.97	+416.48	-162.68	-83.27	-257.77
236	7		+243.20	+301.79	+185.357	+260.20	-233.17	+469.97	-447.71	+274.37	+184.23	-135.97	-413.96	-172.36
238	7	88°21'35.933"E 23°32'57.739"N	+174.06	+430.49	+422.004	+132.62	-337.86	+94.97	-204.03	+377.79	+643.65	-262.22	-189.51	-103.56
240	8		+34.12	+133.22	+99.4494	+229.54	-77.94	+513.47	-292.80	+131.22	+167.86	+245.62	+121.03	+56.16
242	8		-282.47	-189.35	-496.374	+151.20	-215.94	-106.61	-115.44	-199.42	-292.72	+72.84	-77.54	-174.47
244	8		+143.54	+317.44	+511.424	-241.42	-316.97	+338.64	-114.73	+120.45	+147.52	-114.63	+191.56	+111.65
246	8		+606.96	-211.89	+186.398	-469.41	-232.41	+616.79	-161.43	+140.21	+139.12	-147.13	+71.64	+299.29
248	8		-536.27	-405.01	-225.299	-789.57	-665.11	-394.11	-351.21	-749.02	-706.22	-120.60	-272.63	-132.61
250	8		-429.17	-535.92	-682.455	-528.92	-532.33	-56.16	-776.74	-320.74	-301.82	-244.34	-122.24	-131.44
252	8		+3844.49	+337.97	+233.396	-576.02	+410.84	+356.31	-315.19	+235.74	+127.46	-138.12	+122.50	+158.39
254	8		-3236.53	-172.37	+370.458	+606.19	-192.13	+556.41	+318.56	+103.88	+221.92	+87.22	+118.10	+110.77

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
256	8		+259.80	+278.82	+1081.37	+605.57	+204.15	-431.93	-320.74	-3966.84	-667.98	+283.72	+150.39	+130.65
258	8		-68.40	-348.77	-376.472	+291.76	+305.38	-142.62	-3726.75	-221.41	-256.78	+105.10	+191.03	-277.33
260	8		-182.63	-90.80	+100.861	-95.48	+83.85	-120.52	-140.77	-89.32	-190.18	-226.38	+179.79	+100.23
262	8		+6.24	-131.65	+115.738	-94.25	+118.82	-53.25	-82.48	-130.42	-86.64	-103.11	+99.89	+252.69
264	8		+347.68	-90.48	+54.7236	-69.15	+88.74	-325.40	-93.10	-117.75	-162.34	-116.43	+142.91	+154.10
266	8		+407.04	+471.13	+666.344	+356.74	+483.28	-1163.02	-114.76	-277.38	-301.47	+145.08	+130.54	+119.55
268	8		-691.76	+964.14	-1286.34	-923.34	-954.79	-277.12	-128.59	-395.26	-257.52	-105.64	-131.45	-231.53
270	8		-275.57	-211.77	-244.285	-355.60	+238.96	-1036.37	-334.33	-297.04	-484.54	-168.96	+87.08	-254.00
272	8	88°22'47.754"E 23°19'39.318"N	+1027.27	+995.26	+1181.87	+948.91	872.98	-339.72	-337.75	-460.14	-418.03	103.94	+211.50	+90.02
274	9		+369.38	-330.79	-178.37	-377.19	+350.49	-84.39	-514.29	-243.12	-113.87	-261.63	+191.30	-264.17
276	9		+95.70	-53.54	-56.7813	-85.29	+87.53	-46.67	-181.73	-200.17	-232.70	-111.67	+81.32	-164.40
278	9		+386.05	+242.88	+131.423	+356.69	+205.79	-136.51	-133.00	-124.37	-200.76	+118.62	+158.39	+62.31
280	9		-144.59	-209.51	-136.842	-184.27	-140.15	-143.34	-210.02	-72.97	-174.19	-249.11	-144.51	+101.15
282	9		+61.15	-88.92	+60.7086	-56.99	+199.13	-418.72	-80.41	-143.25	-101.15	-98.88	-146.35	-160.55
284	9		+221.67	+86.73	+81.6617	-148.35	+67.14	-97.21	-74.66	-143.96	-154.50	-134.04	+114.22	+97.21
286	9		+91.72	+95.83	+30.6732	+165.80	+112.66	-1381.64	-359.86	-40.95	-97.21	+276.43	+246.06	+118.22

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
288	9		+924.77	+1091.97	+1238.87	+862.55	+1206.42	-390.65	-67.71	-398.08	-288.57	+60.62	+100.25	+129.70
290	9		-73.96	-205.97	-298.4	-255.61	-200.40	-132.13	-543.60	-128.61	-402.66	-114.42	-128.61	-140.69
292	9		+487.03	-431.21	-426.645	+372.25	-421.57	-881.02	-118.18	-88.33	-166.40	+96.92	-222.06	-70.02
294	9		+584.86	+630.63	+1071.96	+497.04	+657.77	+224.48	-63.52	-151.15	-136.04	+143.36	+161.86	+155.75
296	9		+63.77	+147.06	+223.143	-84.07	+127.93	+125.19	-111.65	-142.57	-120.44	-357.25	+85.80	+429.69
298	9		-63.88	+74.56	+9.01138	-109.21	+51.87	+349.79	-109.76	-292.30	-412.43	-166.56	+54.54	+102.90
300	9		-385.85	+451.53	+313.77	+313.73	+352.47	+342.57	-134.76	-427.07	-423.60	+306.59	+102.54	+145.04
302	9		-359.91	+294.86	+280.713	+406.70	+289.18	+121.30	-423.33	-263.66	-217.45	+187.43	+177.71	+82.45
304	9		-80.53	-208.11	+68.1025	-79.33	-106.54	+344.95	-394.60	-114.67	-121.48	-584.43	-74.10	+279.11
306	9	88°27'47.99"E 23°13'42.036"N	+323.28	+136.59	+209.779	+208.08	+65.46	+162.87	-145.60	-125.49	+274.09	+387.43	+160.83	+109.46
308	10		+263.19	+191.17	+171.285	+141.16	-166.42	+328.00	-157.40	-92.62	+116.11	+201.44	+129.59	+94.25
310	10		-706.41	-516.76	+436.799	-465.66	-507.38	+132.15	-46.90	-112.33	+168.42	-159.31	-123.70	+129.34
312	10		-56.30	-175.66	+57.3911	-234.89	-160.19	+530.69	-244.92	-123.10	+104.20	-97.94	-89.86	+202.01
314	10		-842.10	+684.92	+547.68	-776.20	-640.83	+169.90	-124.96	-159.79	+90.71	-89.66	+86.75	+250.91
316	10		+58.78	+126.15	+199.816	+136.14	-109.34	+137.84	-322.72	-140.87	+367.79	+48.73	+94.17	+94.86
318	10		-142.72	-153.26	+116.515	+558.71	-147.45	+94.84	-93.82	-93.84	+100.63	+138.02	-67.85	+78.01

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
320	10		-20.88	-52.73	+42.7734	+68.23	-42.56	+100.67	+102.72	-67.51	+94.47	+116.02	-104.94	+104.64
322	10		-85.74	-84.90	+94.6044	+111.23	-82.38	+190.07	+50.55	-98.61	+149.61	+176.42	-73.71	+137.64
324	10		-141.29	-71.18	-106.38	+469.67	-101.51	-578.81	+143.03	-89.33	-152.97	+389.52	-139.16	-146.76
326	10		+747.10	-766.30	-562.61	+784.53	-710.86	-472.50	+346.09	-503.35	-370.10	+273.74	-250.14	-78.85
328	10		-491.89	-487.29	-481.53	+549.98	-476.01	-313.28	+566.31	-408.86	-374.65	+413.18	-329.22	-65.13
330	10		-528.29	-472.10	-471.34	+499.88	-461.86	-359.02	+267.88	-290.04	-246.95	+151.36	-134.82	-164.03
332	10		-1056.68	-639.72	-315.40	+448.14	-245.33	-1688.53	+148.73	-172.47	-164.10	+136.90	-356.32	-227.52
334	10		-1817.14	-1690.36	-1685.31	+1862.53	-1657.71	-352.70	+298.10	-1329.78	-1459.83	+415.52	-214.51	-294.28
336	10		-356.67	-357.01	-340.54	+138.55	-344.72	-112.42	+1293.73	-245.74	-250.95	+77.36	-212.09	-188.09
338	10		-239.32	-112.51	-66.63	+194.01	-120.05	-147.99	+148.72	-118.07	-188.09	+446.48	-207.74	-96.28
340	10	88°27'13.057"E 23°1'40.939"N	-362.72	-163.47	-184.96	+589.16	-196.44	-405.49	+70.50	-255.42	-216.07	+309.54	+191.04	-116.27
342	11		-478.54	-439.47	-314.96	+1451.62	-366.83	-881.55	+478.66	-175.09	-133.84	+68.60	+209.73	-144.97
344	11		-220.69	-552.83	-619.70	+585.66	-610.93	-358.32	+148.27	-517.07	-554.58	+188.31	+190.56	-205.55
346	11		-220.19	-184.82	-300.06	+138.45	-186.70	-49.45	+592.33	-179.67	-158.90	+132.11	-204.97	-86.52
348	11		-246.72	-148.93	-28.44	+55.52	-157.67	-81.65	+85.00	-101.43	-134.54	+157.13	-155.86	-77.18
350	11		-107.26	-180.17	-21.36	+27.97	-173.84	-170.15	+109.48	-133.30	-115.98	+113.25	-112.88	-136.09

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972			1980			1990			2000		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
352	11		-279.11	-240.20	-372.19	+69.94	-237.00	-38.56	+97.40	-150.52	-102.08	+111.63	-196.73	-102.46
354	11		-43.72	-96.58	-165.92	+376.15	-101.47	-70.48	+96.37	-182.68	-102.46	+281.22	+138.19	-90.05
356	11		-184.09	-306.76	-335.44	+81.58	-264.26	-143.01	+137.74	-75.68	-141.71	+130.28	-98.53	-68.48
358	11		-72.28	-97.39	-248.72	+25.99	-183.45	-47.27	+43.12	-94.78	-117.14	+129.22	-120.90	-136.98
360	11		-116.73	-253.77	-274.31	+31.26	+196.47	-52.99	+78.62	-79.93	-176.79	+92.94	+131.14	-78.97
362	11		-54.50	-116.11	-285.20	+25.89	+112.75	-41.57	+38.57	-77.42	-169.81	+153.71	+78.85	-125.45
364	11		-162.51	-91.21	-155.42	+49.35	+175.00	-112.02	+72.33	-105.47	-148.67	+112.95	+144.88	-159.84
366	11		-8.86	-115.06	-253.22	+105.44	+204.97	-37.10	+68.67	-100.81	-71.46	+105.36	+126.82	-161.06
368	11		-91.00	-93.29	-136.31	+45.81	+121.48	-42.85	+70.75	-53.23	-85.27	+134.46	+169.15	-156.48
370	11		-101.80	-78.53	-92.22	+23.02	+69.30	-48.30	+59.93	-68.96	-111.43	+139.42	+96.41	-114.30
372	11		+73.61	+64.57	-126.28	+48.49	+66.09	-45.11	+71.38	-35.47	-103.91	+144.96	+93.77	+68.01
374	11	88°20'55.414"E 22°47'21.817"N	+54.15	-98.84	-83.78	+85.60	+88.95	-114.81	+87.54	-100.31	-139.96	+126.53	+154.59	-179.09
376	12		+112.77	+203.45	-297.18	+56.39	+164.85	-102.70	+83.70	-132.39	-168.04	+133.18	+108.72	-101.94
378	12		+71.41	+200.09	-193.90	+44.69	+190.24	-86.46	+131.49	-95.40	-123.65	+140.32	+163.04	-106.54
380	12		+114.92	+255.36	-138.41	+72.95	+250.49	-65.01	+54.69	-119.01	-100.35	+216.49	+208.51	-121.02
382	12		-162.56	-97.95	-76.08	71.42	+70.44	-78.54	38.14	-134.81	-154.39	+49.63	+81.54	-113.17

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
384	12		-81.35	-143.12	-138.32	+38.04	+145.72	-53.35	+84.57	-155.31	-118.33	+166.99	+137.51	-109.87
386	12		-116.49	-127.59	-167.90	+65.39	+113.87	-32.25	+127.94	-90.63	-109.72	+116.82	+65.53	-108.20
388	12		-82.54	-148.96	-203.68	+250.69	+138.52	-26.94	+51.89	-104.31	-161.12	+139.54	+121.38	-101.87
390	12		-70.96	-108.69	-155.54	+39.33	+124.56	+42.92	+83.50	-137.53	-101.87	+139.81	+181.99	-172.40
392	12		-135.68	-161.06	-38.87	+61.35	+204.25	+49.57	+75.05	+103.40	-184.24	+151.25	+180.77	-91.93
394	12		-107.44	-54.46	-172.04	+21.70	+73.07	-56.42	+97.16	+70.65	-119.29	+105.48	+156.90	-109.49
396	12		-168.40	-122.85	-111.34	+82.15	+117.40	-116.21	+38.50	+199.88	-68.61	+138.84	+94.17	-116.97
398	12		-75.80	-164.67	-406.64	+40.11	+187.88	-95.42	+18.28	+161.08	-103.75	+164.55	+65.39	-134.93
400	12		-80.09	-101.27	-407.28	+37.95	+98.95	-115.57	+86.65	+114.28	-134.93	+104.16	+96.56	-162.30
402	12		-84.08	-108.94	-186.44	-91.97	-171.75	-33.48	-57.21	-166.15	-110.35	-95.70	-126.79	-84.64
404	12		-213.53	-336.95	-74.34	+60.32	+330.55	-111.72	-104.59	-175.49	-105.13	+67.47	+189.80	-142.79
406	12		-110.13	+220.50	-445.98	+181.87	+148.21	-192.50	-113.34	+83.19	+142.79	+101.38	+87.27	-110.90
408	12	88°17'43.36"E 22°32'56.508"	-31.36	+59.74	-118.98	+88.25	+47.88	-114.56	-44.52	+113.30	-120.96	+117.93	+88.10	-95.84
410	13		-124.17	+9.92	-12.97	+206.62	+114.93	-161.27	-81.07	+38.39	-90.55	+136.90	+96.04	-85.56
412	13		-182.56	+97.74	-55.15	+155.77	+54.11	-95.53	-25.95	+78.92	-85.56	+126.75	+161.75	-90.09
414	13		-176.18	-71.65	-24.34	+65.86	-97.88	-145.00	-70.79	-101.22	-114.79	+170.72	-300.40	-97.07

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
416	13		+68.86	+284.82	-160.42	+151.79	+63.59	-84.96	-39.91	+133.69	+159.16	+113.82	+69.44	-114.66
418	13		-43.51	+85.56	-147.06	-234.31	+192.09	-88.16	-65.38	+83.59	-87.59	-178.04	+80.33	-90.98
420	13		-61.98	+28.97	-128.61	+209.63	+81.83	-52.70	+97.59	+159.96	+126.74	+87.83	+168.51	-121.21
422	13		-74.99	+32.57	-19.46	+118.26	+23.15	-73.68	+87.93	+105.23	-159.03	+79.69	+113.35	-144.12
424	13		+28.93	+155.82	-64.39	+57.35	+21.49	-72.99	+122.31	+87.10	-145.00	+148.24	+138.46	-124.04
426	13		+32.95	+36.70	-86.20	+189.86	+21.03	+103.96	+21.88	+68.66	+90.66	+90.79	+108.18	+248.98
428	13		+41.12	+52.36	+117.02	+144.91	+37.31	+77.81	+54.57	+88.54	+101.83	+104.16	+74.88	+124.59
430	13		+63.31	+86.23	+69.70	+146.46	+31.86	+138.69	+39.18	+108.34	+144.57	+98.58	+45.37	+153.56
432	13		+51.10	+92.45	+34.19	+213.38	+14.68	+123.01	+54.08	+89.33	+97.68	+52.02	+64.37	+112.23
434	12		+40.08	+53.45	+9.156	+101.55	+119.24	+202.30	+74.35	+109.20	+170.02	+107.28	+191.70	+54.20
436	13		+53.57	+91.41	+32.01	+180.60	+26.95	+102.44	+89.63	+122.41	+106.77	+133.48	+190.09	+130.44
438	13		+73.80	+134.29	+35.55	+192.50	+60.58	+34.62	+51.49	+181.19	+71.11	+76.89	+81.40	+129.86
440	13		+124.68	+107.28	+123.84	+27.13	+90.14	+148.83	+92.53	+71.62	+152.84	+71.54	+199.46	+144.87
442	13	88°7'59.015"E 22°23'36.937"N	+115.31	+104.61	+191.69	+113.41	+61.98	+216.69	+123.06	+138.58	+96.75	+168.26	+149.36	+189.87
444	14		+45.81	+106.01	+20.4	+156.57	+57.70	+82.07	+121.13	+116.66	+228.68	+96.37	+137.76	+117.81
446	14		+33.08	+153.63	+52.81	+144.97	+8.15	+46.55	+25.30	+161.69	+167.40	+133.33	+156.31	+146.77

Table 2 (continued)**:** Shift in the course of Hooghly River of years 1972, 1980, 1990 and 2000 w.r.t. year 2010

Distance (km)	Reach No.	Lat/Long	1972 (m)			1980 (m)			1990 (m)			2000 (m)		
			Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank	Left Bank	Center Line	Right Bank
448	14		+56.39	+183.12	+17.12	+264.86	+93.86	58.95	67.56	+115.84	+79.10	+146.33	+177.42	+139.74
450	14		+26.94	+31.78	+177.68	+13.55	+176.57	+22.78	+38.02	+168.13	+127.55	+144.73	+139.63	+205.23
452	14		+58.08	+151.01	+31.51	+15.37	+33.39	+64.84	+42.33	+175.99	+121.28	+215.23	+153.72	+97.39
454	14		+149.22	+175.42	+35.18	+28.86	+145.45	+93.56	+70.92	+95.98	+248.28	+81.69	+64.32	+122.89
456	14		+138.53	+135.35	+64.42	+82.96	+149.70	+95.63	+90.56	+118.90	+109.04	+126.10	+134.96	+47.29
458	14		+40.65	+70.06	+46.18	+79.22	+145.30	+33.00	+80.76	+214.33	+120.25	+120.64	+107.32	+62.02
460	14		+112.74	+78.26	+19.39	+47.49	+70.55	+60.51	+63.93	+130.37	+71.50	+198.32	+185.45	+149.83
462	14		+10.83	+277.90	+74.33	+40.70	+54.50	+43.11	+70.96	+180.80	+168.93	+80.23	+52.87	+122.62
464	14		+68.48	+402.41	+130.70	+23.49	+267.80	+333.72	+49.31	+122.96	+87.93	+114.33	+744.13	+707.84
466	14		+36.68	+725.31	+123.99	+480.42	+206.59	+255.57	+80.42	+379.11	+94.37	+124.11	+647.41	+356.19
468	14		+83.28	+466.39	+17.11	+318.68	+603.36	+282.50	+104.46	+251.86	+67.41	+168.93	+251.86	+678.18
470	14	88°4'12"E 22°11'44.76"N	+90.44	+437.52	+26.40	+294.36	+383.70	+203.94	-86.96	+202.34	+26.40	-86.96	+202.34	+26.40

Table 3 : Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
0	1	49°9'29.719"E 9°8'1.11"N	+87.64	+34.60	+12.86	Farakka	Minimum	-
2	1		-17.73	-40.47	+43.09	New Farakka Station Road	Minimum	-
4	1		-65.15	+30.99	-36.67	Andhua	Minimum	-
6	1		-82.62	-37.66	-55.80	Ballalpur	Minimum	-
8	1		-38.13	-29.97	-22.39	Alaipur	Minimum	-
10	1		-31.29	-35.10	-45.00	Pachula Gram	Minimum	-
12	1		-55.40	-30.87	-69.42	Mamrejpur	Minimum	-
14	1		-45.36	-40.93	-62.84	Phulandar	Minimum	-
16	1		-52.16	-58.45	-27.34	Malancha	Minimum	-
18	1		-57.16	-28.34	-72.93	Antar Dwipa	Minimum	-
20	1		-15.94	-29.30	-210.32	Dogachhi	-	Maximum
22	1		-66.50	-37.01	-164.39	Laskarpur	-	Maximum
24	1		-35.14	-53.54	-216.04	Mahisha Thali	-	Maximum
26	1		-120.59	-31.02	-142.76	Amuha	-	Maximum
28	1		-85.38	-23.94	-146.26	Ekatia	-	Maximum
30	1		-79.17	+62.44	-176.55	Hazipur	-	Maximum
32	1		-80.20	+39.36	-135.71	Kisorpur	-	Maximum
30	1		+87.64	+34.60	+12.86	Farakka	Minimum	-
34	2	49°18'50.851"E 8°54'18.259"N	-126.41	+96.82	-234.18	Ahiran Bus Stop	-	Maximum
36	2		-290.12	+104.10	+281.76	Ghorapakhiaga ngin	-	Maximum
38	2		-44.29	-47.09	-138.44	Rosanpur	-	Maximum
40	2		-233.56	-131.56	-104.05	Char Sekandara	-	Maximum
42	2		-40.72	-42.29	+104.05	Bhabanupur	-	Maximum
44	2		-16.04	-11.58	+79.10	Rampura	Minimum	-

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
46	2		-57.17	+54.02	+31.48	Tantipara	Minimum	-
48	2		-76.23	-49.51	+139.91	Bahura	-	Maximum
50	2		-65.62	-81.59	+68.22	Sahajadpur	Minimum	-
52	2		-56.08	+71.49	+115.50	Raninagar Dwipchar	Minimum	-
54	2		+91.41	-64.41	+70.05	Dighir Pahar	Minimum	-
56	2		-66.76	-58.68	-41.68	Kasia Danga	Minimum	-
58	2		-262.56	-292.17	-377.69	Nutangani	-	Maximum
60	2		+42.73	+54.42	+101.93	Mahammadpur	Minimum	-
62	2		-53.06	-97.26	+93.77	Dair Raghunathpur	Minimum	-
64	2		-62.02	-46.77	+87.25	Basumati	Minimum	-
66	2		-30.63	-60.05	-78.95	Fraser Nagar	Minimum	-
68	3	49°27'4.182"E 8°46'39.746"N	-35.21	-65.17	-184.37	Jumra Nayagram	-	Maximum
70	3		-110.47	+66.59	+53.08	Ujjal Nagar	Minimum	-
72	3		+90.88	+158.05	+221.98	Syampur	Minimum	-
74	3		-75.52	+175.79	-103.37	Rajarampur	Minimum	-
76	3		-129.45	-131.23	-411.37	Rampal	-	Maximum
78	3		+394.51	-327.79	-265.18	Lalitakuri	-	Maximum
80	3		-203.96	+192.66	-135.92	Bhatpara	-	Maximum
82	3		-149.00	-139.72	-118.33	Arijpur	-	Maximum
84	3		-95.64	-57.34	-84.09	Sites Nagar	Minimum	-
86	3		-56.34	-76.25	-60.93	Char Lalitakuri	Minimum	-
88	3		+55.31	-81.41	-91.40	Char Sundarpur	Minimum	-
90	3		-93.24	-101.08	-171.96	Chak Mahammadpur	-	Maximum

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
92	3		-186.45	-52.09	-91.47	Kamarpara	-	Maximum
94	3		-38.00	-61.85	-92.76	Dasturhat	Minimum	-
96	3		-47.06	-62.67	-45.26	Uttar Ganespur	Minimum	-
98	3		-63.99	-79.62	-93.54	Bahadurpur	Minimum	-
100	3		-101.99	-59.21	-37.90	Asanpur	Minimum	-
102	4	49°35'15.677"E 8°39'11.9"N	-65.86	-56.50	-65.54	Jiaganj Azimganj	Minimum	-
104	4		-41.74	-72.61	-35.14	Char Mahimapur	Minimum	-
106	4		-68.37	-41.62	-52.47	Satichauraha	Minimum	-
108	4		-53.19	-75.94	-85.69	Shah Nagar	Minimum	-
110	4		-52.55	-52.37	-31.24	Murshidabad	Minimum	-
112	4		-93.89	-59.77	-70.09	Talgachi	Minimum	-
114	4		-71.46	-82.25	-17.71	Raniswar	Minimum	-
116	4		-85.54	-58.42	-54.72	Khagra Bazar	Minimum	-
118	4		+220.03	-297.03	-387.78	Bazarpara	-	Maximum
120	4		-844.85	-801.43	-804.37	Ajodhya Nagar	-	Maximum
122	4		-940.66	+2649.20	-1474.34	Begpur	-	Maximum
124	4		-1091.85	-747.05	-819.79	Char Narayanpur	-	Maximum
126	4		-119.87	-165.22	-190.16	Fate singdiar	-	Maximum
128	4		-112.98	-77.76	-56.23	Parhalalpur	-	-
130	4		-76.06	-397.36	-579.53	Charmahula	-	Maximum
132	4		-947.32	-890.33	-903.60	Hotnagar	-	Maximum
134	4		-110.55	-169.87	-234.76	Chak Katalia	-	-

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
136	5	49°35'39.553"E 8°24'1.98"N	-117.79	-42.92	-36.86	Banamalipur	-	-
138	5		-293.12	-228.37	-167.83	Barlu	-	Maximum
140	5		-487.48	-325.79	-264.65	Chumarigacha	-	Maximum
142	5		+462.45	+408.94	-503.50	Satui	-	Maximum
144	5		-35.71	-155.23	-269.05	Sona Diar	-	Maximum
146	5		-48.11	+62.44	-179.93	Meliani	Minimum	
148	5		-265.86	+147.44	-174.36	Charkam Nagar	-	Maximum
150	5		-54.30	-95.28	-238.72	Saharbati	Minimum	-
152	5		-194.97	-130.30	-183.45	Sekandarpur	-	Maximum
154	5		-191.15	+64.46	-208.13	Mashimpur	-	Maximum
156	5		-1062.69	+990.11	-1070.24	Chandpur	-	Maximum
158	5		-486.18	+405.59	-497.25	Mahata	-	Maximum
160	5		-375.53	-159.55	-184.59	Arazi Jaykrishnapur	-	Maximum
162	5		+63.44	-40.39	-153.02	Mahammadpur	Minimum	-
164	5		+50.60	+73.95	-153.46	Char Mahammadpur	Minimum	-
166	5		+42.26	+38.90	+133.95	Bidupara	Minimum	-
168	5		+98.71	+55.81	+86.90	Char Ramnagar	Minimum	-
170	6	49°39'48.285"E 8°12'21.992"N	+37.31	+81.69	+164.89	Kadkhali	-	Maximum
172	6		-128.60	+83.00	-165.68	Ghasrdanga	-	Maximum
174	6		-19.95	-56.07	-36.42	Manikdighi	Minimum	-
176	6		-85.48	-84.58	-323.86	Char Gobalpur	-	Maximum
178	6		-229.76	-133.46	-154.91	Nutangram	Minimum	-

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
180	6		-459.87	-339.67	-477.18	Char narayanpur	-	Maximum
182	6		-55.37	-226.13	-359.20	Bishnupur	-	Maximum
184	6		-43.52	-150.05	-381.09	Char Sriharipur	-	Maximum
186	6		-163.29	-327.72	-212.86	Sitahati	-	Maximum
188	6		-2830.25	-2417.49	-2212.46	Uddharonpur	-	Maximum
190	6		-4944.09	-4509.89	-4426.46	Kadihati	-	Maximum
192	6		-6027.92	-5830.35	-5956.02	Khere Bazar	-	Maximum
194	6		-4907.81	-4619.35	-4661.46	Gobindopur	-	Maximum
196	6		-2831.09	-2541.82	-2492.99	Rajnagar	-	Maximum
198	6		-929.83	-780.63	-789.04	Shatghar	-	Maximum
200	6		-272.66	-154.81	-206.65	Char Brajanathpur	-	Maximum
202	6		-138.87	-101.93	-223.77	Char Balidanga	-	Maximum
204	7	49°42'11.459"E 8°2'52.174"N	-126.59	-71.76	-50.21	Kabirajpur	Minimum	-
206	7		-74.86	-121.14	-158.22	Char Khosalpur	-	Maximum
208	7		-804.63	-597.65	-544.90	Akandanga	-	Maximum
210	7		-118.31	-139.03	-174.08	Agradwip	-	Maximum
212	7		-514.77	-497.90	-674.32	Gazipur	-	Maximum
214	7		-112.27	-78.61	-173.39	Chandanpur Simuldanga	-	Maximum
216	7		-527.12	-698.87	-967.11	Mamudpur	-	Maximum
218	7		-430.00	-164.21	-106.92	Patuli	-	Maximum

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
220	7		-195.27	-159.42	-184.36	Jhaudanga	-	Maximum
222	7		-216.97	-66.13	-194.48	Mamudpur	-	Maximum
224	7		-72.98	-162.44	-242.45	Narayanpur	-	Maximum
226	7		-97.83	-181.25	-511.72	Uttar Shrirampur	-	Maximum
228	7		-197.46	-94.03	-235.16	Dampal	-	Maximum
230	7		-546.50	-393.19	-719.64	Uday Chandrapur	-	Maximum
232	7		-275.16	-155.58	-249.39	Dadupur	-	Maximum
234	7		-263.97	-385.84	-618.14	Char Jhaudanga	-	Maximum
236	7		-261.47	-274.01	-296.44	Kashiadanga	-	Maximum
238	8	49°49'20.911"E 8°1'3.387"N	-457.90	-445.41	-438.36	Chandanpur	-	Maximum
240	8		+346.01	340.45	+359.72	Karkaria	-	Maximum
242	8		+879.87	-1194.98	-173.50	Rukunpur	-	Maximum
244	8		-194.14	+105.90	+286.52	Mertala	-	Maximum
246	8		-114.67	+103.14	+135.46	Durgabas	-	Maximum
248	8		-80.45	-138.51	-111.71	Simla	-	Maximum
250	8		-429.16	+419.27	-686.71	Sajira	-	Maximum
252	8		-109.05	+98.48	+127.08	Shankapur	-	Maximum
254	8		+238.67	+427.41	+144.68	Indrakpur	-	Maximum
256	8		+105.75	+123.68	+99.91	Rudrapara	-	Maximum
258	8		+330.06	+389.11	-520.05	Mayapur	-	Maximum
260	8		-68.07	+84.09	+177.82	Hular Ghat	-	Maximum
262	8		-113.57	+68.58	+234.05	Char Brahmanagar	-	Maximum

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
264	8		-171.58	+169.94	+154.63	1 No. Gouranga Colony	-	Maximum
266	8		-102.04	+97.66	+239.75	Parmedia	-	Maximum
268	8		-1306.32	-1009.23	-1067.62	Bankar Dhopadi	-	Maximum
270	8		-104.21	+78.55	-164.57	Bhaluka	-	Maximum
272	9	49°53'19.054"E 7°48'32.539"N	+314.15	+280.60	+414.04	Satkulta	-	Maximum
274	9		-545.76	+809.32	-983.14	Mohisunra	-	Maximum
276	9		-414.37	+133.86	-182.74	Jaluidanga	-	Maximum
278	9		+25.80	+89.11	+166.23	Jalahati	-	Maximum
280	9		-521.47	-436.81	+575.20	Hatsimla	-	Maximum
282	9		-330.05	-318.35	-420.33	Goalpur	-	Maximum
284	9		-97.09	+154.02	+59.35	Bholadanga	Minimum	-
286	9		+288.94	+117.93	+83.79	Mrijapur	-	Maximum
288	9		+397.99	+322.38	+416.19	Gramkalna	-	Maximum
290	9		-444.52	-275.17	+160.92	Piarinagar	-	Maximum
292	9		+723.77	-319.86	+449.13	Krishnadebpur	-	Maximum
294	9		+166.03	+118.82	+322.36	kalna P	-	Maximum
296	9		-251.05	+111.82	+86.77	Nrisinghapur/Kalna	-	Maximum
298	9		+84.36	+97.26	+141.82	Beltala	Minimum	-
300	9		+138.07	+103.88	+163.46	Satgachhi	Minimum	-
302	9		+294.00	+349.44	+350.29	Guptipara Char	-	Maximum
304	9		-736.55	-422.41	+594.38	Chhenrar char	-	Maximum
306	10	49°59'3.327"E 7°43'50.596"N	+807.64	+681.81	+881.93	Ghoshra	-	Maximum
308	10		+641.99	+458.80	+533.40	Malipota	-	Maximum

Table 3 (continued): Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
310	10		-176.43	-1470.60	+1728.20	Nilnagar	-	Maximum
312	10		-490.66	-342.93	+416.59	Char Rampur	-	Maximum
314	10		-423.56	+174.60	+132.07	Rasulpur Char	-	Maximum
316	10		+255.08	+121.60	+340.03	Char Noapara	-	Maximum
318	10		+872.57	-775.07	+1103.07	Sukuria	-	Maximum
320	10		+235.99	-180.83	+394.31	Char Sripur	-	Maximum
322	10		+329.67	-141.43	+152.45	Gosair Char	-	Maximum
324	10		+270.64	-101.00	-225.97	Sibpur	-	Maximum
326	10		+244.47	-115.27	-310.32	Char Gaur Nagar	-	Maximum
328	10		+131.66	-102.44	-196.91	Milangarh	-	Maximum
330	10		+139.34	-132.65	-312.81	Raninagar	-	Maximum
332	10		+205.74	-178.61	-219.48	Charjirat	-	Maximum
334	10		+94.65	-303.76	-200.78	Natun Para	-	Maximum
336	10		+130.68	-112.01	-146.68	Baneswarpur	-	Maximum
338	10		+115.89	-72.60	-140.98	Sukhsagar	Minimum	-
340	11	50°1'9.172"E 7°32'13.243"N	+252.81	+219.91	-226.87	Tarinipur	-	Maximum
342	11		+168.45	+133.87	-306.01	Ganga Manoharpur	-	Maximum
344	11		+97.68	+125.70	-144.87	Char Jajira	-	Maximum
346	11		+137.94	-118.46	-105.98	Gaharpur	-	Maximum
348	11		+121.40	-133.26	-296.28	Jatrasudi	-	Maximum
350	11		+135.30	-138.31	-123.15	Char Kancharapara	-	Maximum
352	11		+218.89	-156.55	-135.43	Char nandan bati	-	Maximum

Table 3 (continued): Shift in the course of Hooghly River of years 1972-2018

			Left Bank (m)	**Center Line (m)**	**Right Bank (m)**		**Minimum**	**Maximum**
354	11		+87.06	-153.64	-274.28	Konamore		Maximum
356	11		+102.43	-87.44	-78.28	Hazi Nagar		Maximum
358	11		+141.77	-107.41	-185.70	Mitrapara		Maximum
360	11		+159.81	+87.94	-306.32	Nimbagan		Maximum
362	11		+119.26	+43.69	-132.27	Arya Samaj		Maximum
364	11		+125.64	+81.40	-109.70	Barabazar		Maximum
366	11		+198.29	+105.05	-161.83	Antpur Ferry Ghat		Maximum
368	11		+47.05	+128.30	-380.18	Noapara		Maximum
370	11		+53.65	+118.23	-291.00	Bichali		Maximum
372	11		+208.71	+97.52	342.10	Sastitala		Maximum
374	12	49°58'40.176"E 7°17'15.902"N	+345.61	+110.80	-243.98	Palta Park		Maximum
376	12		+170.35	+159.91	-306.12	Baidyapara		Maximum

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
378	12		+148.17	+169.92	-130.35	Barrackpur Ferry Ghat	-	Maximum
380	12		+148.69	+80.25	-53.00	Barrackpur Cantonment	Minimum	-
382	12		+103.18	+151.25	-77.58	Titagarh	Minimum	-
384	12		+72.24	+134.74	-116.68	Bose Para Kali Bedi	Minimum	-
386	12		+177.36	+180.80	-195.68	Dutta Bari	-	Maximum
388	12		+108.47	+114.03	-168.44	Kamarhati	-	Maximum
390	12		+104.68	+121.80	-71.14	Uttarpara Kotrung	-	Maximum
392	12		+89.71	+118.97	-110.94	Chaitalpara	Minimum	-
394	12		+90.57	+171.40	-152.66	Baranagar	Minimum	-
396	12		+117.00	+131.01	-135.31	Cossipore	-	Maximum
398	12		+85.10	+143.27	-269.45	Kumartuli	Minimum	-
400	12		+72.08	+135.33	-93.54	Jorabagan	Minimum	-
402	12		+59.12	-75.69	-80.96	BBD Bag	Minimum	-
404	12		+75.93	+159.36	-83.78	Fort William	Minimum	-
406	12		+82.92	+145.82	-173.61	Khidirpur	-	Maximum
408	13	49°58'56.483"E 7°2'50.839"N	+114.35	+131.23	-102.54	Atabag Basti	-	Maximum
410	13		+39.51	+124.32	-208.94	Rajabagan Dock Yard	-	Maximum
412	13		+153.13	+226.19	-137.45	Sishu Udyan	-	Maximum
414	13		+84.39	-137.02	-210.56	Badartala	Minimum	

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
416	13		+91.19	+90.47	-167.97	Kanchantala	Minimum	-
418	13		-118.95	+143.58	-147.46	Akra Puratan Bazar	Minimum	-
420	13		+288.32	+223.98	-106.28	Batanagar	-	Maximum
422	13		+21.23	+206.84	-140.88	Hirapur	Minimum	-
424	13		+96.10	+186.60	-208.07	Chakmadhu	Minimum	-
426	13		+69.98	+161.94	+105.58	Hat Bauria	Minimum	-
428	13		+128.86	+335.47	+76.20	Kalipur	-	Maximum
430	13		+82.92	+160.51	+167.32	Pujali	Minimum	-
432	13		+114.35	+189.03	+167.97	Boikunthopur	-	Maximum
434	13		+39.51	+144.10	+147.46	Achipur	Minimum	-
436	13		+153.13	+140.85	+106.28	Jagatballavpur	-	Maximum
438	13		+84.39	+134.33	+140.88	Birlapur	-	Maximum
440	13		+91.19	+144.09	+208.07	Dakshin Raypur	-	Maximum
442	14	49°52'18.167"E 6°52'0.068"N	+96.10	+146.31	105.58	Godakhali	Minimum	-
444	14		+69.98	+146.31	+76.20	Naldari	Minimum	-
446	14		+128.86	+144.10	+102.54	Burul	Minimum	-
448	14		+39.51	+140.85	+208.94	Baidya Khali	-	Maximum
450	14		+153.13	+134.33	+137.45	Kasipur	-	Maximum
452	14		+84.39	+144.09	+95.27	Rajarampur	Minimum	-
454	14		+91.19	+134.33	+147.46	Basulat	Minimum	-
456	14		+96.10	+144.09	+72.23	Bishra	Minimum	-
458	14		+96.10	+146.31	+68.83	Akalmegh	Minimum	-
460	14		+69.98	+146.31	+208.07	Ramnagar	-	Maximum

Table 3 (continued)**:** Shift in the course of Hooghly River of years 1972-2018

Distance (km)	Reach No.	Lat/Long	Shifting of the river course (1972 - 2018)			Site Name	Shifting	
			Left Bank (m)	Center Line (m)	Right Bank (m)		Minimum	Maximum
462	14		+128.86	+146.31	+106.28	Noorpur	-	Maximum
464	14		+39.51	+146.31	+140.88	Sukdebpur	Minimum	-
466	14		+153.13	+144.10	+208.07	Durgapur	-	Maximum
468	14		+84.39	+140.85	+275.26	Geonkhali	-	Maximum
470	14		-82.21	+134.33	+34.45	Tentul Berya	Minimum	-

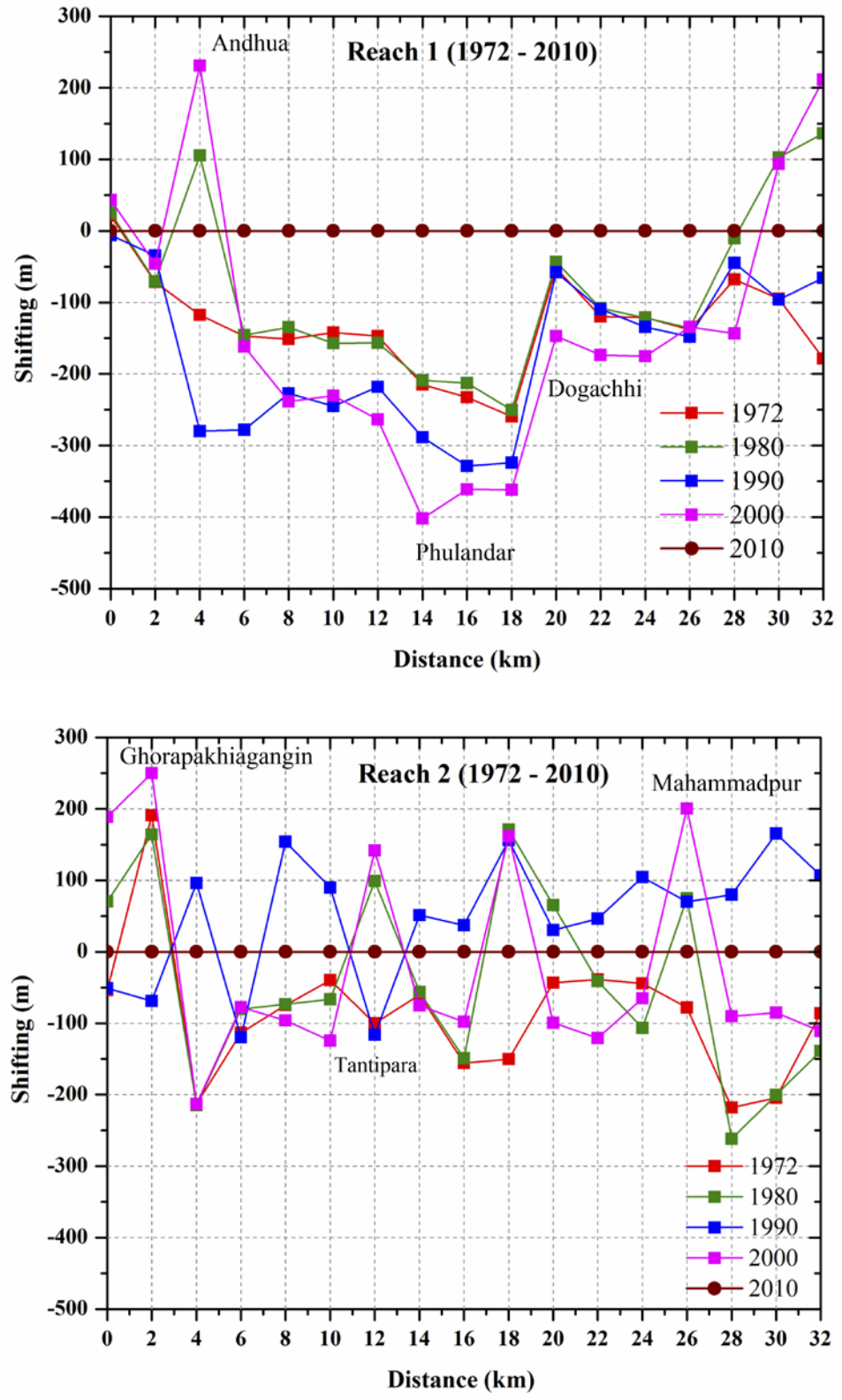
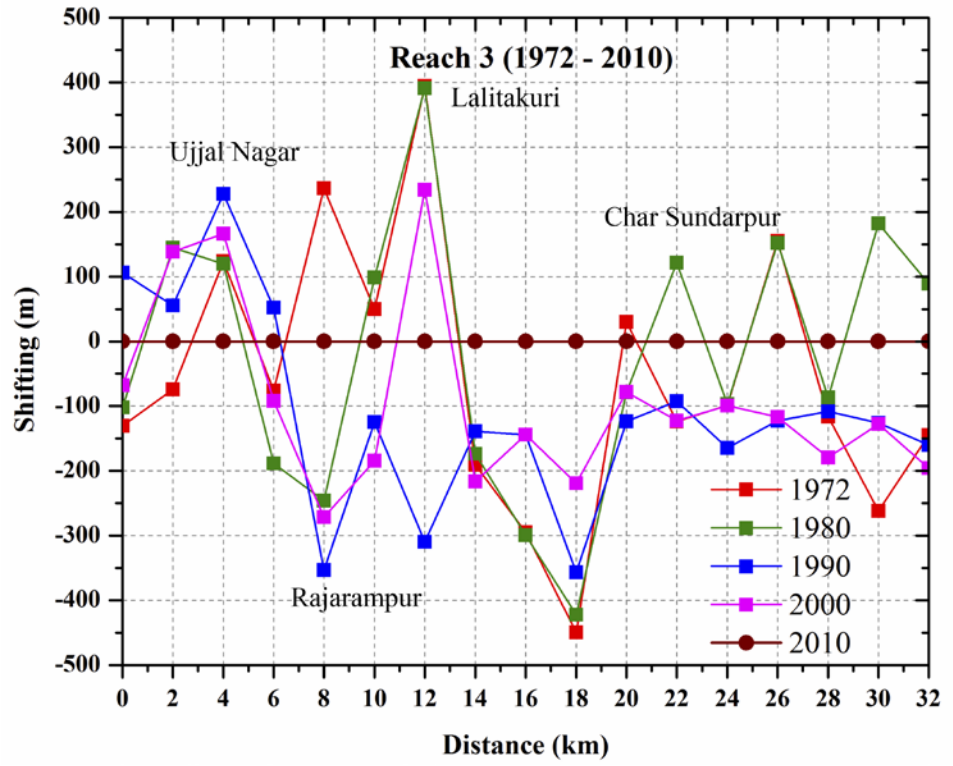


Figure 9.1: Shifting of the center line of Hooghly river for reach number 1 and 2



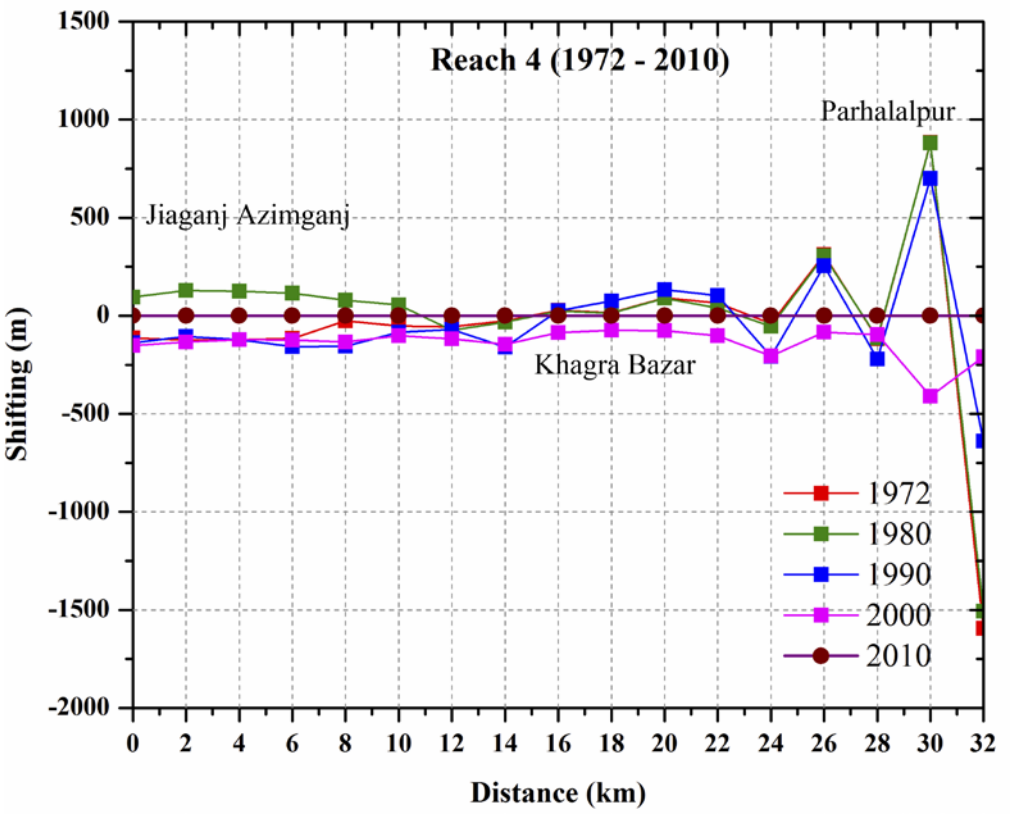


Figure 9.2: Shifting of the center line of Hooghly river for reach number 3 and 4

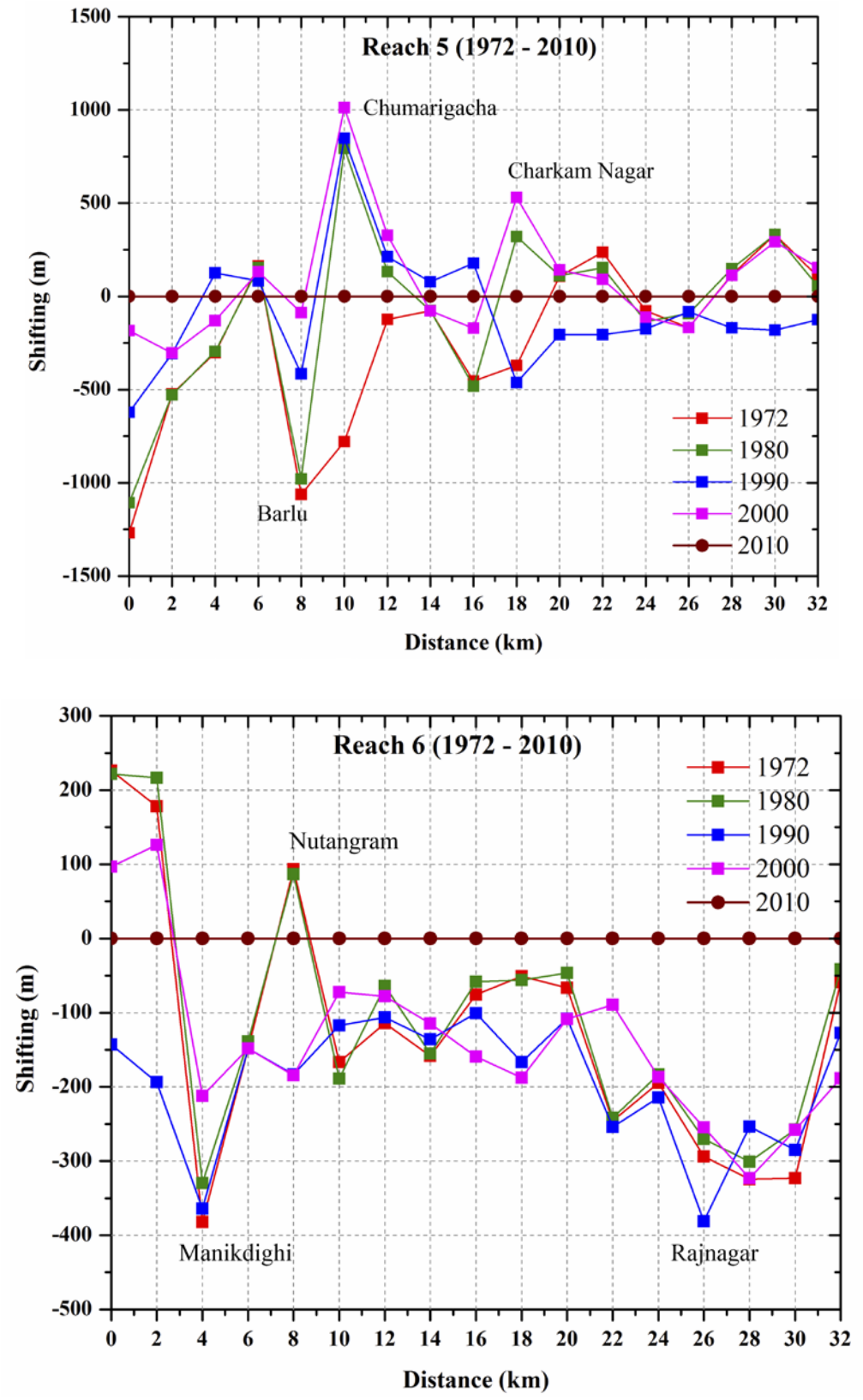


Figure 9.3: Shifting of the center line of Hooghly river for reach number 5 and 6

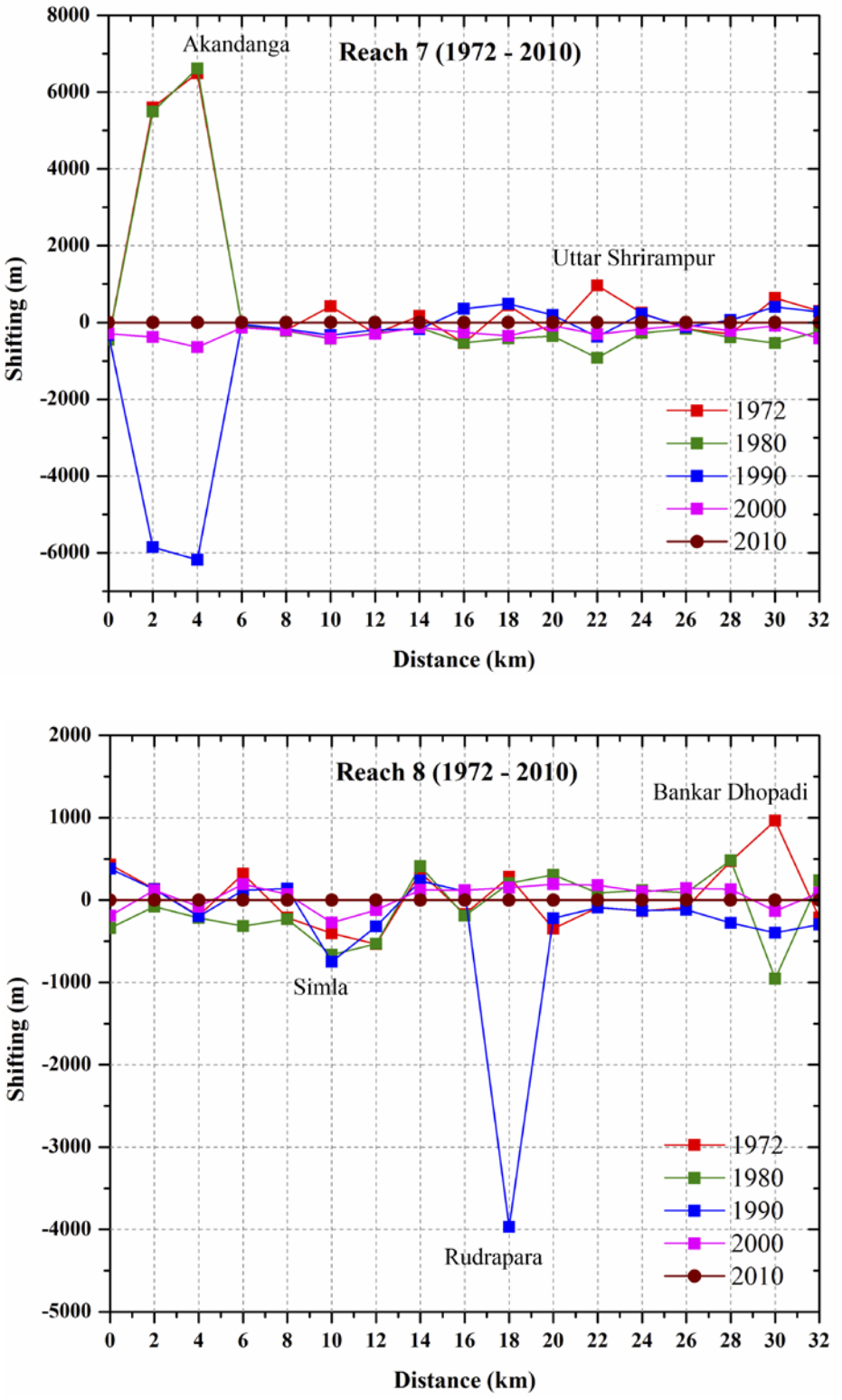


Figure 9.4: Shifting of the center line of Hooghly river for reach number 7 and 8

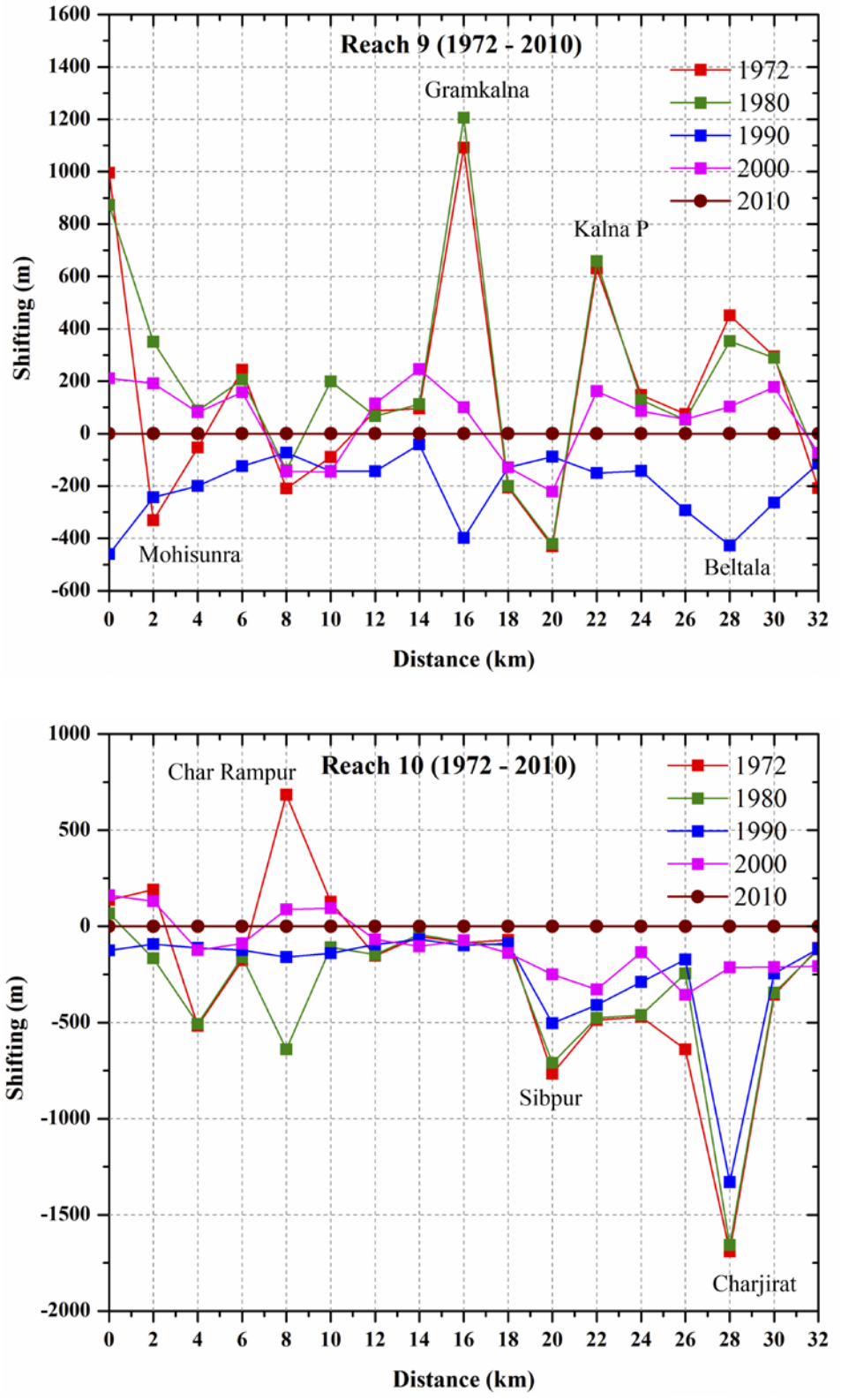


Figure 9.5: Shifting of the center line of Hooghly river for reach number 9 and 10

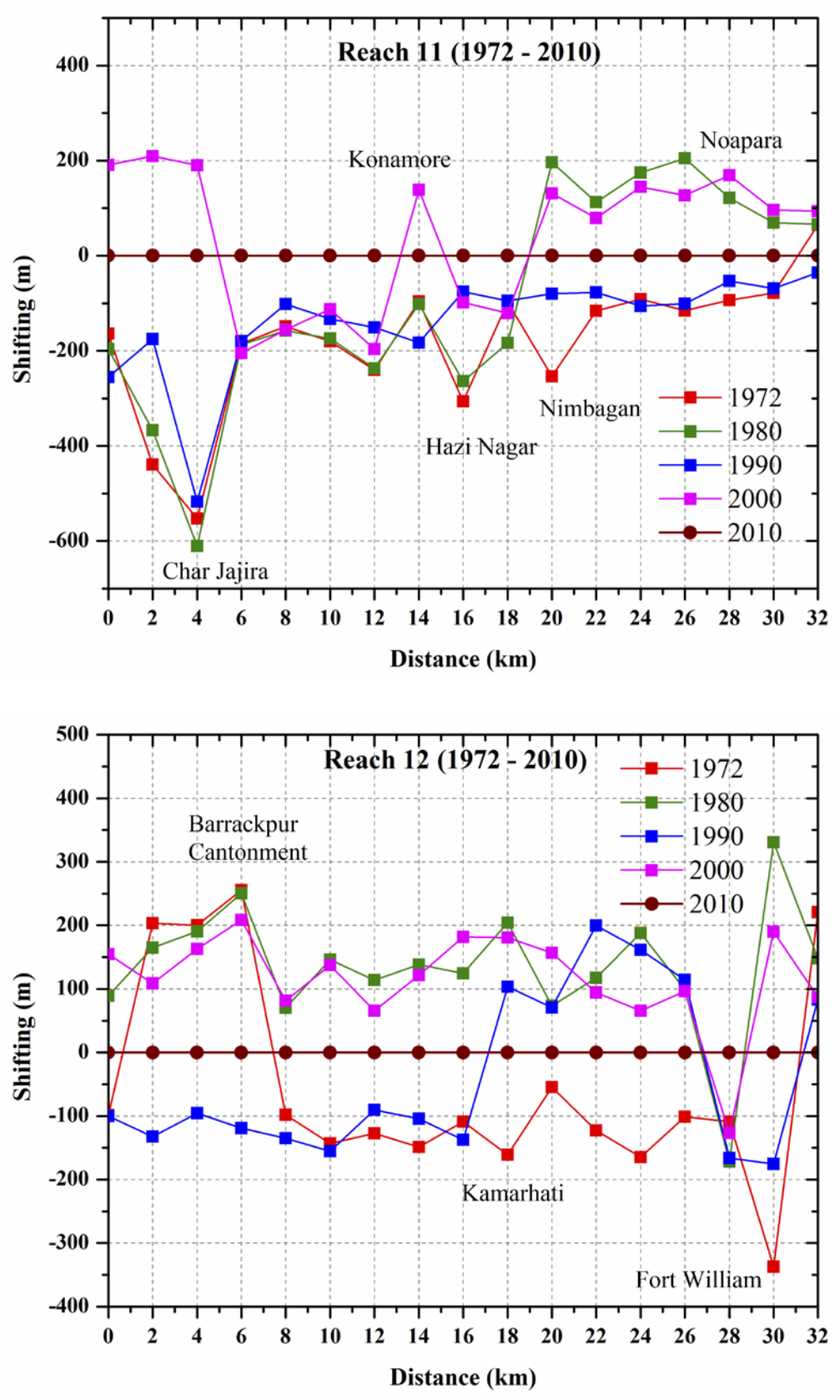


Figure 9.6: Shifting of the center line of Hooghly river for reach number 11 and 12

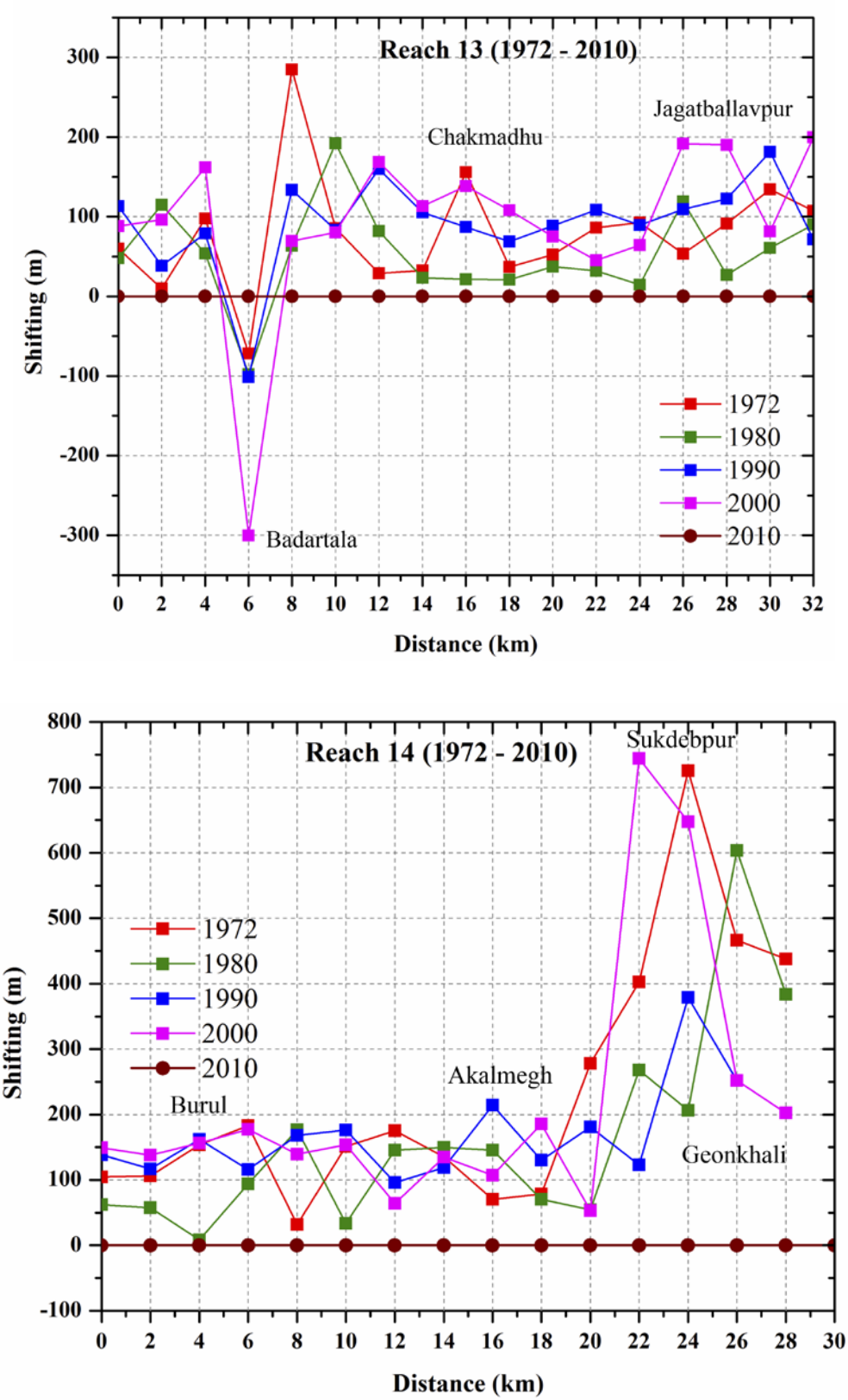


Figure 9.7: Shifting of the center line of Hooghly river for reach number 13 and 14

5.3. Identification of bank erosion and deposition:

A river is a dynamic system and tends to adjust its channel roughness, geometry, pattern and profile with time. From source to mouth a river flows with erosion, Transportation and Deposition Process. Two main reasons involved in erosion are hydraulic action and mass failure. The removal of bank material by hydraulic action is closely related to near-bank velocity conditions (Odgaard, 1987; Hasegawa, 1989). River transport the eroded materials. When a river carries high sediment loads, it tends to deposit it wherever the slope is gently leading to the formation of multichannel and development of meanders. A river tries to maintain its course, unless it is disturbed by diastrophic movements, natural calamities like flood, landslides or by human activity. A change in discharge, sediment load size and slopes may disturb the rivers equilibrium state, resulting in aggradations or degradation of the river. This process of aggradation or degradation continues for a long time until a new equilibrium is established. So the river channel is migrated. Lawler (1993) did a review on a measurement of the riverbank erosion and lateral channel changes. Measurement of the area of erosion, deposition, and shifting of riverbank lines is an important objective of fluvial morphology (Pati et al. 2008). Yang (1996) did satellite remote sensing and geographic information system (GIS)-based monitoring of the dynamic environmental change of the active Yellow River Delta, China. The main source of data in this study was a series of time-sequential Landsat images spanning a period of approximately 19 years. A GIS was used to support modernized channel position mapping and measurement. The study demonstrated the efficacy of satellite remote sensing, integrated with a GIS in investigating channel migration.

Satellite Images of the year 1972 to 2018 has been collected from USGS Earth Explorer, which covers the basin area provided by CWC. Banklines of the river were extracted for years 1972 to 2018. The whole river was divided into many reaches. Both the banklines were intersected to identify and estimate the amount of erosion and deposition at different reaches along the main river. The shifting characteristics of the river were evaluated for the identified reaches both on the right as well as left banks of the river courses (Table 3). The analysis was carried out on a yearly basis and river position was identified and compared to previous years of data to calculate the shifts in the river position. Erosion involves the wearing away of rock and soil found along the river bed and banks. Deposition is the process where the material transported by a river is deposited. Deposition occurs when a river loses energy. The total length of the Hooghly River is divided into 14 reaches. The total amount of erosion and deposition in the Hooghly River from 1972 to 2010 was also estimated as shown in Table 4. Erosion and deposition of the reaches are shown in the Figure 10.1 to 10.2.

Table 4: Erosion and Deposition of Hooghly River left and right bank

River Reach	Left Bank (1972-1980)		Right Bank (1972-1980)	
	Erosion (ha)	Deposition (ha)	Erosion (ha)	Deposition(ha)
Reach-1	2.57	249.21	29.52	317.43
Reach-2	43.88	95.05	204.40	199.17
Reach-3	53.84	87.66	60.67	161.53
Reach-4	39.79	59.93	88.94	134.29
Reach-5	24.49	126.49	72.44	206.04
Reach-6	17.41	54.47	192.32	288.92
Reach-7	100.83	49.92	196.57	152.65
Reach-8	22.37	5.62	272.65	209.20
Reach-9	51.53	51.57	357.72	196.91
Reach-10	144.16	120.51	137.23	329.33
Reach-11	405.90	28.87	340.14	623.98
Reach-12	223.17	4.42	420.56	15.26
Reach-13	305.84	23.77	607.40	83.28
Reach-14	123.73	194.62	167.45	150.19

Table 4 (continued): Erosion and Deposition of Hooghly River left and right bank

River Reach	Left Bank (1980-1990)		Right Bank (1980-1990)	
	Erosion (ha)	Deposition (ha)	Erosion (ha)	Deposition(ha)
Reach-1	61.88	3.26	390.76	94.09
Reach-2	216.09	34.43	261.15	82.72
Reach-3	213.52	74.45	135.45	68.31
Reach-4	130.26	106.31	89.14	157.01
Reach-5	380.61	277.91	214.25	70.46
Reach-6	478.23	166.97	149.39	14.22
Reach-7	350.24	298.82	127.91	137.55
Reach-8	429.11	508.82	196.14	162.36
Reach-9	429.84	459.25	235.38	231.41
Reach-10	387.25	299.06	250.96	279.74
Reach-11	184.77	294.02	154.74	260.54
Reach-12	111.00	44.30	139.71	64.68
Reach-13	12.80	336.03	42.63	355.15
Reach-14	138.33	156.67	100.15	123.20

Table 4 (continued): Erosion and Deposition of Hooghly River left and right bank

River Reach	Left Bank (1990-2000)		Right Bank (1990-2000)	
	Erosion (ha)	Deposition (ha)	Erosion (ha)	Deposition(ha)
Reach-1	38.47	103.90	455.39	1.02
Reach-2	68.719	83.31	201.09	50.94
Reach-3	54.37	105.06	78.55	105.07
Reach-4	52.87	72.78	70.49	57.67
Reach-5	56.97	225.51	205.81	247.90
Reach-6	189.66	177.06	272.39	139.65
Reach-7	181.39	598.84	281.86	999.26
Reach-8	202.35	282.91	1002.88	197.61
Reach-9	154.57	339.30	234.46	145.86
Reach-10	165.44	392.58	334.39	93.16
Reach-11	219.59	287.04	350.95	57.03
Reach-12	90.15	26.52	69.53	41.78
Reach-13	82.19	31.71	108.55	50.19
Reach-14	92.02	38.05	36.39	100.52

Table 4 (continued): Erosion and Deposition of Hooghly River left and right bank

River Reach	Left Bank (2000-2010)		Right Bank (2000-2010)	
	Erosion (ha)	Deposition (ha)	Erosion (ha)	Deposition(ha)
Reach-1	3.69	559.00	4.013	802.30
Reach-2	37.19	219.98	112.21	217.79
Reach-3	66.94	305.03	117.20	175.05
Reach-4	273.73	89.18	69.74	115.12
Reach-5	222.06	264.54	210.54	442.08
Reach-6	312.80	150.72	146.80	595.36
Reach-7	210.34	346.67	141.36	633.86
Reach-8	159.86	94.11	102.60	242.56
Reach-9	313.40	46.78	98.12	191.86
Reach-10	401.24	44.60	107.11	266.10
Reach-11	327.08	24.74	114.13	133.63
Reach-12	33.18	36.68	34.64	61.62
Reach-13	52.17	43.35	25.62	139.43
Reach-14	19.09	91.13	79.61	56.24

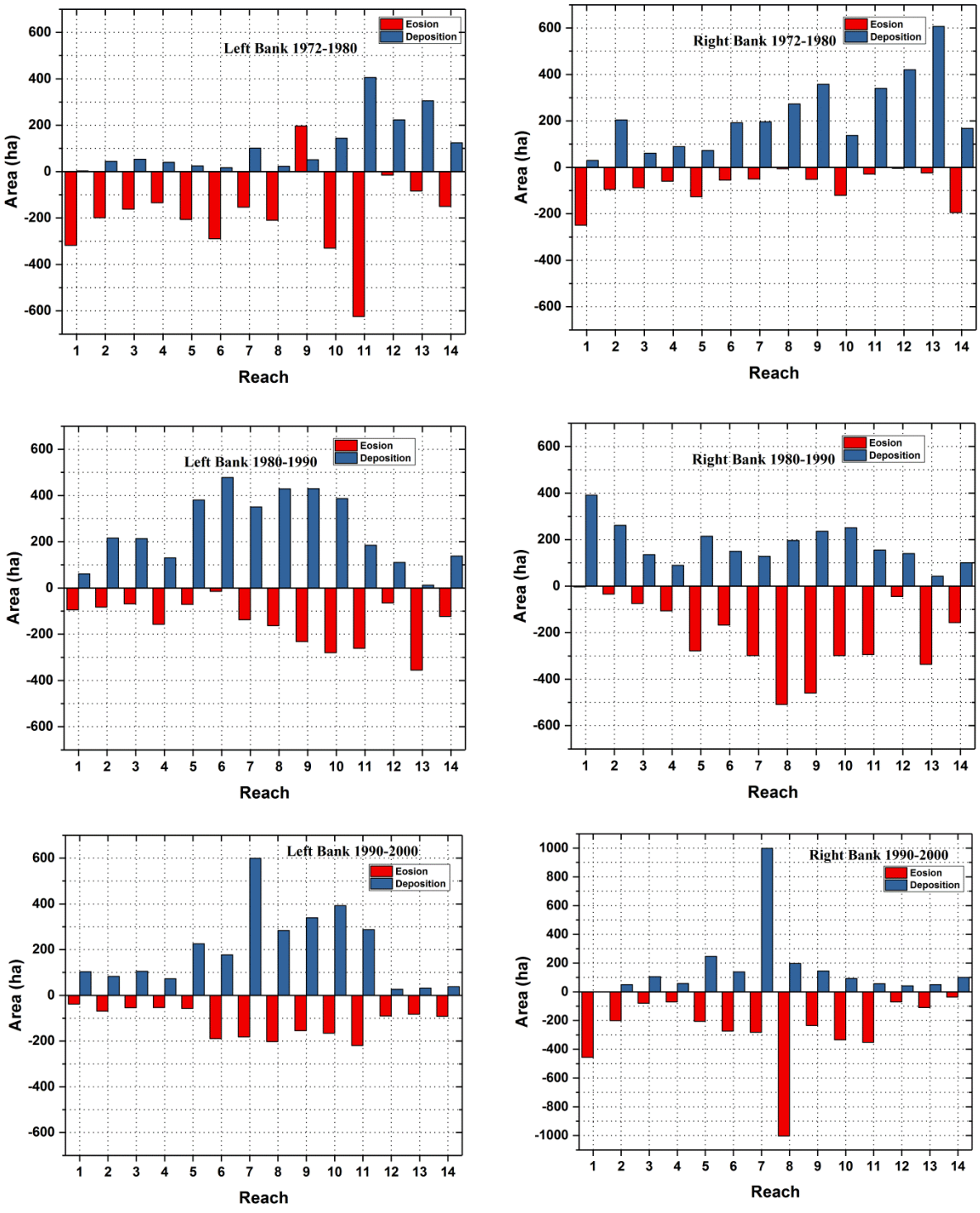


Figure 10.1: Hooghly river left and right bank erosion and deposition

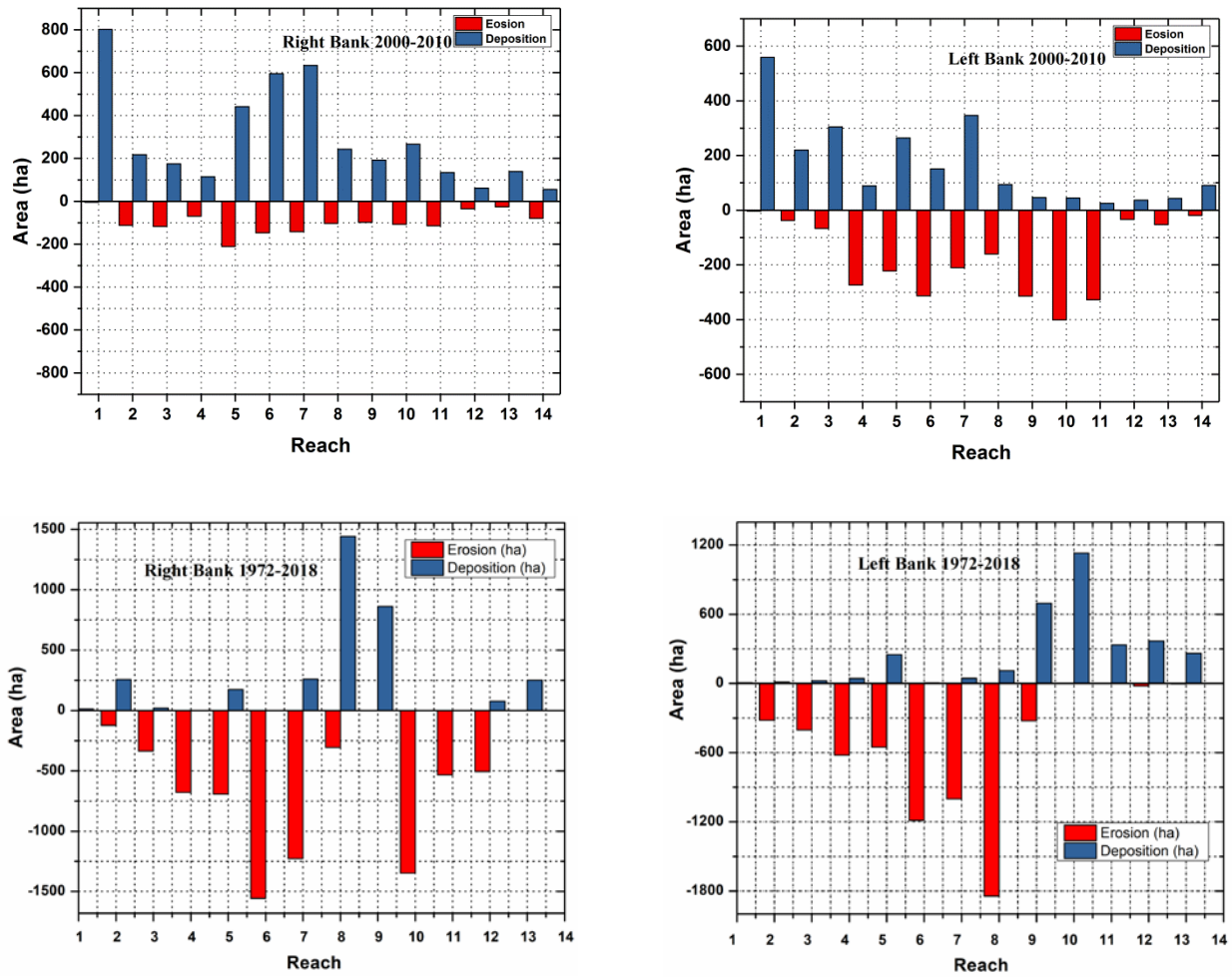


Figure 10.2: Hooghly river left and right bank erosion and deposition

5.4. Land use / land cover changes and its impact on river morphology:

Land-use and land-cover changes have also contributed to the river dynamics along in the Bhagirathi-Hooghly Basin. Impact on river dynamics of land-use is of major concern as it directly influences livelihood of the floodplain dwellers. Change in a land-use pattern in association with river dynamics can be effectively used as an indicator for evaluating the socioeconomic impact of a river in hazards on human beings. Temporal changes can be identified by the land-use map. Land-use of 1980 and 2000 has been done in the Hooghly Basin. Many classes were used in the land-use map such as agricultural land, River, water bodies and river channel, sand, vegetation, forest, waste land, built-up land. Land-use and land-cover map has used to know the present status of the study area. The Land-use and land cover changes increase impervious ground surfaces, decrease the infiltration rate and increase runoff rate, hence causing low base flow during the dry seasons. The Land-use change showed that there is an increase in settlement and agriculture and a decrease in the total area covered by grasslands. The areas affected by erosion - deposition and river migration

processes comprise primarily of agricultural land. The effect of land use changes on soil erosion is also assessed after all the transformation. Table 5 showing area statistics of land use and land cover of the Hooghly river basin. The classification (1972, 1980, 1990 and 2000) of the Hooghly river basin land use and land cover maps and area statistics were prepared by the GIS technique (Figure 11.1 to 11.5).

In the present study, investigated LULC impact on Hooghly river morphological changes using topographic and satellite data. The results show that agriculture land, forest, vegetation decrease inside of river bank during 1972-2010 with a substantial increase in urbanization. Thus, built-up land is continuously increased in the river bank. Highly morphological changes also show that major towns like Rahamanpur, Tantipara, Azimganj, Beharampur, Khagra, Katwa, Kalna and Nabadwip areas. These locations are highly flooded inundation areas for the 100-year return period. It is observed that maximum changes in peak discharge when very low return period compared to higher return periods. We have also investigated some part of the river areas highly morphological changes because of low vegetation and forest land comparing agriculture land during 1972-2010. Increased Built-up and agriculture land inside of river areas crucial factor for changes of river morphology.

Table 5: Area statistics of LULC classes

LULC Type	**1972**	**1980**	**1990**	**2000**	**2010**
	Area (Sq. Km)	Area (Sq. Km)	Area (Sq. Km)	Area (Sq. Km)	Area (Sq. Km)
Agricultural land	23886.02	23425.02	22876.12	21586.75	21172.25
Water body and channel	591.68	544.67	428.78	346.70	301.50
Built Up land	503.53	890.66	1746.12	3452.27	4024.27
Forest	908.23	876.87	785.10	569.52	482.32
Vegetation	1024.47	1209.30	985.17	644.02	583.02
Waste land	210.52	243.91	445.52	835.58	885.58
River	410.57	386.76	345.67	209.87	205.87
Sand	263.54	220.86	185.56	154.05	144.05

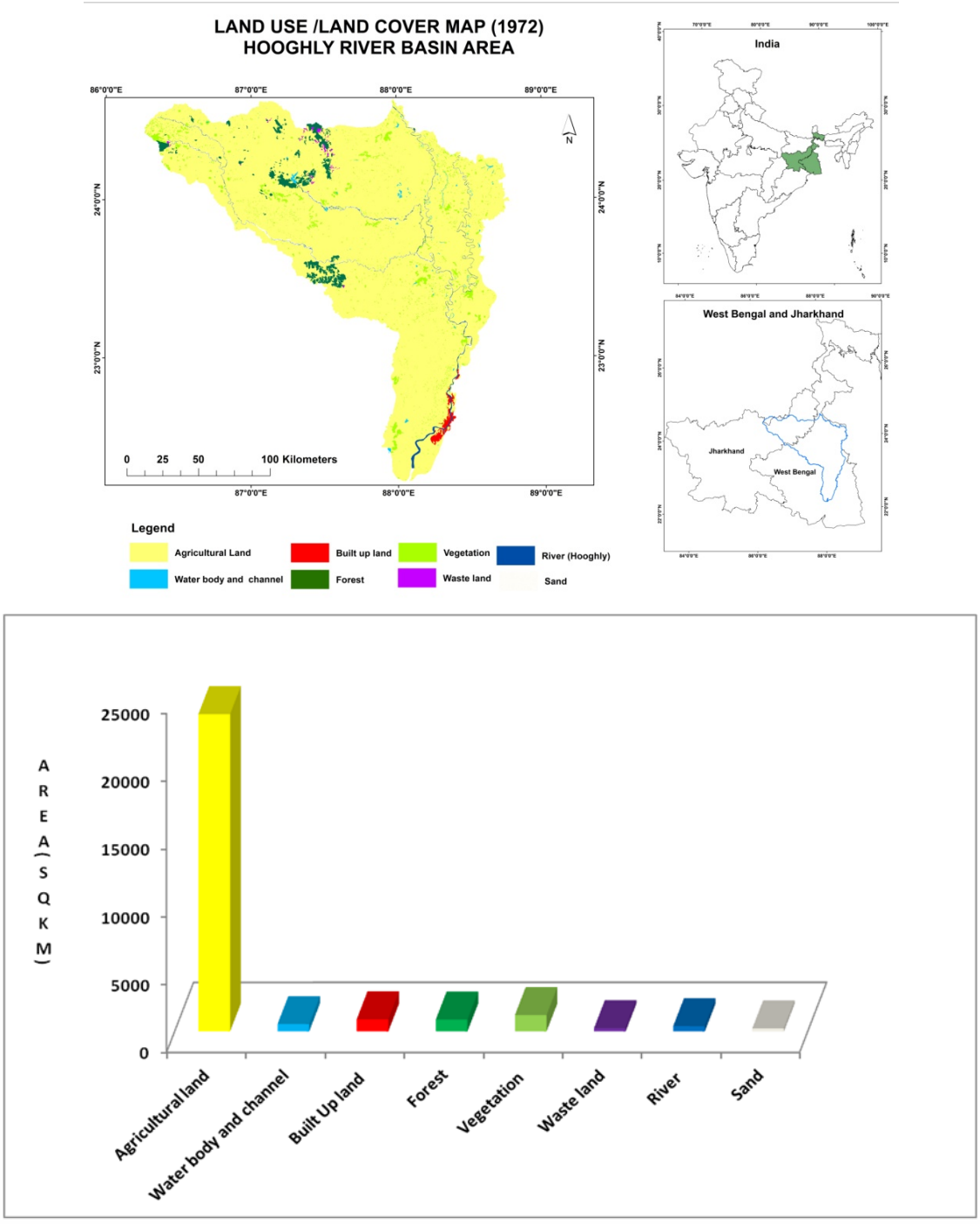


Figure 11.1: Land Use / Land Cover Map and area statistics of Hooghly River Basin (1972)

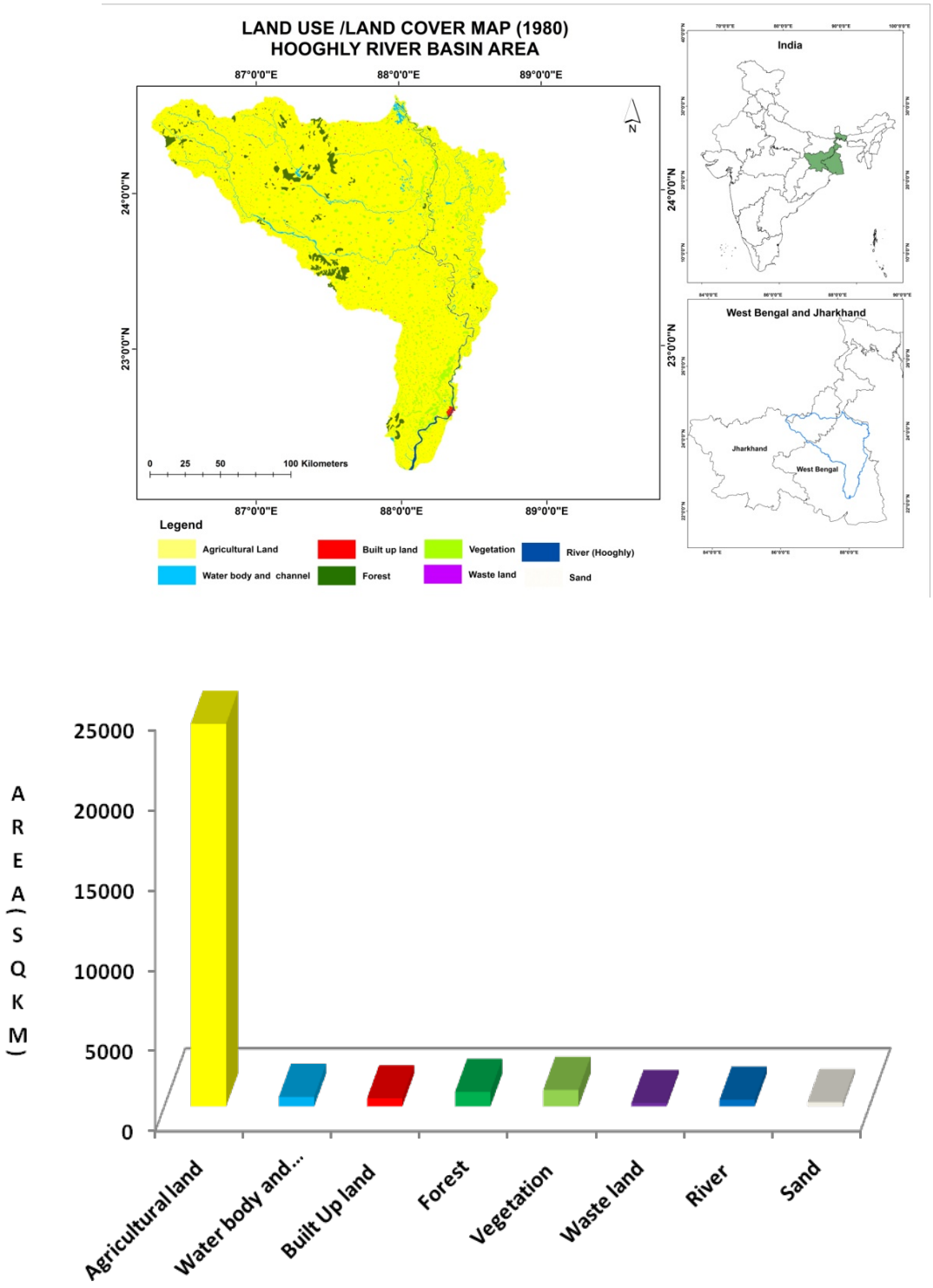


Figure 11.2: Land Use / Land Cover Map and area statistics of Hooghly River Basin (1980)

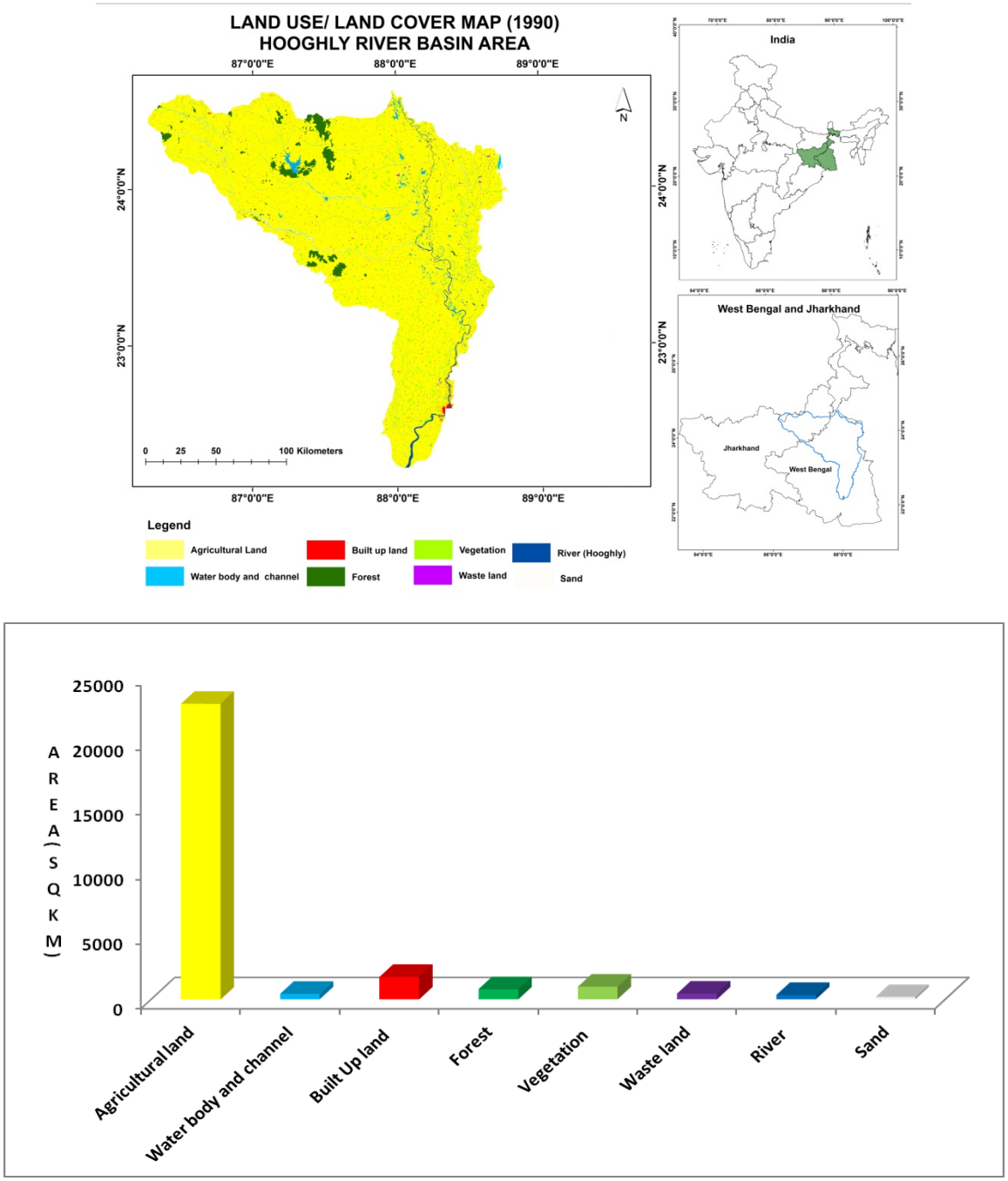


Figure 11.3: Land Use / Land Cover Map and area statistics of Hooghly River Basin (1990)

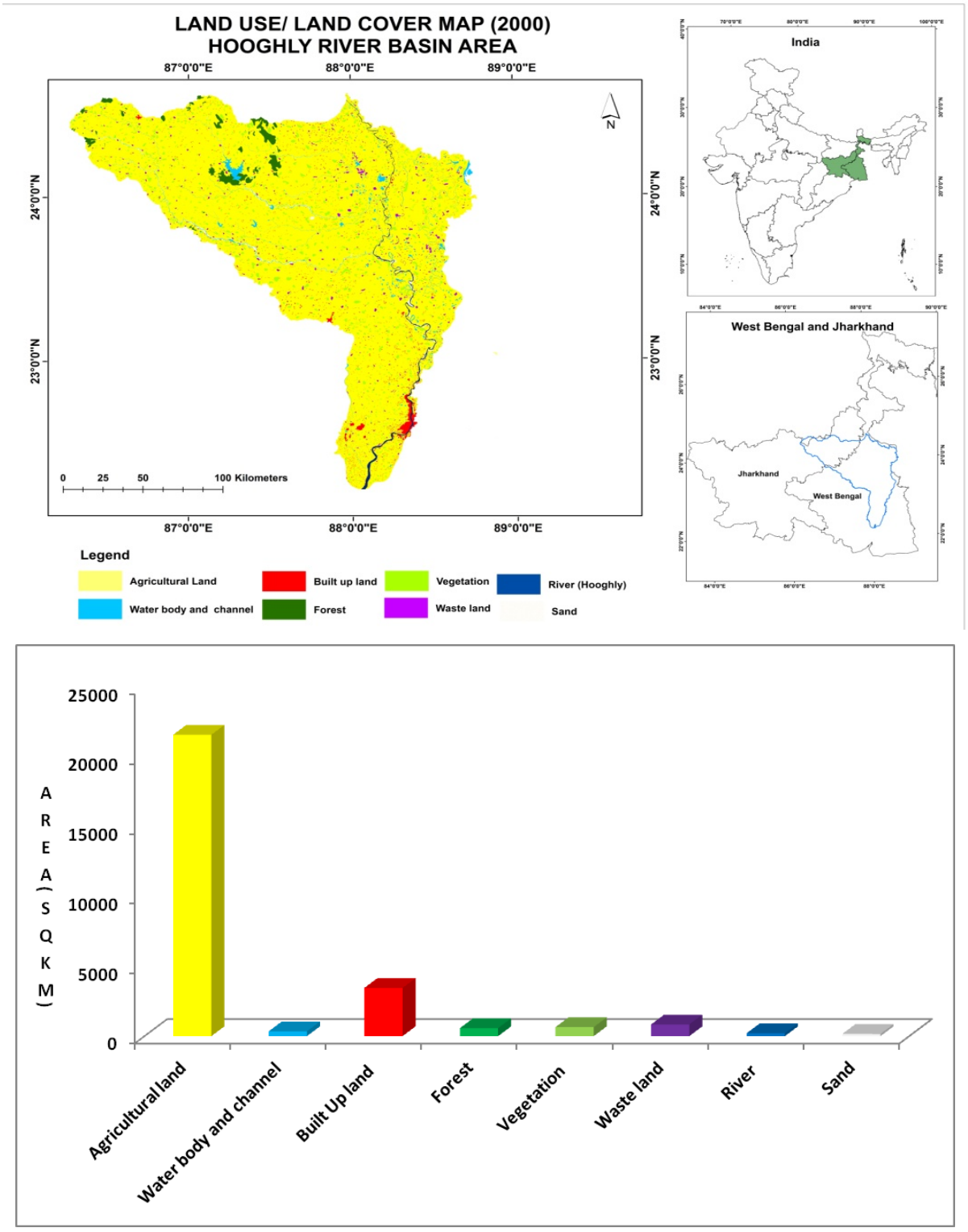
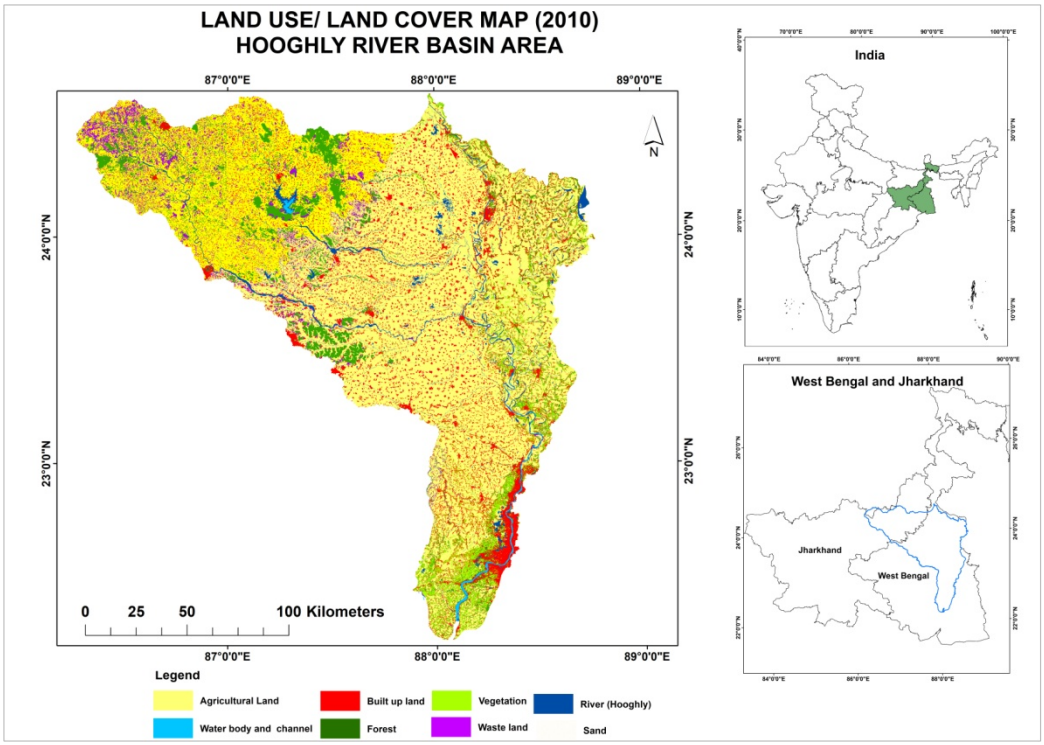


Figure 11.4: Land Use / Land Cover Map and area statistics of Hooghly River Basin (2000)



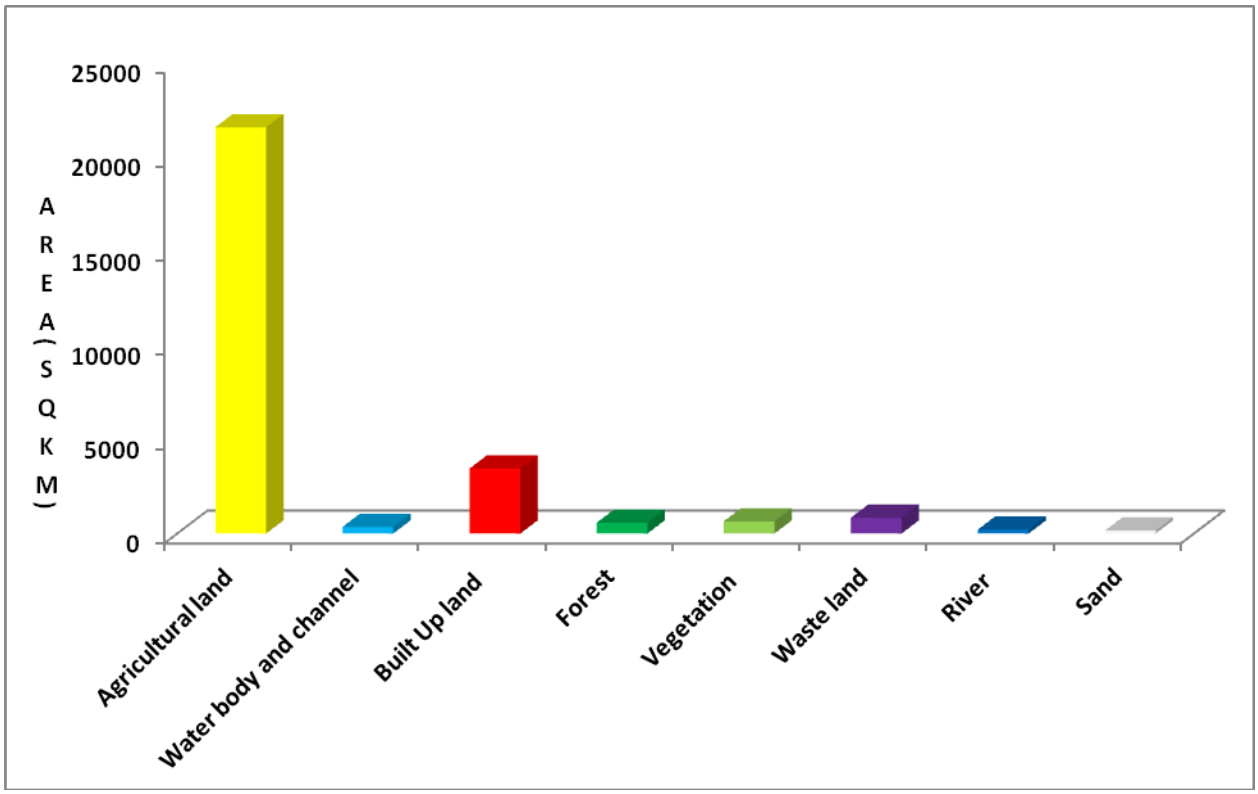


Figure 11.5: Land Use / Land Cover Map and area statistics of Hooghly River Basin (2010)

5.5. Evaluate braiding pattern of the river

5.5.1. Sinuosity index

A river's sinuosity is its tendency to move back and forth across its floodplain, in an S-shaped pattern, over time. Table 6 to 10 shows the analyzed values of river lengths (for reach 1-14); straight valley lengths and shows the calculated sinuosity index for the years 1972 to 2010.

Table 6: Sinuosity index of Hooghly River (1972)

River Reach	Channel Length(m)	Straight Length(m)	Sinuosity index
Reach-1	34,640.68	31,167.31	1.11
Reach-2	37,053.98	24,076.57	1.53
Reach-3	28,403.96	15,940.73	1.78
Reach-4	33,313.03	28,014.00	1.18
Reach-5	34,341.59	24,723.18	1.38
Reach-6	36,008.42	18,083.57	1.99
Reach-7	34,256.40	11,592.32	2.95
Reach-8	32,374.89	17,079.22	1.89
Reach-9	31,519.99	19,094.74	1.65
Reach-10	34,265.89	21,875.58	1.56
Reach-11	33,764.69	27,608.10	1.22
Reach-12	34,525.78	29,269.65	1.17
Reach-13	32,929.25	32,515.19	1.01
Reach-14	35,615.93	30,085.81	1.18

Table 7: Sinuosity index of Hooghly River (1980)

River Reach	Channel Length(m)	Straight Length(m)	Sinuosity index
Reach-1	34,593.77	31,167.31	1.10
Reach-2	37,734.49	24,076.57	1.56
Reach-3	29,150.34	16,067.90	1.81
Reach-4	34,017.35	28,140.15	1.20
Reach-5	33,479.41	24,557.04	1.36
Reach-6	36,024.53	17,914.39	2.01
Reach-7	35,237.38	11,658.93	3.02
Reach-8	31,997.15	17,239.48	1.85
Reach-9	32,051.95	19,095.52	1.67
Reach-10	34,988.37	22,011.35	1.58
Reach-11	33,343.78	28,135.02	1.18
Reach-12	35,504.18	29,178.66	1.21
Reach-13	33,209.73	26,466.37	1.25
Reach-14	35,417.66	30,208.90	1.17

Table 8: Sinuosity index of Hooghly River (1990)

River Reach	Channel Length(m)	Straight Length(m)	Sinuosity index
Reach-1	32192.36	31268.69	1.02
Reach-2	34559.65	24168.27	1.42
Reach-3	37295.05	16056.18	2.32
Reach-4	28919.78	27795.48	1.04
Reach-5	31171.63	24368.30	1.27
Reach-6	34639.73	18448.54	1.87
Reach-7	34641.69	11522.53	3.00
Reach-8	36163.52	16970.70	2.13
Reach-9	33637.73	18439.65	1.82
Reach-10	31321.76	21697.89	1.44
Reach-11	34757.19	27795.48	1.25
Reach-12	33725.26	29386.07	1.14
Reach-13	34014.08	26762.97	1.27
Reach-14	32006.74	29022.45	1.10

Table 9: Sinuosity index of Hooghly River (2000)

River Reach	Channel Length(m)	Straight Length(m)	Sinuosity index
Reach-1	32559.96	31307.06	1.04
Reach-2	34468.74	24398.02	1.41
Reach-3	36361.96	16139.72	2.25
Reach-4	28797.54	27990.63	1.02
Reach-5	30731.84	24062.20	1.27
Reach-6	36729.25	18939.42	1.93
Reach-7	34471.55	11074.19	3.11
Reach-8	25836.52	16767.90	1.54
Reach-9	24515.21	18617.16	1.31
Reach-10	31760.36	21496.02	1.47
Reach-11	34509.17	28078.84	1.22
Reach-12	33261.54	29267.05	1.13
Reach-13	34142.12	26871.74	1.27
Reach-14	31866.90	29134.58	1.09

Table 10: Sinuosity index of Hooghly River (2010)

River Reach	Channel Length(m)	Straight Length(m)	Sinuosity index
Reach-1	34777.04	31248.91	1.11

Reach-2	36907.94	24114.17	1.53
Reach-3	28464.54	15940.60	1.78
Reach-4	30893.17	27779.24	1.11
Reach-5	36376.94	23906.44	1.52
Reach-6	35276.17	19379.75	1.82
Reach-7	27706.39	10519.80	2.63
Reach-8	25235.13	16718.43	1.50
Reach-9	31733.16	18603.91	1.70
Reach-10	35268.83	21654.28	1.62
Reach-11	32584.93	27547.64	1.18
Reach-12	34154.18	29259.10	1.16
Reach-13	31863.84	26771.70	1.19
Reach-14	32280.58	29421.92	1.09

5.5.2 Radius of curvature:

Radius of curvature is a measure of the “tightness” of an individual meander bend and is negatively correlated with sinuosity. Radius of curvature is measured from the outside of the bankfull channel to the intersection point of two lines that perpendicularly bisect the tangent lines of each curve departure point (Table 11 to 15).

Table 11: Reach wise Radius of curvature 1972

River Reach	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)
Reach-1	-	-	-	-	-	-	-
Reach-2	551.96	333.10	528.67	450.57	830.81	556.80	-
Reach-3	638.03	960.30	456.87	861.46	590.58	287.50	-
Reach-4	613.68	592.19		-	-	-	-
Reach-5	824.04	370.42	803.39	237.07	761.39	383.34	482.82
Reach-6	677.67	385.24	603.34	615.40	378.82	661.45	-
Reach-7	1,056.35	450.57	873.12	901.14	-	-	-
Reach-8	903.08	1,005.77	820.63	1190.92	430.71	-	-
Reach-9	925.67	771.39	359.21	497.19	-	-	-
Reach-10	1,776.4	845.14	701.583	-	-	-	-
Reach-11	627.52	890.52	700.80	-	-	-	-
Reach-12	728.36	926.63	-	-	-	-	-
Reach-13	689.95	725.86	645.93	-	-	-	-
Reach-14	832.41	-	-	-	-	-	-

Table 12: Reach wise Radius of curvature 1980

River Reach	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)
Reach-1	-	-	-	-	-	-	-
Reach-2	864.30	260.89	772.93	341.84	479.80	747.59	430.38
Reach-3	983.15	543.75	887.09	377.69	755.86	222.47	-
Reach-4	715.17	648.04	-	-	-	-	-
Reach-5	748.76	338.90	826.71	469.70	548.96	476.91	
Reach-6	458.67	241.29	438.38	332.12	740.34	787.25	736.48
Reach-7	1,074.3	444.93	863.71	896.78	-	-	
Reach-8	663.58	329.31	757.30	459.42	-	-	-
Reach-9	973.06	742.24	460.98	345.31	164.09		-
Reach-10	1,661.4	1,085.81	834.24	-	-	-	-
Reach-11	606.98	452.41	687.86	-	-	-	-
Reach-12	696.12	487.21	912.81	-	-	-	-
Reach-13	892.88	904.19	-	-	-	-	-
Reach-14	867.78	-	-	-	-	-	-

Table 13: Reach wise Radius of curvature 1990

River Reach	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)
Reach-1	-	-	-	-	-	-	-
Reach-2	593.05	297.09	703.61	714.38	370.42	639.40	327.27
Reach-3	1,010.9	430.71	856.94	450.57	695.25	292.24	-
Reach-4	582.08	674.56	-	-	-		-
Reach-5	269.82	587.47	319.70	452.89	397.82	301.67	754.06
Reach-6	427.45	438.36	357.19	443.72	607.10	515.94	-
Reach-7	748.06	465.67	511.95	750.15	-	-	-
Reach-8	501.79	550.74	428.07	402.72	353.00	-	-
Reach-9	609.12	503.41	482.82	-	-	-	-
Reach-10	1,505.3	976.04	532.46	-	-	-	-
Reach-11	456.74	476.99	352.02	-	-	-	-
Reach-12	565.15	481.55	441.25	-	-	-	-

Reach-13	837.21	763.41	-	-	-	-	-
Reach-14	752.78	-	-	-	-	-	-

Table 14: Reach wise Radius of curvature 2000

River Reach (2000)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)
Reach-1	-	-	-	-	-	-	-
Reach-2	598.98	266.64	383.35	643.76	426.63	584.48	357.19
Reach-3	679.34	477.90	755.11	436.56	568.24	396.88	-
Reach-4	515.94	603.34	-	-	-		-
Reach-5	369.77	533.29	325.73	398.25	500.49	554.40	603.34
Reach-6	591.63	523.85	654.54	669.35	582.08	-	-
Reach-7	735.90	898.03	536.26	845.87	-	-	-
Reach-8	477.90	515.94	508.25	317.50	-	-	-
Reach-9	484.45	443.72	476.25	-	-	-	-
Reach-10	1,477.0	887.44	694.25	-	-	-	-
Reach-11	538.39	499.49	402.35	-	-	-	-
Reach-12	711.92	748.36	946.60	-	-	-	-
Reach-13	861.42	853.26	-	-	-	-	-
Reach-14	783.25	-	-	-	-	-	-

Table 15: Reach wise Radius of curvature 2010

River Reach (2010)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)	Radius length (m)
Reach-1	-	-	-	-	-	-	-
Reach-2	517.46	517.46	365.90	357.19	390.88	427.45	358.36
Reach-3	874.03	398.86	529.50	398.86	398.86	-	-
Reach-4	555.63	568.24	-	-	-	-	-
Reach-5	450.57	508.94	378.83	410.74	332.38	429.95	793.75
Reach-6	766.49	533.94	539.81	694.25	-	-	-
Reach-7	669.98	594.18	770.48	731.86	-	-	-
Reach-8	470.06	725.35	449.84	402.35	-	-	-
Reach-9	563.21	403.71	431.22	-	-	-	-
Reach-10	1,464.2	924.15	905.79	-	-	-	-
Reach-11	487.87	793.75	873.13	-	-	-	-
Reach-12	776.73	873.13	809.47	-	-	-	-
Reach-13	828.70	844.76	-	-	-	-	-
Reach-14	713.25	-	-	-			

5.6. Channel Evolution Analysis

5.6.1. Longitudinal Profile:

The longitudinal profile characterizes average stream slopes and depths of riffles, pools, runs, glides, rapids and step/pools. It shows how the river's gradient change as it flows from its source to mouth. The long profile also shows the river's gradient is steep in upstream, but it gradually becomes flat as the river erodes towards its downstream. 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 headwaters area. This is their most obvious and persistent feature regardless of the climatic conditions, the length of the river or the rock cut by the riverbed. (Wheeler, 1979). According to Gilbert (1877), the slope of the longitudinal profile is inversely proportional to the discharge. Further studies were concerned that the effect that the discharge, the characteristics of the river bed material, the sediment discharge (suspended or bed load) and the type of rock formations of the stream bed profile. The conclusion was that the variation of the discharge (Q), the riverbed material diameter (DMM), and the sediment load (Qs) are the most important in explaining the shape of the profile. All other factors caused in the evolution of the river profile in the different stages. A steady preoccupation was to fend for describing the form of longitudinal profiles. The objective was to define the evolution of the Hooghly River based on an analysis of the longitudinal profile form and thus estimate their long-term evolutionary tendencies. The evolutionary estimates refer to both prediction and post-diction of profiles.

The channel cross-section analysis is very important to estimate the conditions of substrate movement at various levels of streamflow. The cross-sectional channel widths are determined relative to the stream center line and measure to zero elevation at the level of water surface (Figure 12.1 to 12.3). Channel slope calculation depends on the highest and lowest elevation value and also the horizontal distance of the cross-section in the river. For the Hooghly river study, channel slope calculation has been performed based on channel cross-sectional data from the Inland Waterways Authority of India, Kolkata. Finally, the average depth and channel slope have been calculated using 1 km of cross-sectional data from 2013-2016 starting from the Diamond Harbour block (on the downstream end of the Hooghly river stretch). The results show that minor fluctuation of the channel slope over the Hooghly river. The slope calculations based on river cross–sectional data are presented in Table-16 at an interval of 1 km.

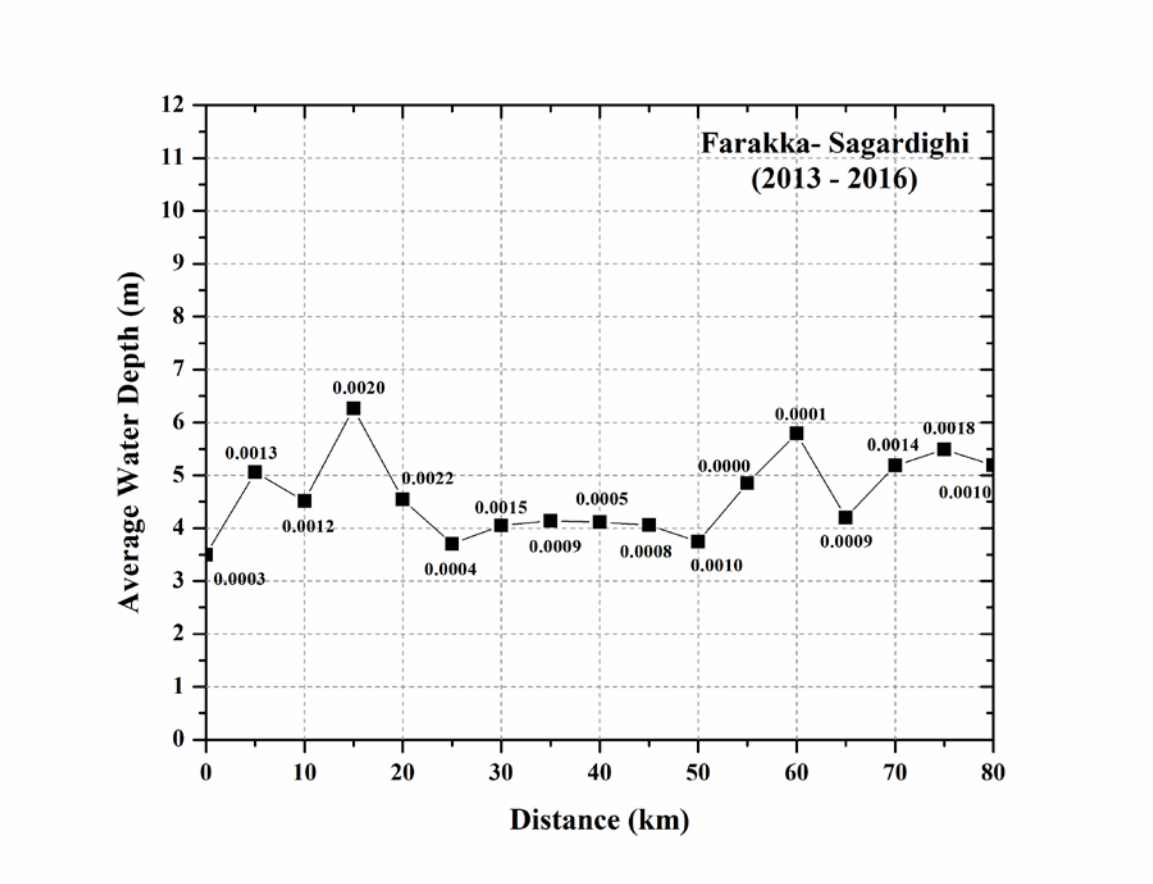


Figure12.1: Line plot between distance and average water depth with slope values for Farakka to Sagardighi

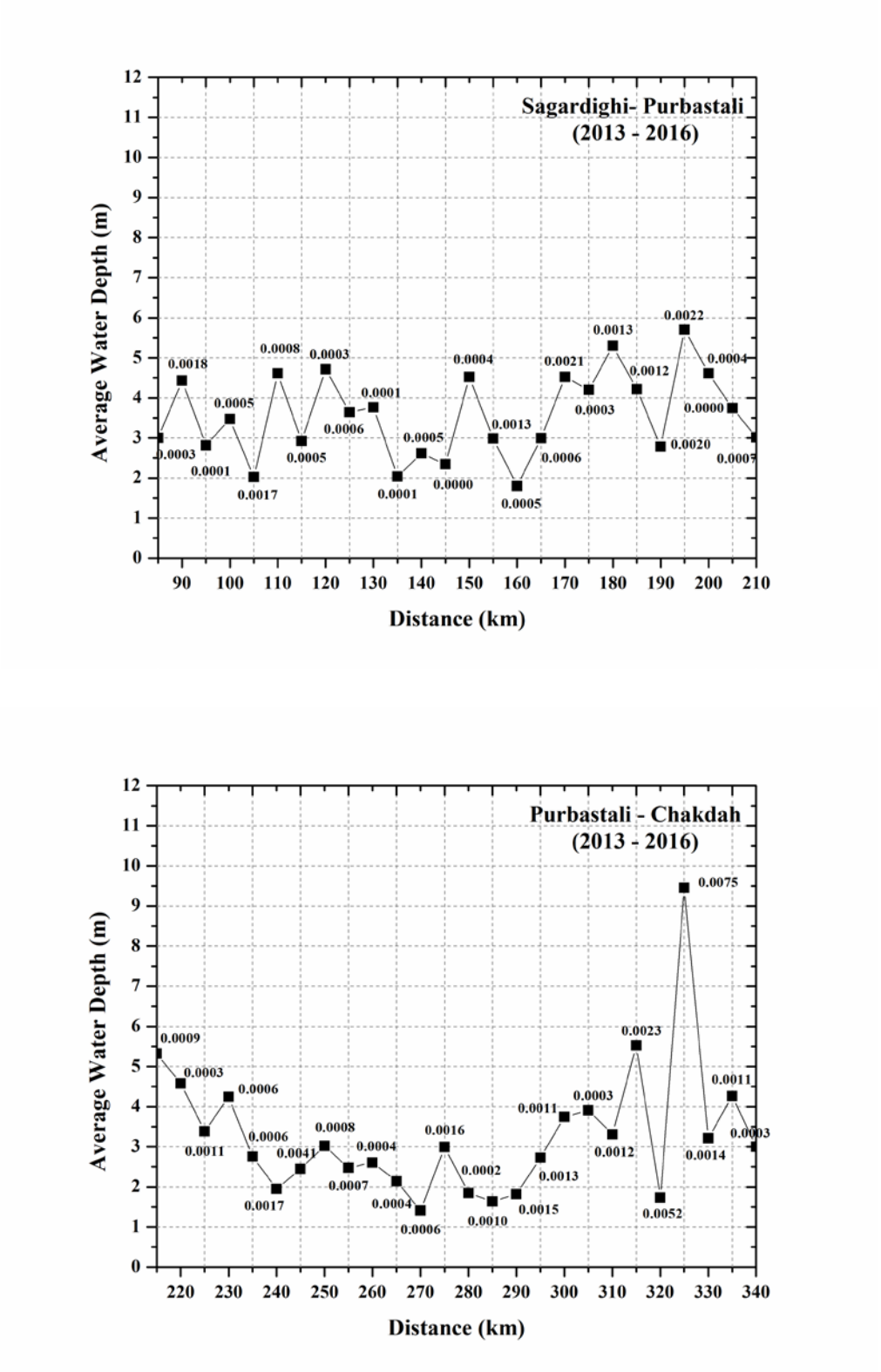


Figure 12.2: Line plot between distance and average water depth with slope values for Sagardighi to Chakdah

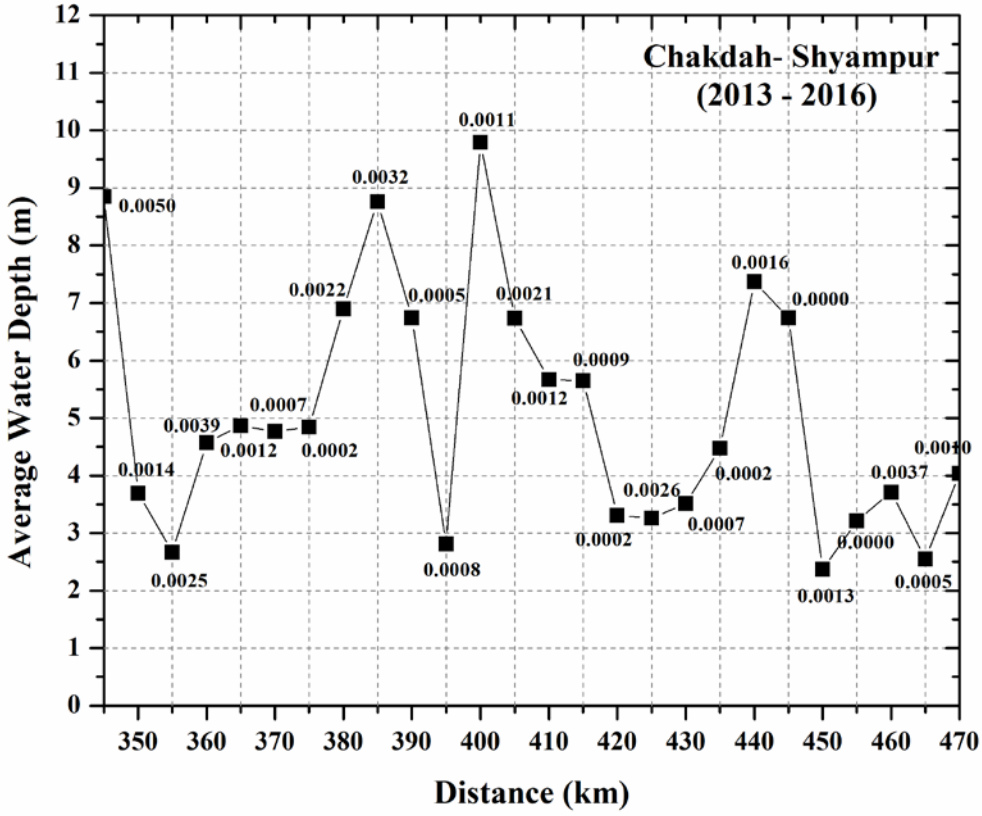


Figure 12.3: Line plot between distance and average water depth with slope values for Chakdah to Shyampur

Table 16: Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
1	1	8.84	0.0050	River areas	East_ Midnapur-South 24 Parganas
2	1	3.78	0.0008	River areas	East_ Midnapur-South 24 Parganas
3	1	4.65	0.0012	River areas	East_ Midnapur-South 24 Parganas
4	1	3.42	0.0002	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
5	1	3.69	0.0014	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
6	1	5.17	0.0007	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
7	1	4.47	0.0017	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
8	1	6.20	0.0033	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
9	1	2.90	0.0002	Shyampur I-Diamond Harbour II	Howrah-South 24 Parganas
10	1	2.66	0.0025	Shyampur I-Falta	Howrah-South 24 Parganas
11	1	5.21	0.0002	Shyampur I-Falta	Howrah-South 24 Parganas
12	1	5.48	0.0001	Shyampur I-Falta	Howrah-South 24 Parganas
13	1	5.36	0.0004	Shyampur I-Falta	Howrah-South 24 Parganas
14	1	5.82	0.0012	Shyampur I-Falta	Howrah-South 24 Parganas
15	1	4.57	0.0039	Shyampur I-Falta	Howrah-South 24 Parganas
16	1	8.50	0.0034	Shyampur I-Falta	Howrah-South 24 Parganas
17	1	5.05	0.0018	Shyampur I-Falta	Howrah-South 24 Parganas
18	1	3.18	0.0000	Shyampur I-Falta	Howrah-South 24 Parganas
19	1	3.23	0.0016	Shyampur I-Falta	Howrah-South 24 Parganas
20	1	4.86	0.0012	Shyampur I-Falta	Howrah-South 24 Parganas
21	1	3.60	0.0026	Shyampur I-Falta	Howrah-South 24 Parganas
22	1	6.23	0.00002	Shyampur I-Falta	Howrah-South 24 Parganas

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
23	1	6.25	0.0017	Shyampur I-Budge BudgeII	Howrah-South 24 Parganas
24	1	4.46	0.0003	Shyampur I-Budge BudgeII	Howrah-South 24 Parganas
25	1	4.76	0.0007	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
26	1	5.55	0.0009	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
27	1	4.63	0.0005	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
28	1	5.21	0.0002	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
29	1	4.97	0.0001	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
30	1	4.84	0.0002	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
31	1	5.11	0.0019	Uluberia I-Budge Budge II	Howrah-South 24 Parganas
32	1	7.03	0.0018	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
33	1	5.19	0.0009	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
34	1	4.23	0.0026	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
35	1	6.90	0.0022	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
36	1	4.68	0.0005	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
37	1	4.14	0.0015	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
38	1	5.69	0.0020	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
39	1	7.70	0.0010	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
40	1	8.76	0.0032	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
41	1	5.49	0.0014	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
42	1	4.07	0.0007	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
43	1	4.78	0.0010	Uluberia I-Budge Budge I	Howrah-South 24 Parganas
44	1	5.84	0.0009	Budge Budge I	South 24 Parganas

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
45	1	6.73	0.0005	Budge Budge I	South 24 Parganas
46	1	6.20	0.0013	Sankraile-Budge Budge I	Howrah-South 24 Parganas
47	1	4.89	0.0071	Sankraile-Maheshtala	Howrah-South 24 Parganas
48	1	12.02	0.0035	Sankraile-Maheshtala	Howrah-South 24 Parganas
49	1	8.43	0.0056	Sankraile-Maheshtala	Howrah-South 24 Parganas
50	1	2.81	0.0008	Sankraile-Maheshtala	Howrah-South 24 Parganas
51	1	3.67	0.0023	Sankraile-Maheshtala	Howrah-South 24 Parganas
52	1	6.00	0.0010	Sankraile-Maheshtala	Howrah-South 24 Parganas
53	1	5.00	0.0019	Sankraile-Maheshtala	Howrah-South 24 Parganas
54	1	6.98	0.0028	Sankraile-Maheshtala	Howrah-South 24 Parganas
55	1	9.79	0.0011	Sankraile-Maheshtala	Howrah-South 24 Parganas
56	1	8.69	0.0016	Sankraile-Maheshtala	Howrah-South 24 Parganas
57	1	7.00	0.0010	Sankraile-Maheshtala	Howrah-South 24 Parganas
58	1	8.06	0.0011	Sankraile-Maheshtala	Howrah-South 24 Parganas
59	1	6.95	0.0002	Sankraile-Maheshtala	Howrah-South 24 Parganas
60	1	6.73	0.0021	Sankraile-Kolkata	Howrah-South 24 Parganas
61	1	4.61	0.0011	Howrah-Kolkata	Howrah-South 24 Parganas
62	1	5.80	0.0006	Howrah-Kolkata	Howrah-South 24 Parganas
63	1	5.13	0.0025	Howrah-Kolkata	Howrah-South 24 Parganas
64	1	7.69	0.0020	Howrah-Kolkata	Howrah-South 24 Parganas
65	1	5.67	0.0012	Howrah-Kolkata	Howrah-South 24 Parganas
66	1	6.91	0.0031	Howrah-Kolkata	Howrah-South 24 Parganas

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
67	1	3.77	0.0004	Howrah-Kolkata	Howrah-South 24 Parganas
68	1	3.27	0.0006	Howrah-Kolkata	Howrah-South 24 Parganas
69	1	3.90	0.0017	Howrah-Kolkata	Howrah-South 24 Parganas
70	1	5.64	0.0009	Howrah-Kolkata	Howrah-South 24 Parganas
71	1	4.71	0.0008	Howrah-Kolkata	Howrah-South 24 Parganas
72	1	3.88	0.0004	Bally-Jagachha-Kolkata	Howrah-South 24 Parganas
73	1	4.36	0.0004	Bally-Jagachha-Kolkata	Howrah-South 24 Parganas
74	1	3.88	0.0005	Bally-Jagachha-Kolkata	Howrah-South 24 Parganas
75	1	3.30	0.0002	Bally-Jagachha-Barrackpur I	Howrah-North 24 Parganas
76	1	3.01	0.0026	Bally-Jagachha-Barrackpur I	Howrah-North 24 Parganas
77	1	5.64	0.0012	Bally-Jagachha-Barrackpur I	Howrah-North 24 Parganas
78	1	4.41	0.0010	Serampore-Uttarpara-Barrackpur I	Howrah-North 24 Parganas
79	1	3.34	0.0000	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
80	1	3.26	0.0026	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
81	1	5.94	0.0020	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
82	1	3.92	0.0008	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
83	1	3.05	0.0002	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
84	1	3.30	0.0002	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
85	1	3.51	0.0007	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
86	1	4.22	0.0033	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
87	1	7.53	0.0011	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
88	1	6.40	0.0010	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
89	1	7.45	0.0029	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
90	1	4.47	0.0002	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
91	1	4.71	0.0007	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
92	1	3.93	0.0011	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
93	1	5.09	0.0021	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
94	1	7.22	0.0001	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
95	1	7.37	0.0016	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
96	1	5.75	0.0008	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
97	1	4.95	0.0028	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
98	1	7.75	0.0009	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
99	1	6.84	0.0001	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
100	1	6.74	0.0000	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
101	1	6.75	0.0030	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
102	1	3.66	0.0005	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
103	1	3.07	0.0007	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
104	1	2.30	0.0000	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
105	1	2.37	0.0013	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
106	1	3.74	0.0067	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
107	1	10.52	0.0044	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
108	1	6.12	0.0021	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas
109	1	4.010	0.0008	Serampore-Uttarpara-Barrackpur I	Hoogly-North 24 Parganas

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
111	1	3.24	0.0003	Chinsurah Morga-Barrackpur I	Hoogly-North 24 Parganas
112	1	2.88	0.0013	Chinsurah Morga-Barrackpur I	Hoogly-North 24 Parganas
113	1	4.20	0.0010	Chinsurah Morga-Barrackpur I	Hoogly-North 24 Parganas
114	1	5.26	0.0015	Chinsurah Morga-Barrackpur I	Hoogly-North 24 Parganas
115	1	3.71	0.0037	Chinsurah Morga-Chakdah	Hoogly-North 24 Parganas
116	1	3.00	0.0006	Chinsurah Morga-Chakdah	Hoogly-North 24 Parganas
117	1	3.67	0.0016	Chinsurah Morga-Chakdah	Hoogly-North 24 Parganas
118	1	5.36	0.0013	Chinsurah Morga-Chakdah	Hoogly-North 24 Parganas
119	1	4.04	0.0015	Chinsurah Morga-Chakdah	Hoogly-Nadia
120	1	2.54	0.0005	Chinsurah Morga-Chakdah	Hoogly-Nadia
121	1	3.06	0.0004	Chinsurah Morga-Chakdah	Hoogly-Nadia
122	1	3.52	0.0005	Chakdah	Nadia
123	1	4.06	0.0003	Chakdah	Nadia
124	1	4.39	0.0003	Chakdah	Nadia
125	1	4.03	0.0010	Chakdah	Nadia
126	1	2.97	0.0028	Chakdah	Nadia
127	1	5.80	0.0002	Balagar-Chakdah	Hoogly-Nadia
128	1	6.09	0.0006	Balagar-Chakdah	Hoogly-Nadia
129	1	5.45	0.0001	Balagar-Chakdah	Hoogly-Nadia
130	1	5.32	0.0009	Balagar-Chakdah	Hoogly-Nadia
131	1	4.38	0.0009	Balagar-Chakdah	Hoogly-Nadia
132	1	3.40	0.0005	Balagar-Chakdah	Hoogly-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
133	1	3.98	0.0001	Balagar-Chakdah	Hoogly-Nadia
134	1	3.82	0.0007	Chakdah	Nadia
135	1	4.57	0.0003	Chakdah	Nadia
136	1	4.24	0.0009	Chakdah	Nadia
137	1	3.30	0.0001	Chakdah	Nadia
138	1	3.16	0.0007	Chakdah	Nadia
139	1	3.88	0.0005	Chakdah	Nadia
140	1	3.38	0.0011	Balagar	Hoogly
141	1	2.21	0.0012	Balagar	Hoogly
142	1	3.44	0.0005	Balagar	Hoogly
143	1	2.87	0.0028	Chakdah	Nadia
144	1	5.67	0.0014	Chakdah	Nadia
145	1	4.24	0.000	Ranaghta I	Nadia
146	1	3.55	0.0004	Balagar-Ranaghta I	Hoogly-Nadia
147	1	3.12	0.0008	Balagar-Ranaghta I	Hoogly-Nadia
148	1	3.97	0.0012	Balagar-Ranaghta I	Hoogly-Nadia
149	1	5.20	0.0024	Balagar-Ranaghta I	Hoogly-Nadia
150	1	2.75	0.0006	Balagar-Ranaghta I	Hoogly-Nadia
151	1	2.05	0.0020	Balagar-Ranaghta I	Hoogly-Nadia
152	1	4.05	0.0006	Balagar-Ranaghta I	Hoogly-Nadia
153	1	4.65	0.0004	Balagar-Ranaghta I	Hoogly-Nadia
154	1	4.16	0.0022	Balagar-Ranaghta I	Hoogly-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
155	1	1.95	0.0017	Balagar-Ranaghta I	Hoogly-Nadia
156	1	3.67	0.0001	Balagar-Ranaghta I	Hoogly-Nadia
157	1	3.48	0.0002	Balagar-Ranaghta I	Hoogly-Nadia
158	1	3.77	0.0003	Balagar-Ranaghta I	Hoogly-Nadia
159	1	3.45	0.0010	Balagar-Ranaghta I	Hoogly-Nadia
160	1	2.44	0.0041	Santipur	Nadia
161	1	6.60	0.0038	Balagar-Santipur	Hoogly-Nadia
162	1	2.73	0.0004	Balagar-Santipur	Hoogly-Nadia
163	1	2.25	0.00006	Balagar-Santipur	Hoogly-Nadia
164	1	2.18	0.0008	Balagar-Santipur	Hoogly-Nadia
165	1	3.02	0.0008	Balagar-Santipur	Hoogly-Nadia
166	1	3.88	0.0028	Balagar-Santipur	Hoogly-Nadia
167	1	6.68	0.0042	Balagar-Santipur	Hoogly-Nadia
168	1	2.45	0.0002	Balagar-Santipur	Hoogly-Nadia
169	1	2.71	0.0002	Balagar-Santipur	Hoogly-Nadia
170	1	2.47	0.0007	Balagar-Santipur	Hoogly-Nadia
171	1	1.71	0.0021	Kalna II	Budwan
172	1	3.90	0.0007	Kalna II-Santipur	Budwan-Nadia
173	1	4.68	0.0018	Kalna II-Santipur	Budwan-Nadia
174	1	2.87	0.0002	Kalna II-Santipur	Budwan-Nadia
175	1	2.60	0.0004	Kalna I-Santipur	Budwan-Nadia
176	1	3.07	0.0006	Kalna I-Santipur	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
177	1	2.40	0.00001	Kalna I-Santipur	Budwan-Nadia
178	1	2.39	0.0010	Kalna I	Budwan
179	1	3.47	0.0013	Kalna I	Budwan
180	1	2.14	0.0004	Kalna I	Budwan
181	1	2.59	0.0012	Kalna I	Budwan
182	1	3.87	0.0004	Kalna I	Budwan
183	1	3.42	0.0037	Kalna I	Budwan
184	1	7.18	0.0057	Kalna I	Budwan
185	1	1.41	0.0006	Kalna I	Budwan
186	1	2.06	0.0002	Kalna I	Budwan
187	1	1.84	0.0014	Kalna I	Budwan
188	1	3.26	0.0020	Santipur	Nadia
189	1	5.26	0.0022	Kalna I	Budwan
190	1	2.99	0.0016	Santipur-Nawadip	Nadia
191	1	4.62	0.0006	Santipur-Nawadip	Nadia
192	1	5.26	0.0015	Santipur-Nawadip	Nadia
193	1	3.74	0.0004	Purbasthali I-Nawadip	Budwan-Nadia
194	1	3.26	0.0014	Purbasthali I-Nawadip	Budwan-Nadia
195	1	1.85	0.0002	Purbasthali I-Nawadip	Budwan-Nadia
196	1	2.06	0.0006	Purbasthali I-Nawadip	Budwan-Nadia
197	1	1.38	0.0003	Nawadip	Budwan-Nadia
198	1	1.76	0.0006	Nawadip	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
199	1	2.38	0.0007	Nawadip	Budwan-Nadia
200	1	1.63	0.0010	Nawadip	Budwan-Nadia
201	1	2.69	0.0010	Nawadip-Krishnagar I	Nadia
202	1	3.74	0.0003	Nawadip-Krishnagar I	Nadia
203	1	4.03	0.0013	Nawadip-Krishnagar I	Nadia
204	1	2.71	0.0009	Nawadip-Krishnagar I	Nadia
205	1	1.81	0.0015	Nawadip	Nadia
206	1	3.40	0.0002	Nawadip	Nadia
207	1	3.69	0.0024	Nawadip	Nadia
208	1	1.27	0.0003	Nawadip	Nadia
209	1	1.66	0.0010	Nawadip	Nadia
210	1	2.72	0.0013	Nawadip	Nadia
211	1	1.35	0.0008	Nawadip	Nadia
212	1	2.17	0.0013	Nawadip	Nadia
213	1	3.51	0.0011	Nawadip	Nadia
214	1	2.36	0.0013	Nawadip	Nadia
215	1	3.74	0.0011	Nawadip	Nadia
216	1	2.64	0.0011	Nawadip	Nadia
217	1	7.24	0.0035	Nawadip	Nadia
218	1	3.68	0.0002	Nawadip	Nadia
219	1	3.45	0.0004	Nawadip	Nadia
220	1	3.91	0.0003	Nawadip	Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
221	1	3.53	0.0001	Purbastali I-Krishnagar II	Budwan-Nadia
222	1	3.43	0.0016	Purbastali I	Budwan
223	1	5.03	0.0009	Purbastali I	Budwan
224	1	4.07	0.0007	Purbastali I	Budwan
225	1	3.31	0.0012	Purbastali I	Budwan
226	1	4.57	0.0022	Purbastali I	Budwan
227	1	2.33	0.0029	Purbastali I	Budwan
228	1	5.27	0.0029	Purbastali I	Budwan
229	1	2.32	0.0032	Purbasthali II-Krishnagar II	Budwan-Nadia
230	1	5.52	0.0023	Purbasthali II-Krishnagar II	Budwan-Nadia
231	1	3.16	0.0000	Purbastali II-Nakshipara	Budwan-Nadia
232	1	3.16	0.0005	Purbastali II-Nakshipara	Budwan-Nadia
233	1	2.66	0.0016	Purbastali II-Nakshipara	Budwan-Nadia
234	1	4.28	0.0025	Purbastali II-Nakshipara	Budwan-Nadia
235	1	1.73	0.0052	Purbastali II-Nakshipara	Budwan-Nadia
236	1	6.98	0.0011	Purbastali II-Nakshipara	Budwan-Nadia
237	1	5.86	0.0022	Purbastali II-Nakshipara	Budwan-Nadia
238	1	3.67	0.0011	Purbastali II-Nakshipara	Budwan-Nadia
239	1	4.78	0.0046	Purbastali II-Nakshipara	Budwan-Nadia
240	1	9.45	0.0075	Purbastali II-Nakshipara	Budwan-Nadia
241	1	1.90	0.0004	Purbastali II-Nakshipara	Budwan-Nadia
242	1	1.41	0.0045	Purbastali II-Nakshipara	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
243	1	6.00	0.0038	Purbastali II-Nakshipara	Budwan-Nadia
244	1	2.15	0.0010	Purbastali II-Nakshipara	Budwan-Nadia
245	1	3.21	0.0014	Purbastali II-Nakshipara	Budwan-Nadia
246	1	1.81	0.0018	Purbastali II-Nakshipara	Budwan-Nadia
247	1	3.65	0.0023	Purbastali II-Nakshipara	Budwan-Nadia
248	1	1.32	0.0021	Purbastali II-Nakshipara	Budwan-Nadia
249	1	3.46	0.0012	Purbastali II-Nakshipara	Budwan-Nadia
250	1	4.26	0.0011	Purbastali II-Nakshipara	Budwan-Nadia
251	1	3.11	0.0021	Purbastali II-Nakshipara	Budwan-Nadia
252	1	5.26	0.0034	Purbastali II-Nakshipara	Budwan-Nadia
253	1	1.78	0.0018	Purbastali II-Nakshipara	Budwan-Nadia
254	1	3.65	0.0006	Purbastali II-Nakshipara	Budwan-Nadia
255	1	2.99	0.0003	Purbastali II-Nakshipara	Budwan-Nadia
256	1	2.65	0.0002	Purbastali II-Nakshipara	Budwan-Nadia
257	1	2.44	0.0029	Purbastali II-Nakshipara	Budwan-Nadia
258	1	5.41	0.0008	Purbastali II-Nakshipara	Budwan-Nadia
259	1	4.52	0.0000	Katwa II-Nakshipara	Budwan-Nadia
260	1	4.43	0.0018	Katwa II-Nakshipara	Budwan-Nadia
261	1	2.63	0.0000	Katwa II-Nakshipara	Budwan-Nadia
262	1	2.685	0.0002	Katwa II-Nakshipara	Budwan-Nadia
263	1	2.91	0.0002	Katwa II-Nakshipara	Budwan-Nadia
264	1	2.67	0.0001	Katwa II-Nakshipara	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
267	1	2.03	0.0005	Katwa II-Nakshipara	Budwan-Nadia
268	1	2.54	0.0014	Katwa I-Kaliganj	Budwan-Nadia
269	1	4.01	0.0005	Katwa I-Kaliganj	Budwan-Nadia
270	1	3.47	0.0005	Katwa I-Kaliganj	Budwan-Nadia
271	1	2.90	0.0016	Kaliganj	Budwan-Nadia
272	1	4.53	0.0016	Kaliganj	Budwan-Nadia
273	1	2.85	0.0007	Kaliganj	Budwan-Nadia
274	1	3.62	0.0016	Kaliganj	Budwan-Nadia
275	1	2.02	0.0017	Katwa I-Kaliganj	Budwan-Nadia
276	1	3.81	0.0009	Katwa I-Kaliganj	Budwan-Nadia
277	1	2.85	0.0000	Katwa I-Kaliganj	Budwan-Nadia
278	1	2.79	0.0014	Katwa I-Kaliganj	Budwan-Nadia
279	1	4.20	0.0004	Ketugram II-Kaliganj	Budwan-Nadia
280	1	4.60	0.0008	Ketugram II-Kaliganj	Budwan-Nadia
281	1	3.79	0.0001	Ketugram II-Kaliganj	Budwan-Nadia
282	1	3.91	0.0002	Ketugram II-Kaliganj	Budwan-Nadia
283	1	3.66	0.0019	Ketugram II-Kaliganj	Budwan-Nadia
284	1	5.61	0.0026	Ketugram II-Kaliganj	Budwan-Nadia
285	1	2.92	0.0005	Kaliganj	Nadia
286	1	3.49	0.0008	Kaliganj	Nadia
287	1	2.59	0.0008	Ketugram II-Kaliganj	Budwan-Nadia
288	1	3.44	0.0006	Ketugram II-Kaliganj	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
267	1	2.03	0.0005	Katwa II-Nakshipara	Budwan-Nadia
268	1	2.54	0.0014	Katwa I-Kaliganj	Budwan-Nadia
269	1	4.01	0.0005	Katwa I-Kaliganj	Budwan-Nadia
270	1	3.47	0.0005	Katwa I-Kaliganj	Budwan-Nadia
271	1	2.90	0.0016	Kaliganj	Budwan-Nadia
272	1	4.53	0.0016	Kaliganj	Budwan-Nadia
273	1	2.85	0.0007	Kaliganj	Budwan-Nadia
274	1	3.62	0.0016	Kaliganj	Budwan-Nadia
275	1	2.02	0.0017	Katwa I-Kaliganj	Budwan-Nadia
276	1	3.81	0.0009	Katwa I-Kaliganj	Budwan-Nadia
277	1	2.85	0.00006	Katwa I-Kaliganj	Budwan-Nadia
278	1	2.79	0.0014	Katwa I-Kaliganj	Budwan-Nadia
279	1	4.20	0.0004	Ketugram II-Kaliganj	Budwan-Nadia
280	1	4.60	0.0008	Ketugram II-Kaliganj	Budwan-Nadia
281	1	3.79	0.0001	Ketugram II-Kaliganj	Budwan-Nadia
282	1	3.91	0.0002	Ketugram II-Kaliganj	Budwan-Nadia
283	1	3.66	0.0019	Ketugram II-Kaliganj	Budwan-Nadia
284	1	5.61	0.0026	Ketugram II-Kaliganj	Budwan-Nadia
285	1	2.92	0.0005	Kaliganj	Nadia
286	1	3.49	0.0008	Kaliganj	Nadia
287	1	2.59	0.0008	Ketugram II-Kaliganj	Budwan-Nadia
288	1	3.44	0.0006	Ketugram II-Kaliganj	Budwan-Nadia

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
289	1	4.08	0.0006	Ketugram II-Kaliganj	Budwan-Nadia
290	1	4.71	0.0003	Ketugram II-Kaliganj	Budwan-Nadia
291	1	5.03	0.0030	Ketugram II-Kaliganj	Budwan-Nadia
292	1	2.00	0.0046	Ketugram II-Kaliganj	Budwan-Nadia
293	1	6.62	0.0027	Ketugram II-Kaliganj	Budwan-Nadia
294	1	3.89	0.0002	Ketugram II-Kaliganj	Budwan-Nadia
295	1	3.64	0.0006	Ketugram II-Kaliganj	Budwan-Nadia
296	1	4.27	0.0007	Kaliganj	Nadia
297	1	4.97	0.0016	Kaliganj	Nadia
298	1	3.35	0.0004	Kaliganj	Nadia
299	1	3.78	0.0000	Beldanga II	Murshidabad
300	1	3.76	0.0001	Beldanga II	Murshidabad
301	1	3.95	0.0013	Beldanga II	Murshidabad
302	1	2.58	0.0005	Beldanga II	Murshidabad
303	1	2.03	0.0016	Beldanga II	Murshidabad
304	1	3.73	0.0016	Beldanga II	Murshidabad
305	1	2.03	0.0001	Beldanga II	Murshidabad
306	1	1.90	0.0020	Beldanga II	Murshidabad
307	1	3.91	0.0007	Beldanga II	Murshidabad
308	1	3.16	0.0008	Beldanga II	Murshidabad
309	1	2.33	0.0002	Beldanga II	Murshidabad
310	1	2.61	0.0005	Beldanga II	Murshidabad
311	1	3.14	0.0011	Beldanga II	Murshidabad
312	1	2.02	0.0004	Beldanga II	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
315	1	2.34	0.00006	Beldanga II	Murshidabad
316	1	2.27	0.0004	Beldanga II	Murshidabad
317	1	2.72	0.0009	Beldanga II	Murshidabad
318	1	3.70	0.0006	Beldanga II	Murshidabad
319	1	3.06	0.0014	Beldanga II	Murshidabad
320	1	4.52	0.0004	Beldanga II	Murshidabad
321	1	4.08	0.0026	Beldanga II	Murshidabad
322	1	1.43	0.0010	Beldanga I	Murshidabad
323	1	2.52	0.0011	Beldanga I	Murshidabad
324	1	3.67	0.0006	Beldanga I	Murshidabad
325	1	2.98	0.0013	Beldanga I	Murshidabad
326	1	1.66	0.0016	Berhampur	Murshidabad
327	1	1.56	0.0006	Berhampur	Murshidabad
328	1	2.20	0.0025	Berhampur	Murshidabad
329	1	4.78	0.0029	Berhampur	Murshidabad
330	1	1.80	0.0005	Berhampur	Murshidabad
331	1	2.36	0.0015	Berhampur	Murshidabad
332	1	3.92	0.0011	Berhampur	Murshidabad
333	1	2.74	0.0003	Berhampur	Murshidabad
334	1	2.38	0.0006	Berhampur	Murshidabad
335	1	2.99	0.0006	Berhampur	Murshidabad
336	1	2.33	0.0000	Berhampur	Murshidabad
337	1	2.27	0.0003	Beldanga I	Murshidabad
338	1	2.61	0.0009	Beldanga I	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
339	1	1.65	0.0028	Beldanga I	Murshidabad
340	1	4.52	0.0021	Beldanga I	Murshidabad
341	1	2.39	0.0003	Berhampur	Murshidabad
342	1	2.76	0.0003	Berhampur	Murshidabad
343	1	2.38	0.0007	Berhampur	Murshidabad
344	1	1.59	0.0026	Berhampur	Murshidabad
345	1	4.20	0.0003	Berhampur	Murshidabad
346	1	3.82	0.0002	Berhampur	Murshidabad
347	1	4.04	0.0008	Berhampur	Murshidabad
348	1	3.19	0.0026	Berhampur	Murshidabad
349	1	5.82	0.0005	Berhampur	Murshidabad
350	1	5.30	0.0023	Berhampur	Murshidabad
351	1	2.91	0.0007	Berhampur	Murshidabad
352	1	2.14	0.0003	Berhampur	Murshidabad
353	1	1.76	0.0001	Berhampur	Murshidabad
354	1	1.90	0.0023	Berhampur	Murshidabad
355	1	4.21	0.0006	Berhampur	Murshidabad
356	1	4.88	0.0025	Berhampur	Murshidabad
357	1	2.30	0.0037	Jaiganj-Murshidabad	Murshidabad
358	1	6.06	0.0031	Jaiganj-Murshidabad	Murshidabad
359	1	2.95	0.0001	Jaiganj-Murshidabad	Murshidabad
360	1	2.78	0.0006	Jaiganj-Murshidabad	Murshidabad
361	1	2.10	0.0001	Jaiganj-Murshidabad	Murshidabad
362	1	2.20	0.00004	Jaiganj-Murshidabad	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
363	1	2.25	0.0004	Jaiganj-Murshidabad	Murshidabad
364	1	1.81	0.0038	Jaiganj-Murshidabad	Murshidabad
365	1	5.70	0.0022	Jaiganj-Murshidabad	Murshidabad
366	1	3.46	0.0007	Jaiganj-Murshidabad	Murshidabad
367	1	4.20	0.0010	Jaiganj-Murshidabad	Murshidabad
368	1	5.23	0.0001	Jaiganj-Murshidabad	Murshidabad
369	1	5.13	0.0010	Jaiganj-Murshidabad	Murshidabad
370	1	4.07	0.0005	Jaiganj-Murshidabad	Murshidabad
370	1	4.60	0.0004	Jaiganj-Murshidabad	Murshidabad
372	1	5.04	0.0013	Sagardighi	Murshidabad
373	1	3.66	0.0011	Sagardighi	Murshidabad
374	1	2.49	0.0012	Sagardighi	Murshidabad
375	1	3.74	0.00007	Sagardighi	Murshidabad
376	1	3.82	0.0023	Sagardighi	Murshidabad
377	1	1.51	0.0016	Sagardighi	Murshidabad
378	1	3.11	0.0006	Sagardighi	Murshidabad
379	1	3.72	0.0007	Sagardighi	Murshidabad
380	1	3.01	0.0007	Sagardighi	Murshidabad
381	1	2.29	0.0007	Sagardighi	Murshidabad
382	1	3.07	0.0011	Sagardighi	Murshidabad
383	1	4.22	0.0003	Sagardighi	Murshidabad
384	1	4.56	0.0010	Sagardighi	Murshidabad
385	1	3.49	0.0003	Sagardighi	Murshidabad
386	1	3.84	0.0004	Sagardighi	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
387	1	4.32	0.00008	Sagardighi	Murshidabad
388	1	4.41	0.0002	Sagardighi	Murshidabad
389	1	4.67	0.0003	Bhagwangola I	Murshidabad
390	1	5.06	0.0013	Bhagwangola I	Murshidabad
391	1	3.67	0.0019	Sagardighi	Murshidabad
392	1	1.77	0.0005	Sagardighi	Murshidabad
393	1	2.35	0.0010	Sagardighi	Murshidabad
394	1	3.37	0.0011	Sagardighi	Murshidabad
395	1	4.51	0.0012	Sagardighi	Murshidabad
396	1	5.78	0.0010	Sagardighi	Murshidabad
397	1	4.75	0.0003	Sagardighi	Murshidabad
398	1	5.06	0.0006	Sagardighi	Murshidabad
399	1	5.70	0.0005	Sagardighi	Murshidabad
400	1	6.26	0.0020	Sagardighi	Murshidabad
401	1	4.24	0.0017	Sagardighi	Murshidabad
402	1	6.02	0.0023	Sagardighi	Murshidabad
403	1	3.65	0.0034	Sagardighi	Murshidabad
404	1	7.10	0.0025	Raghunathganj I	Murshidabad
405	1	4.54	0.0022	Raghunathganj I	Murshidabad
406	1	6.77	0.0036	Raghunathganj I	Murshidabad
407	1	3.13	0.0007	Raghunathganj I	Murshidabad
408	1	2.35	0.00003	Raghunathganj I	Murshidabad
409	1	2.38	0.0013	Raghunathganj I	Murshidabad
410	1	3.70	0.0004	Raghunathganj I	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
411	1	4.16	0.0006	Raghunathganj I	Murshidabad
412	1	4.78	0.0026	Raghunathganj I	Murshidabad
413	1	2.15	0.0030	Raghunathganj I	Murshidabad
414	1	5.17	0.0011	Raghunathganj II	Murshidabad
415	1	4.05	0.0015	Raghunathganj II	Murshidabad
416	1	5.64	0.0022	Raghunathganj II	Murshidabad
417	1	3.37	0.00005	Raghunathganj I	Murshidabad
418	1	3.32	0.0001	Raghunathganj I	Murshidabad
419	1	3.51	0.0006	Raghunathganj I	Murshidabad
420	1	4.14	0.0009	Raghunathganj I	Murshidabad
421	1	5.06	0.0014	Raghunathganj I	Murshidabad
422	1	6.55	0.0022	Raghunathganj I	Murshidabad
423	1	4.31	0.0002	Raghunathganj I	Murshidabad
424	1	4.07	0.0000	Raghunathganj I	Murshidabad
425	1	4.11	0.0005	Raghunathganj I	Murshidabad
426	1	3.57	0.0008	Raghunathganj I	Murshidabad
427	1	2.74	0.0001	Raghunathganj I	Murshidabad
428	1	2.58	0.0007	Raghunathganj I	Murshidabad
429	1	3.36	0.0006	Raghunathganj I	Murshidabad
430	1	4.05	0.0008	Raghunathganj II	Murshidabad
431	1	3.17	0.0014	Suti I	Murshidabad
432	1	1.76	0.0017	Suti I	Murshidabad
433	1	3.56	0.0020	Suti I	Murshidabad
434	1	5.58	0.0018	Suti I	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
435	1	3.74	0.0010	Suti II	Murshidabad
436	1	2.65	0.0027	Suti II	Murshidabad
437	1	5.39	0.0003	Suti II	Murshidabad
438	1	5.77	0.0003	Suti II	Murshidabad
439	1	6.16	0.0013	Suti II	Murshidabad
440	1	4.85	0.00003	Suti II	Murshidabad
441	1	4.88	0.0010	Suti II	Murshidabad
442	1	3.88	0.0004	Suti II	Murshidabad
443	1	4.29	0.0002	Suti II	Murshidabad
444	1	4.49	0.0012	Suti II	Murshidabad
445	1	5.78	0.0001	Samsherganj	Murshidabad
446	1	5.61	0.0011	Samsherganj	Murshidabad
447	1	4.46	0.0020	Samsherganj	Murshidabad
448	1	6.51	0.0004	Samsherganj	Murshidabad
449	1	6.98	0.0027	Samsherganj	Murshidabad
450	1	4.20	0.0009	Samsherganj	Murshidabad
451	1	5.17	0.0011	Samsherganj	Murshidabad
452	1	4.00	0.0005	Samsherganj	Murshidabad
453	1	3.42	0.0005	Samsherganj	Murshidabad
454	1	3.99	0.0011	Samsherganj	Murshidabad
455	1	5.18	0.0014	Farraka	Murshidabad
456	1	6.65	0.0002	Farraka	Murshidabad
457	1	6.42	0.0001	Farraka	Murshidabad
458	1	6.30	0.0003	Farraka	Murshidabad

Table 16: (continued) Slope calculation based on river cross-sectional data (2013-2016)

Cross Section No.	Distance (km)	Average Depth (m)	Slope	Block	District
459	1	5.92	0.0004	Farraka	Murshidabad
460	1	5.49	0.0018	Farraka	Murshidabad
461	1	3.60	0.0031	Farraka	Murshidabad
462	1	6.76	0.0034	Farakka	Murshidabad
463	1	10.22	0.0060	Farakka	Murshidabad
464	1	4.13	0.0010	Farakka	Murshidabad
465	1	5.18	0.0010	Farakka	Murshidabad

5.7. Probability of Exceedance and Recurrence Interval

Peak discharge data for all the respective years were identified. These data were arranged in a descending order. For the ranking of discharge data, a serial rank number (r) ranging from 1 to n (number of observations) is assigned. Subsequently, the probability has been determined that should be assigned to each of the discharge value. If the data are ranked in descending order, with the highest value first and the lowest value last, the probability estimated would indicate the probability with which that the corresponding discharge will be exceeded. When data are ranked from the lowest to the highest value, the probability refers to the probability of non-exceedance. Hence the probabilities are estimates of cumulative probabilities. We calculate the probability of exceedance for the respective discharge values using Weibull's equation (Annexure I). They are formed by summing the probabilities of occurrence of all events greater than (probability of exceedance) or less than (probability of non-exceedance) some discharge value. The probability of exceedance calculated for the respective discharge value using Weibull's equation is given in Figure 13.1 to 13.3.

The probability of exceedance describes the likelihood of a specified discharge (or volume flow rate) being exceeded in a given year. The probability of capacity exceedance describes the likelihood of the design flow rate (or volume of water with specified duration) of a hydraulic structure being exceeded in a given year. The Hooghly River has been located six hydrological observation stations (Bazarsau, Berharmpore, HR Farakha Feeder, Kalna EBB, Kalna Flow and Katwa) from which observed discharge data are available. These are used for the present analysis.

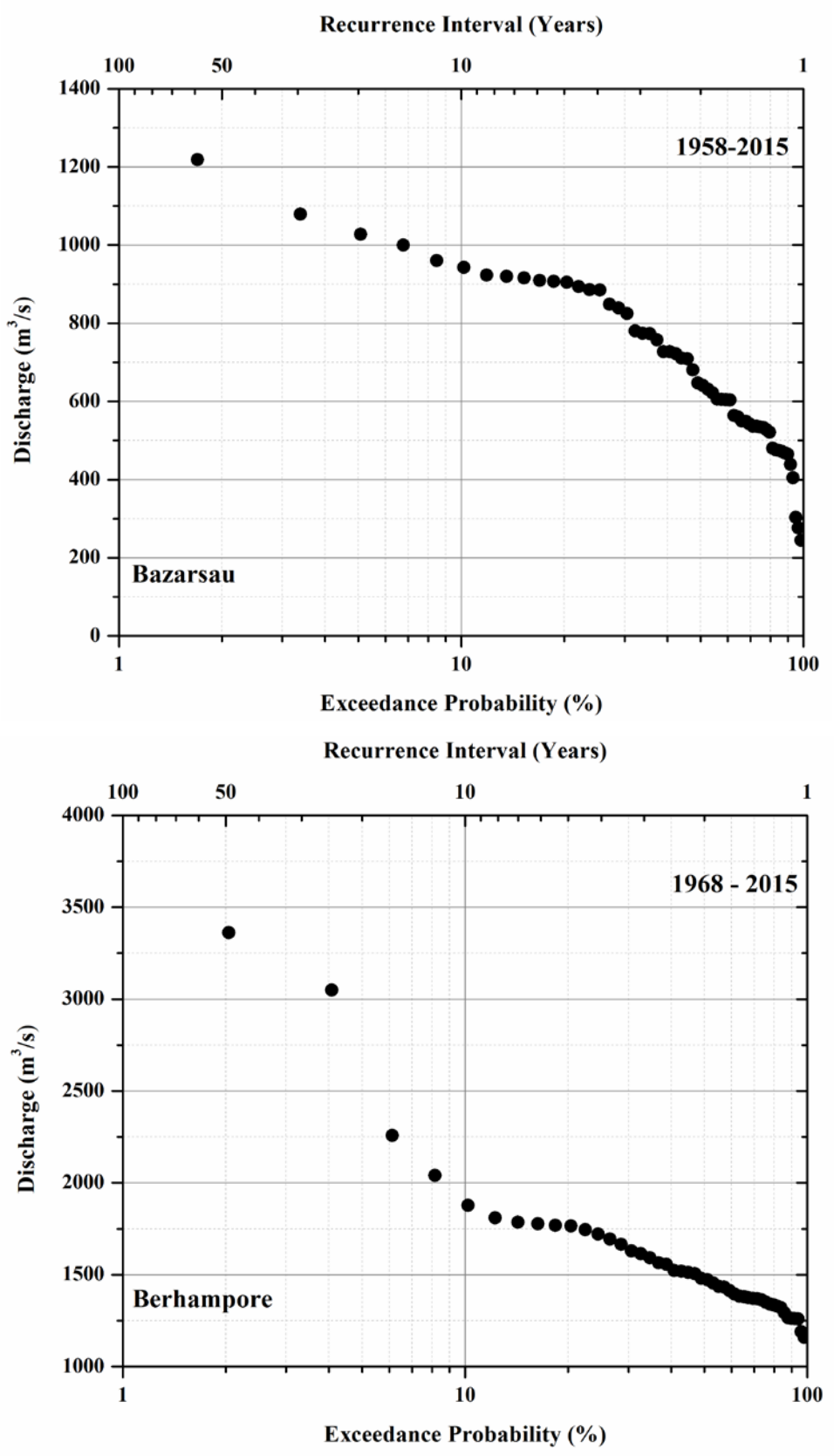


Figure 13.1: Exceedance probability and recurrence interval for Bazarsau and Berhampore

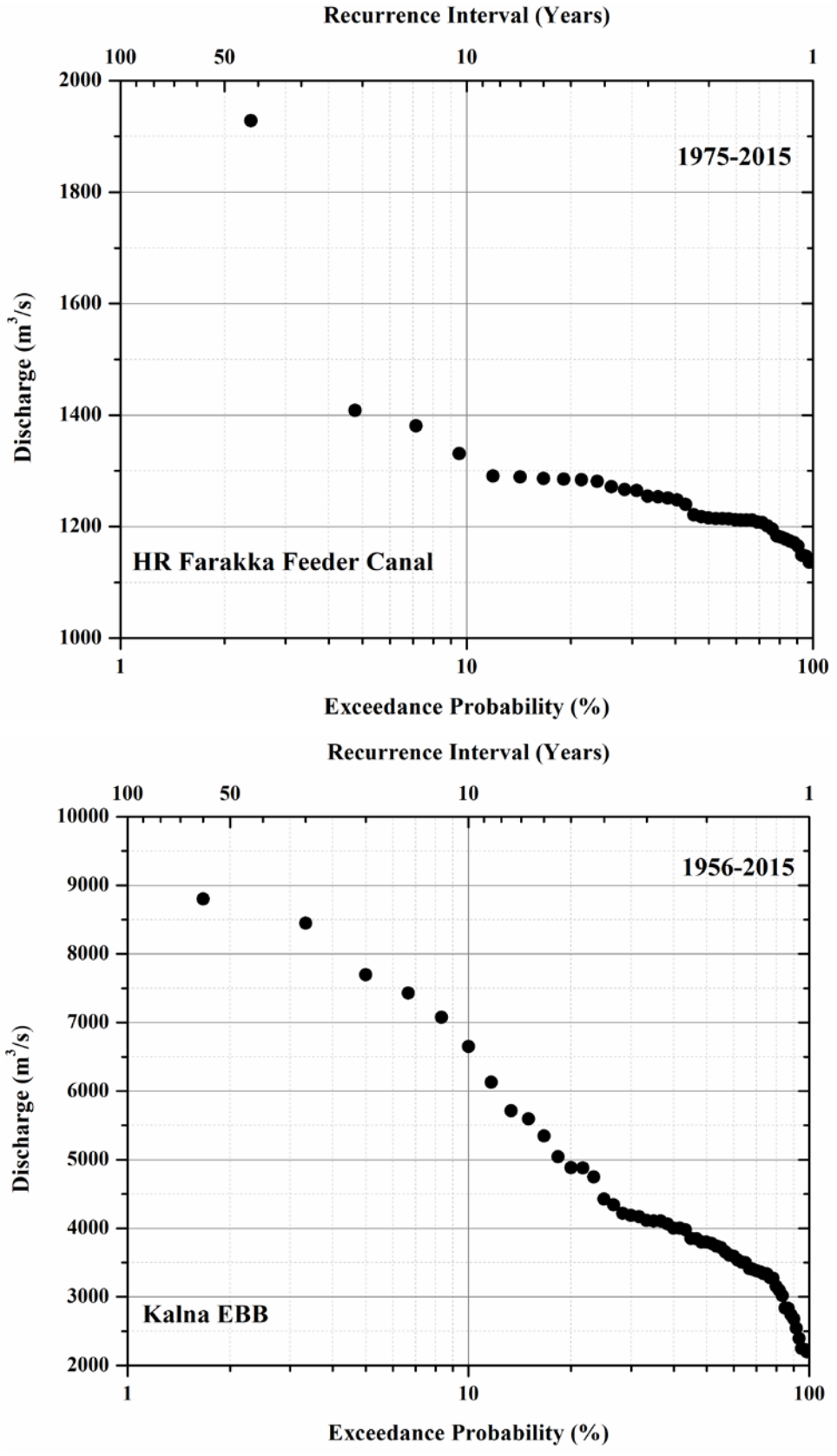


Figure 13.2: Exceedance probability and recurrence interval for HR Farakka and Kalna EBB

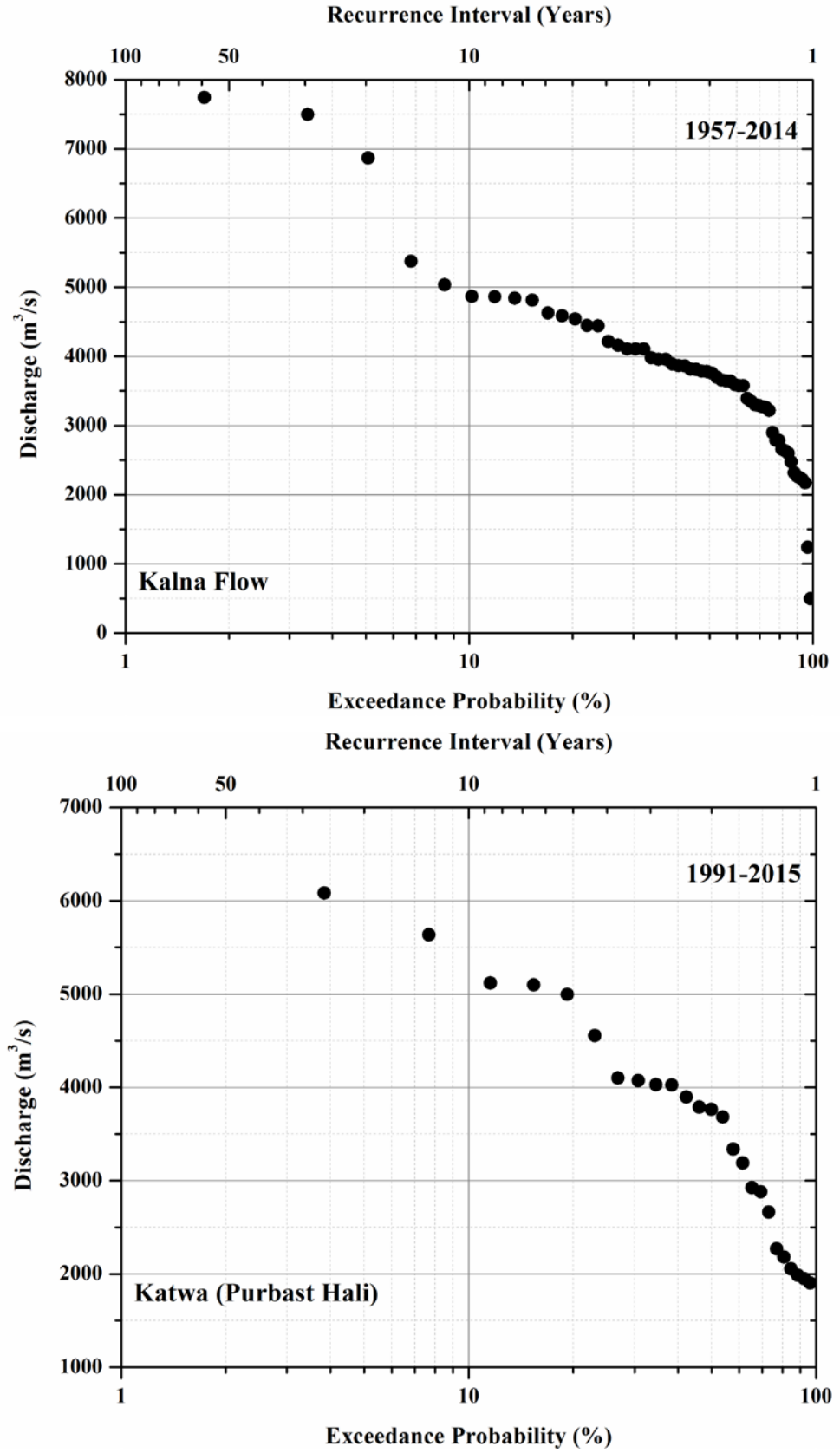


Figure 13.3: Exceedance probability and recurrence interval for Kalna flow and Katwa

5.8. Water level:

River stage is an important concept when analyzing how much water is moving in a stream at any given moment. The stage is the water level above some arbitrary point, usually with the zero height being near the river bed, in the river and is commonly measured in feet or meters. In this work, we calculate the annual water level (meter) of Hooghly River HO stations (Figure 14.1 to 14.5).

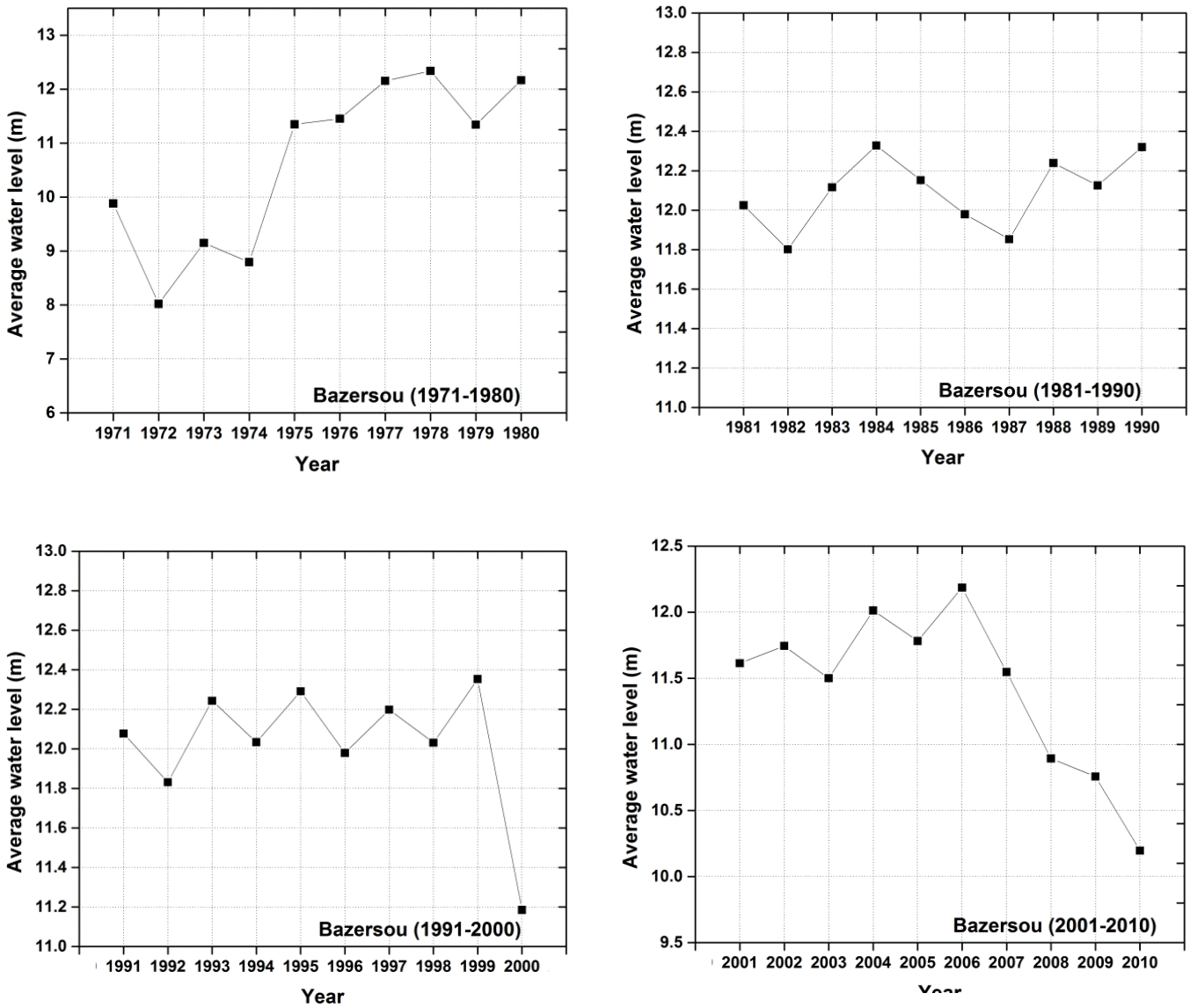


Figure 14.1: The average annual water level of Bazersou station in Hooghly river (1971-2010)

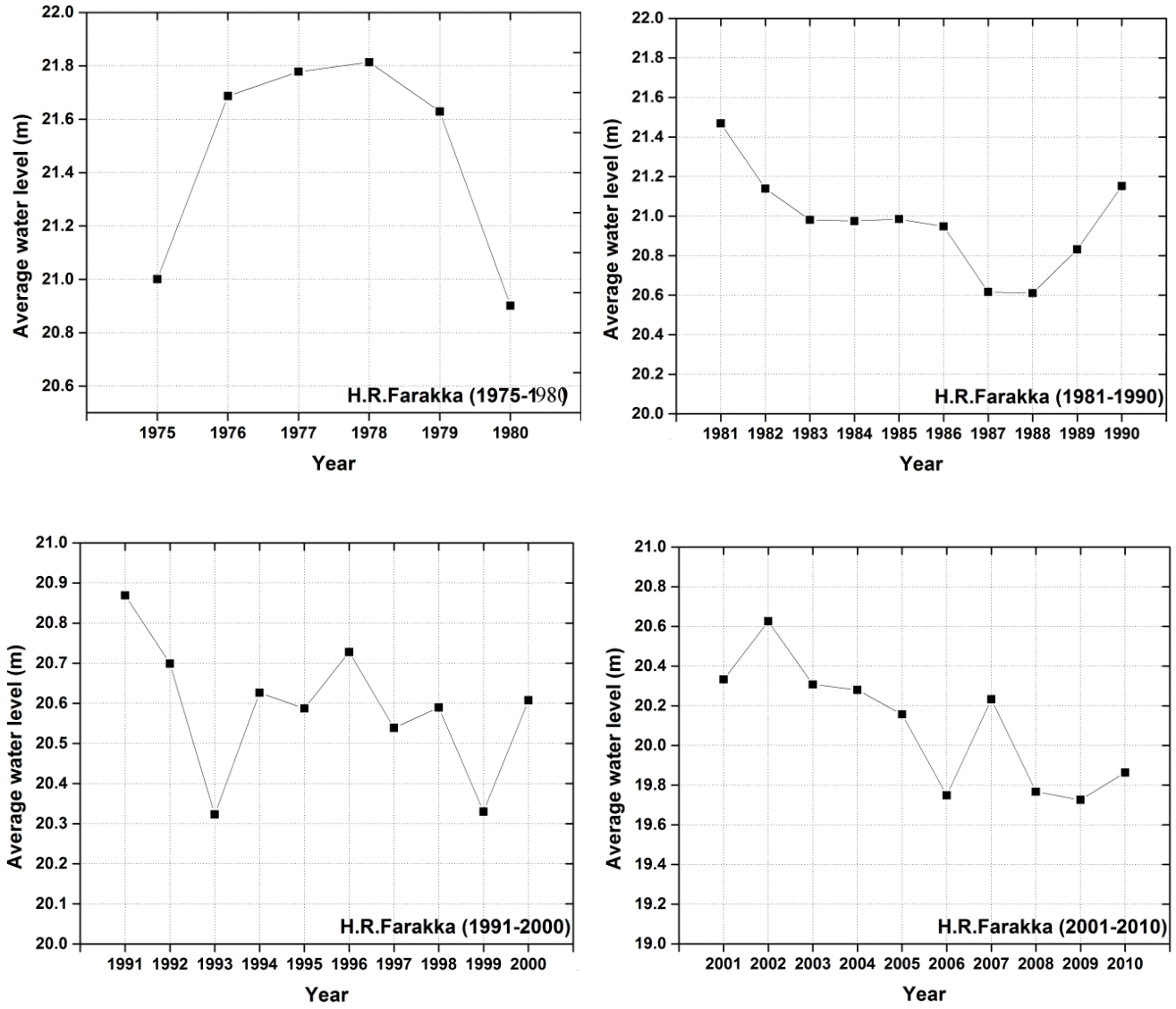


Figure 14.2: The average annual water level of H.R. Farakka station in Hooghly river (1975-2010)

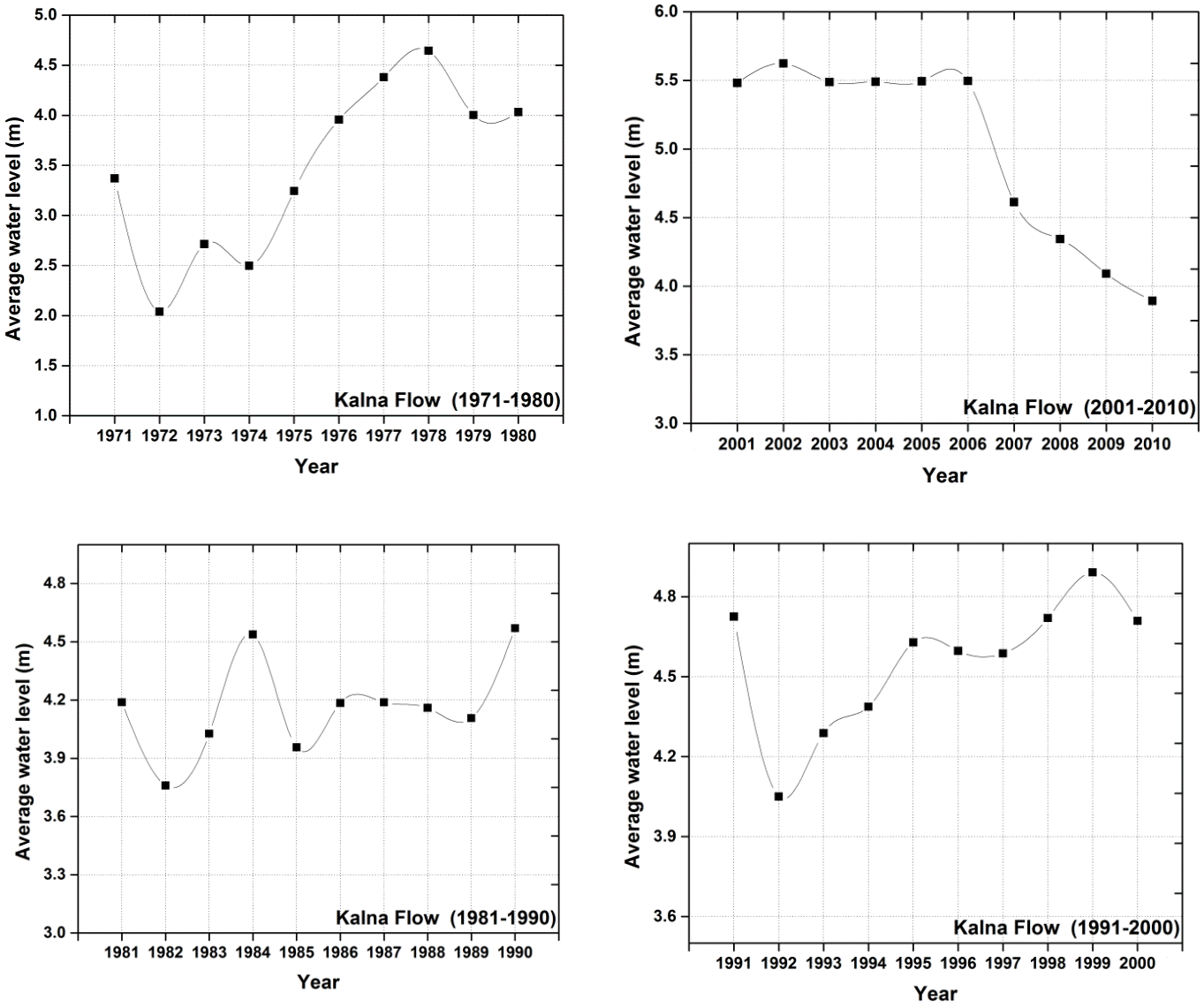


Figure 14.3: The average annual water level of Kalna Flow station in Hooghly river (1971-2010)

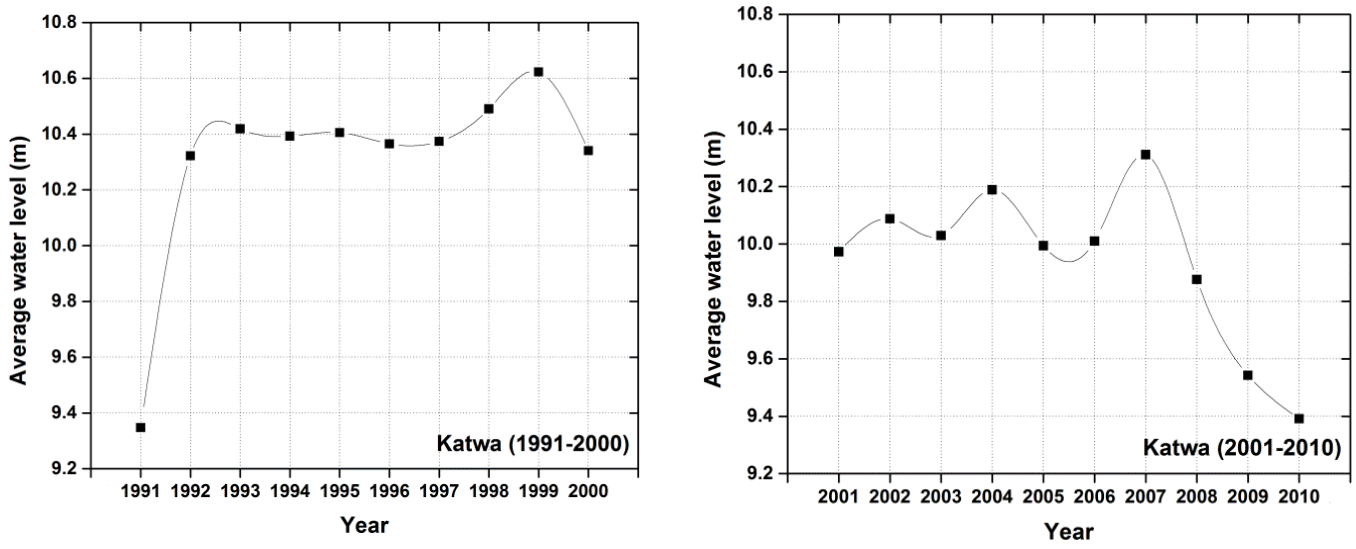
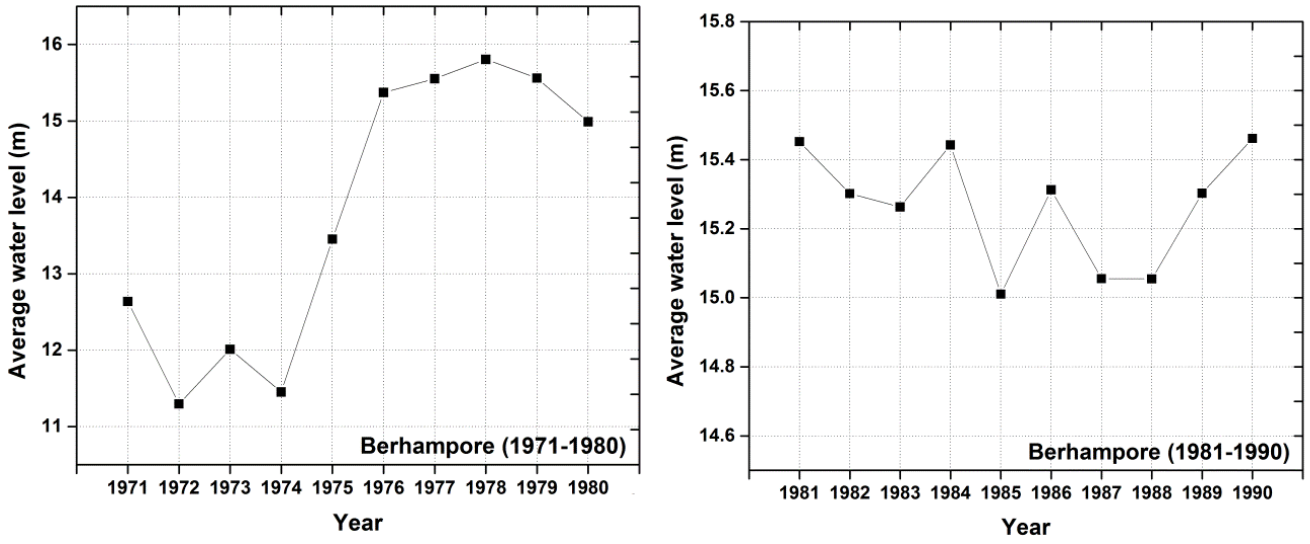


Figure 14.4: The average annual water level of Katwa station in Hooghly river (1991-2010)



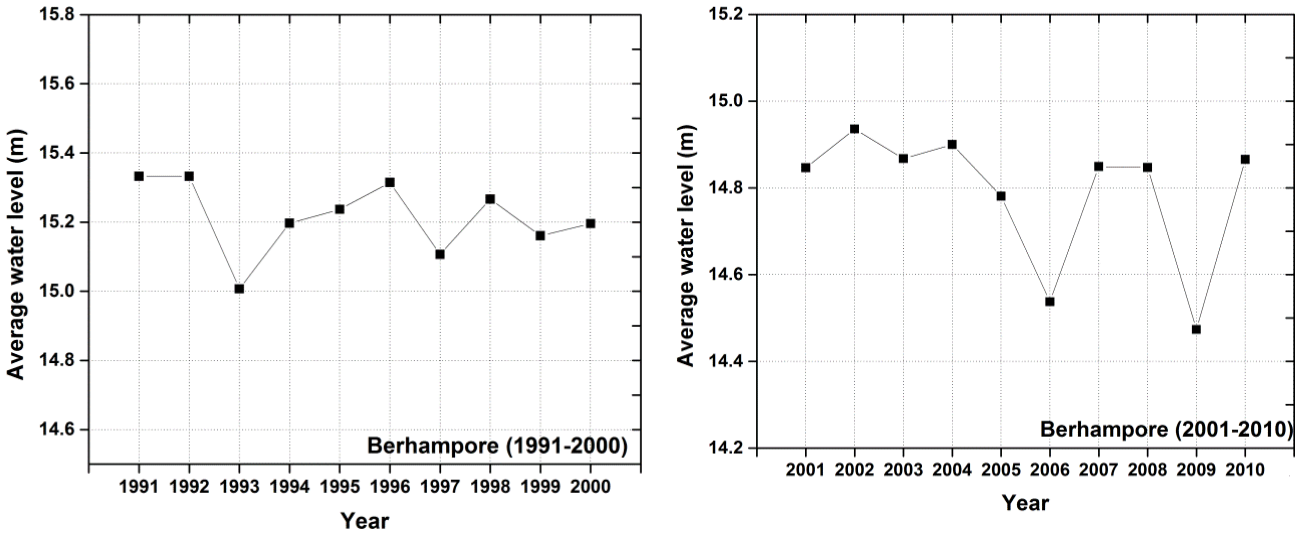


Figure 14.5: The average annual water level of Berhampore station in Hooghly river (1975-2010)

5.9. Soil erosion of Hooghly river reach

Riverbank erosion occurs both naturally and through human impact. Rivers and streams are dynamic systems as they are constantly changing. The natural process of riverbank erosion can produce favorable outcomes such as the formation of productive flood plains and alluvial terraces. In this study, the RUSLE (Revised universal soil loss equation) method is employed along with remote sensing and GIS techniques to estimate the soil loss from the banks of the Hooghly river within a 2 km buffer. GIS data layers including rainfall passivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were calculated to calculate their effects on the yearly soil loss in the Hooghly river riparian region. The river is divided into 14 reaches and each reach is nearby 34 km in length. The soil erosion map is classified into three classes (Low, Moderate, and High). Soil erosion of the Hooghly river reaches is depicted in Figures 15.1 to 15.13.

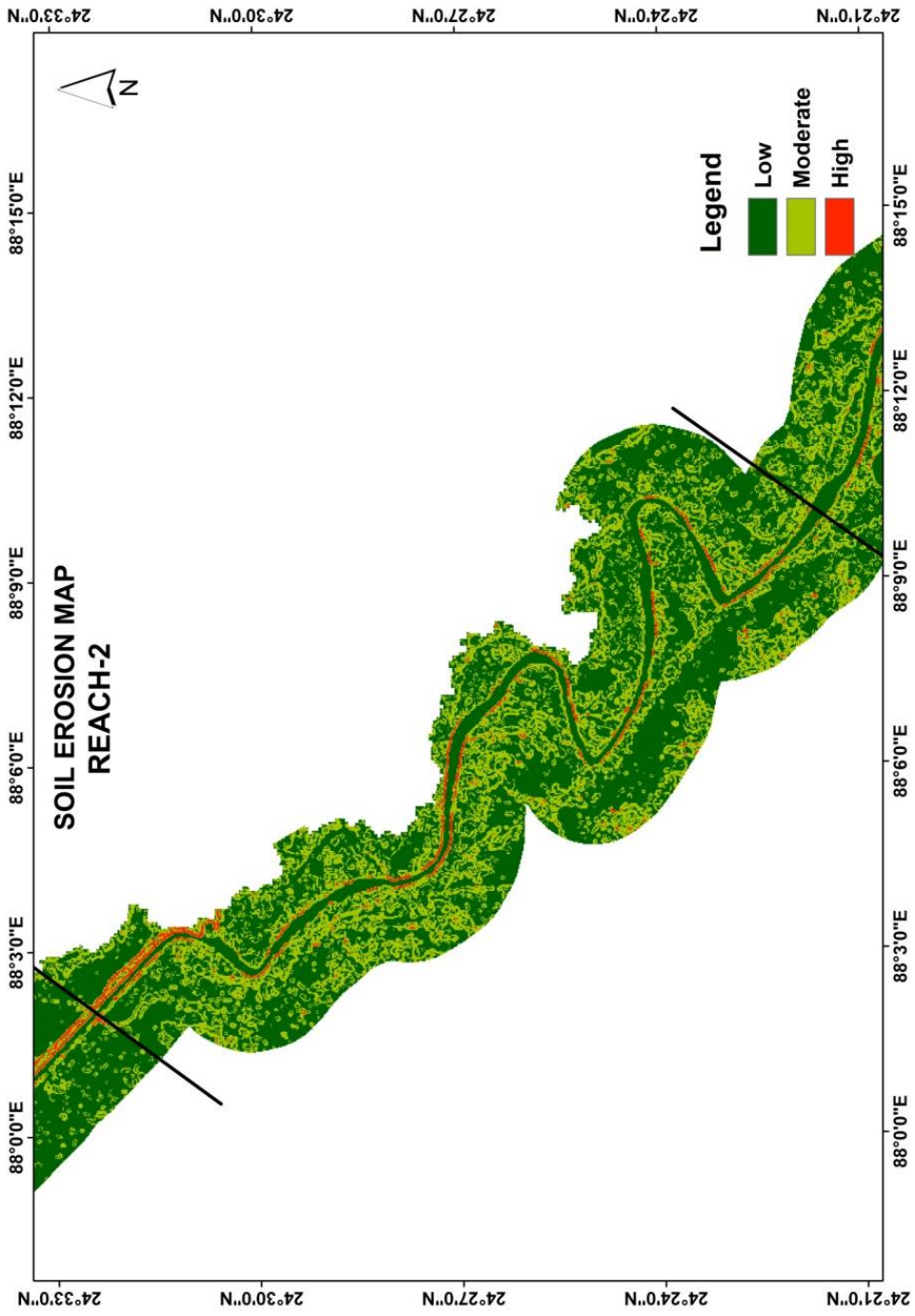


Figure 15.1: Soil erosion in the course of Hooghly River reach 2

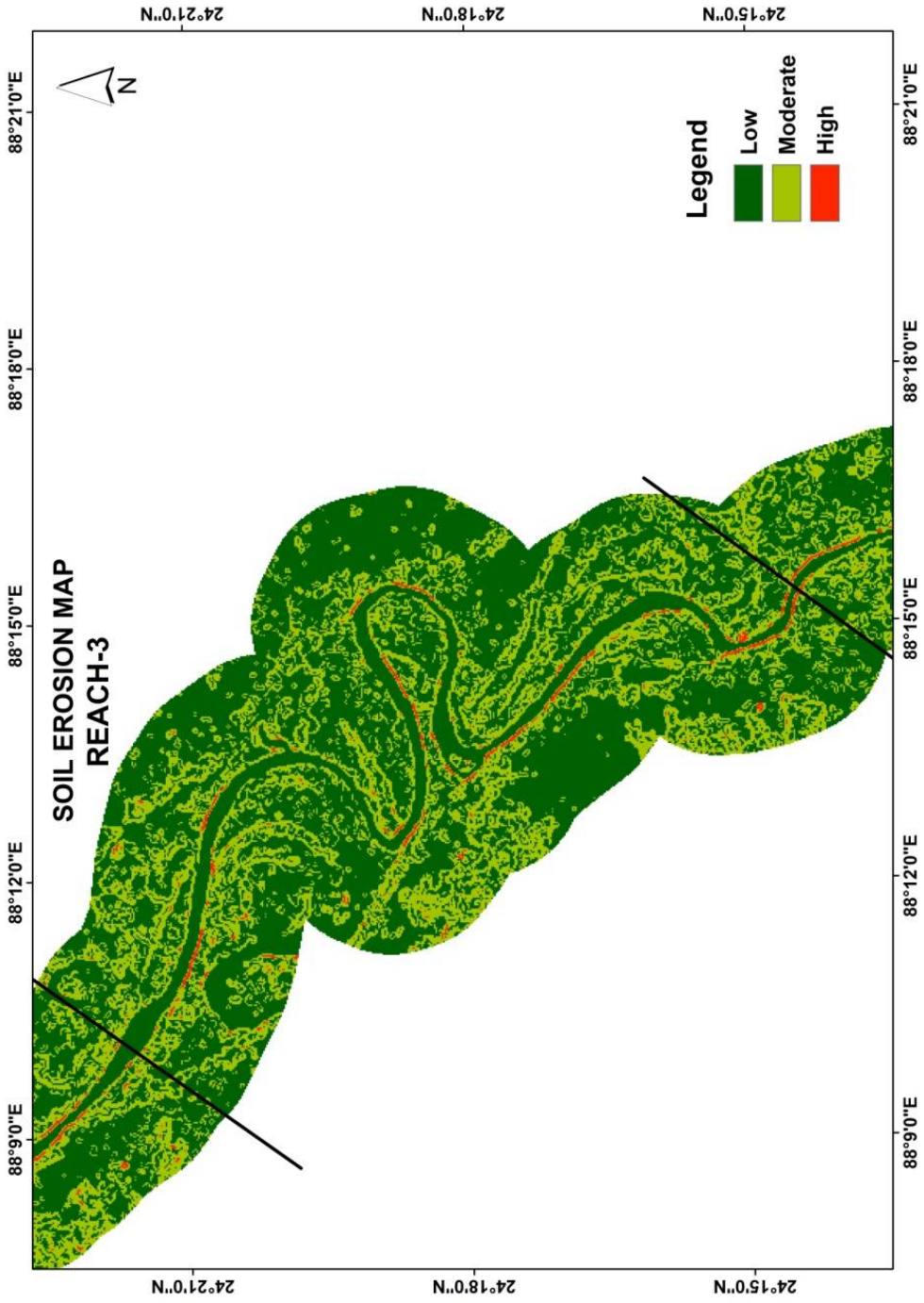


Figure 15.2: Soil erosion in the course of Hooghly River reach 3

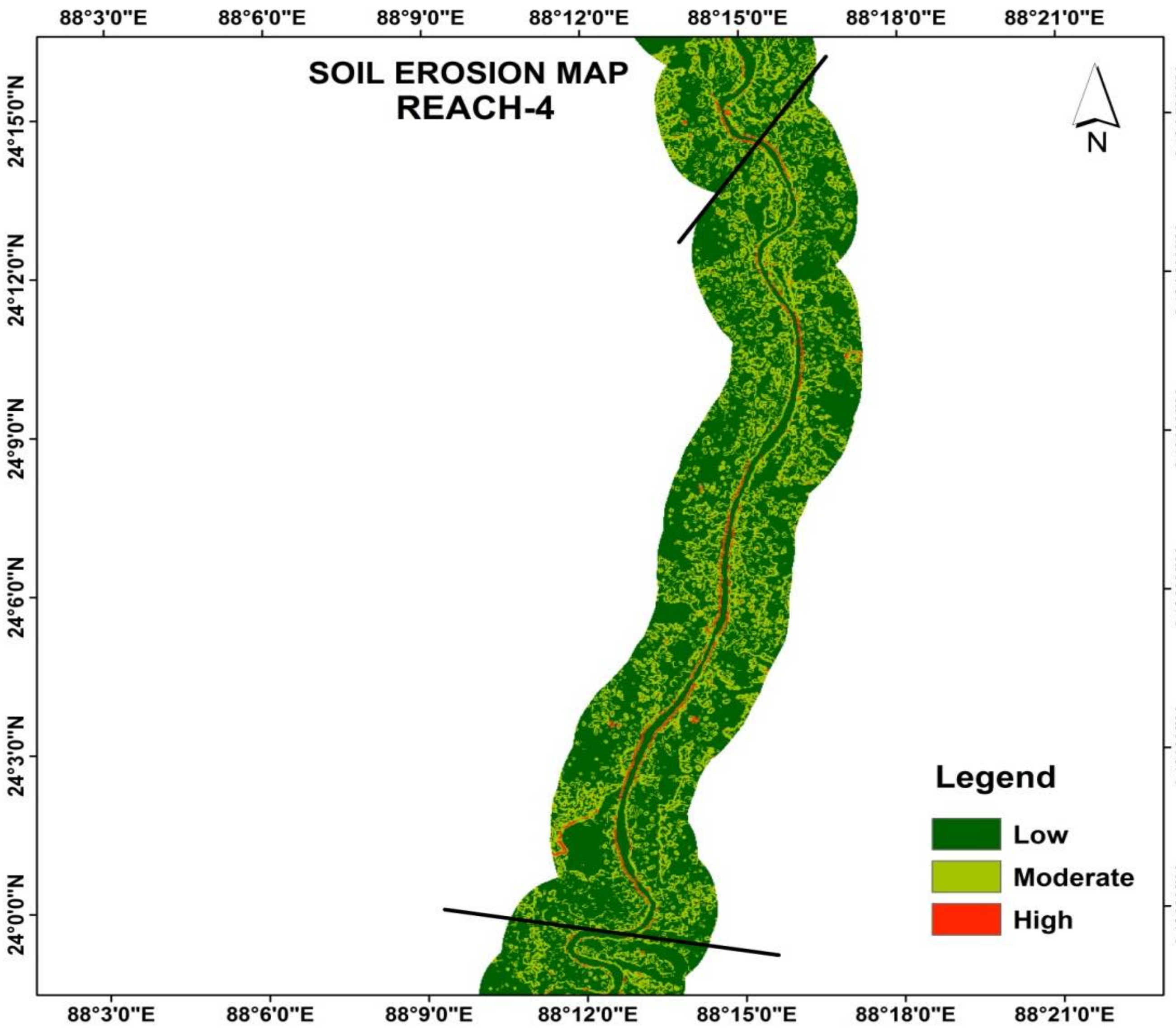


Figure 15.3: Soil erosion in the course of Hooghly River reach 4

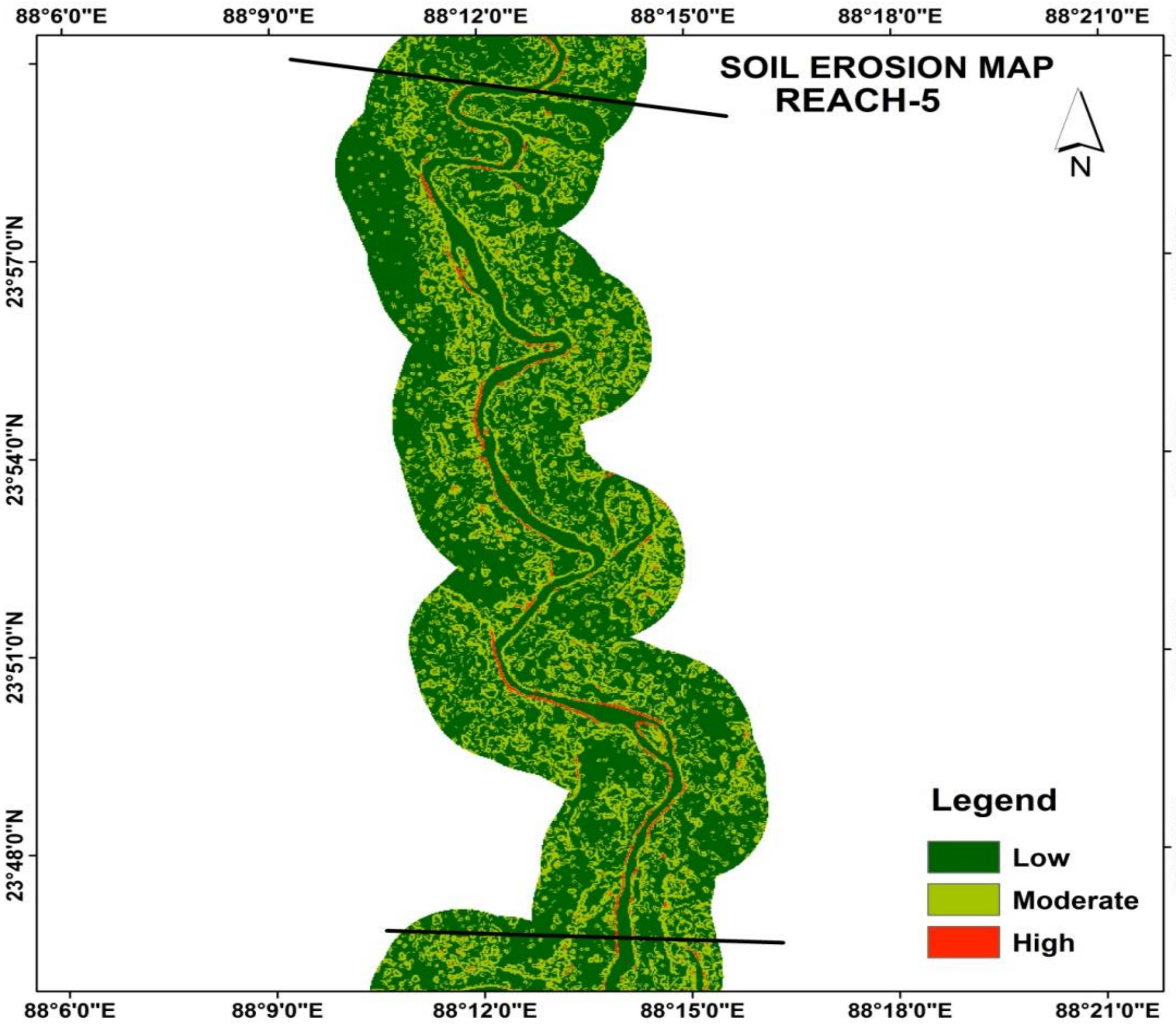


Figure 15.4: Soil erosion in the course of Hooghly River reach 5

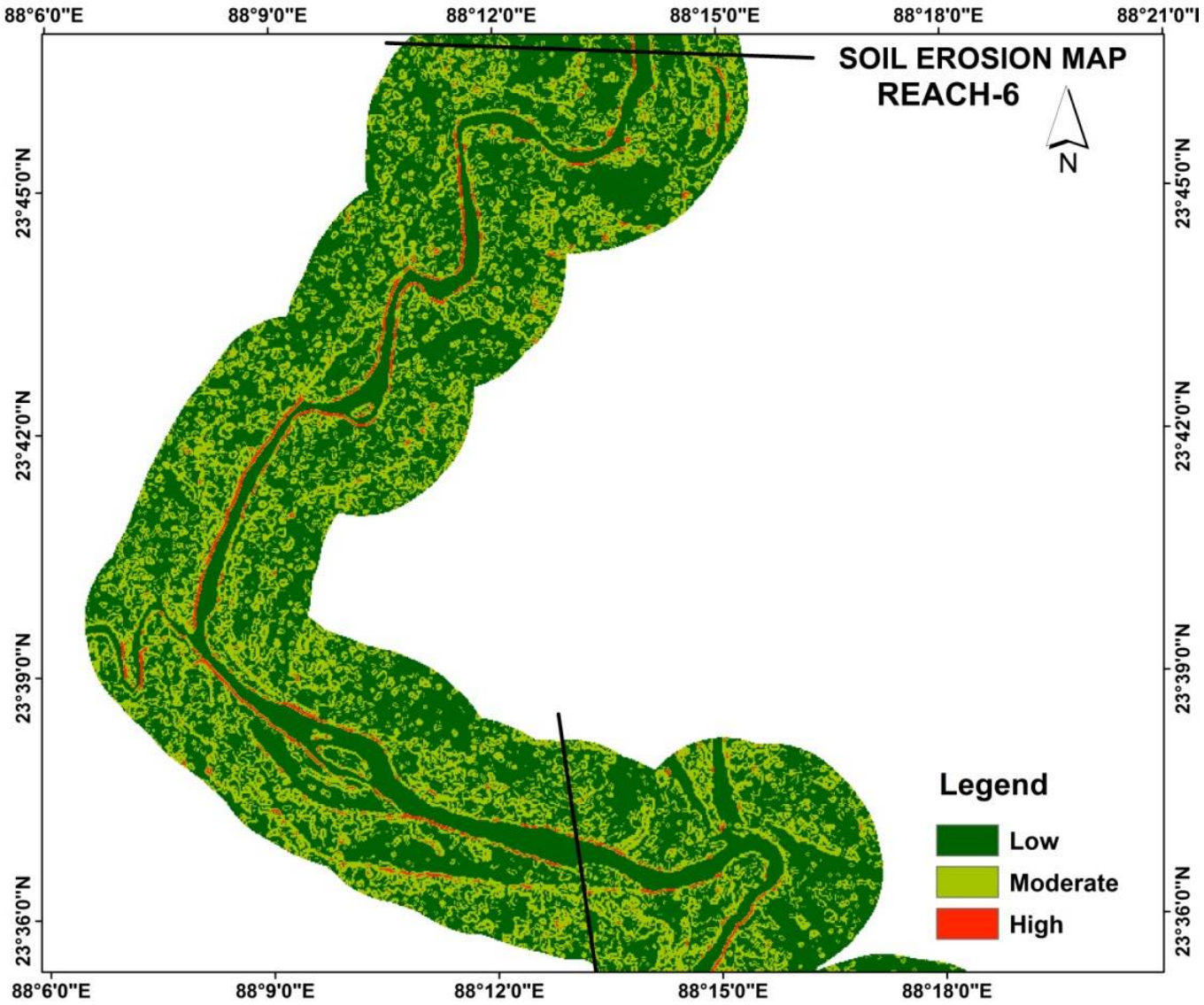


Figure 15.5: Soil erosion in the course of Hooghly River reach 6

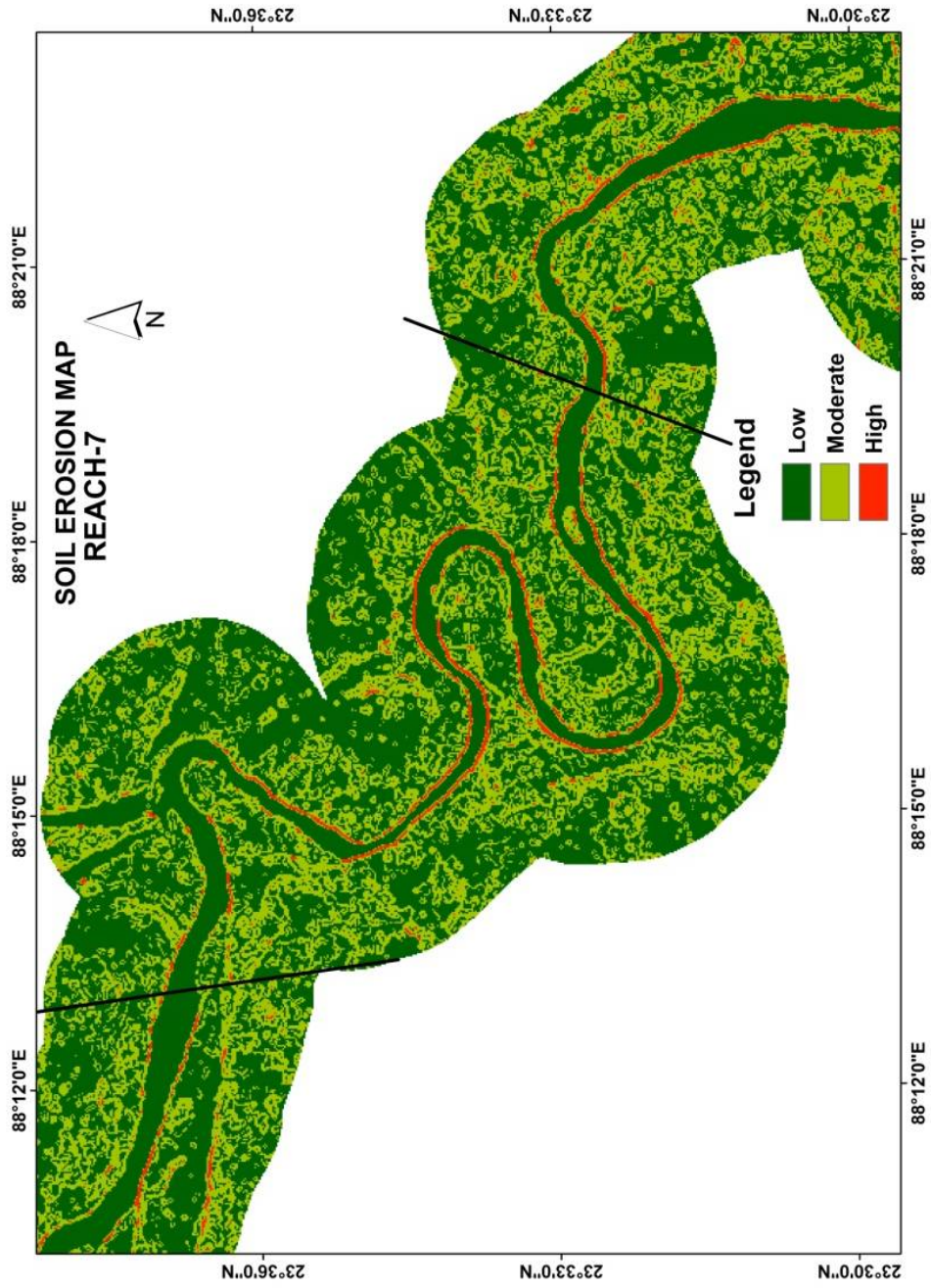


Figure 15.6: Soil erosion in the course of Hooghly River reach7

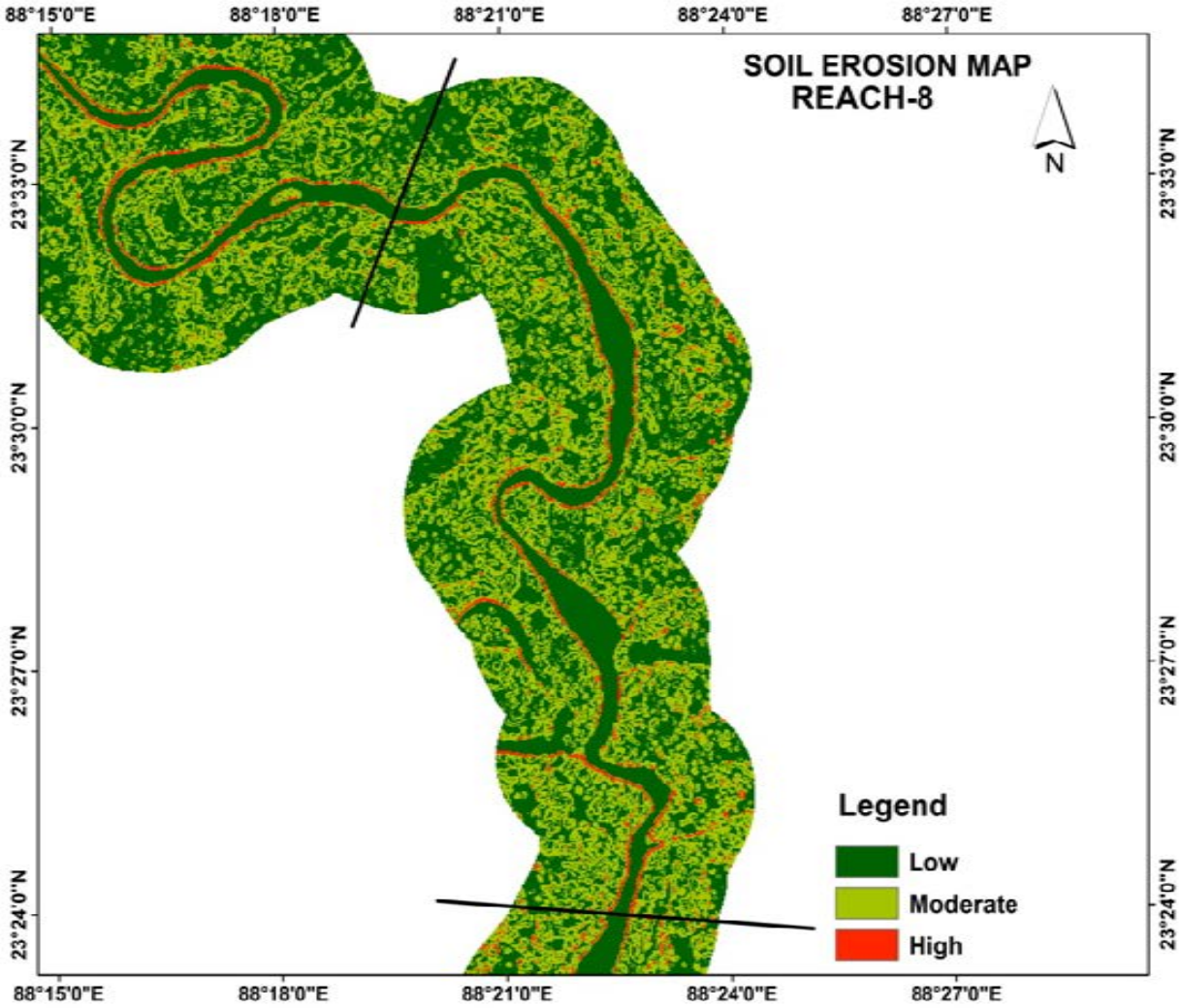


Figure 15.7: Soil erosion in the course of Hooghly River reach 8

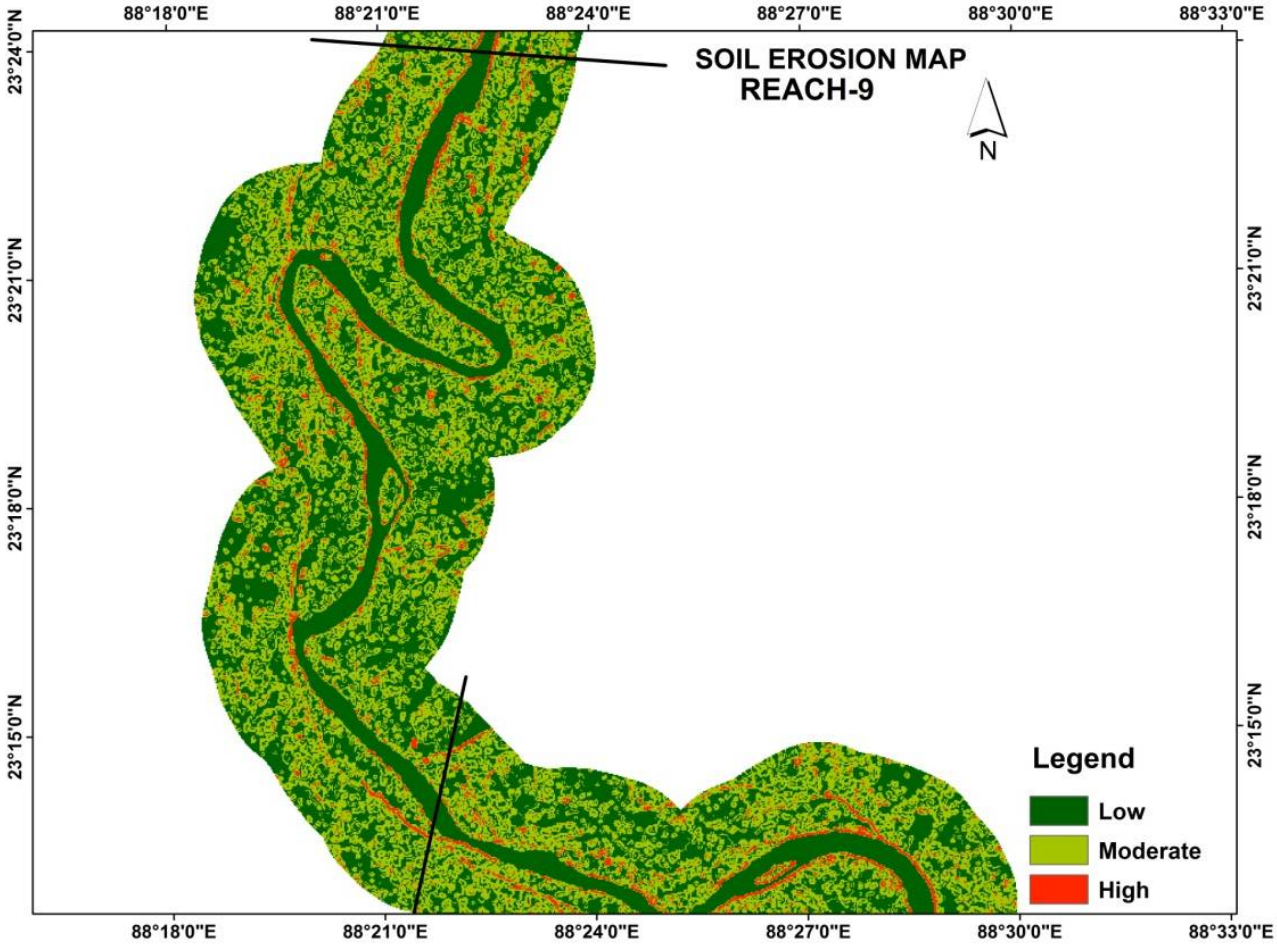


Figure 15.8: Soil erosion in the course of Hooghly River reach 9

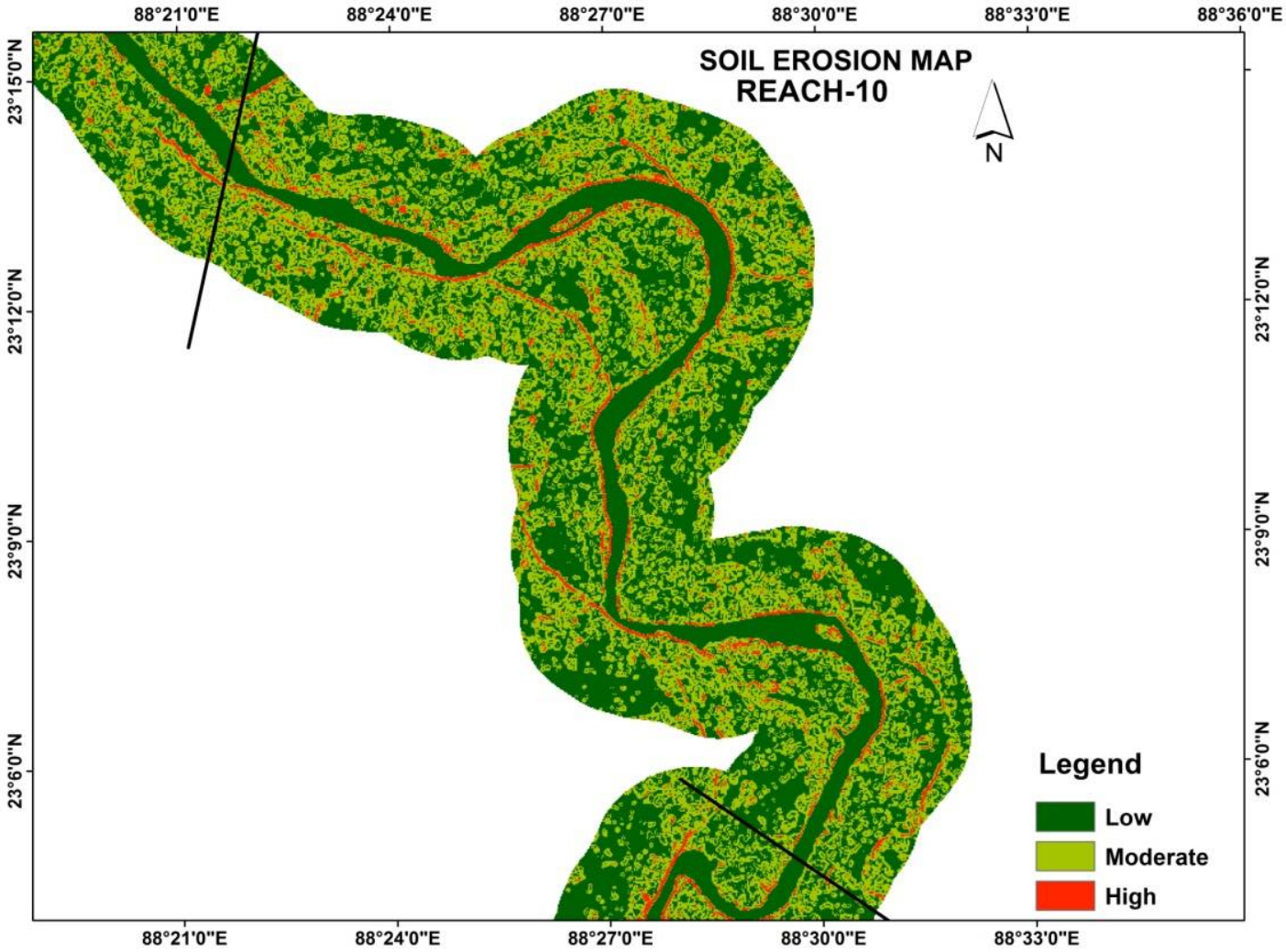


Figure 15.9: Soil erosion in the course of Hooghly River reach 10

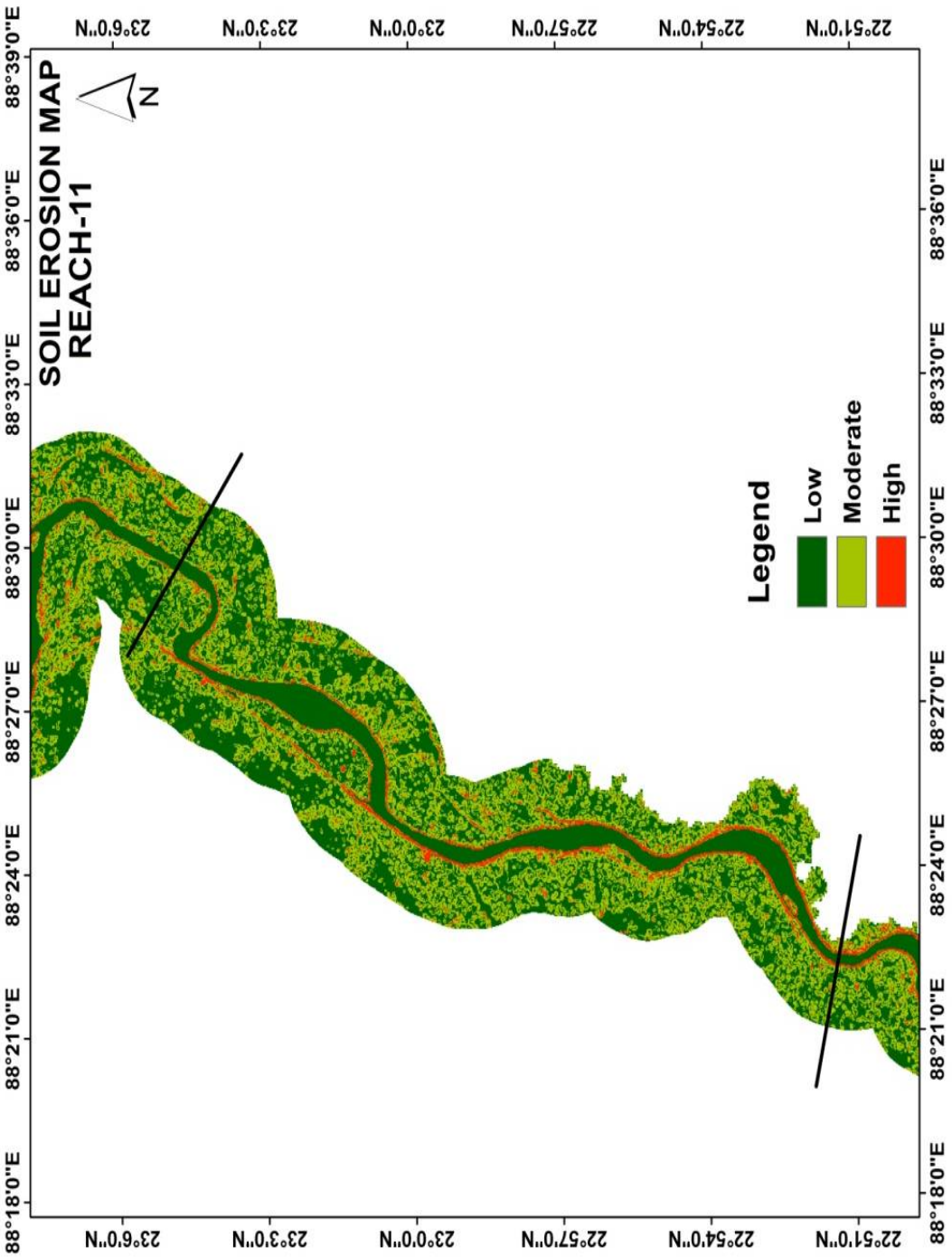


Figure 15.10: Soil erosion in the course of Hooghly River reach 11

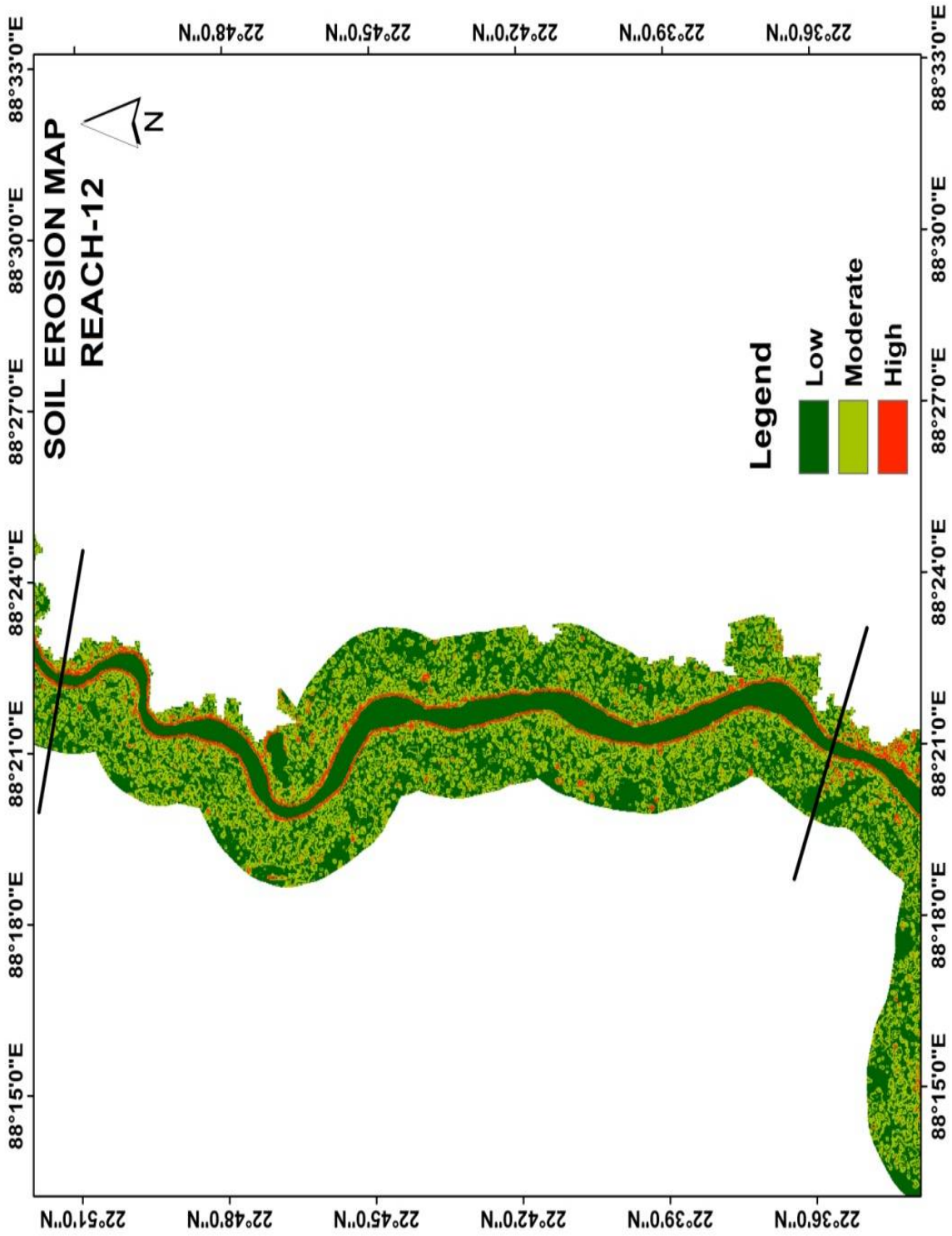


Figure 15.11: Soil erosion in the course of Hooghly River reach 12

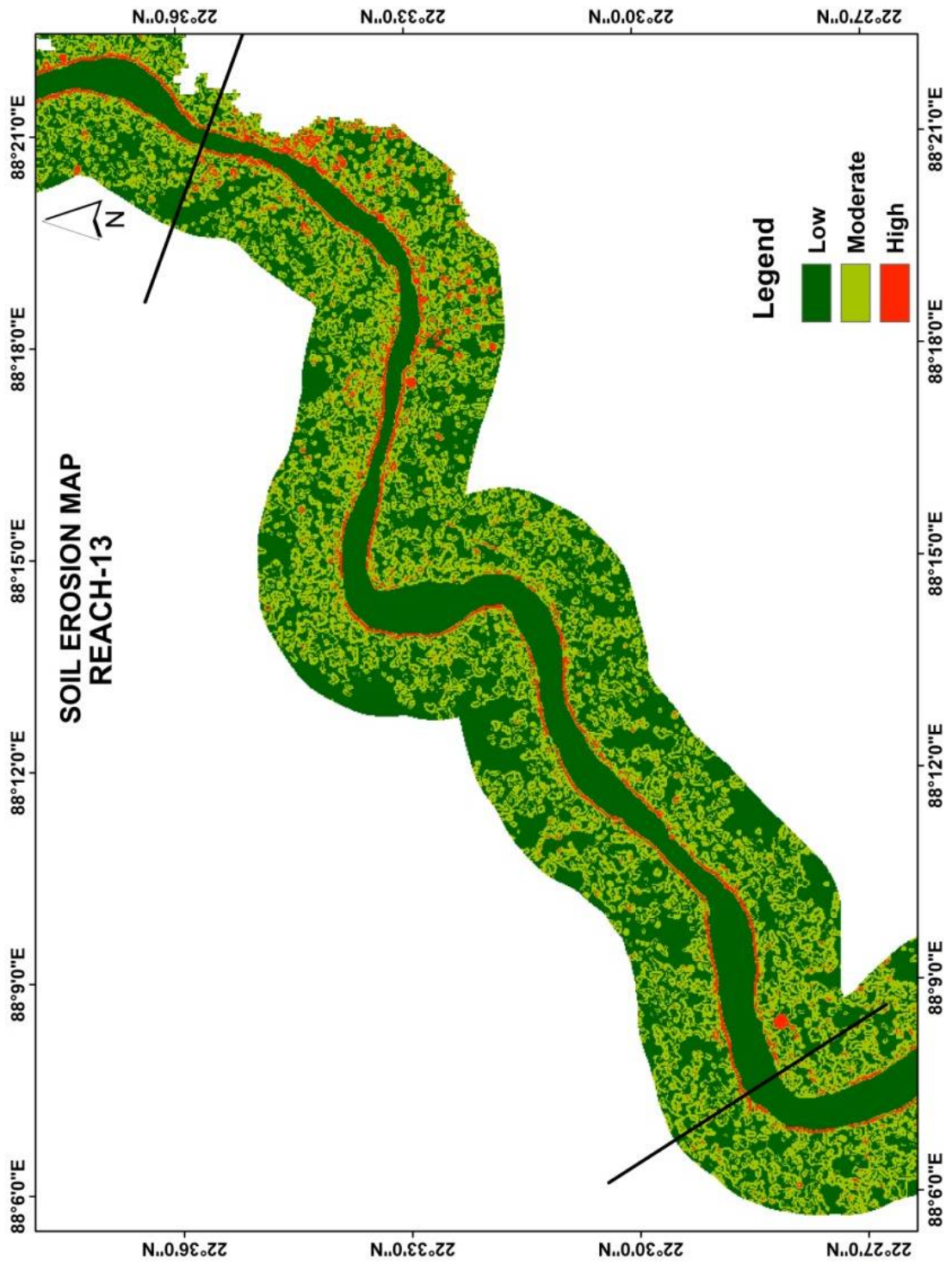


Figure 15.12: Soil erosion in the course of Hooghly River reach 13

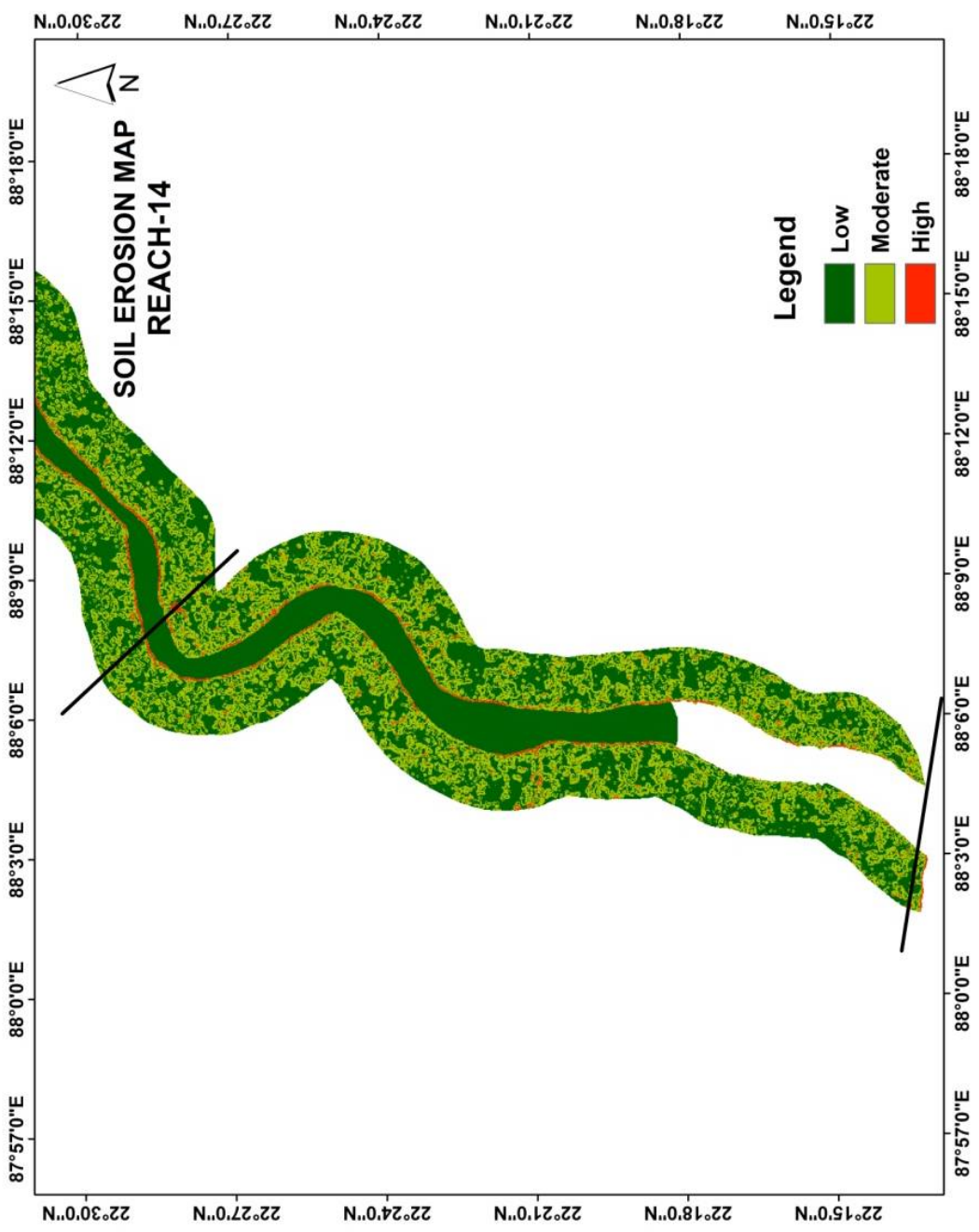


Figure 15.13: Soil erosion in the course of Hooghly River reach 14

5.10.Critical Reaches of Hooghly

Critical zone is defined as a section within a reach of the river that is undergoing or likely to undergo drastic change in morphology, like migration. It is important for the planning of the natural resource management framework (Table 17). A reach is typically defined as a length of the river as explained in the previous sections and the river Hooghly is divided into 14 reaches, each of length 34 km (approximately). The objective of this study is to identify the current morphological changes and to predict the potential trends of a critical reaches of the river. Satellite data (Landsat MSS for the years 1972 and 1980, IRS LISS-I for 1990, IRS LISS-II for 2000, IRS LISS-III for 2010 and Landsat OLI for 2018) are used to delineate the river course and identify the morphologically critical stretches of the river. Landsat MSS data are downloaded from the website of the United States Geological Survey (USGS). IRS LISS-I, IRS LISS-II, and IRS LISS-III data are collected from the National Remote Sensing Centre, Hyderabad. Identification of critical reaches is based on critical erosion-prone areas using remote sensing and GIS techniques. Erosion prone areas are identified by comparing two different images of the same location at two different times by overlaying the respective bank lines (left and right). Finally, the critical zones are identified under each reach based on maximum erosion-prone areas in the river.

Analyses of the multi-temporal satellite data with the help of a GIS platform were to identify the critical zone of the Hooghly River by assessing bank erosion between the years 2000 to 2018. As mentioned before, the total length of the Hooghly river has been divided into 14 reaches, of which the reaches around Murshidabad, Nadia, Hooghly, and Braddhaman districts, that is, the middle portion of the river like reaches 6, 7, 8, 9, 10, 11 covering the Blocks of Agradwip, Bandhagachhi, Balagarh, Patuli, Naliapur, Dhatrigram, Kaligangi and Sujapur are seen to lie within the highly critical zone categorization. Detailed information of the reaches is shown in Figures 16 to 29.

Table 17: Identification of critical site name under critical reach in Hooghly river basin

Critical Reach Number	Critical Site name	District Name
2	Alampur	Murshidabad
2	Jehelinagar	Murshidabad
2	Char Sekendara	Murshidabad
2	Bahura	Murshidabad
2	Nutangani	Murshidabad
3	Jumra Nayagram	Murshidabad
3	Rampal	Murshidabad
3	Lalitakuri	Murshidabad
3	Bhatpara	Murshidabad
3	Arijpur	Murshidabad
3	Chak Mahammadpur	Murshidabad
3	Kamarpara	Murshidabad
4	Bazarpara	Murshidabad
4	Ajodhya Nagar	Murshidabad
4	Begpur	Murshidabad
4	Char Narayanpur	Murshidabad
4	Fate singdiar	Murshidabad
4	Charmahula	Murshidabad
4	Hotnagar	Murshidabad
5	Barlu	Murshidabad
5	Chumarigacha	Murshidabad
5	Satui	Murshidabad
5	Sona Diar	Murshidabad
5	Charkam Nagar	Murshidabad
5	Sekandarpur	Murshidabad
5	Mashimpur	Murshidabad
5	Chandpur	Murshidabad
5	Mahata	Murshidabad
5	Arazi Jaykrishnapur	Murshidabad
6	Kadkhali	Nadia
6	Ghasrdanga	Nadia
6	Char Gobalpur	Nadia
6	Char narayanpur	Nadia
6	Bishnupur	Nadia
6	Char Sriharipur	Nadia
6	Sitahati	Nadia
6	Uddharonpur	Nadia
6	Kadihati	Nadia

Table 17: (continued) Identification of critical site name under critical reach in Hooghly river basin

Critical Reach Number	Critical Site name	District Name
6	Khere Bazar	Nadia
6	Gobindopur	Nadia
6	Rajnagar	Nadia
6	Shatghar	Nadia
6	Char Brajanathpur	Nadia
6	Char Balidanga	Nadia
7	Char Khosalpur	Nadia
7	Akandanga	Nadia
7	Agradwip	Nadia
7	Gazipur	Nadia
7	Chandanpur	Nadia
7	Mamudpur	Nadia
7	Patuli	Nadia
7	Jhaudanga	Nadia
7	Mamudpur	Nadia
7	Narayanpur	Nadia
7	Uttar Shrirampur	Nadia
7	Dampal	Nadia
7	Uday Chandrapur	Nadia
7	Dadupur	Nadia
7	Char Jhaudanga	Nadia
7	Kashiadanga	Nadia
8	Chandanpur	Nadia
8	Karkaria	Nadia
8	Rukunpur	Nadia
8	Mertala	Nadia
8	Durgabas	Nadia
8	Simla	Nadia
8	Sajira	Nadia
8	Shankapur	Nadia
8	Indrakpur	Nadia
8	Rudrapara	Nadia
8	Mayapur	Nadia
8	Hular Ghat	Nadia
8	Char Brahmanagar	Nadia
8	1 No. Gouranga	Nadia
8	Parmedia	Nadia
8	Bankar Dhopadi	Nadia

Table 17: (continued)**:** Identification of critical site name under critical reach in Hooghly river basin

Critical Reach Number	Critical Site name	District Name
9	Satkulta	Nadia
9	Mohisunra	Nadia
9	Jaluidanga	Bardhaman
9	Jalahati	Bardhaman
9	Hatsimla	Bardhaman
9	Goalpur	Bardhaman
9	Mrijapur	Bardhaman
9	Gramkalna	Bardhaman
9	Piarinagar	Bardhaman
9	Krishnadebpur	Bardhaman
9	kalna P	Bardhaman
9	Nrisinghapur/Kalna	Bardhaman
9	Guptipara Char	Bardhaman
9	Chhenrar char	Bardhaman
10	Ghoshra	Bardhaman
10	Nilnagar	Bardhaman
10	Char Rampur	Bardhaman
10	Rasulpur Char	Bardhaman
10	Char Noapara	Bardhaman
10	Sukuria	Bardhaman
10	Char Sripur	Bardhaman
10	Gosair Char	Nadia
10	Sibpur	Bardhaman
10	Char Gaur Nagar	Hooghly
10	Milangarh	Hooghly
10	Raninagar	Hooghly
10	Charjirat	Hooghly
10	Natun Para	Hooghly
10	Baneswarpur	Hooghly
11	Tarinipur	Nadia
11	Ganga Manoharpur	Nadia
11	Char Jajira	Nadia
11	Gaharpur	Hooghly
11	Jatrasudi	Hooghly
11	Char Kancharapara	Nadia
11	Char nandan bati	Nadia
11	Konamore	Hooghly
11	Hazi Nagar	North 24 Parganas

Table 17: (continued)**:** Identification of critical site name under critical reach in Hooghly river basin

Critical Reach Number	Critical Site name	District Name
11	Mitrapara	Hooghly
11	Nimbagan	Hooghly
11	Arya Samaj	Hooghly
11	Barabazar	Hooghly
11	Antpur Ferry Ghat	Hooghly
11	Noapara	Hooghly
11	Bichali	Hooghly
11	Sastitala	Hooghly
12	Palta Park	Hooghly
12	Baidyapara	Hooghly
12	Barrackpur Ferry	North 24 Parganas
12	Dutta Bari	Kolkata
12	Kamarhati	North 24 Parganas
12	Uttarpara Kotrung	Hooghly
12	Cossipore	Kolkata
12	Khidirpur	Kolkata
13	Atabag Basti	Kolkata
13	Rajabagan Dock	Kolkata
13	Sishu Udyan	Kolkata
13	Batanagar	South 24 Parganas
13	Kalipur	South 24 Parganas
13	Boikunthopur	Howrah
13	Jagatballavpur	Howrah
13	Birlapur	South 24 Parganas
13	Dakshin Raypur	South 24 Parganas
14	Baidya Khali	South 24 Parganas
14	Kasipur	South 24 Parganas
14	Baidya Khali	South 24 Parganas
14	Kasipur	South 24 Parganas
14	Ramnagar	South 24 Parganas
14	Noorpur	South 24 Parganas
14	Durgapur	South 24 Parganas
14	Geonkhali	East Midnapore

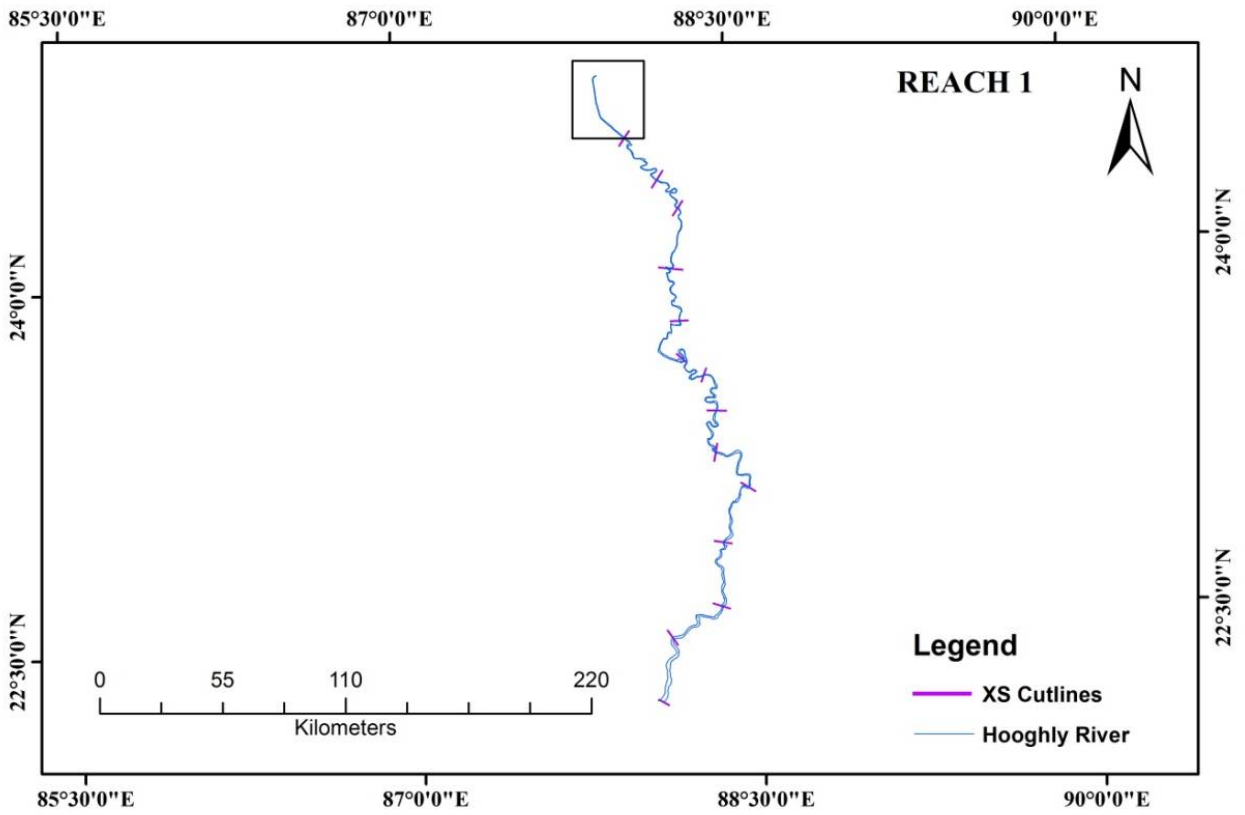


Figure 16: Location of reach number 1 in the Hooghly river

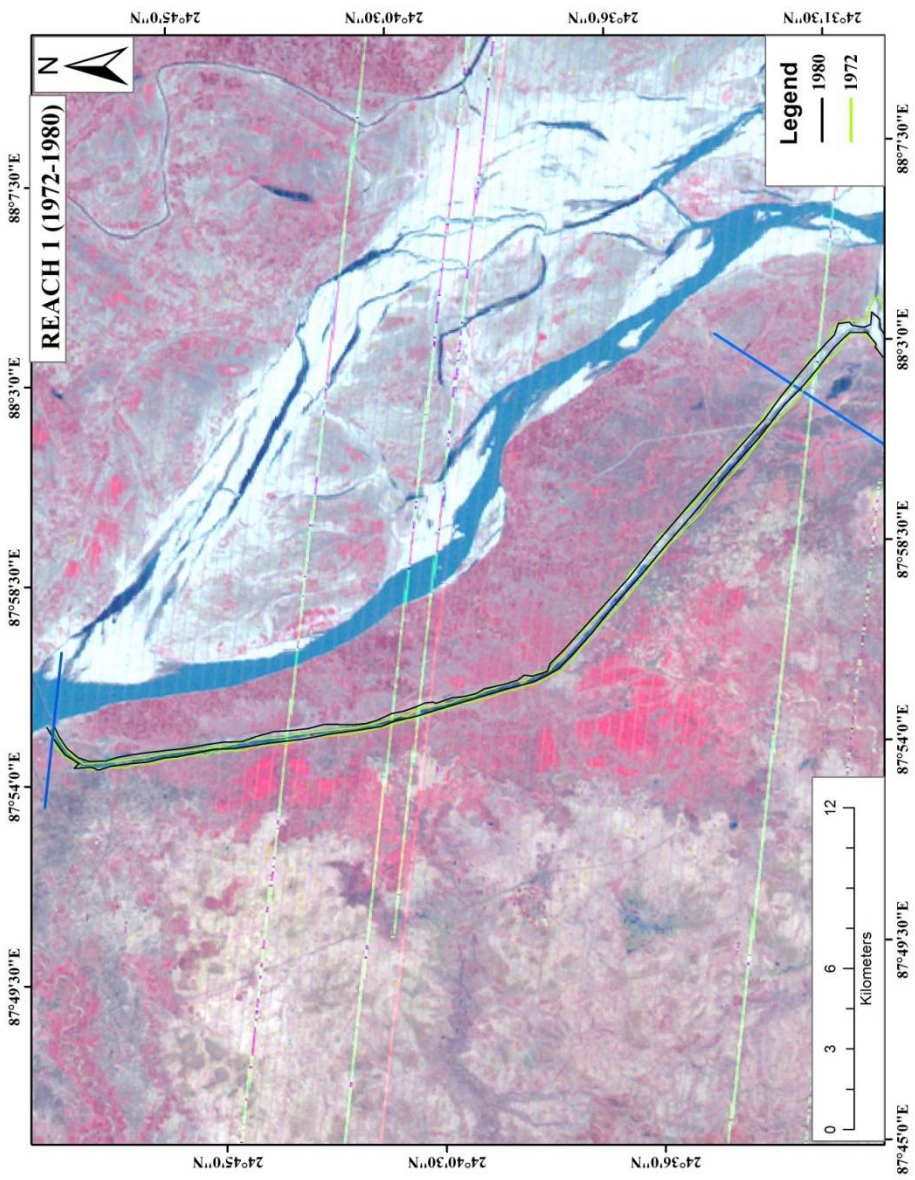


Figure 16.1: Changes in the course of Hooghly River of Year 1972-1980

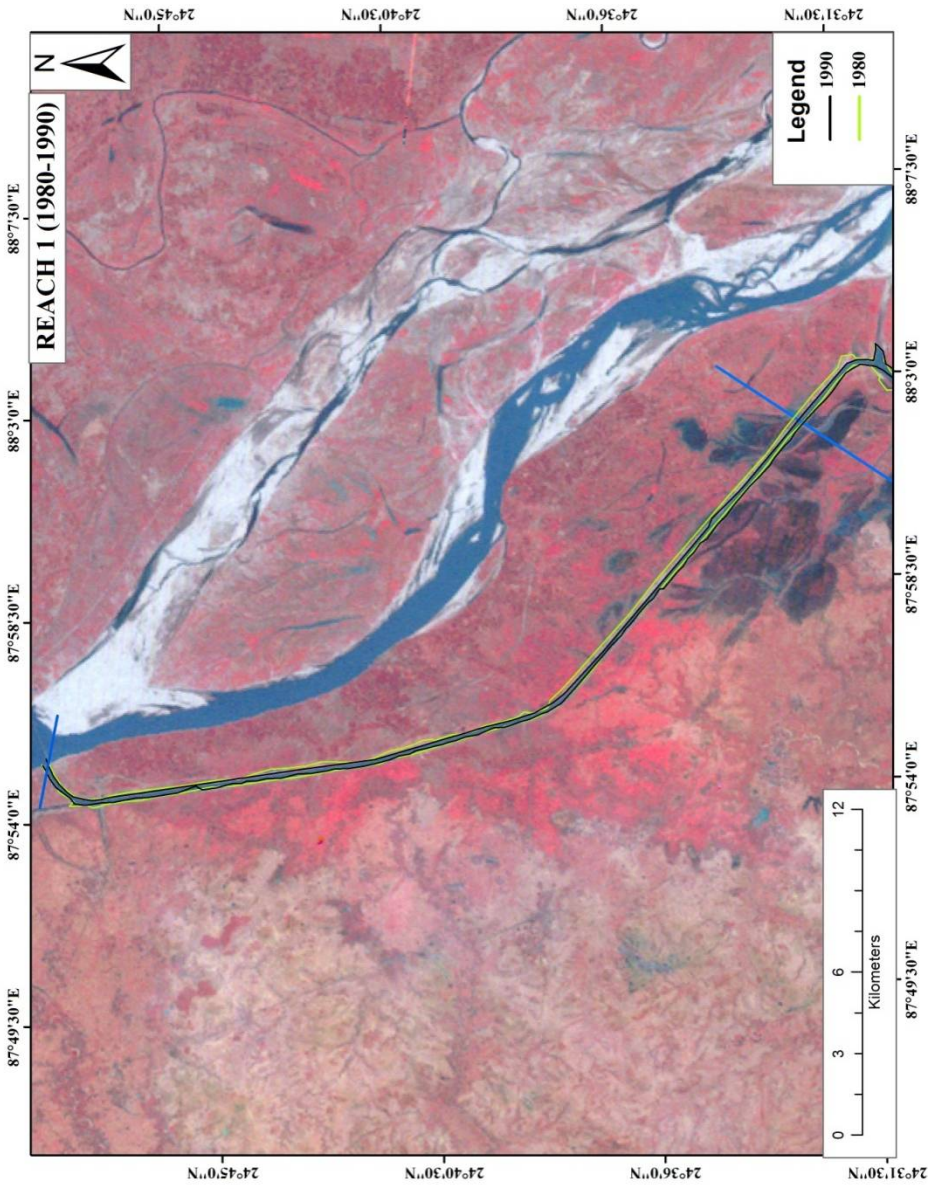


Figure 16.2: Changes in the course of Hooghly River of Year 1980-1990

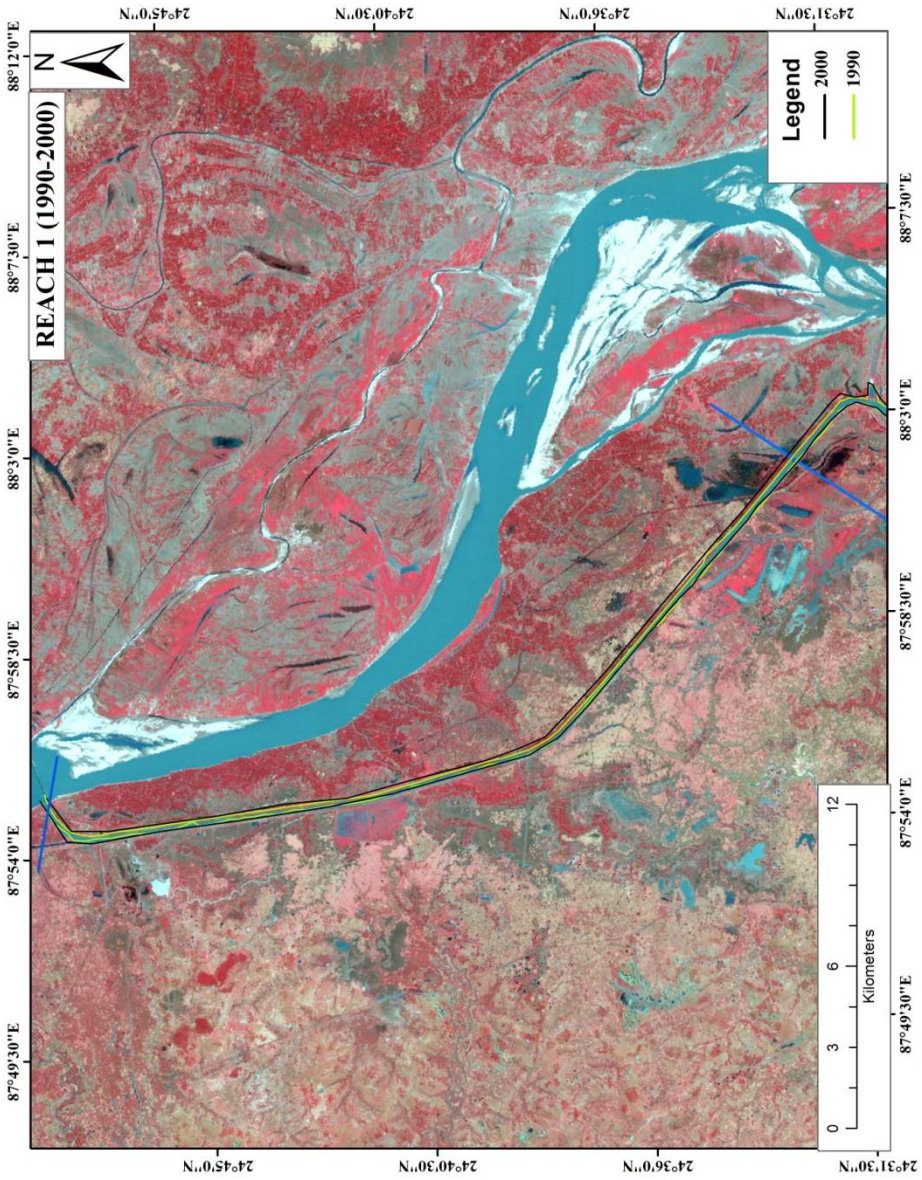


Figure 16.3: Changes in the course of Hooghly River of Year 1990-2000

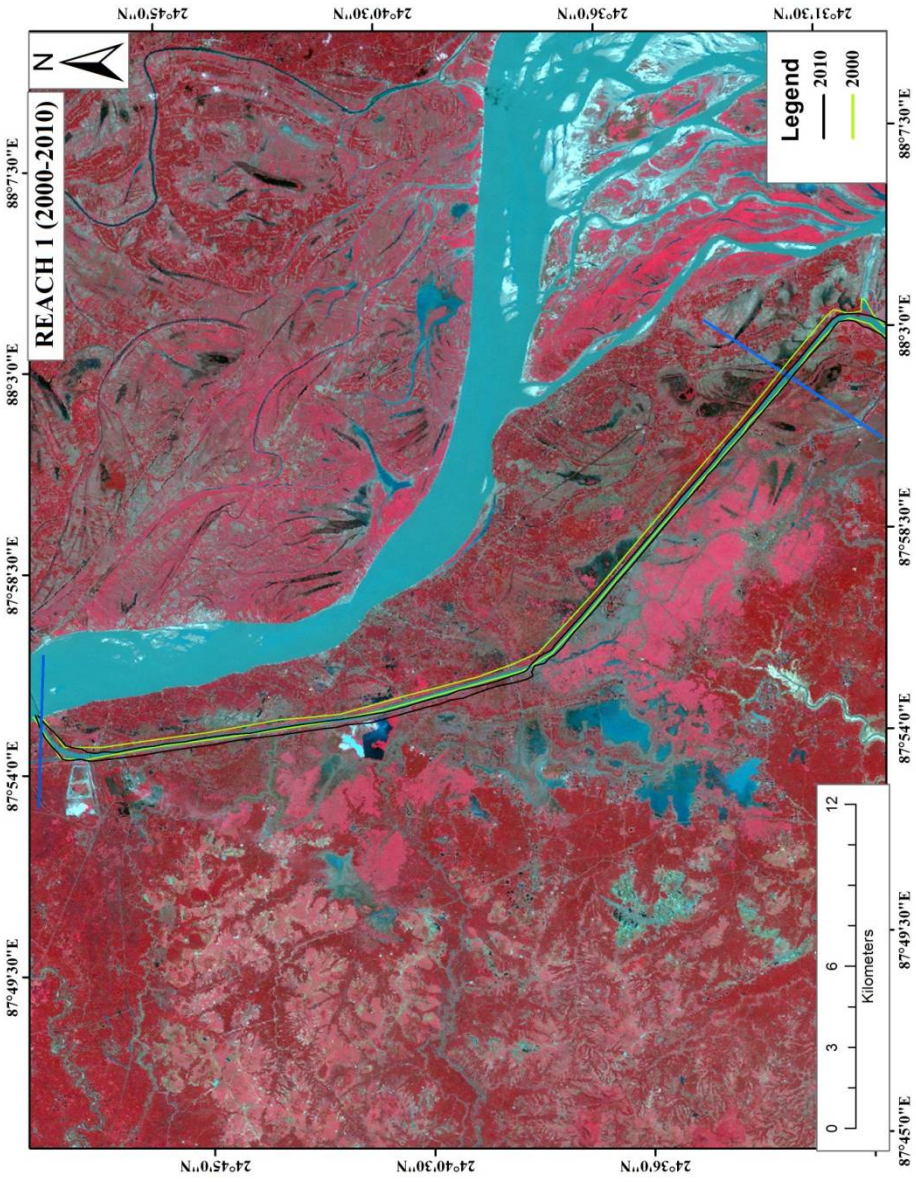


Figure 16.4: Changes in the course of Hooghly River of Year 2000-2010

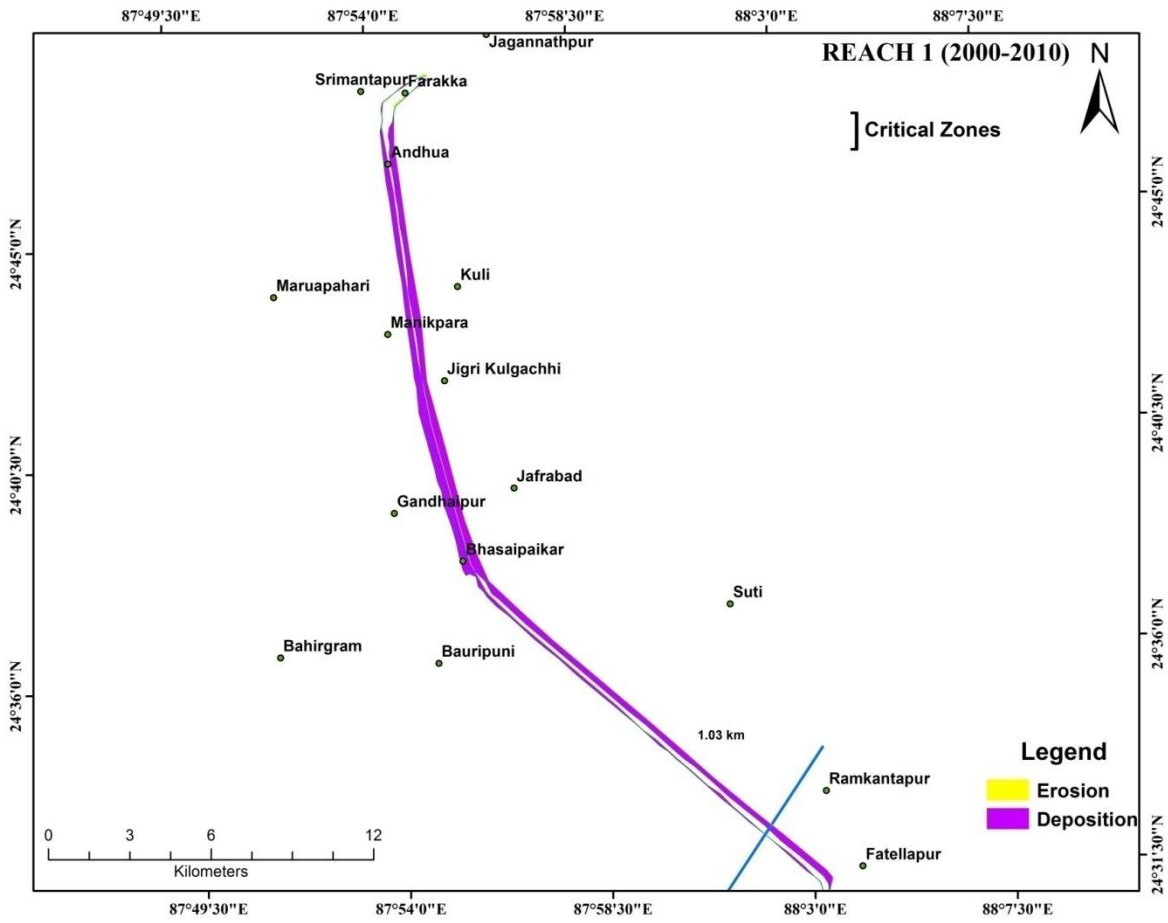


Figure 16.5: Identification of critical zones for Hooghly River of Year 2000-2010

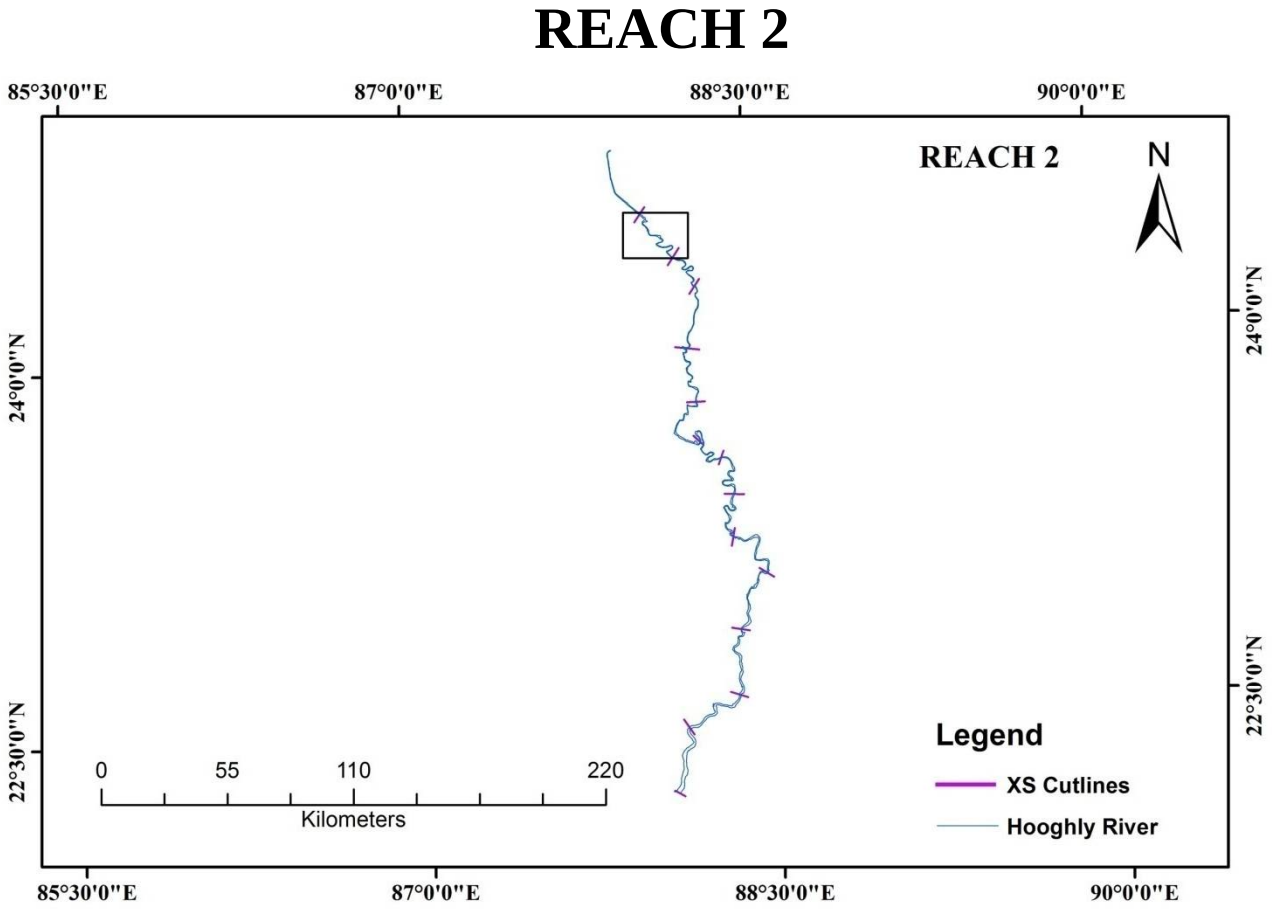


Figure 17: Location of reach number 2 in the Hooghly river

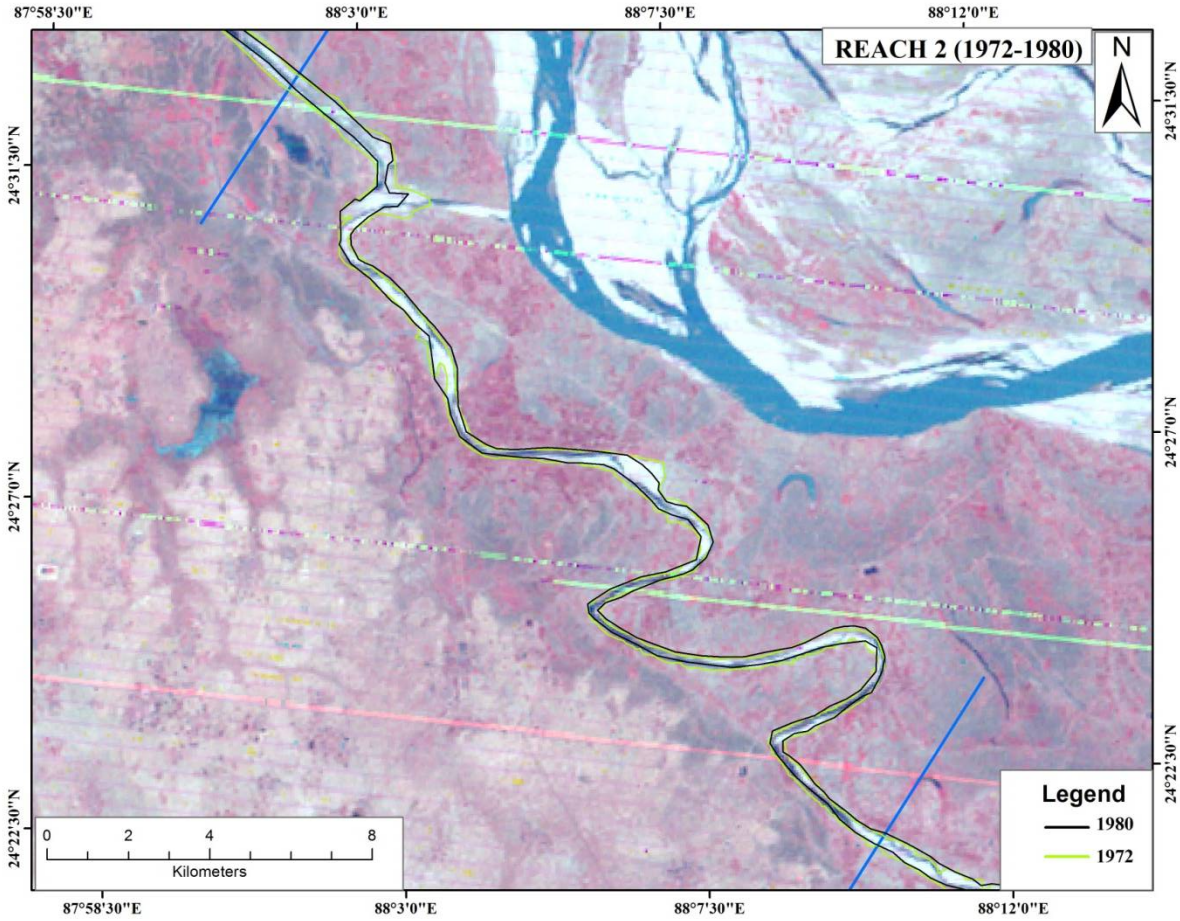


Figure 17.1: Changes in the course of Hooghly River of Year 1972-1980

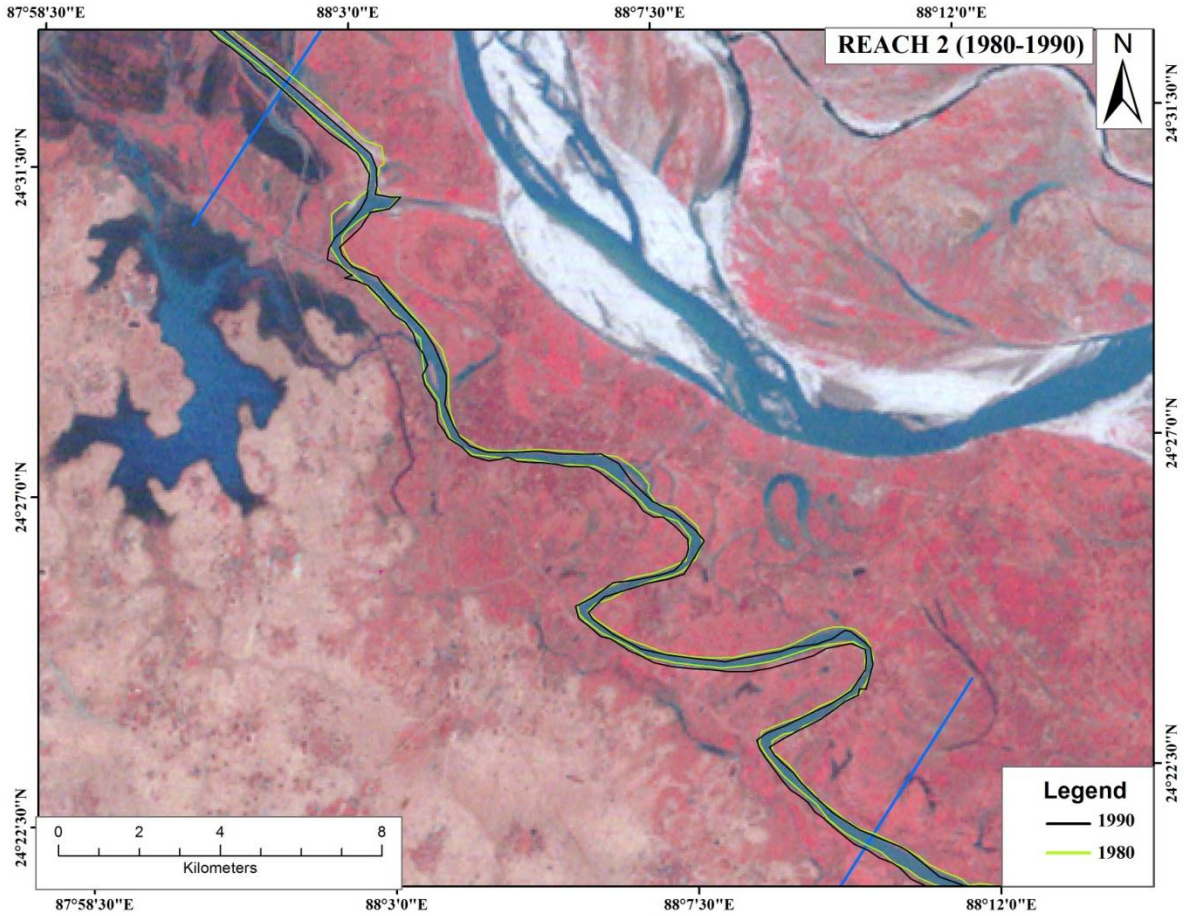


Figure 17.2: Changes in the course of Hooghly River of Year 1980-1990

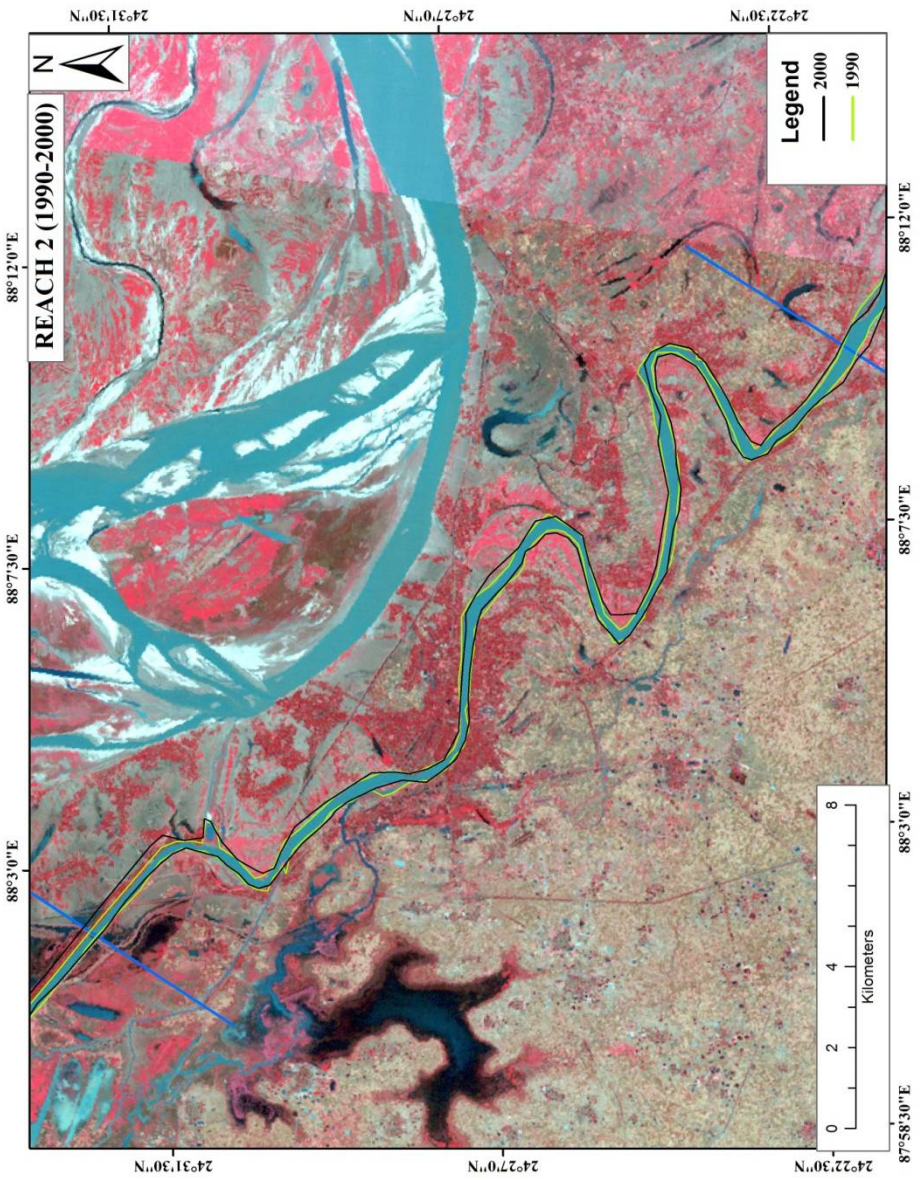


Figure 17.3: Changes in the course of Hooghly River of Year 1990-2000

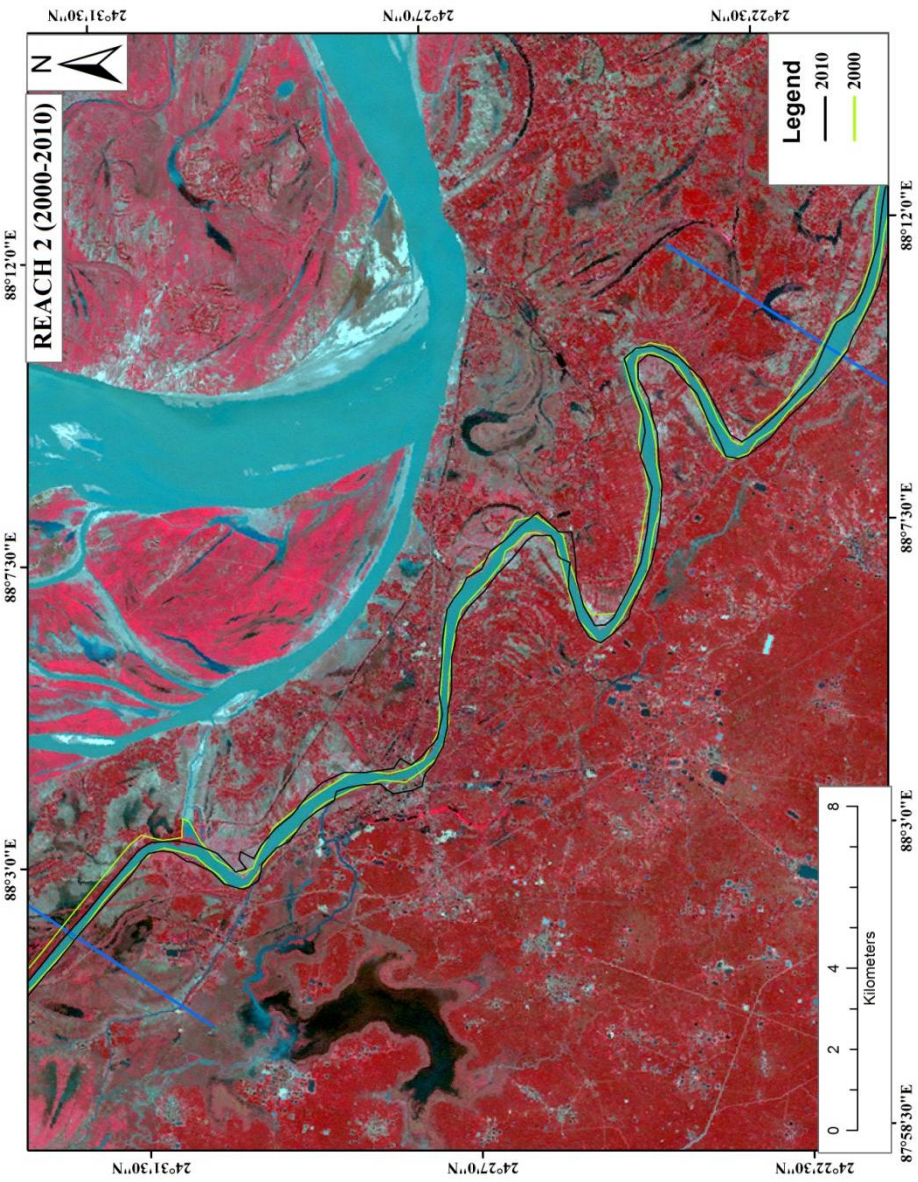


Figure 17.4: Changes in the course of Hooghly River of Year 2000-2010

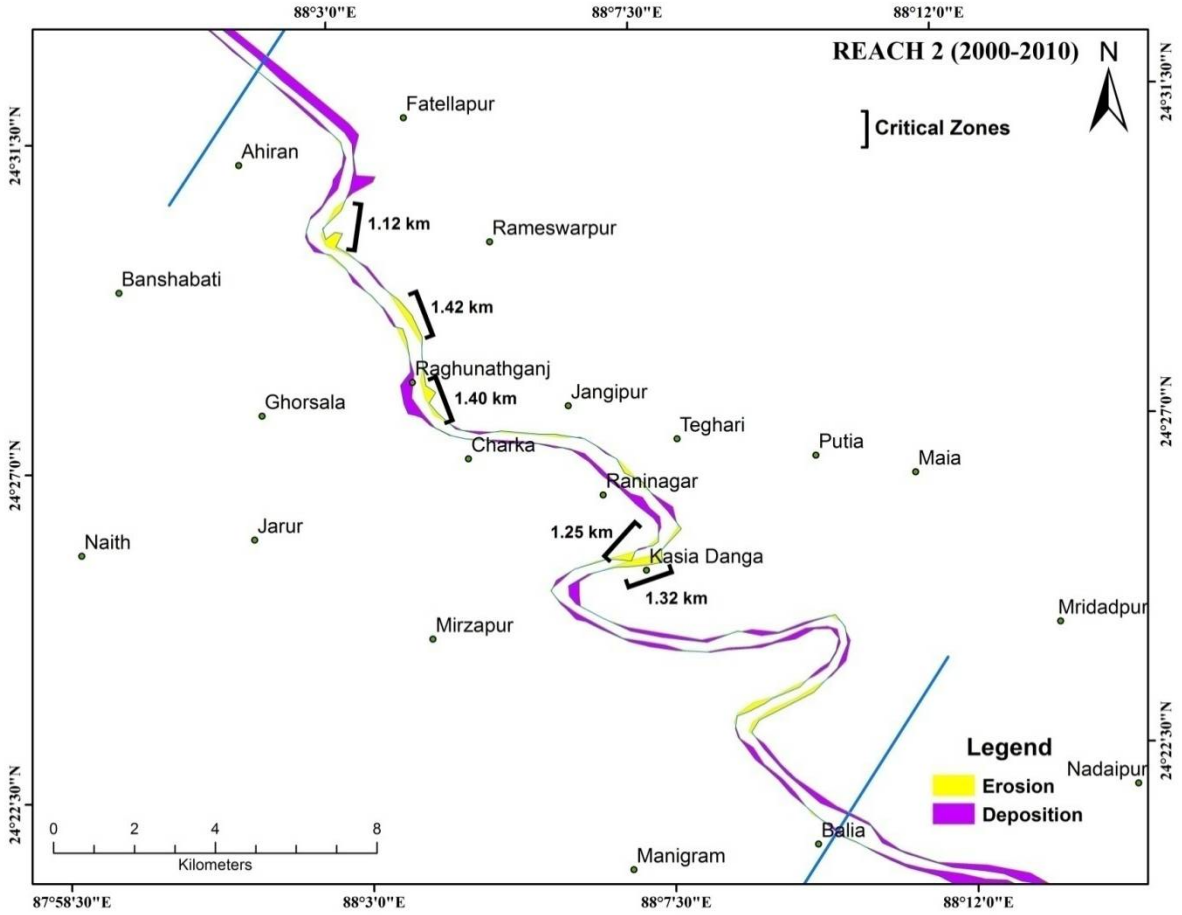


Figure 17.5: Identification of critical zones for Hooghly River of Year 2000-2010

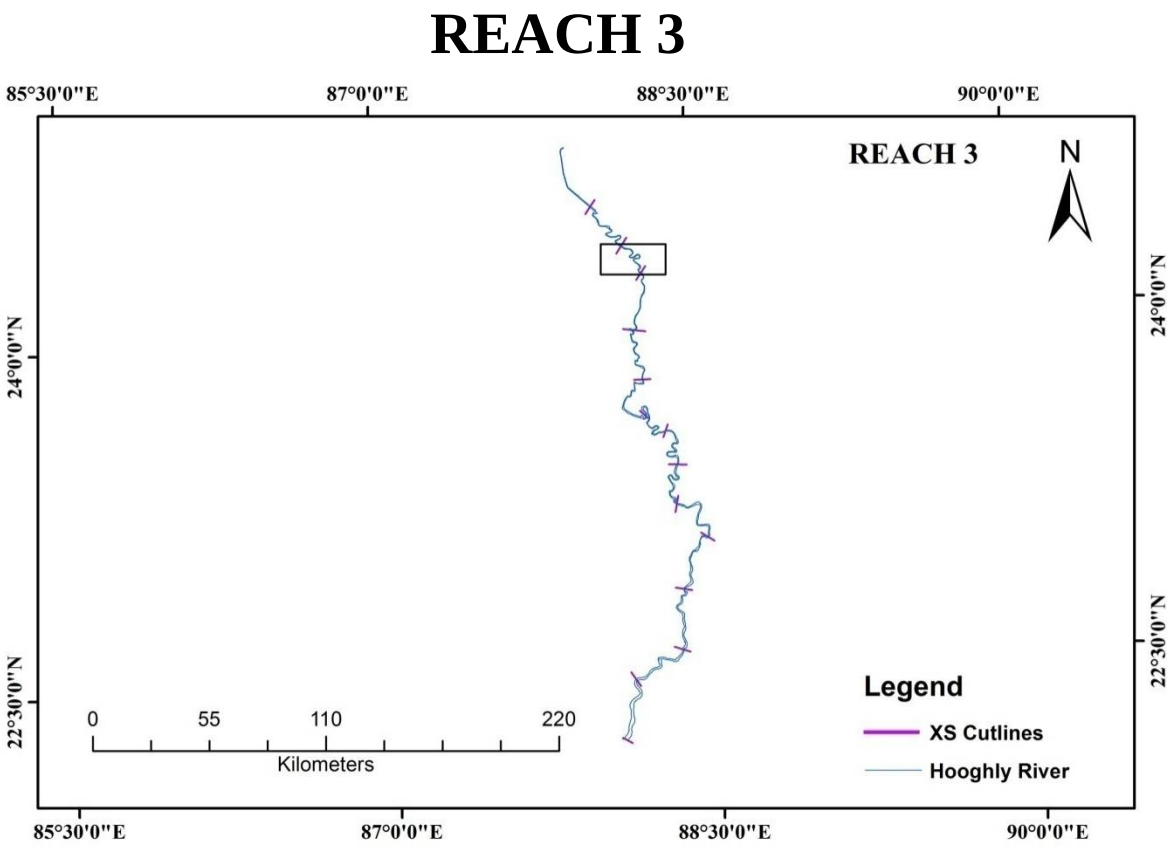


Figure 18: Location of reach number 3 in the Hooghly river

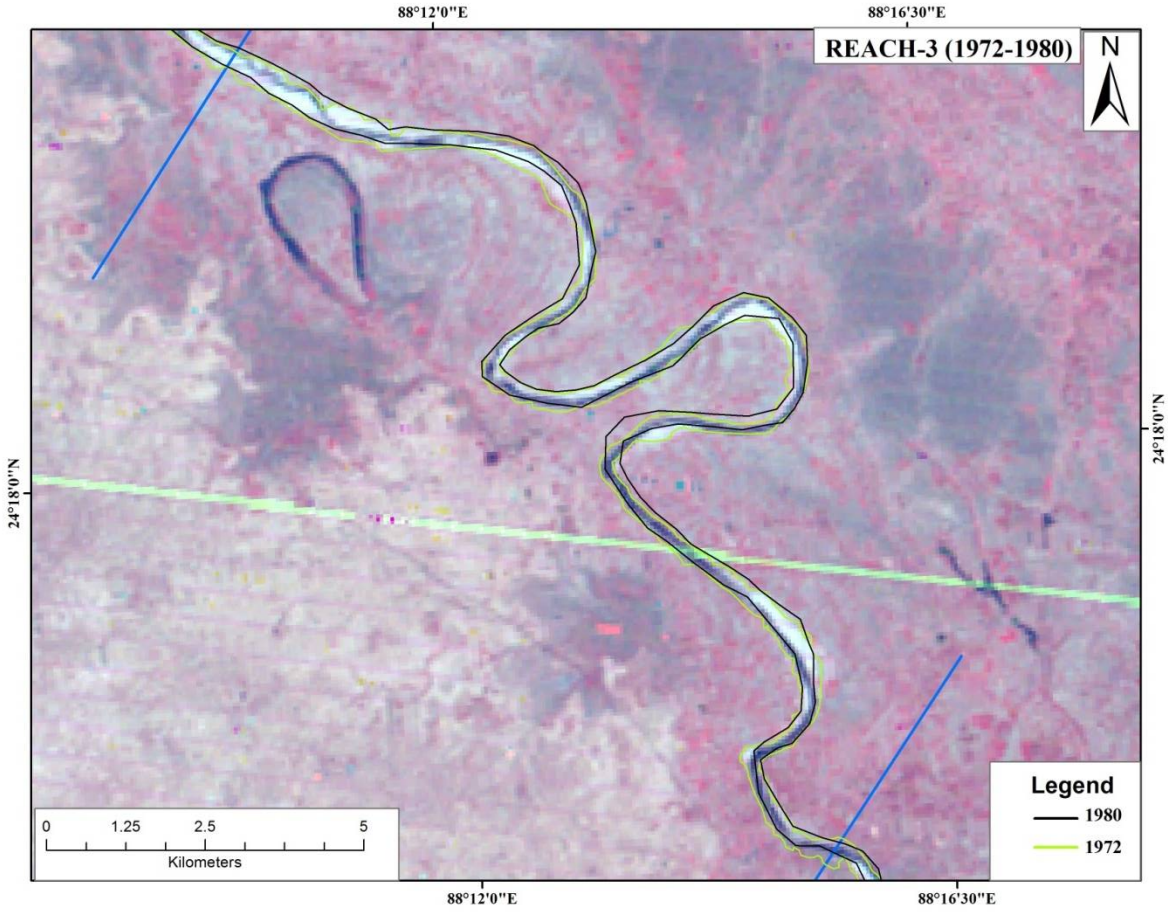


Figure 18.1: Changes in the course of Hooghly River of Year 1972-1980

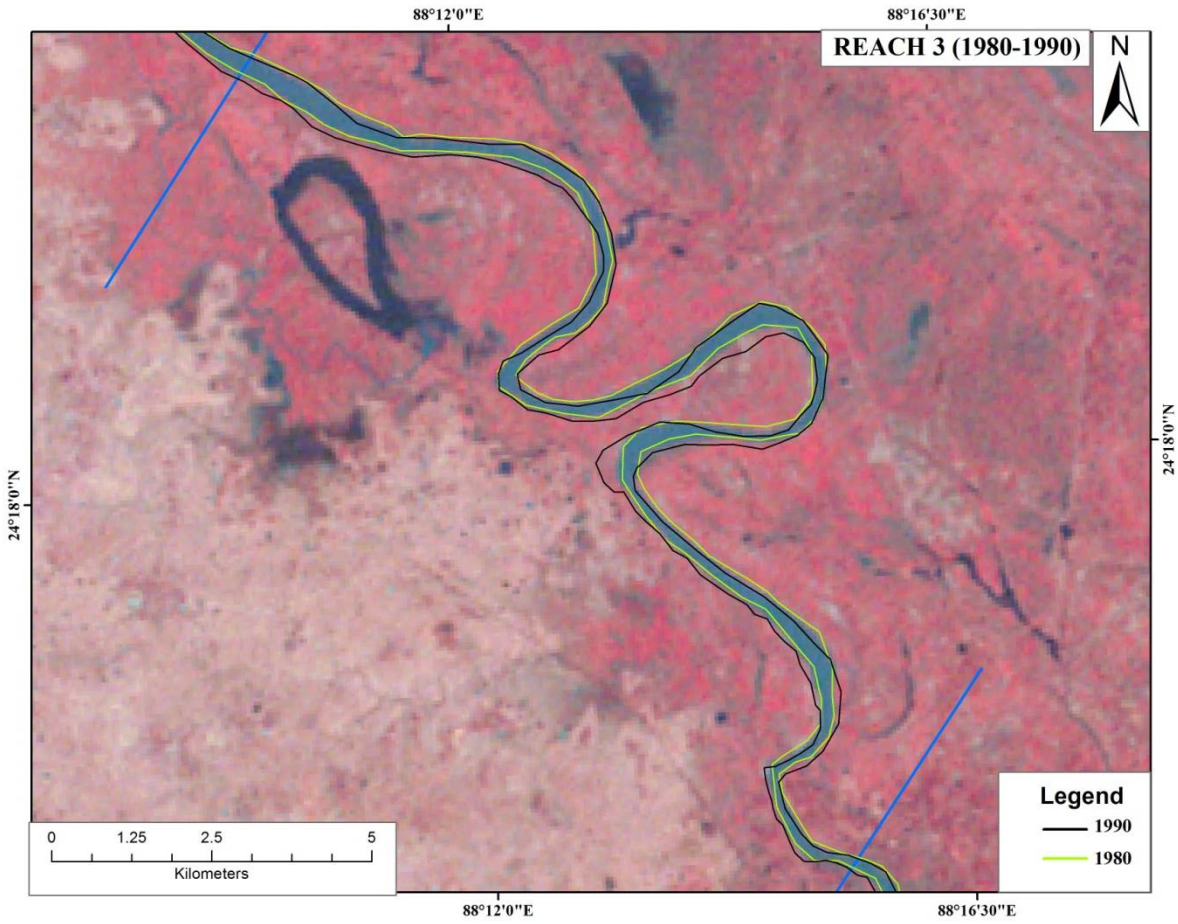


Figure 18.2: Changes in the course of Hooghly River of Year 1980-1990

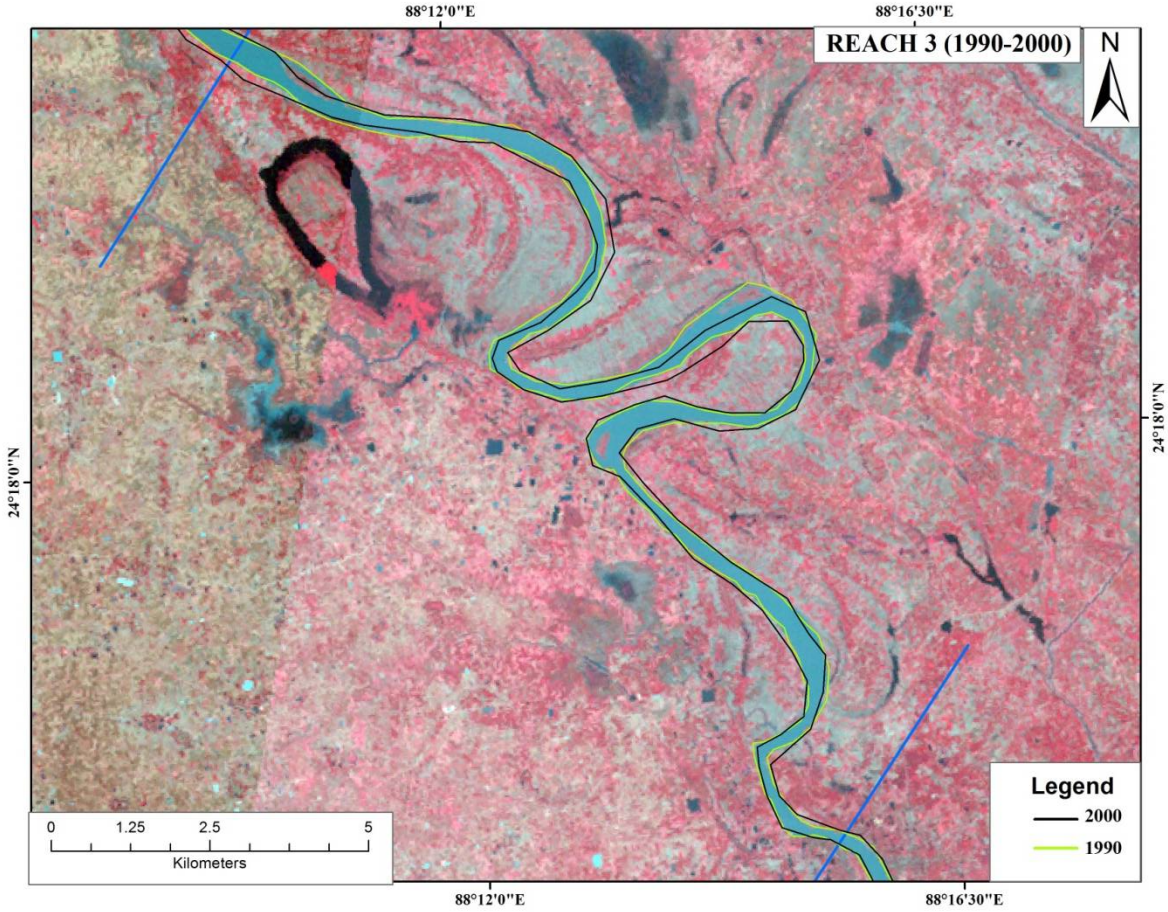


Figure 18.3: Changes in the course of Hooghly River of Year 1990-2000

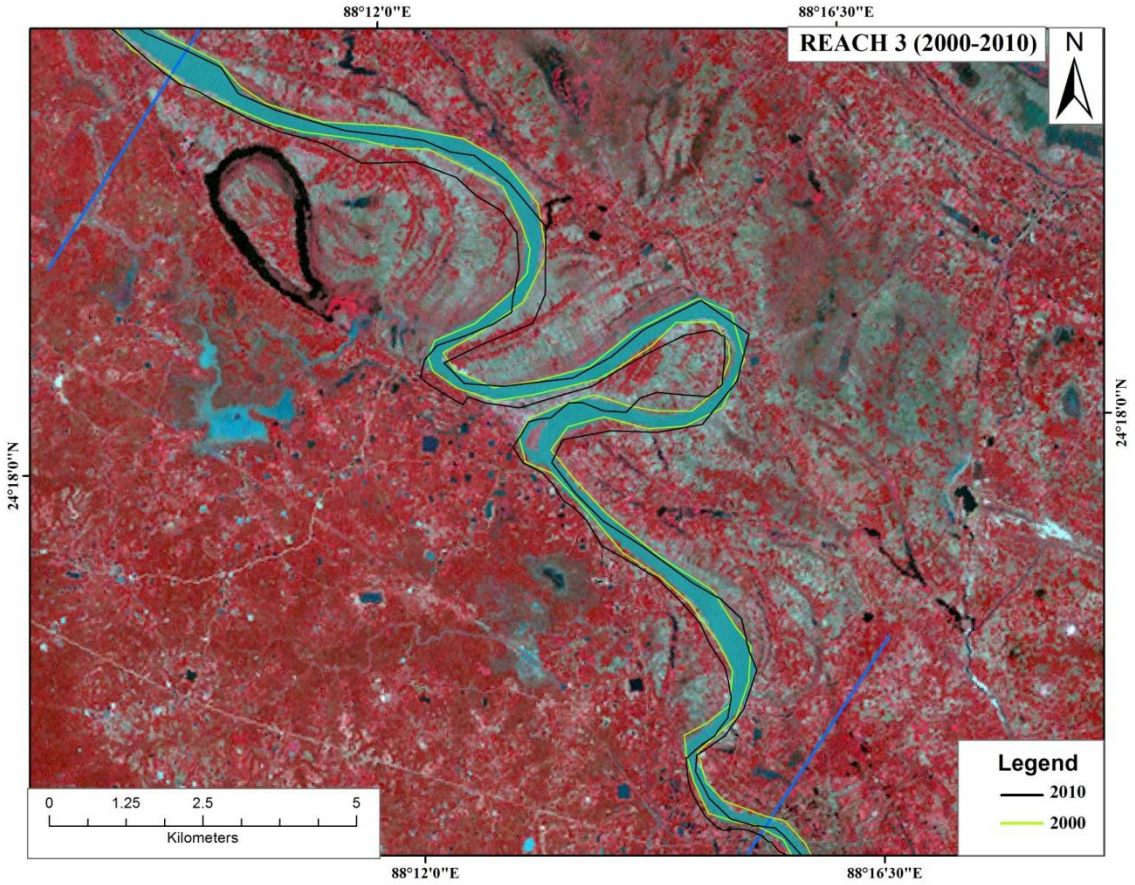


Figure 18.4: Changes in the course of Hooghly River of Year 2000-2010

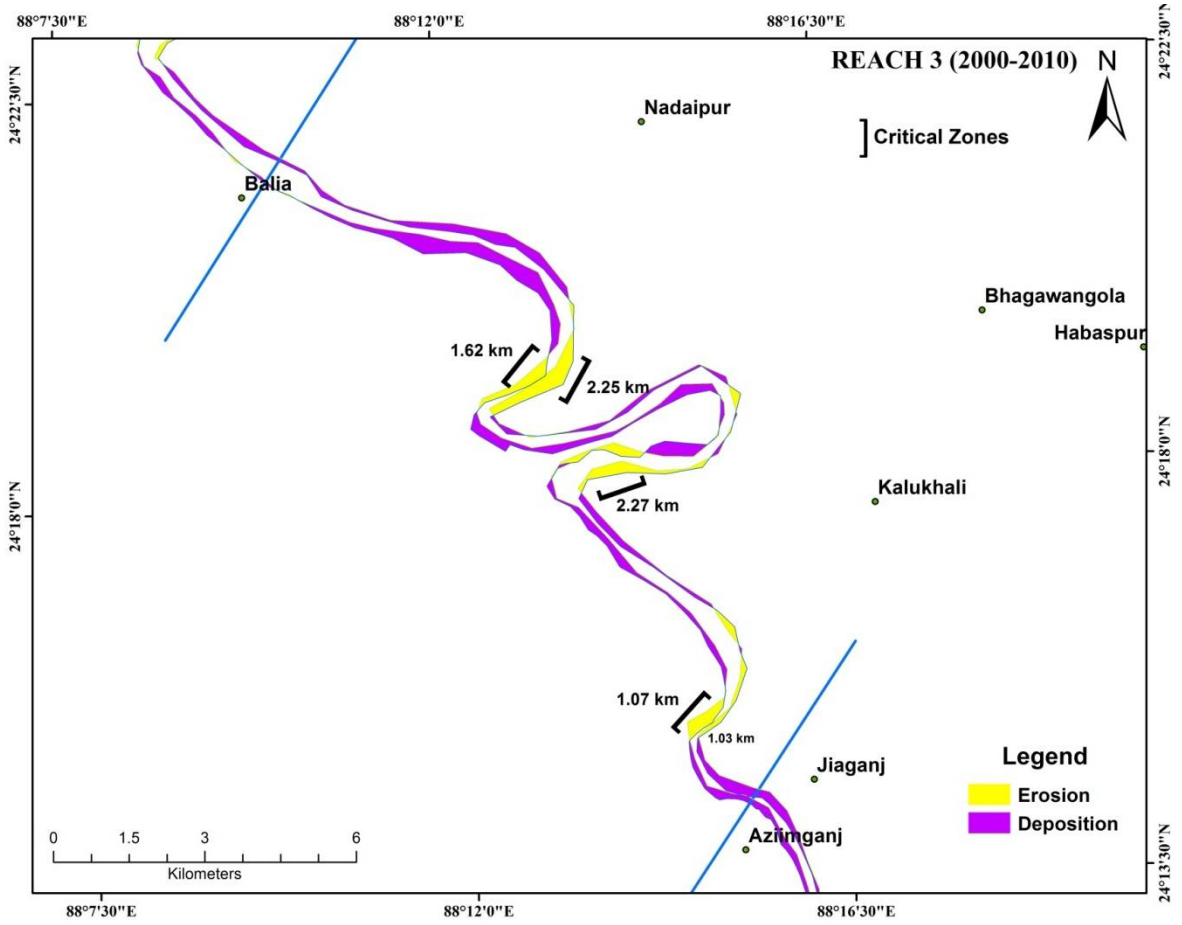


Figure 18.5: Identification of critical zones for Hooghly River of Year 2000-2010

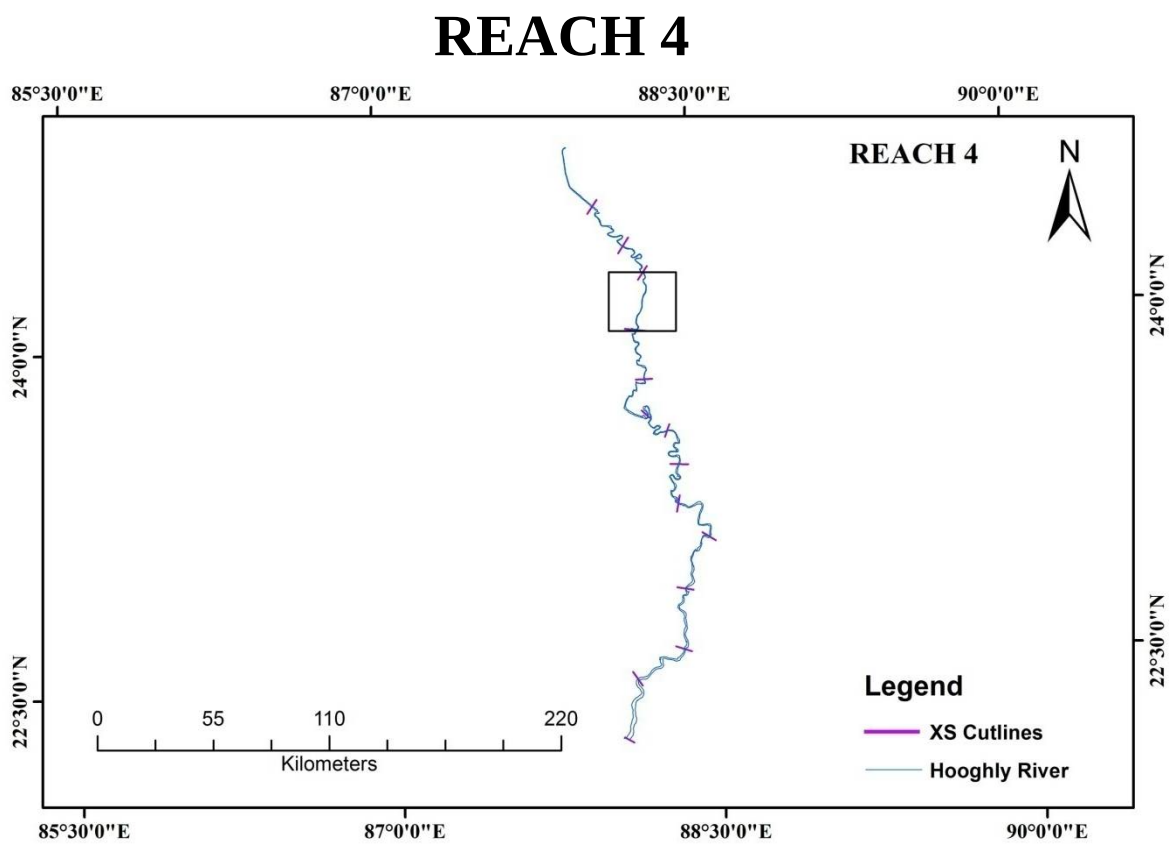


Figure 19: Location of reach number 4 in the Hooghly river

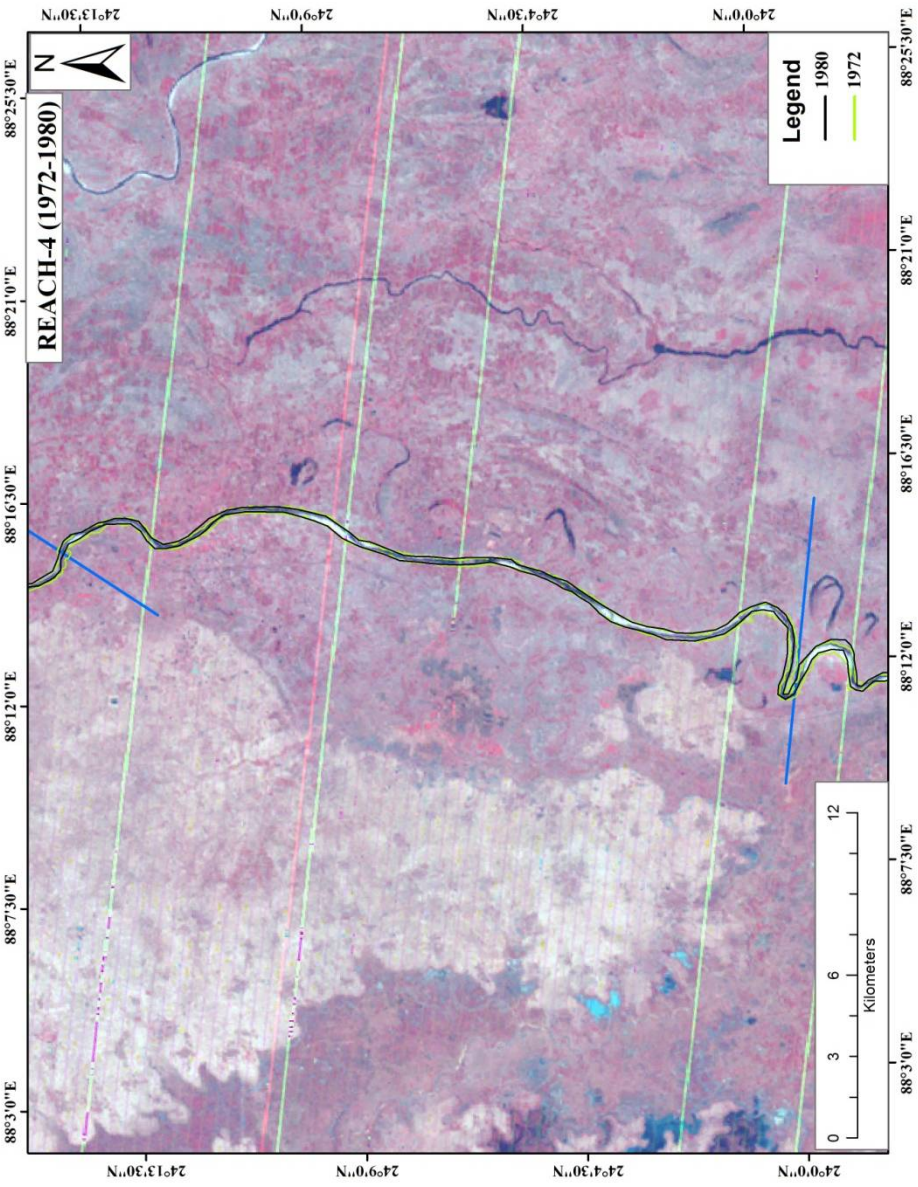


Figure 19.1: Changes in the course of Hooghly River of Year 1972-1980

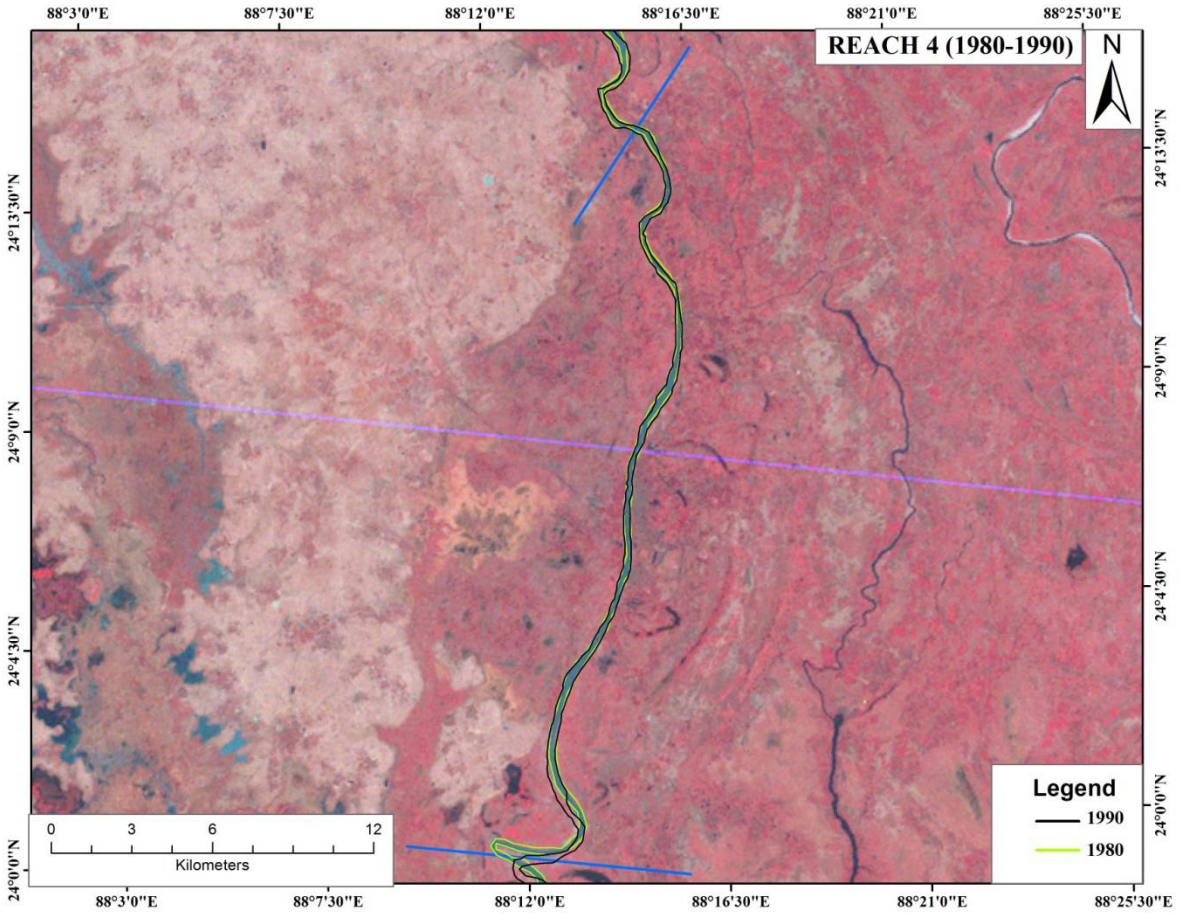


Figure 19.2: Changes in the course of Hooghly River of Year 1980-1990

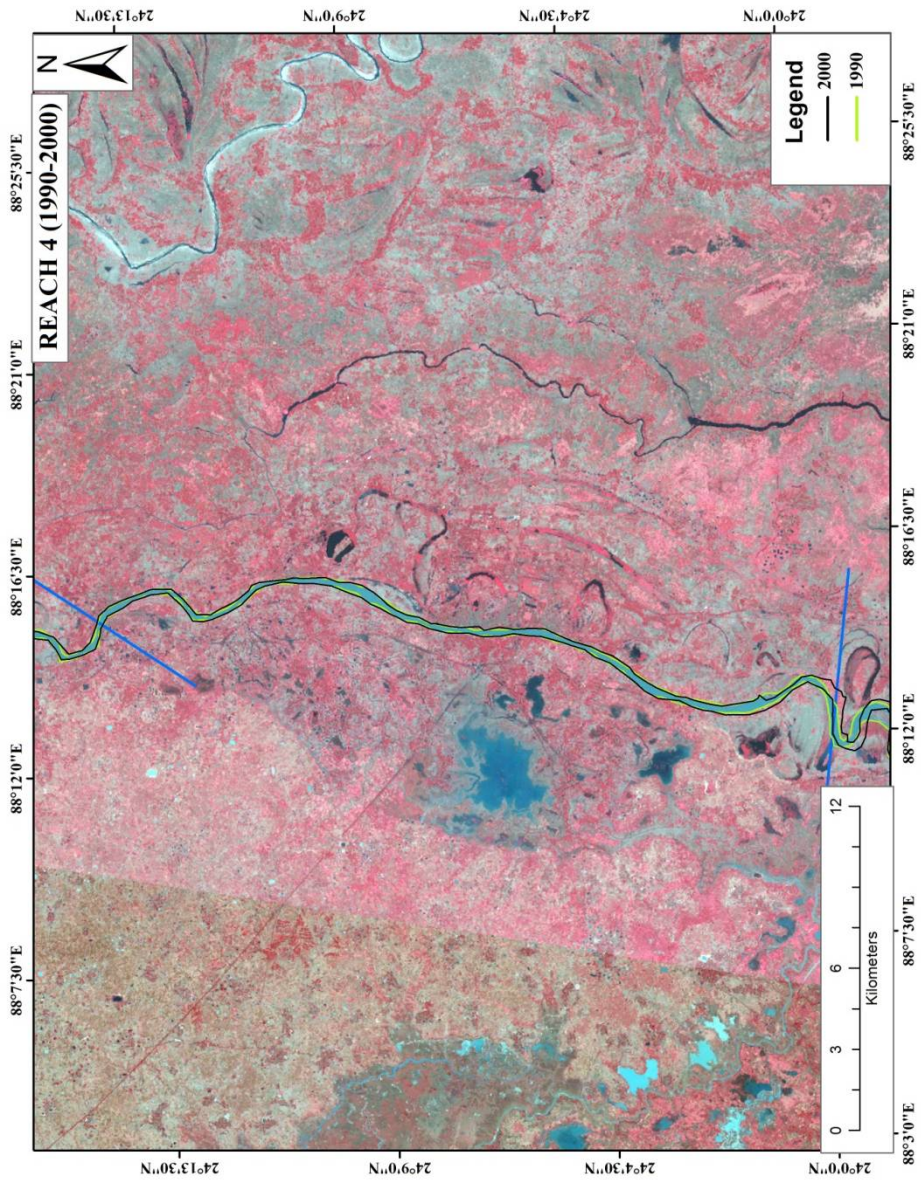


Figure 19.3: Changes in the course of Hooghly River of Year 1990-2000

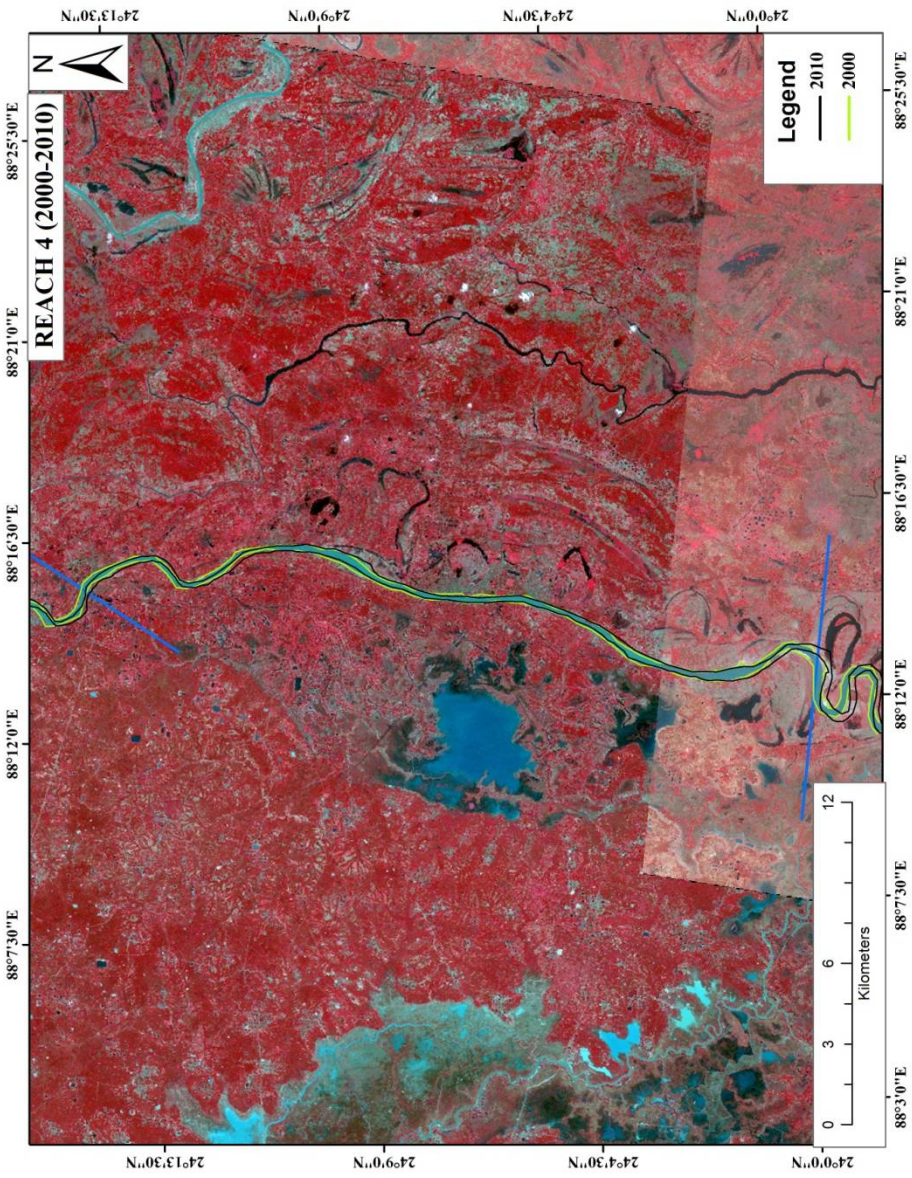


Figure 19.4: Changes in the course of Hooghly River of Year 2000-2010

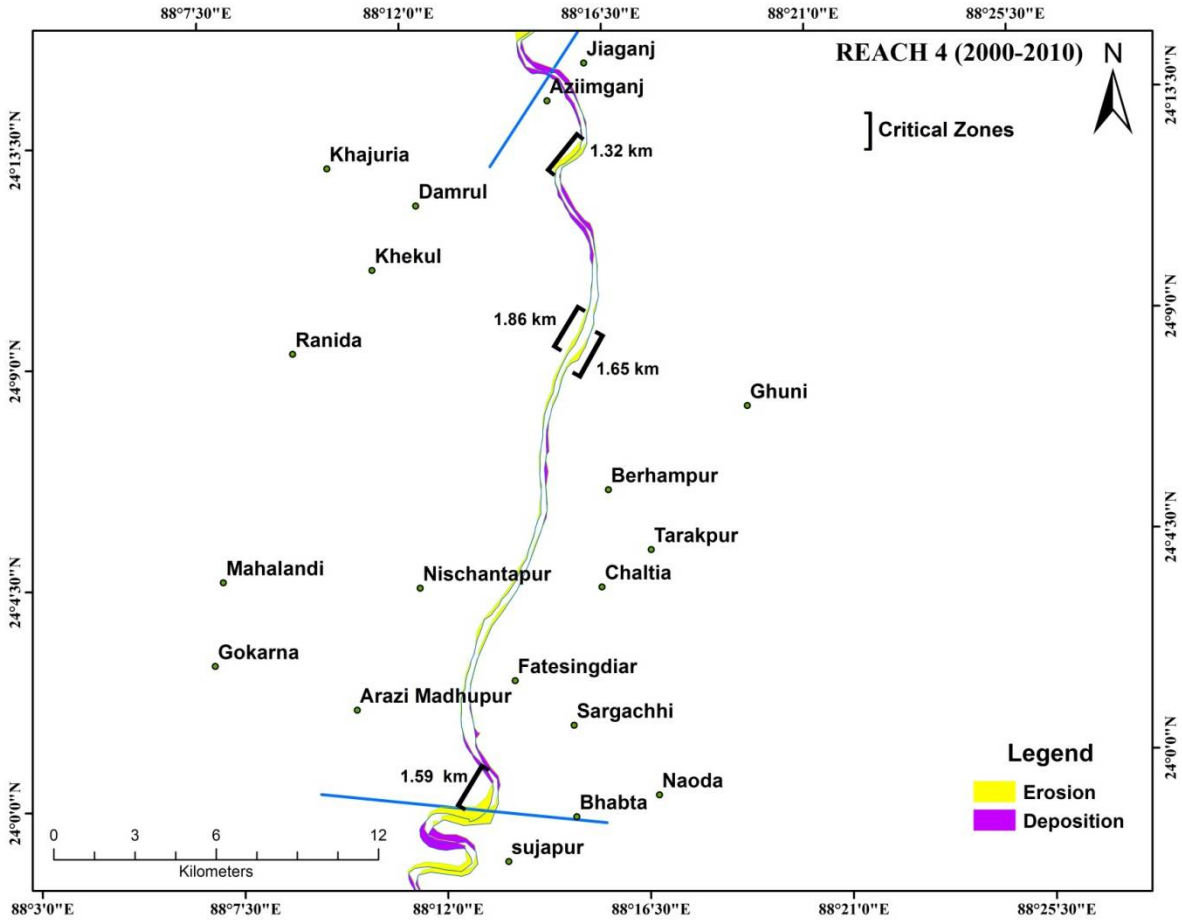


Figure 19.5: Identification of critical zones for Hooghly River of Year 2000-2010

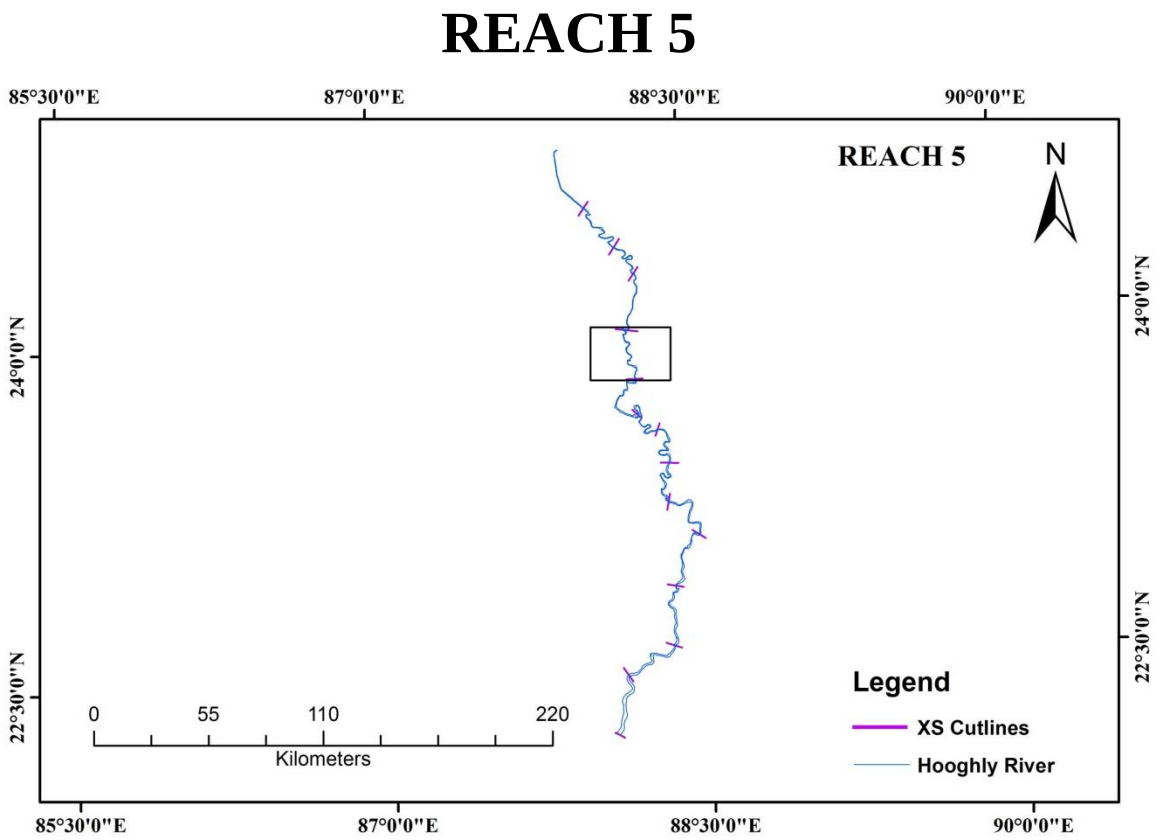


Figure 20: Location of reach number 5 in the Hooghly river

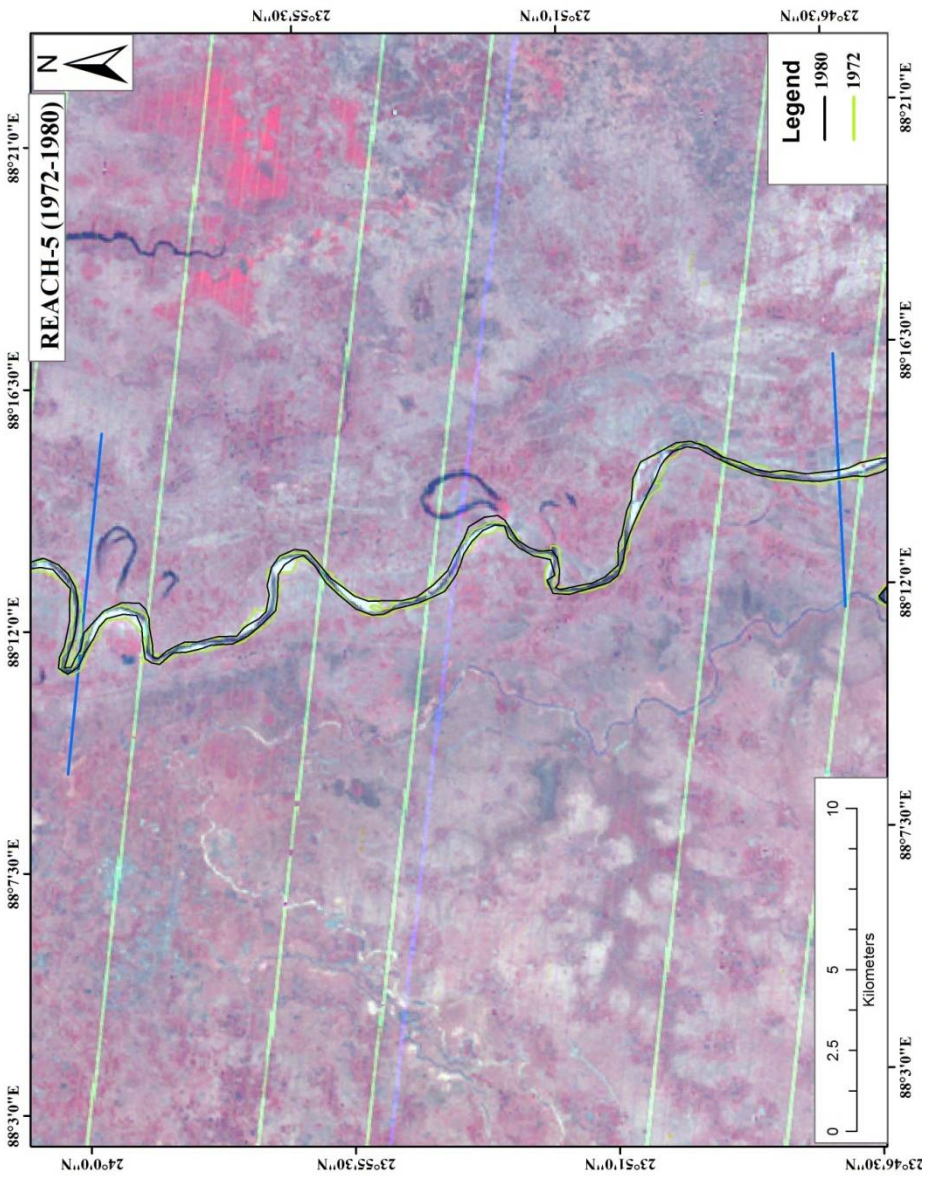


Figure 20.1: Changes in the course of Hooghly River of Year 1972-1980

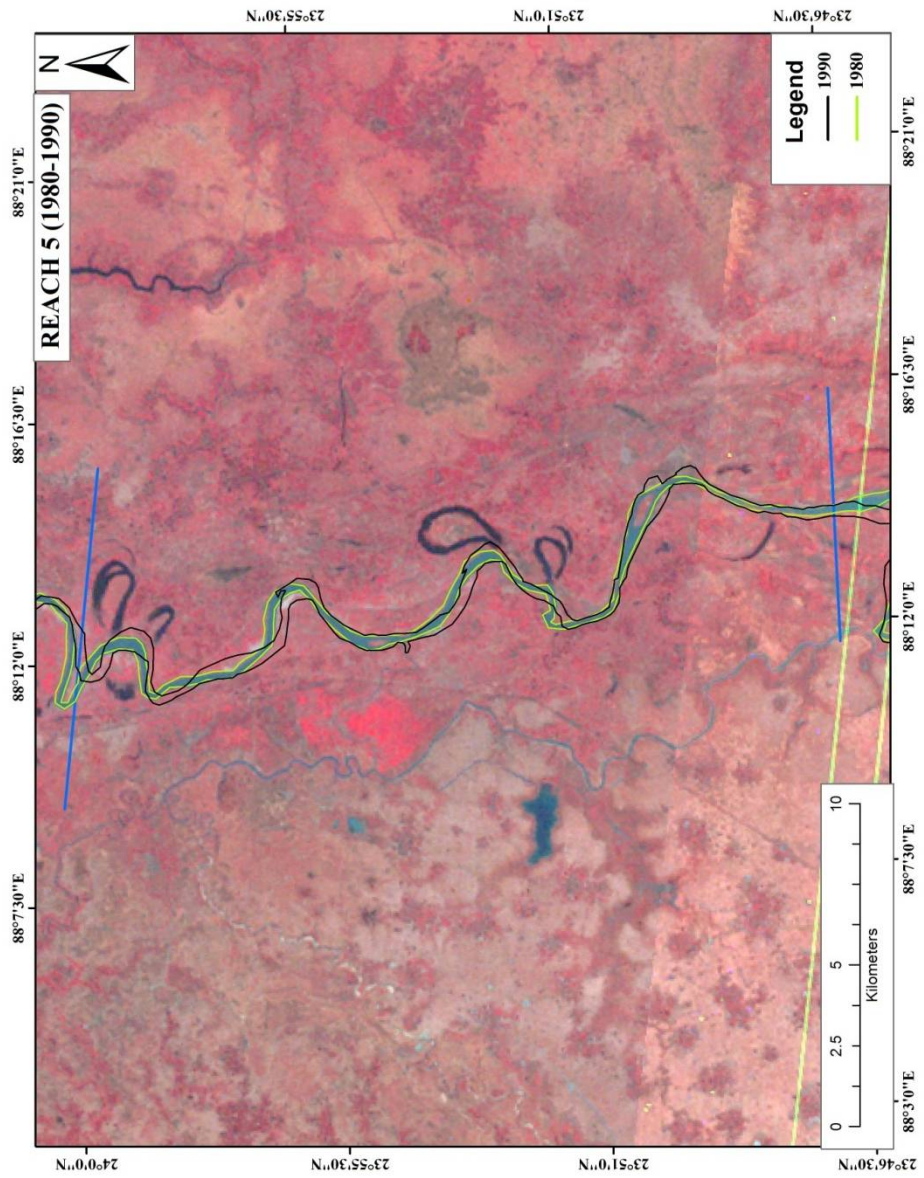


Figure 20.2: Changes in the course of Hooghly River of Year 1980-1990

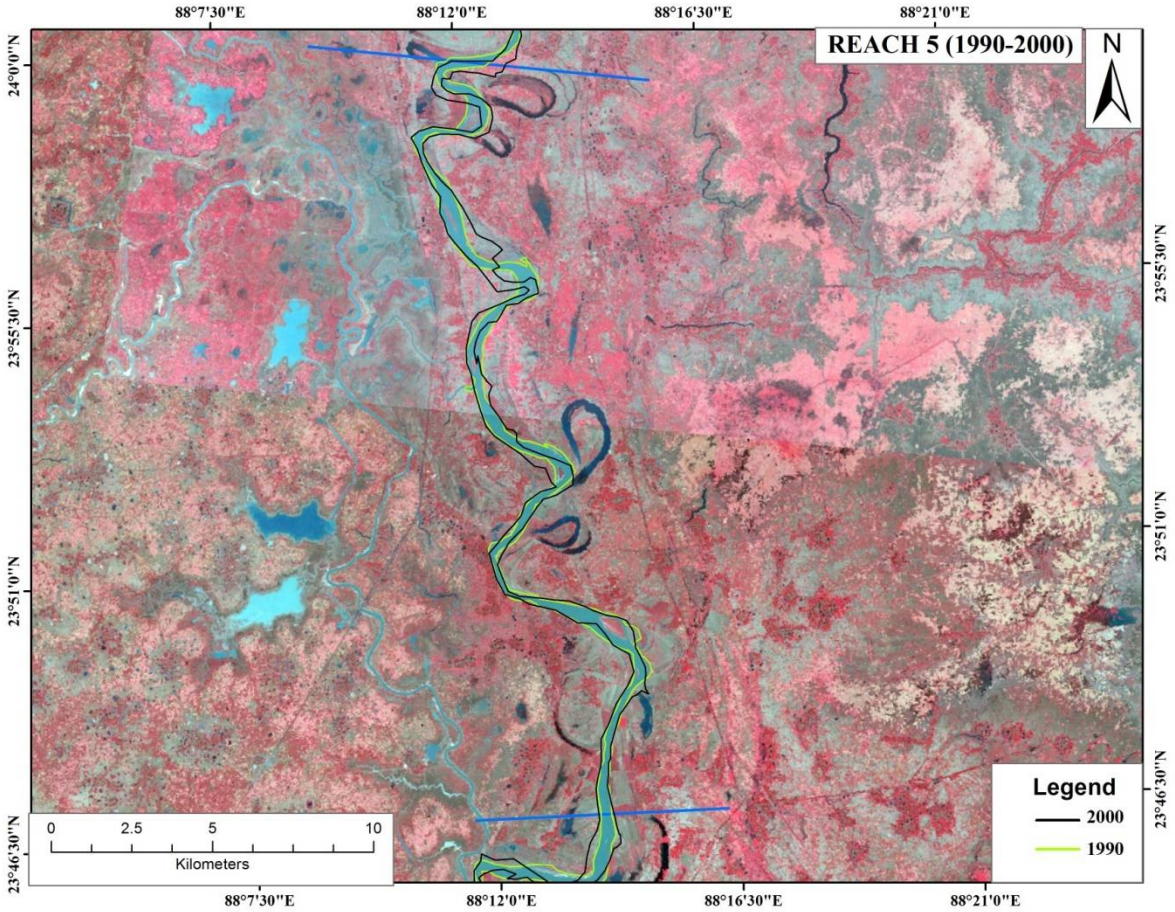


Figure 20.3: Changes in the course of Hooghly River of Year 1990-2000

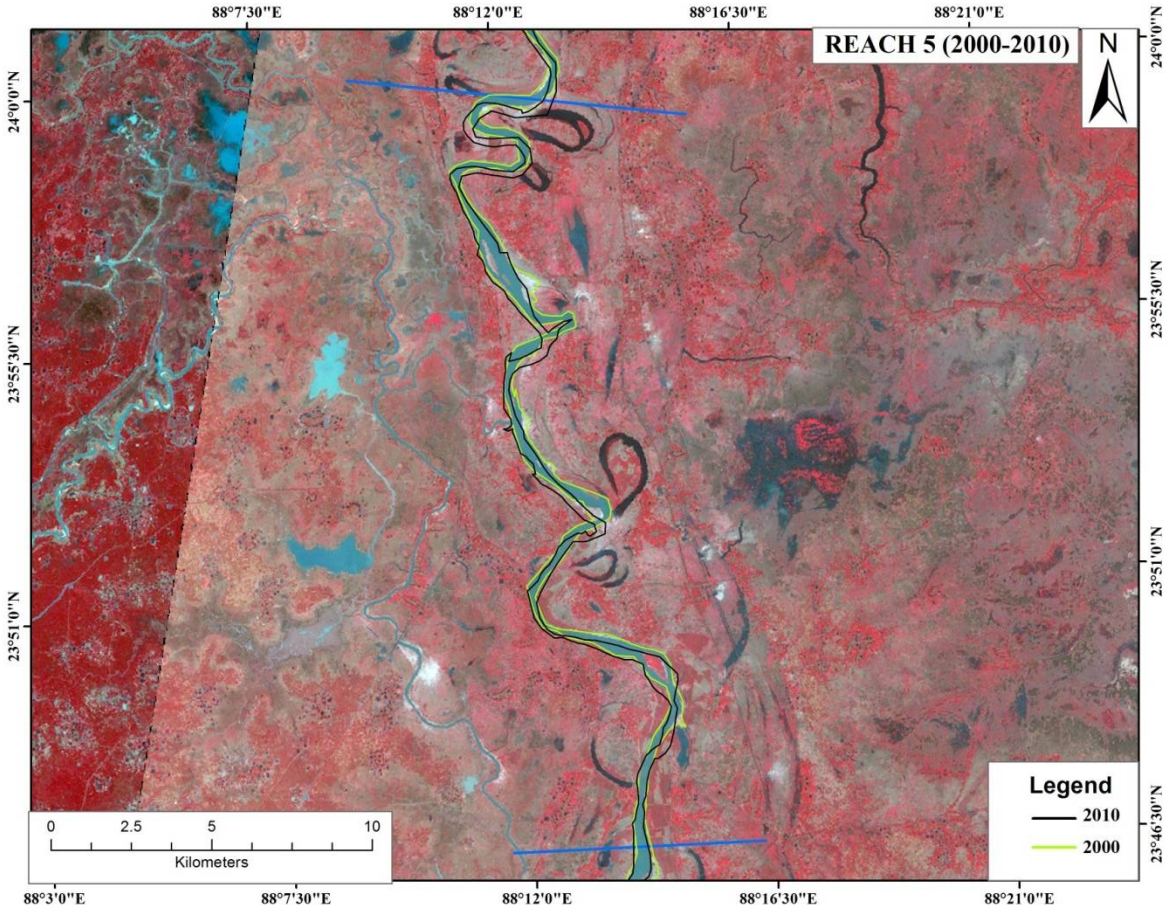


Figure 20.4: Changes in the course of Hooghly River of Year 2000-2010

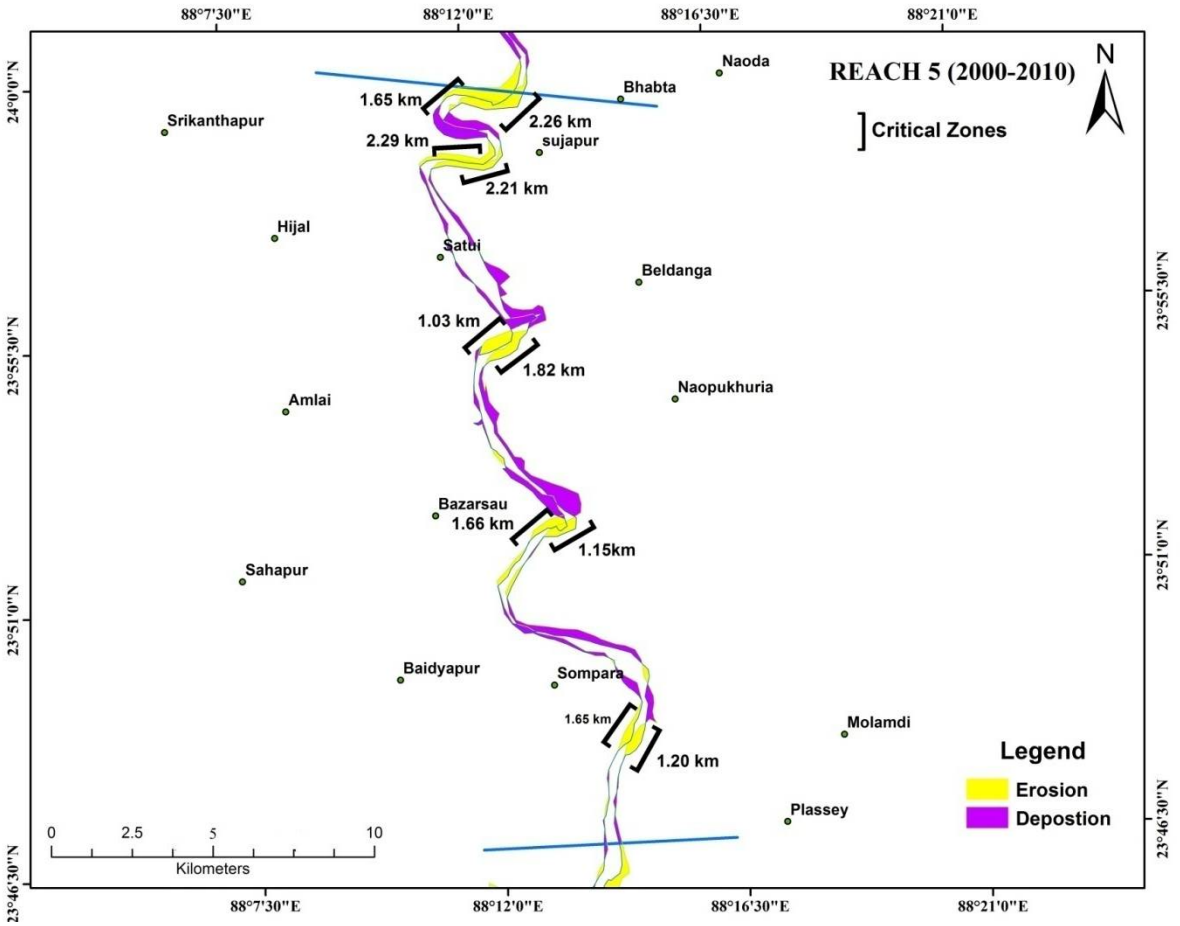


Figure 20.5: Identification of critical zones for Hooghly River of Year 2000-2010

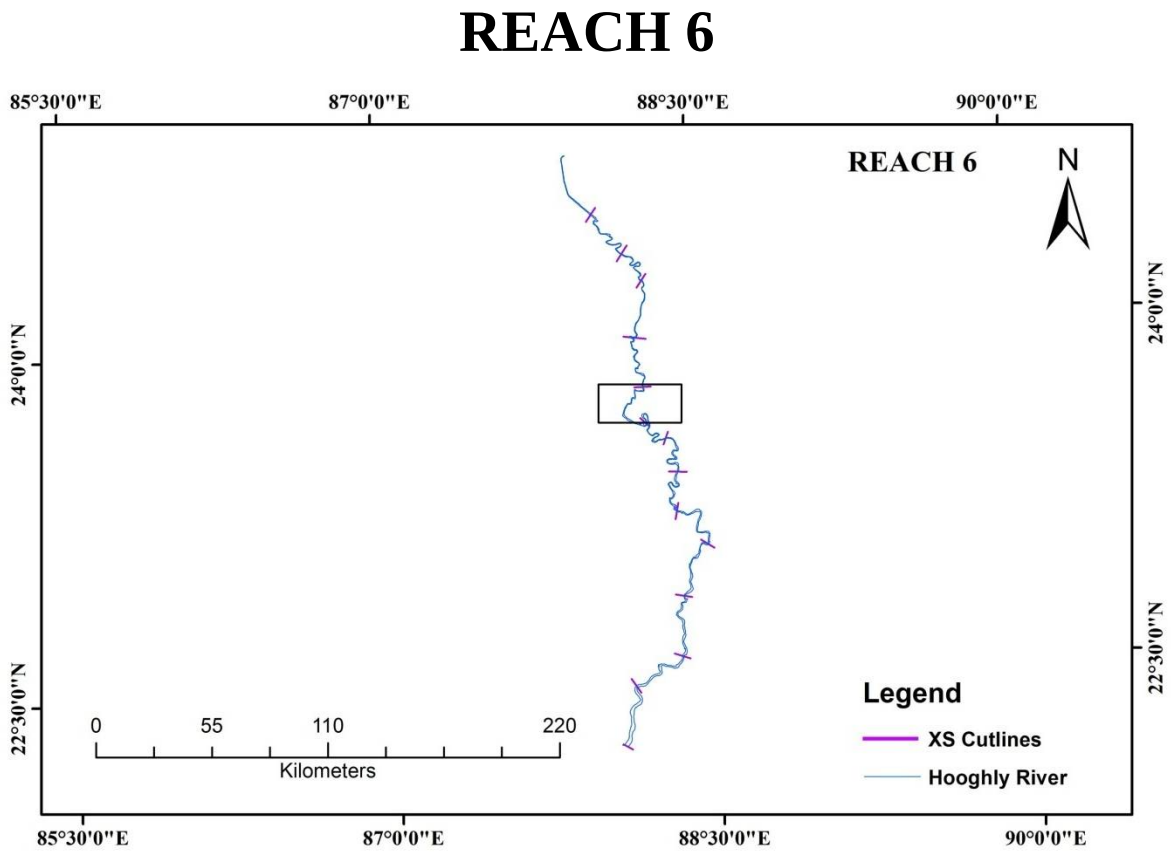


Figure 21: Location of reach number 6 in the Hooghly river

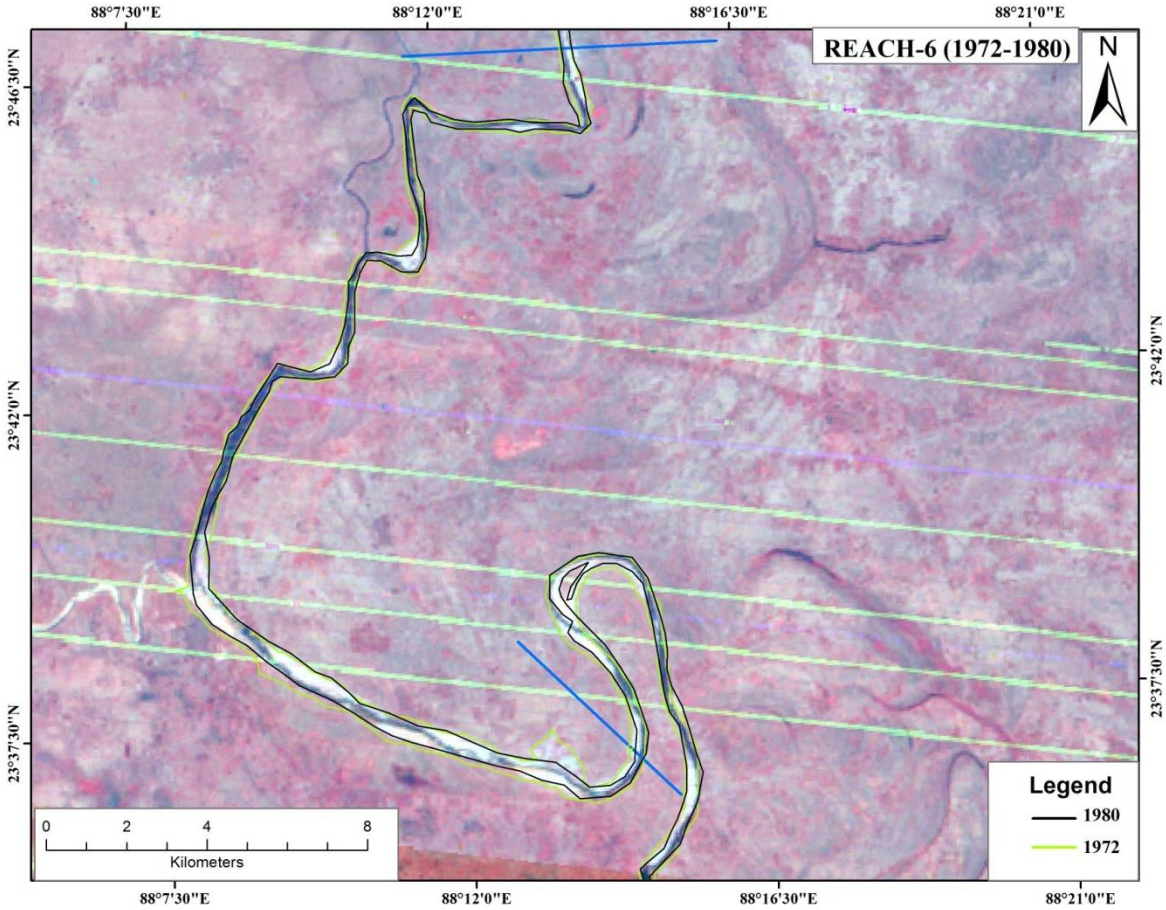


Figure 21.1: Changes in the course of Hooghly River of Year 1972-1980

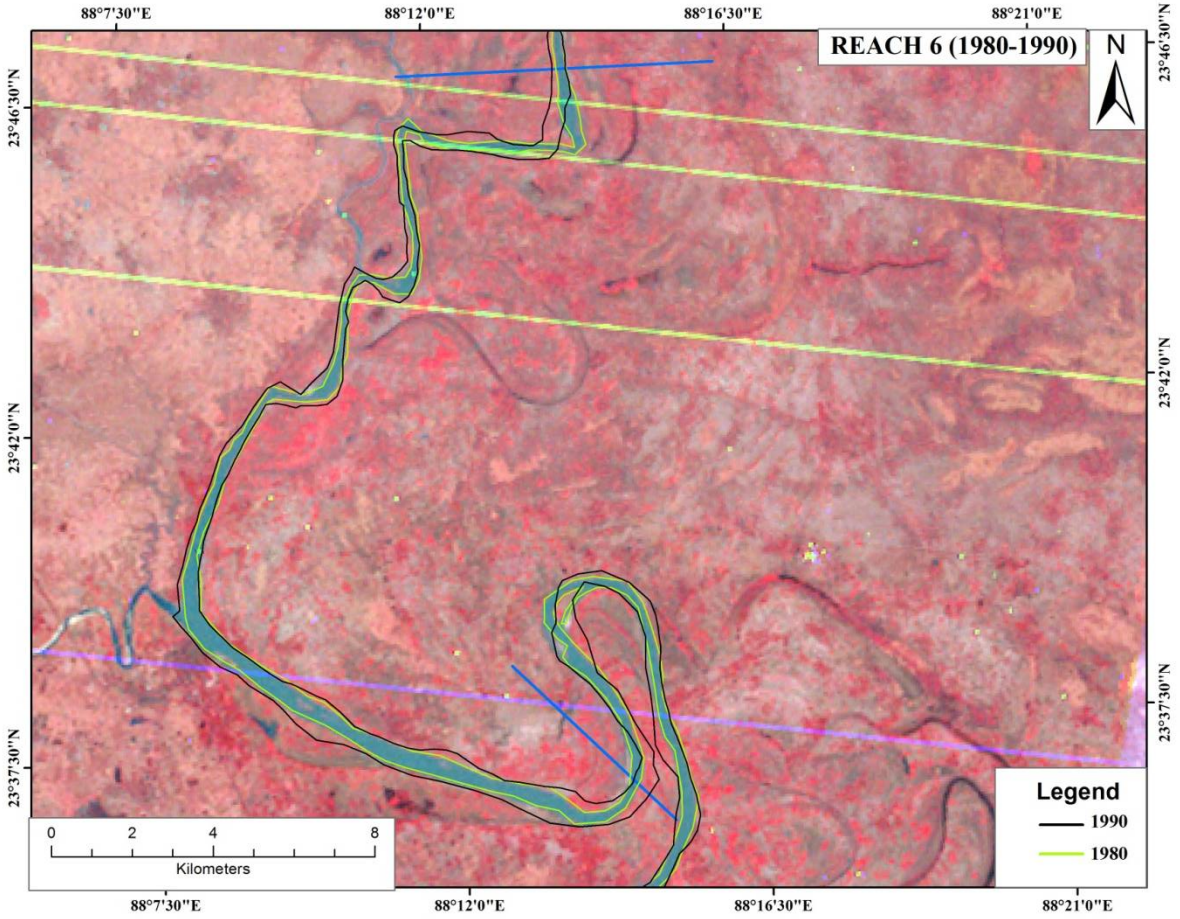


Figure 21.2: Changes in the course of Hooghly River of Year 1980-1990

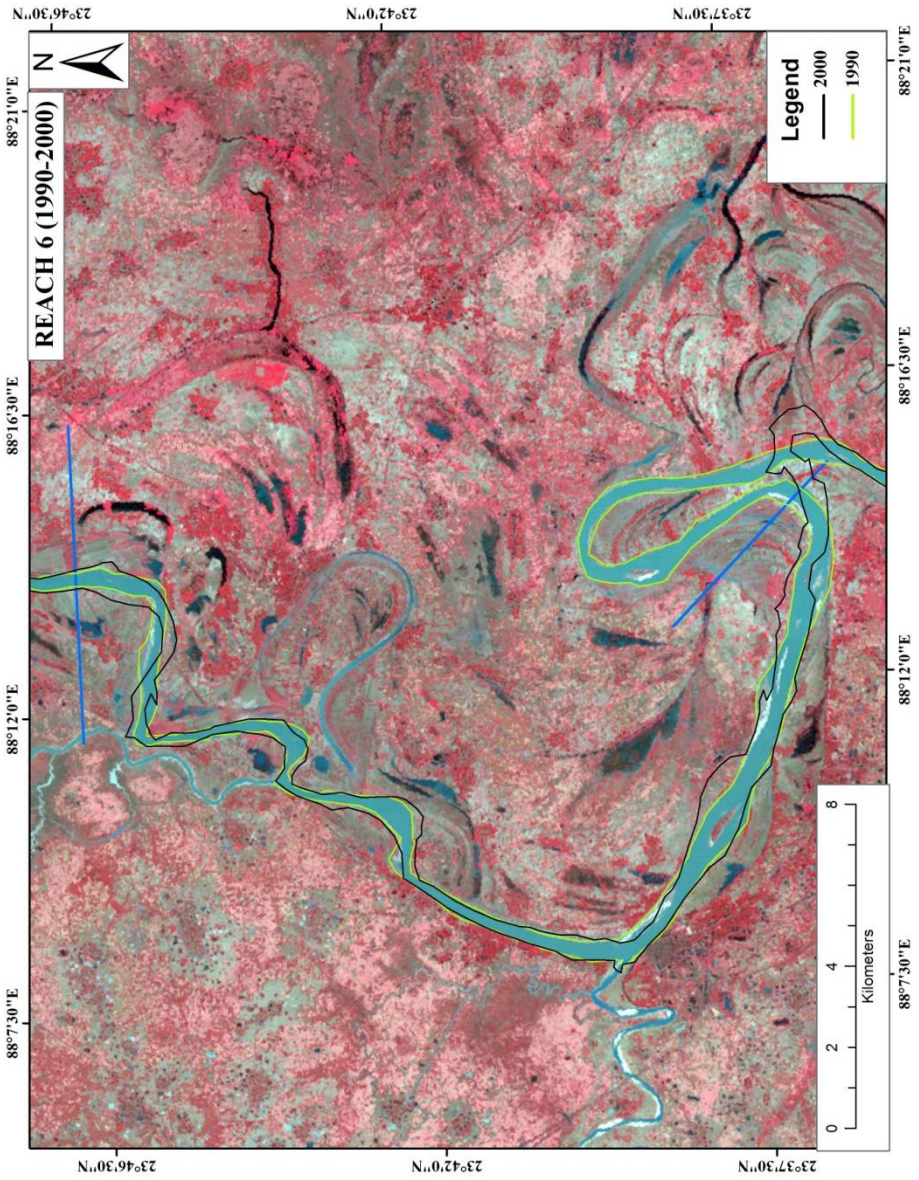


Figure 21.3: Changes in the course of Hooghly River of Year 1990-2000

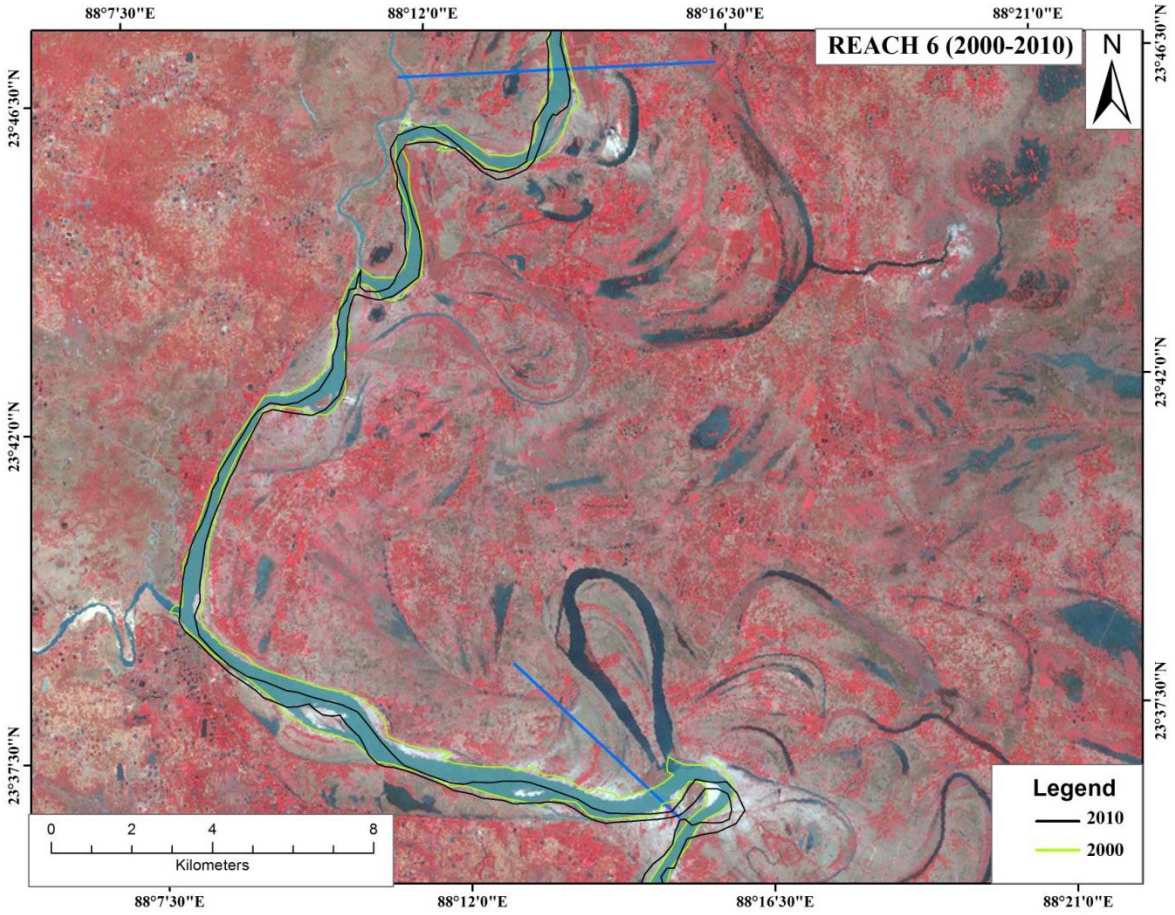


Figure 21.4: Changes in the course of Hooghly River of Year 2000-2010

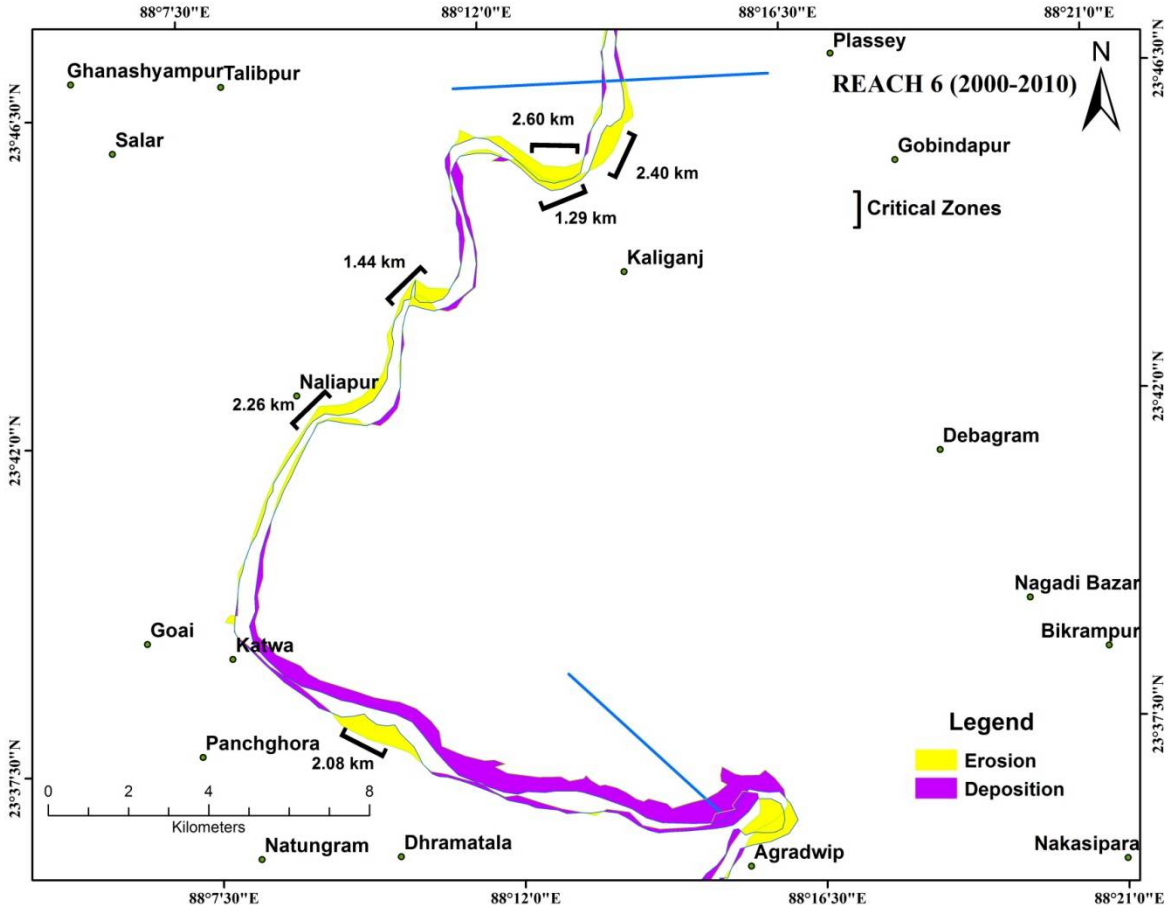


Figure 21.5: Identification of critical zones for Hooghly River of Year 2000-2010

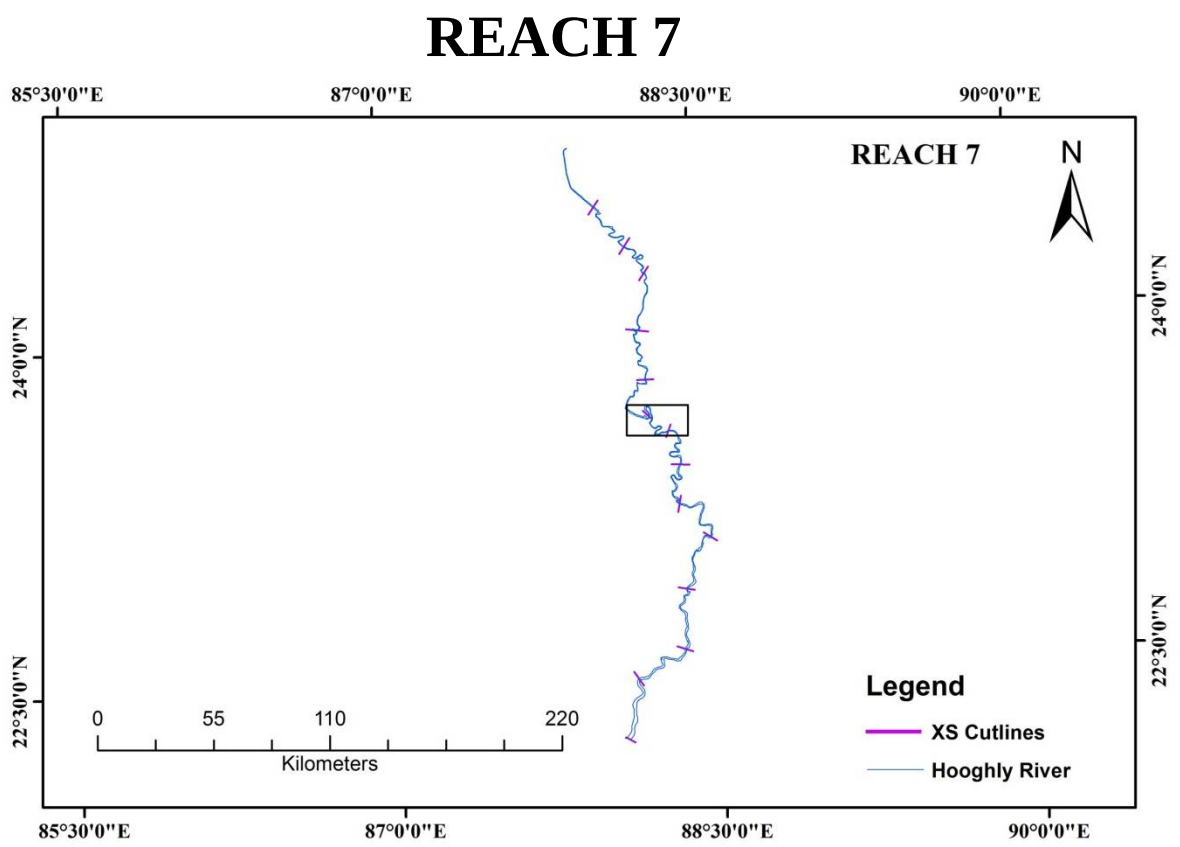


Figure 22: Location of reach number 7 in the Hooghly river

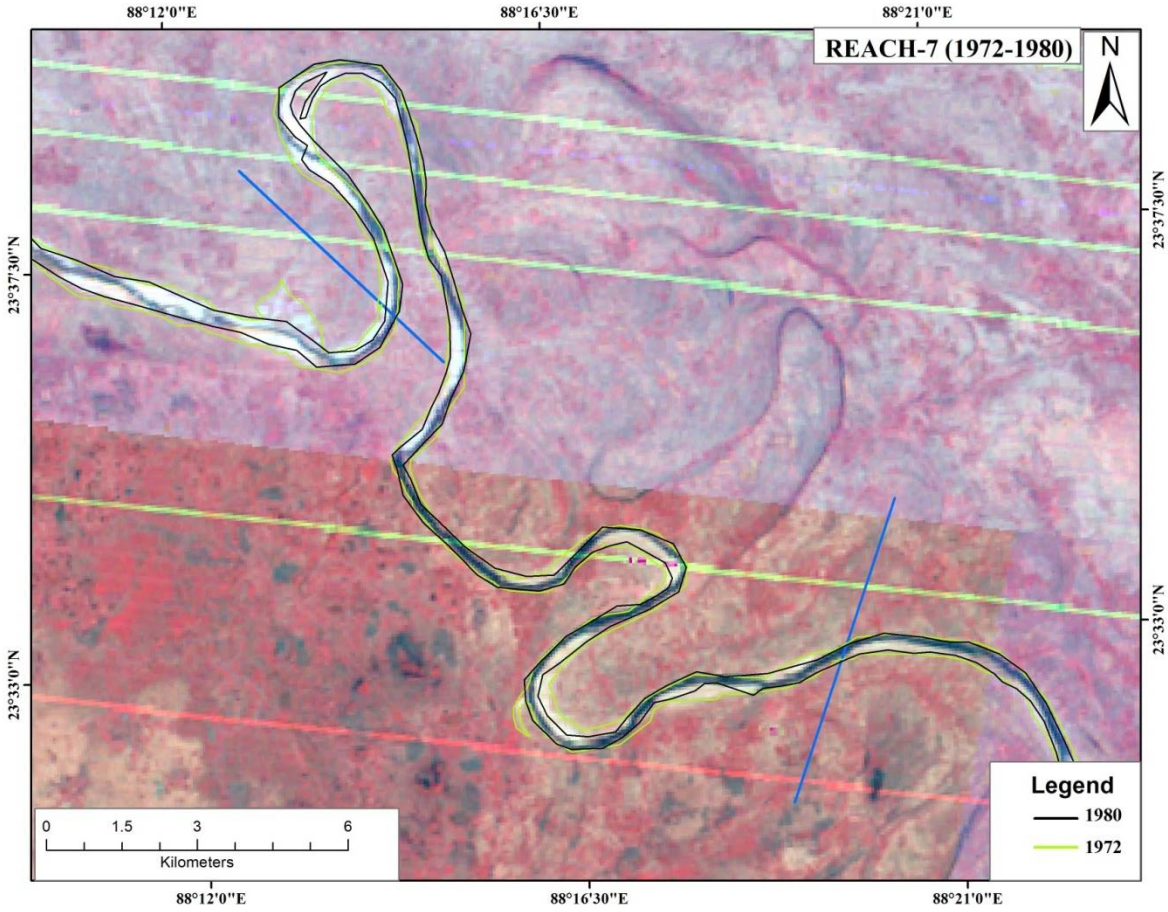


Figure 22.1: Changes in the course of Hooghly River of Year 1972-1980

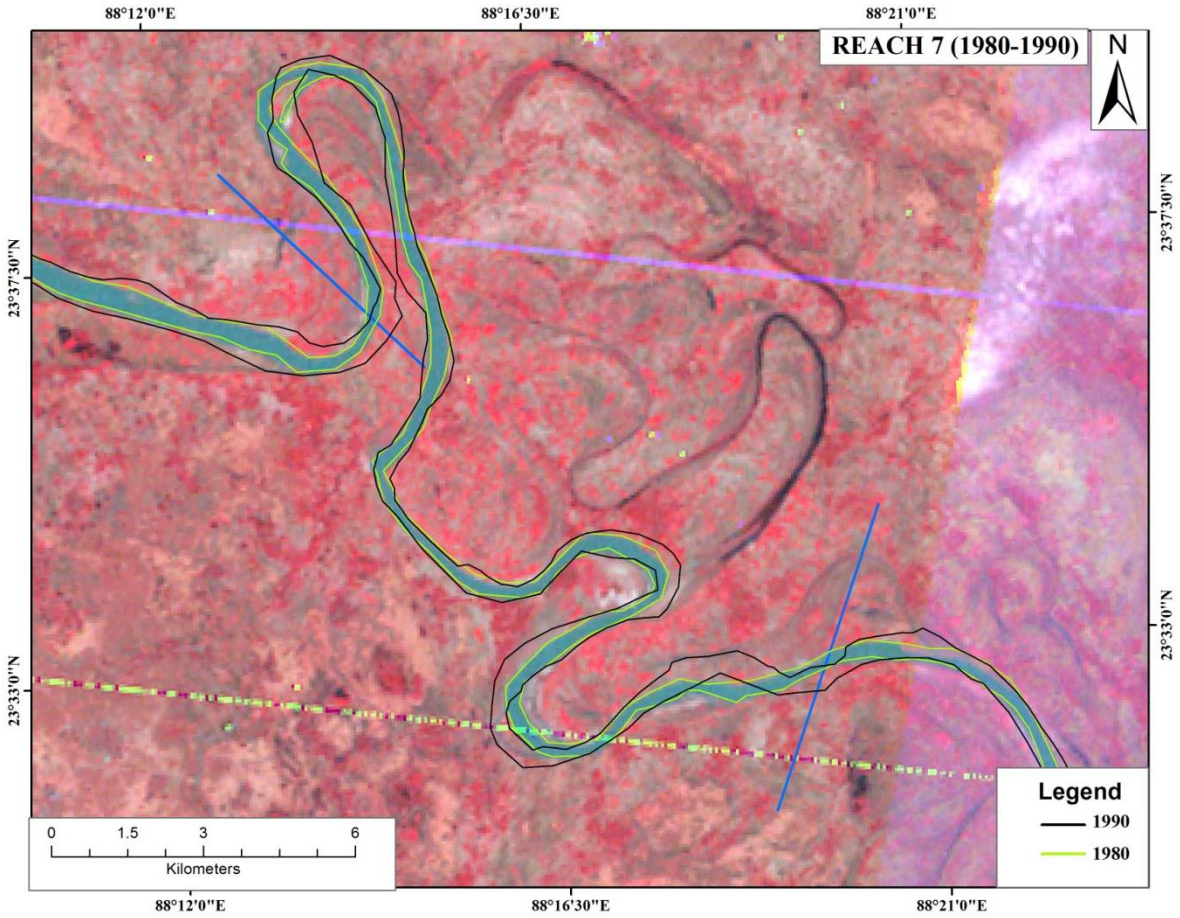


Figure 22.2: Changes in the course of Hooghly River of Year 1980-1990

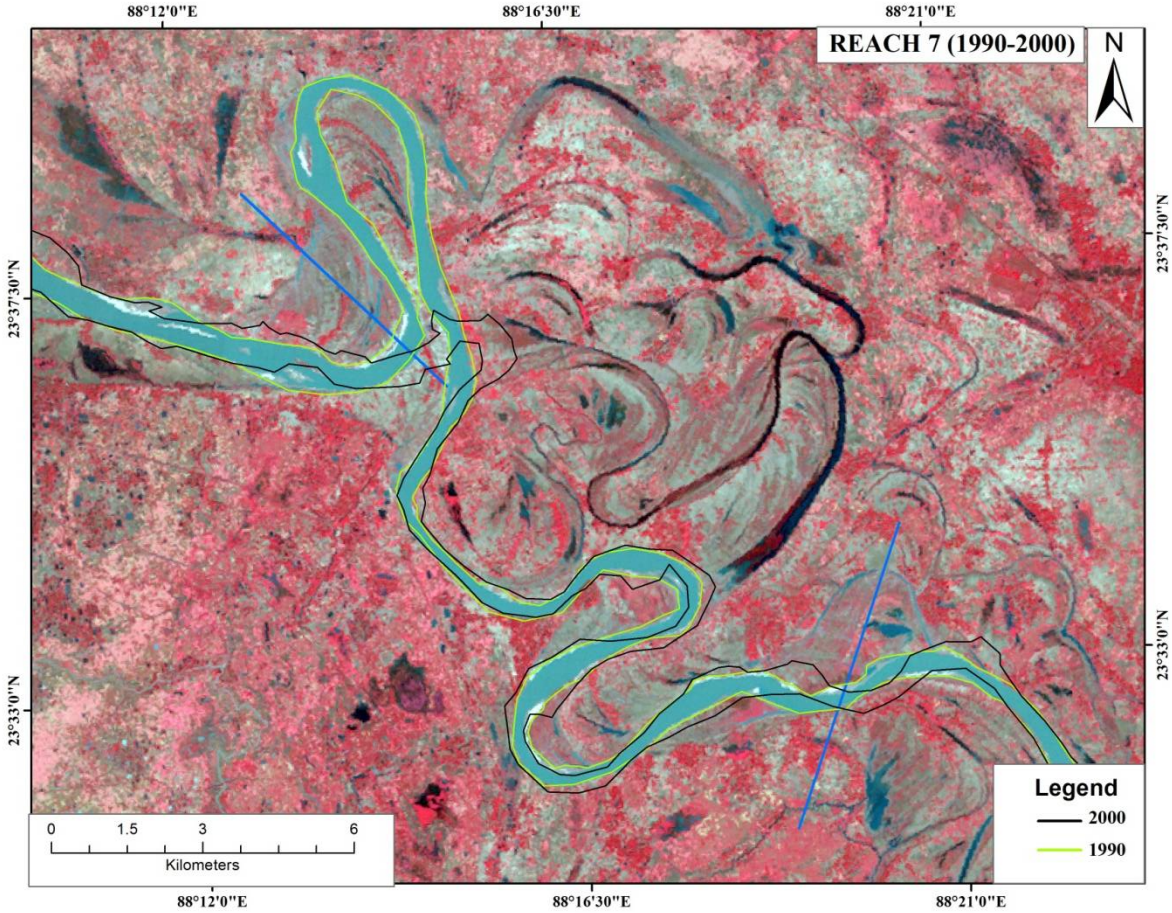


Figure 22.3: Changes in the course of Hooghly River of Year 1990-2000

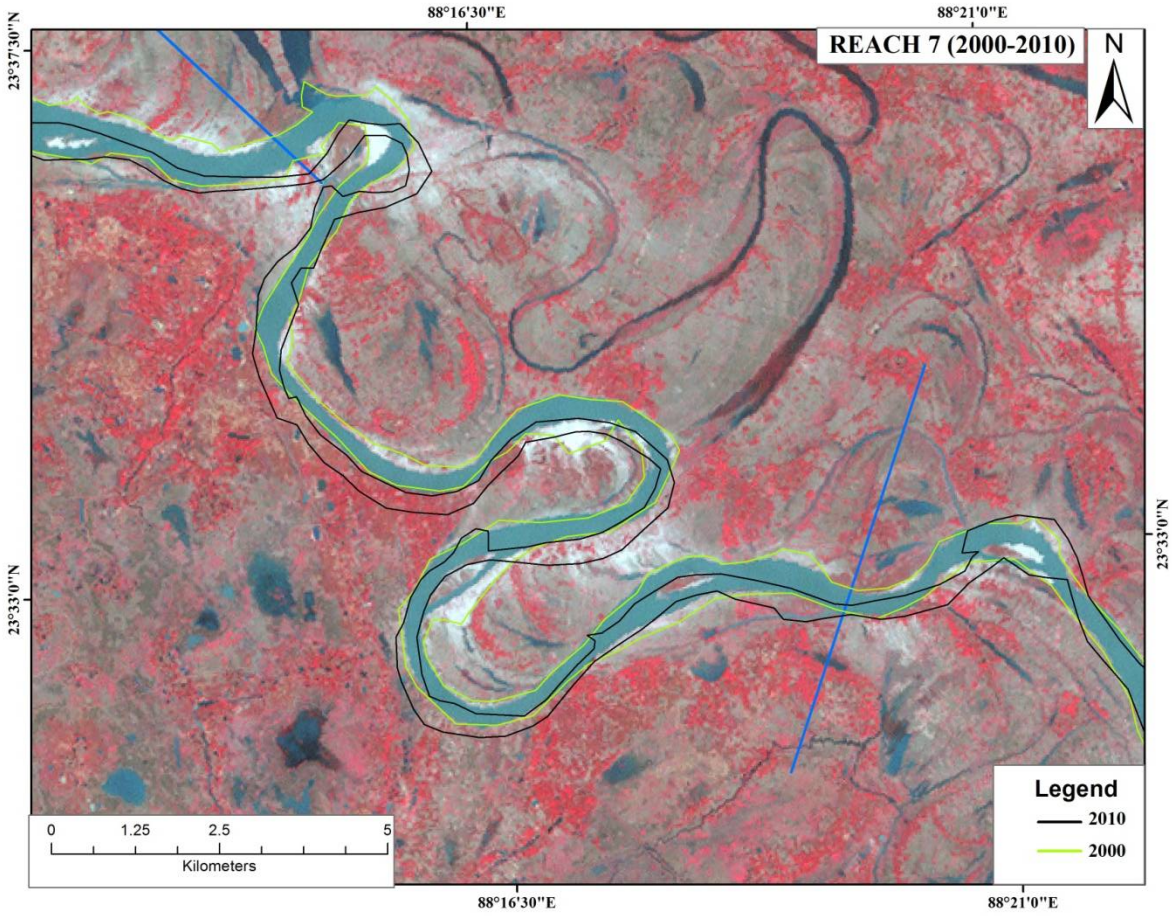


Figure 22.4: Changes in the course of Hooghly River of Year 2000-2010

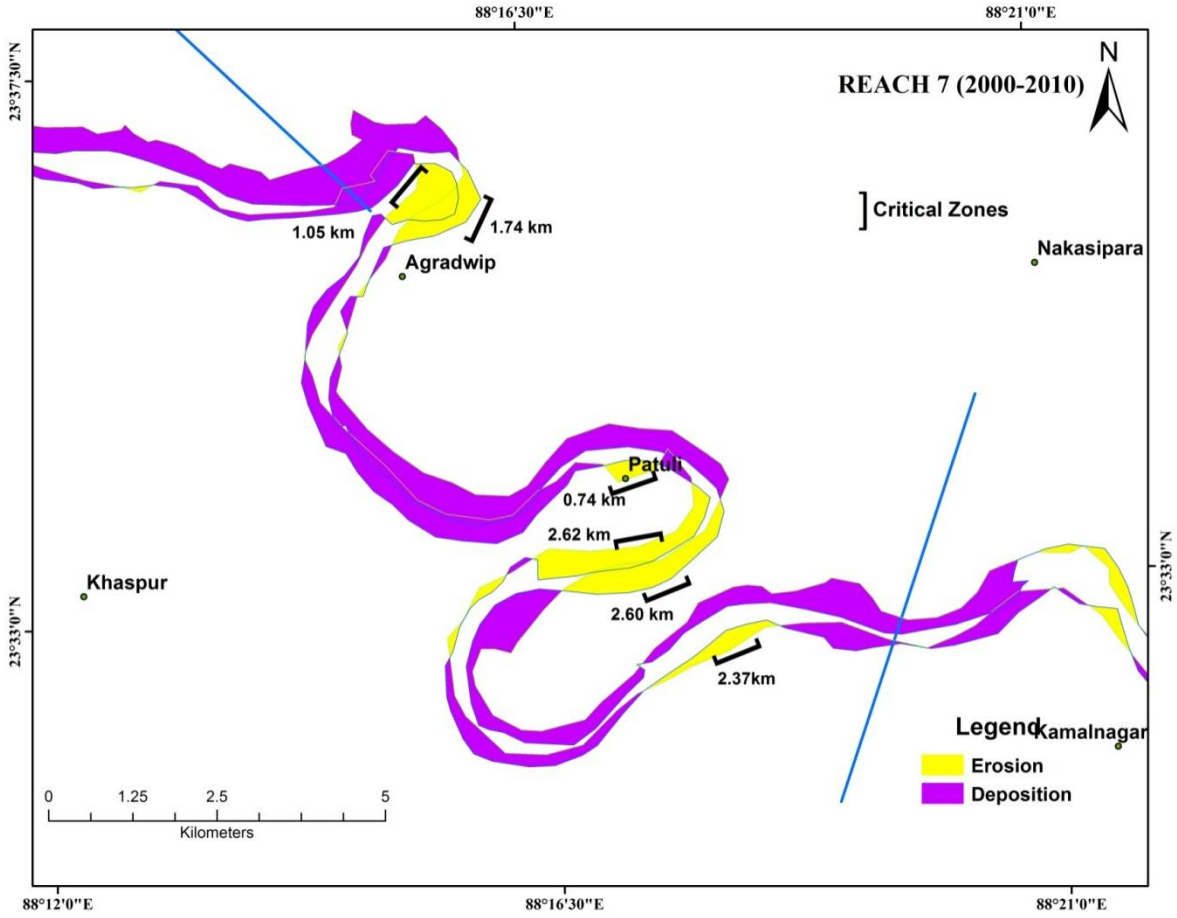


Figure 22.5: Identification of critical zones for Hooghly River of Year 2000-2010

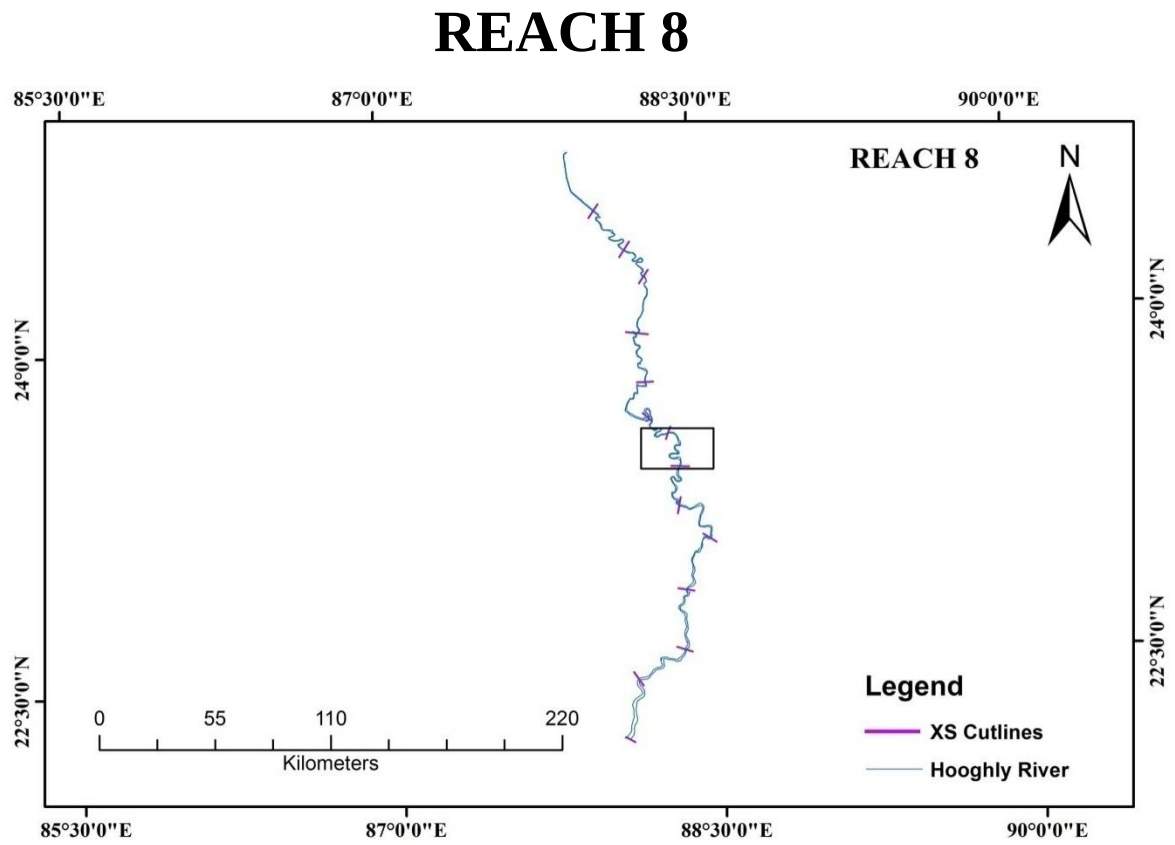


Figure 23: Location of reach number 8 in the Hooghly river

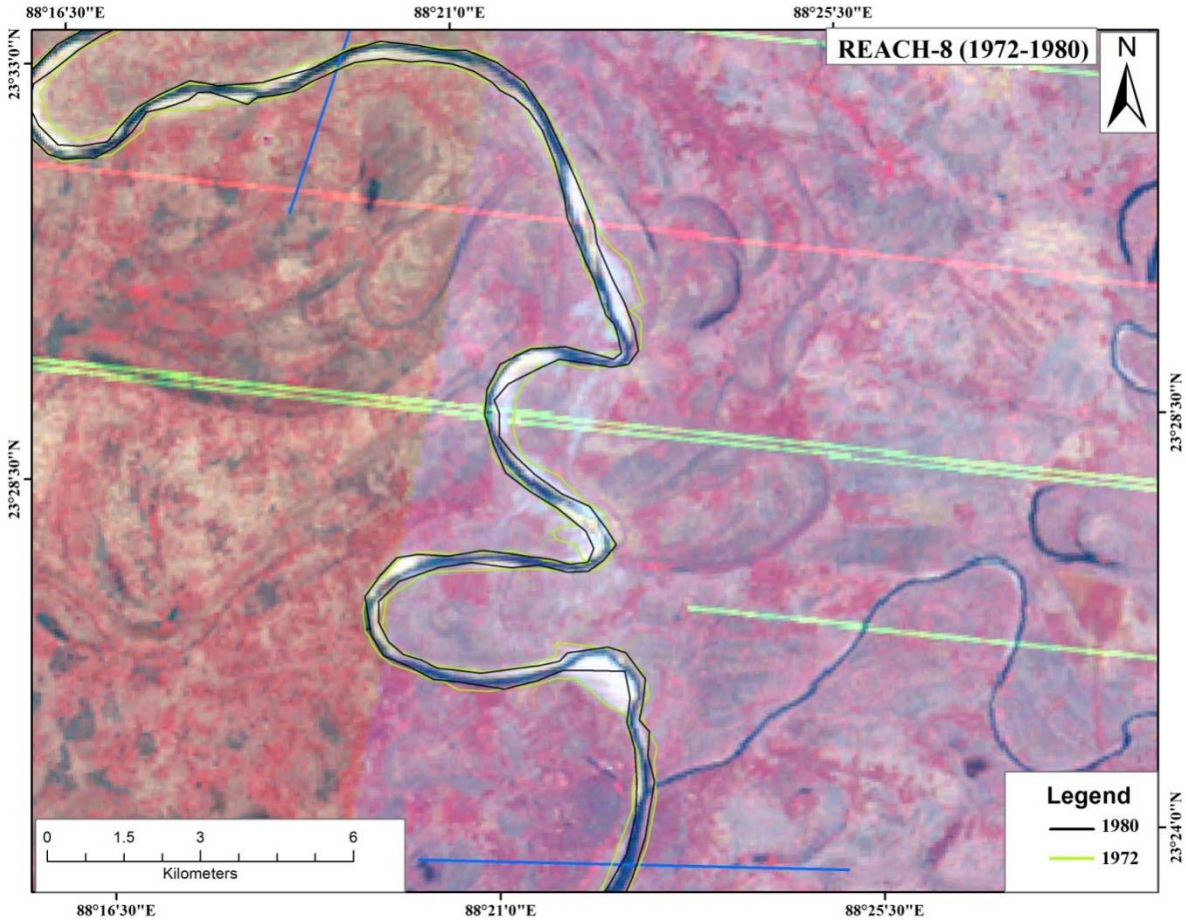


Figure 23.1: Changes in the course of Hooghly River of Year 1972-1980

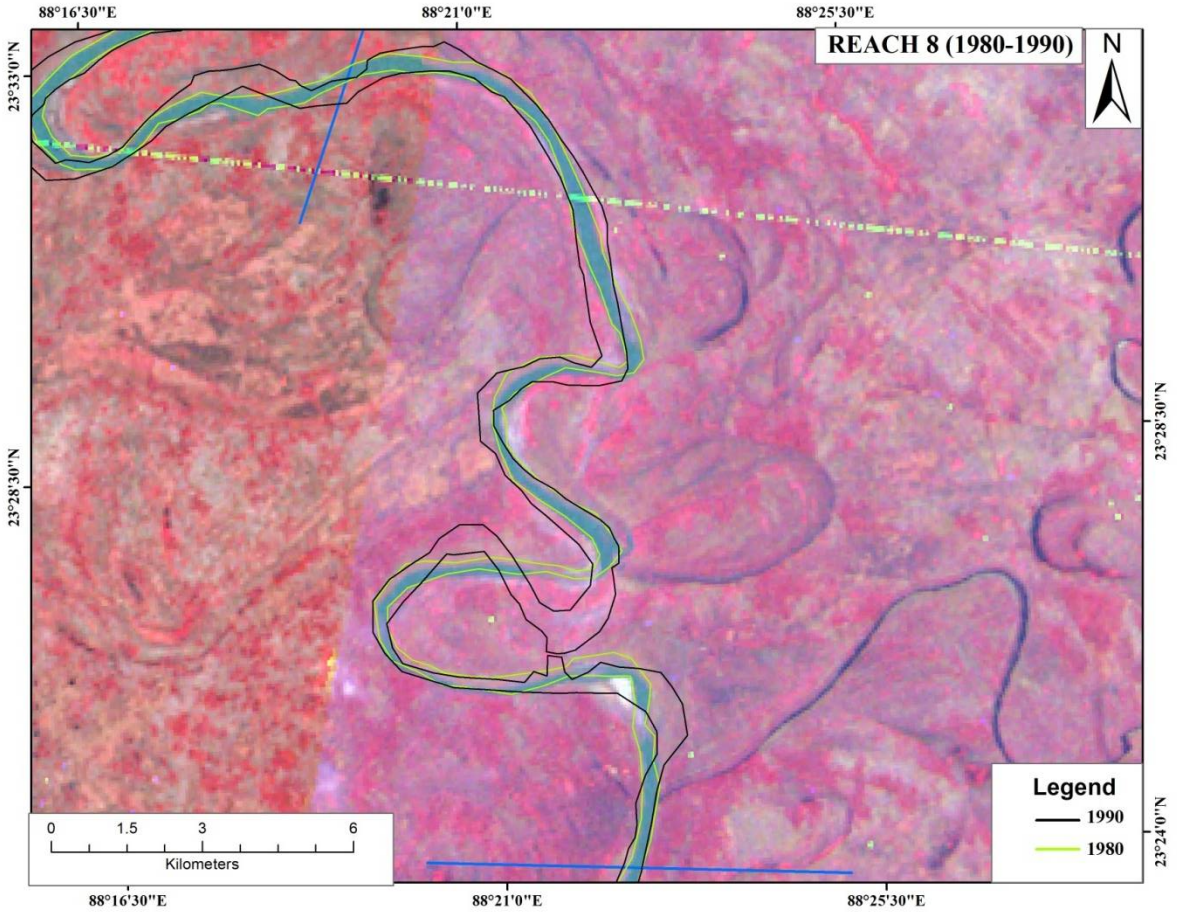


Figure 23.2: Changes in the course of Hooghly River of Year 1980-1990

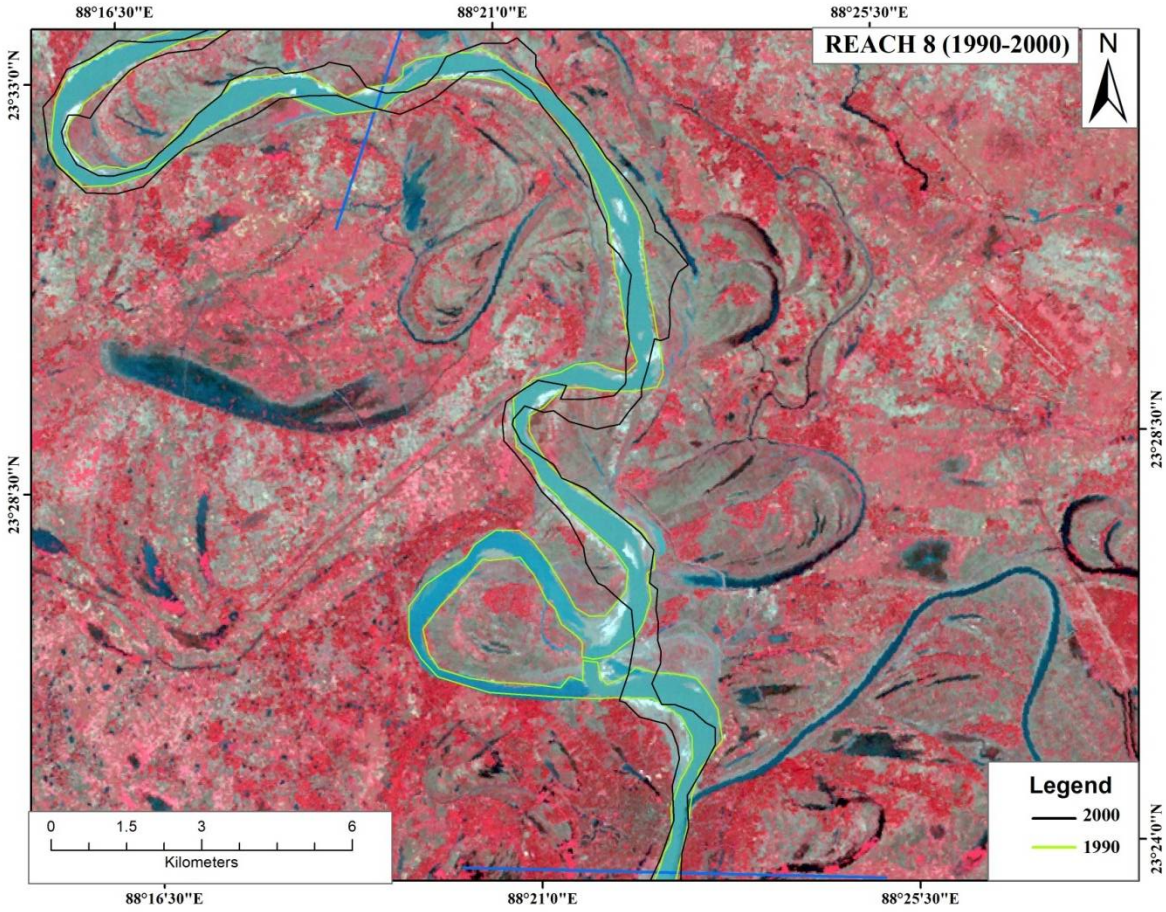


Figure 23.3: Changes in the course of Hooghly River of Year 1990-2000

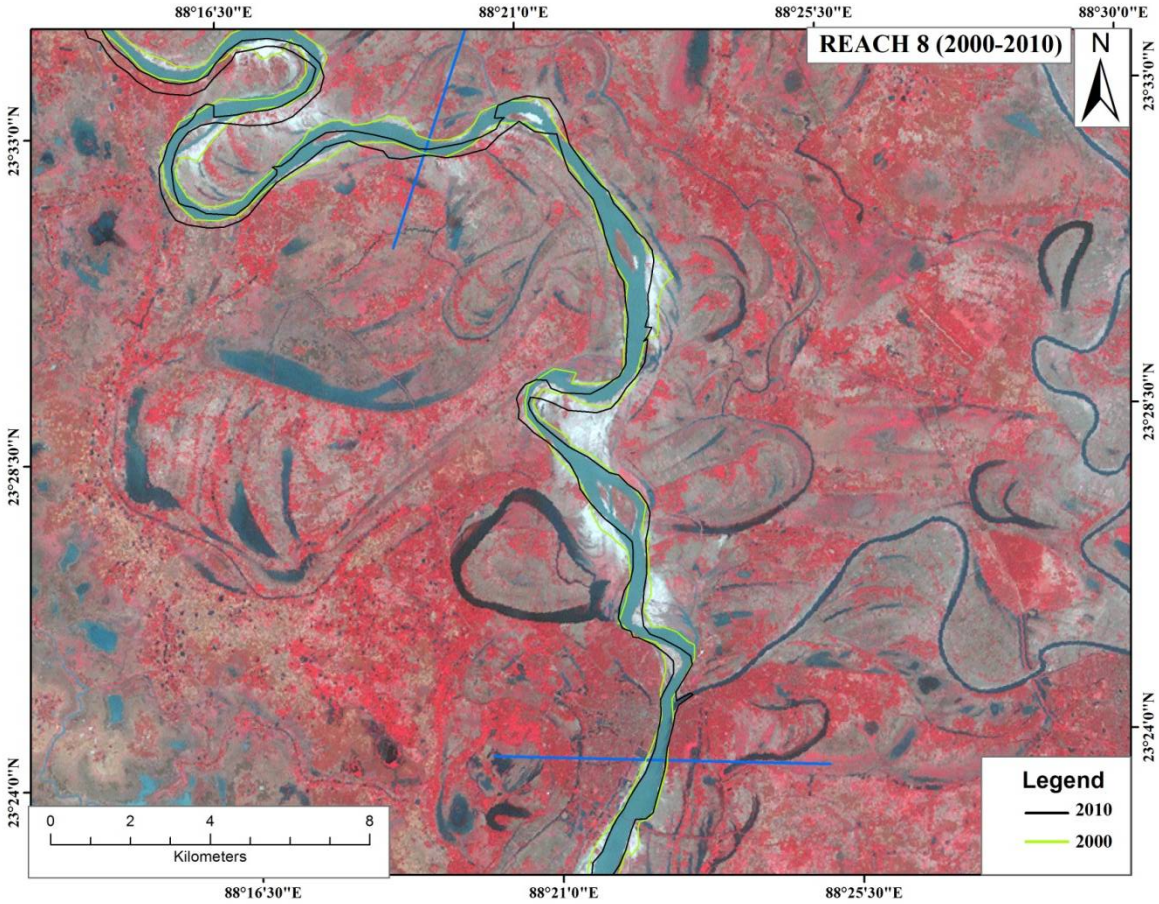


Figure 23.4: Changes in the course of Hooghly River of Year 2000-2010

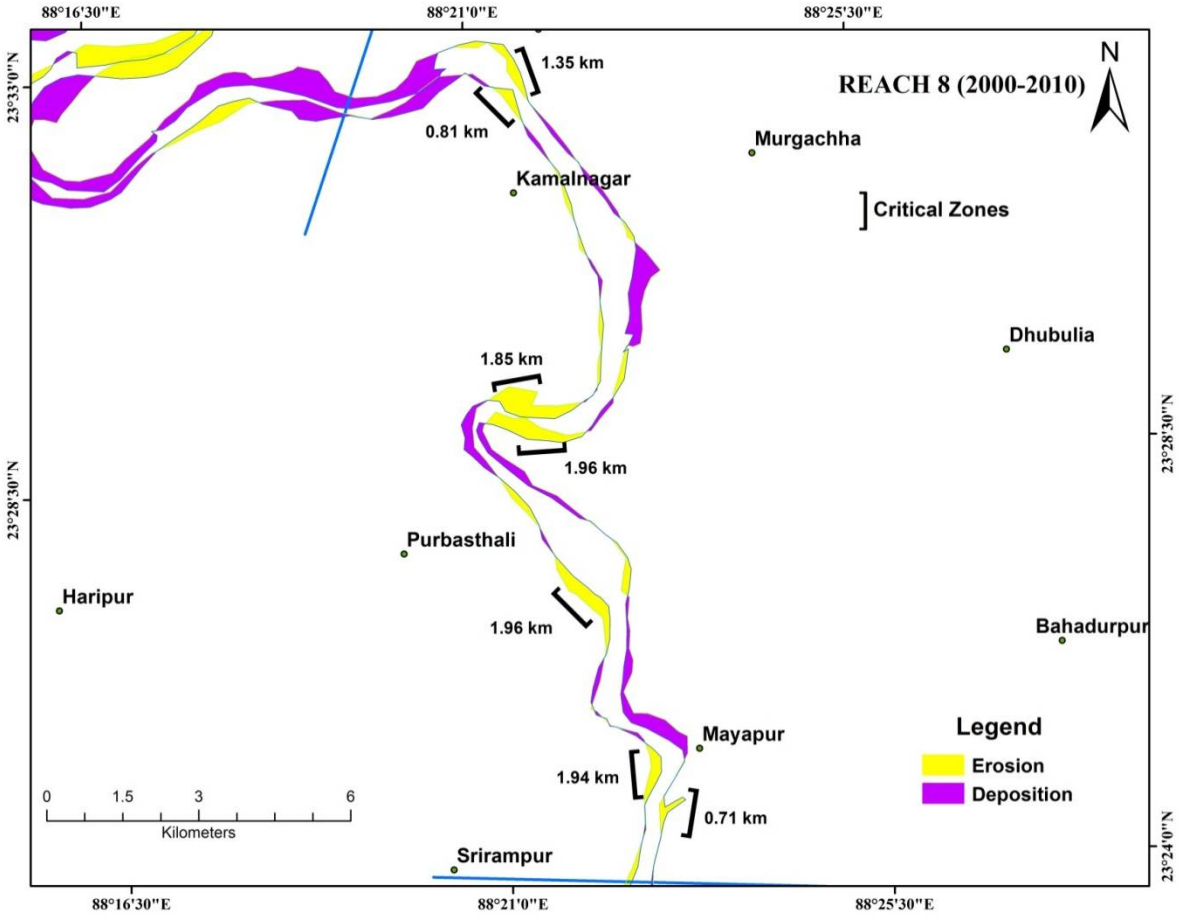


Figure 23.5: Identification of critical zones for Hooghly River of Year 2000-2010

REACH 9

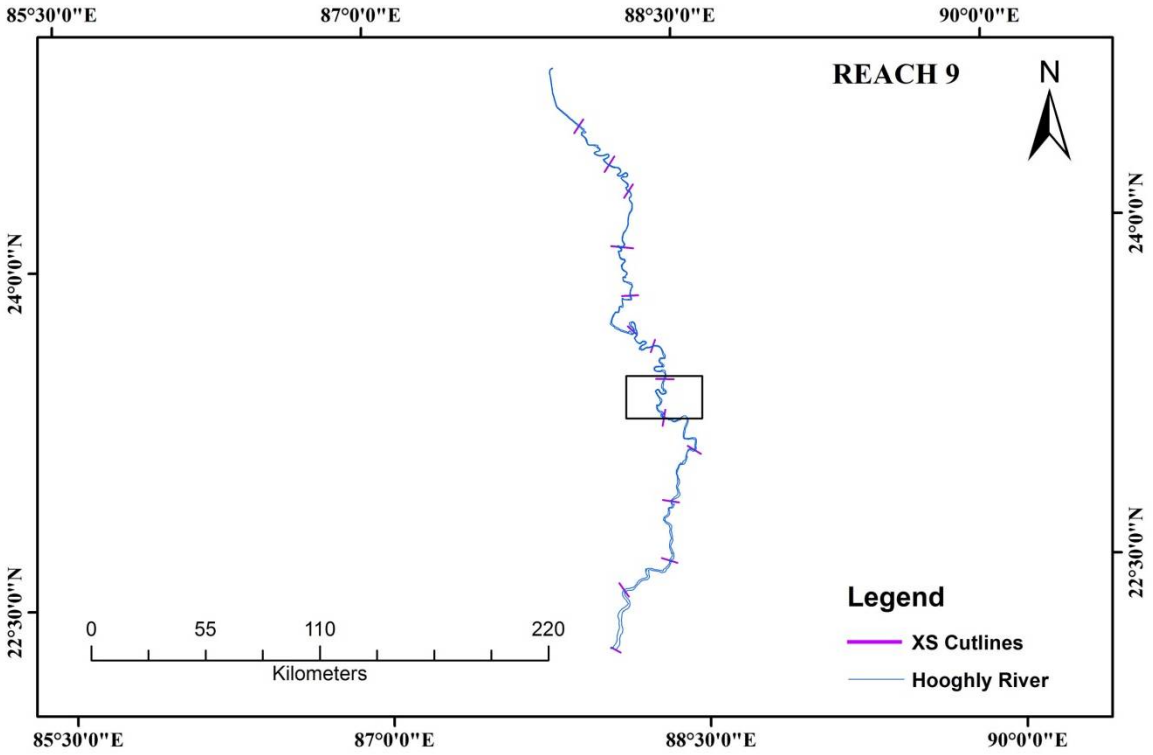


Figure 24: Location of reach number 9 in the Hooghly river

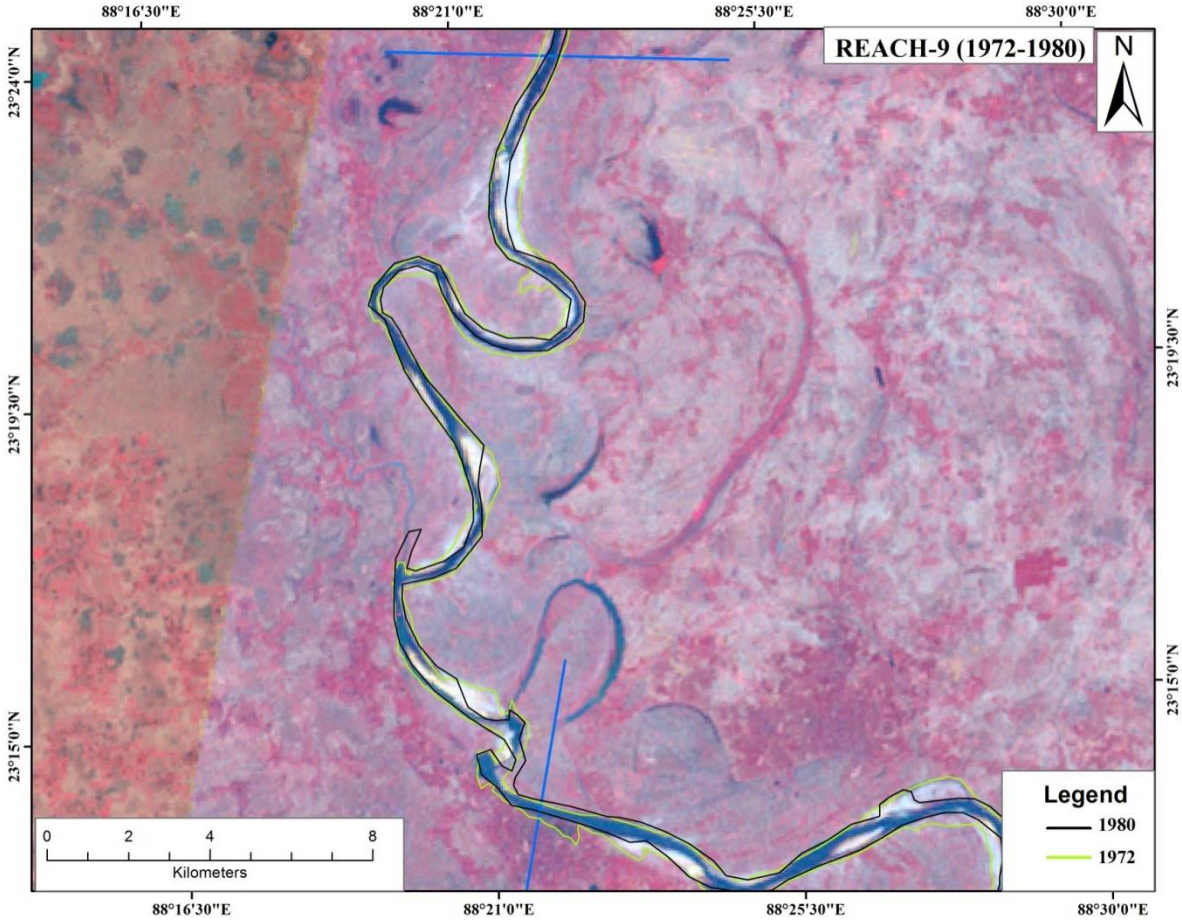


Figure 24.1: Changes in the course of Hooghly River of Year 1972-1980

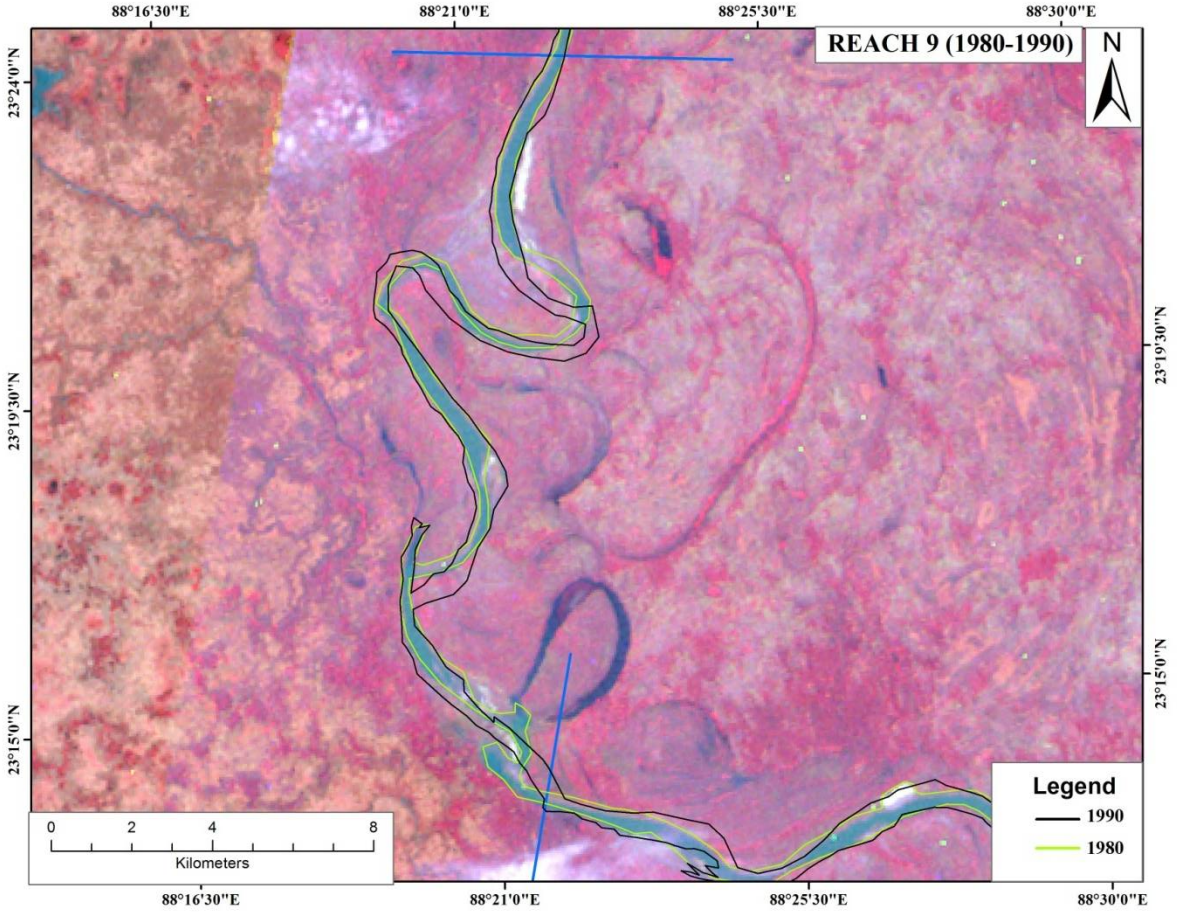


Figure 24.2: Changes in the course of Hooghly River of Year 1980-1990

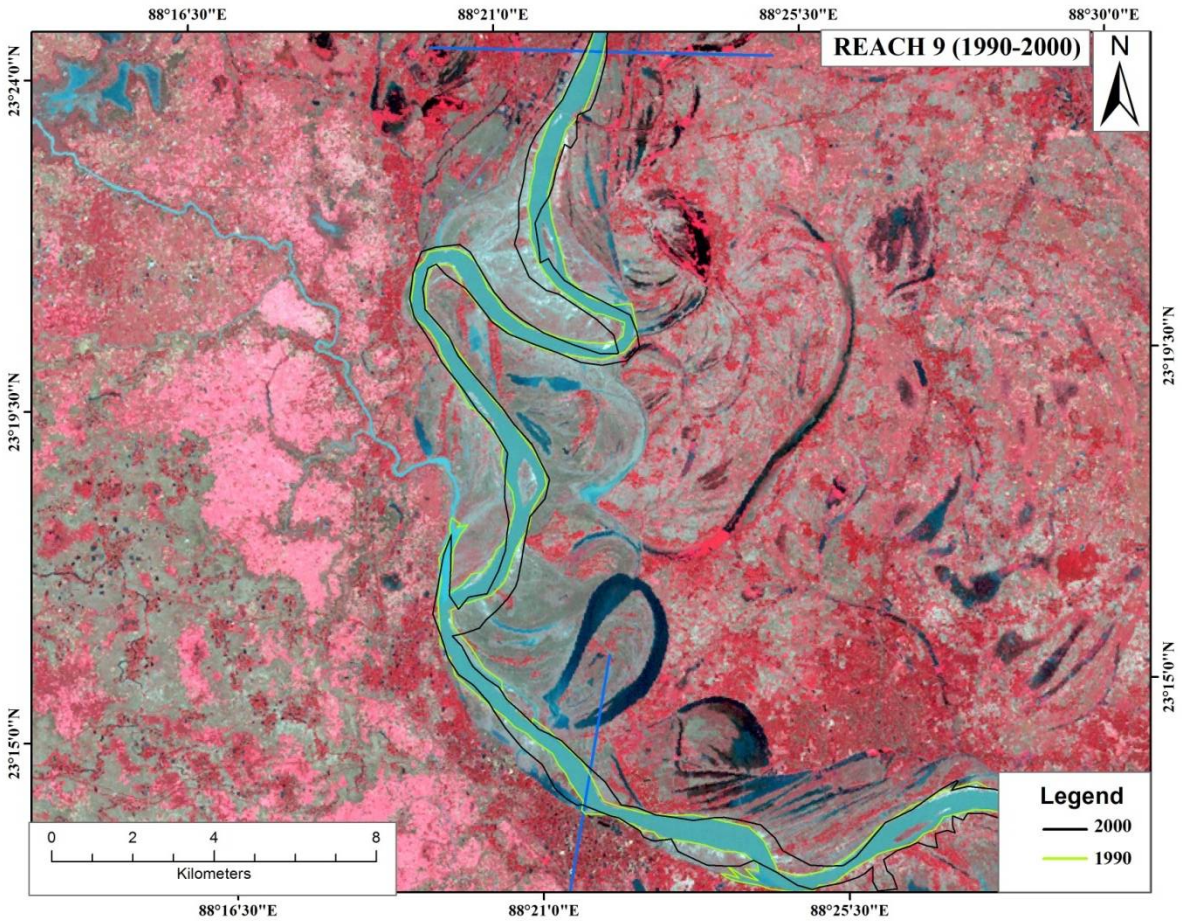


Figure 24.3: Changes in the course of Hooghly River of Year 1990-2000

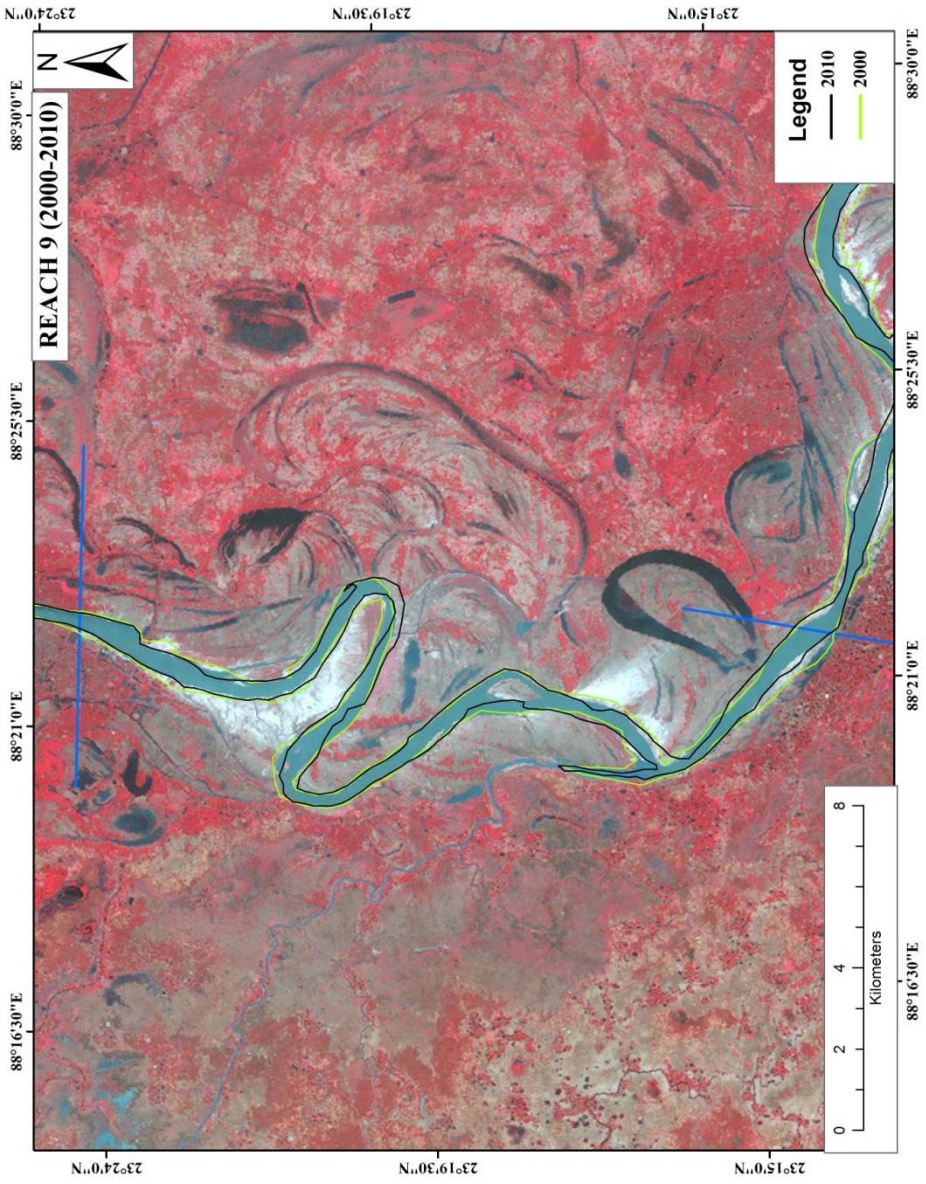


Figure 24.4: Changes in the course of Hooghly River of Year 2000-2010

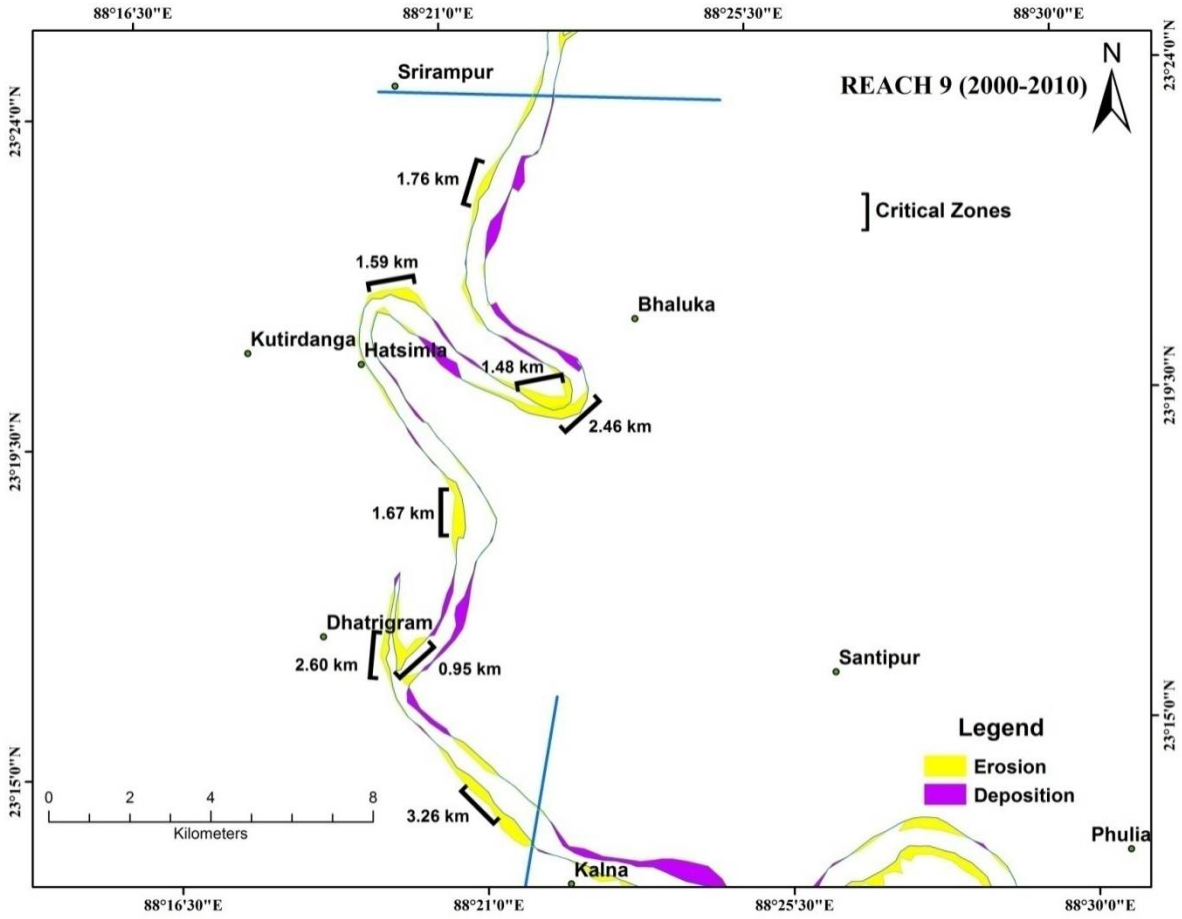


Figure 24.5: Identification of critical zones for Hooghly River of Year 2000-2010

REACH 10

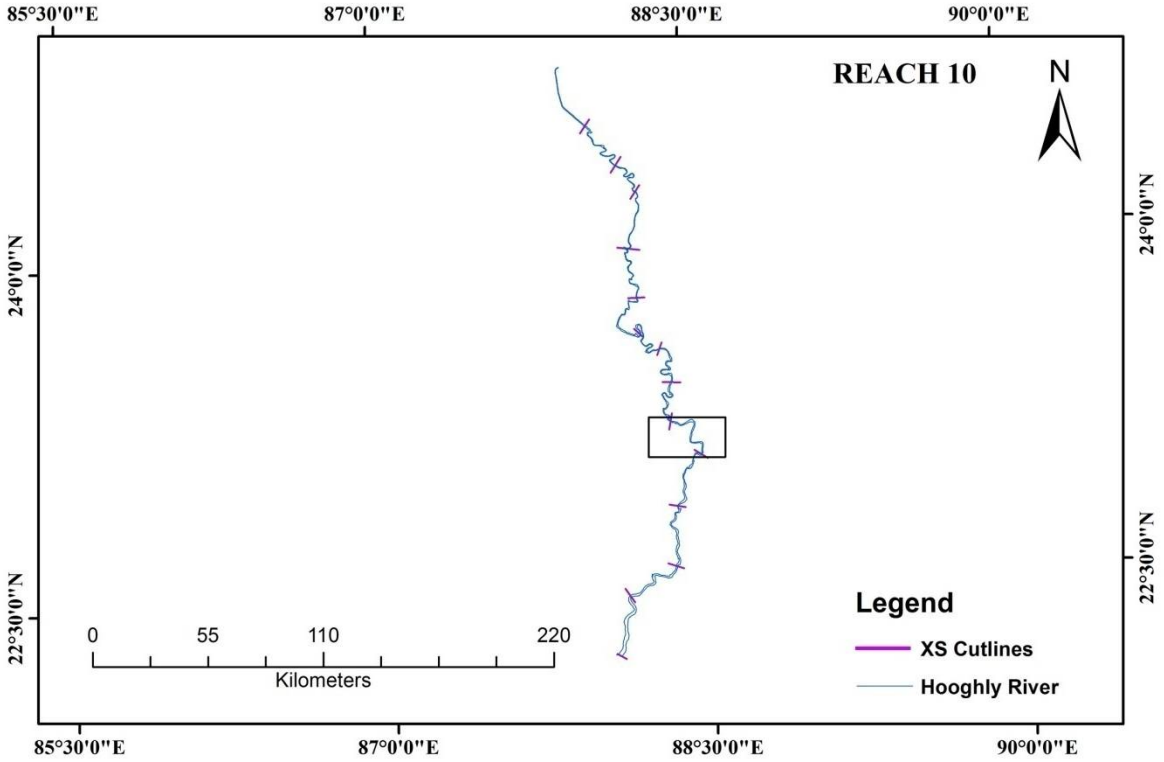


Figure 25: Location of reach number 10 in the Hooghly river

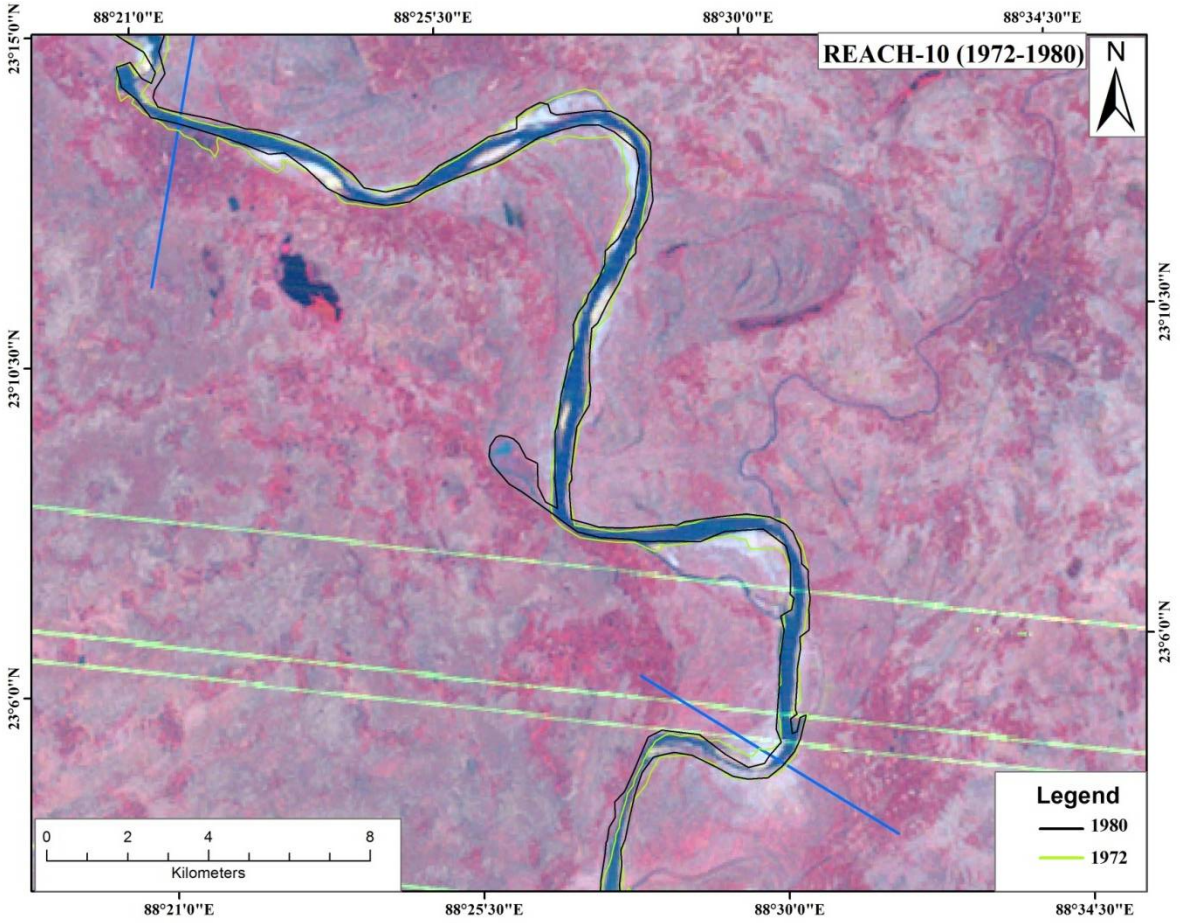


Figure 25.1: Changes in the course of Hooghly River of Year 1972-1980

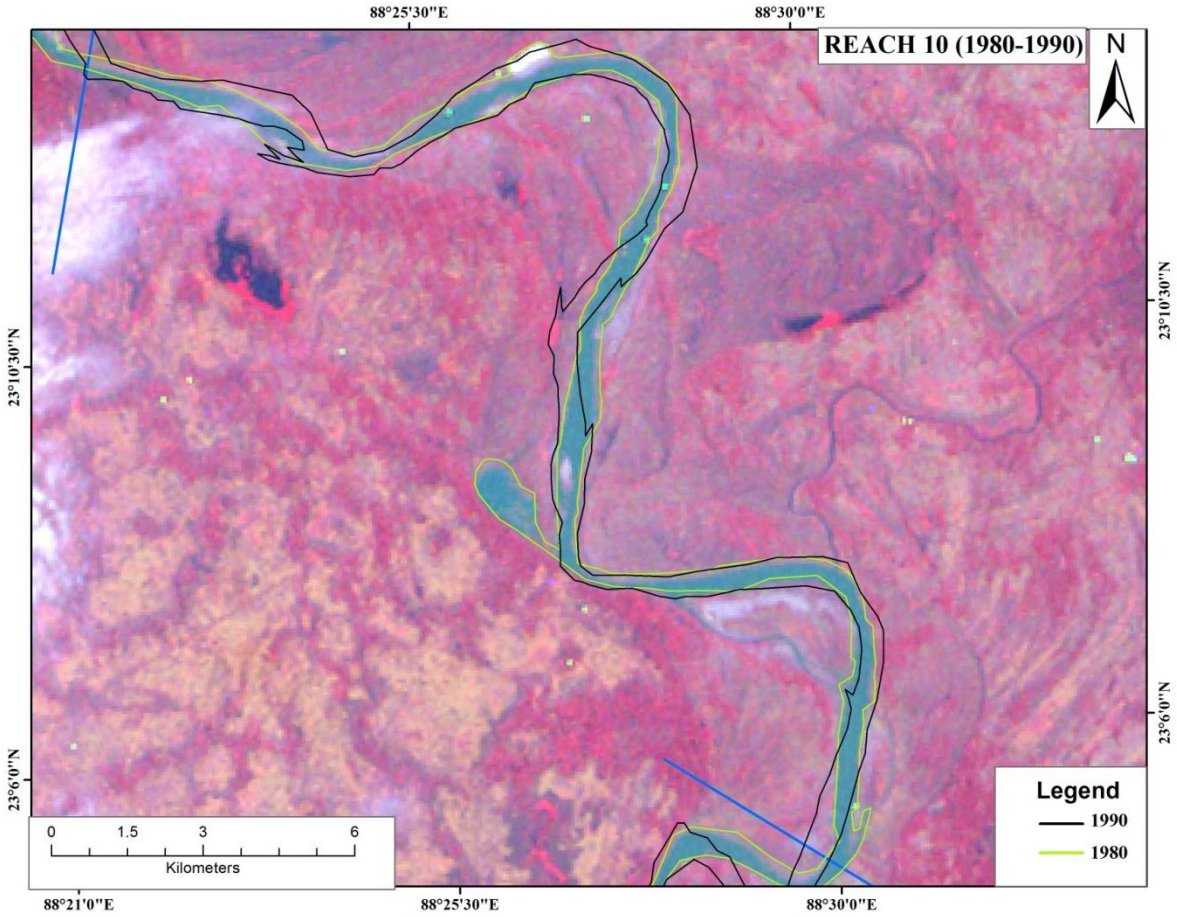


Figure 25.2: Changes in the course of Hooghly River of Year 1980-1990

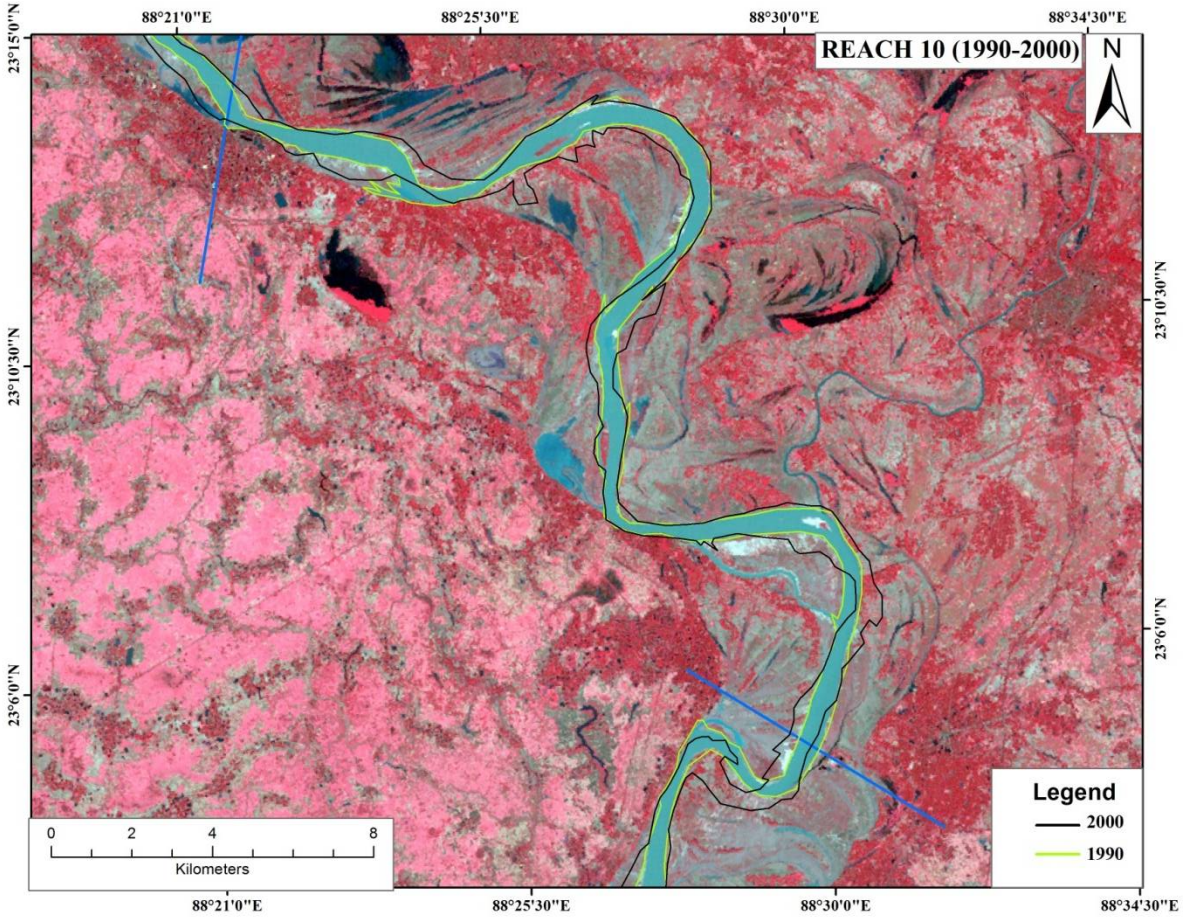


Figure 25.3: Changes in the course of Hooghly River of Year 1990-2000

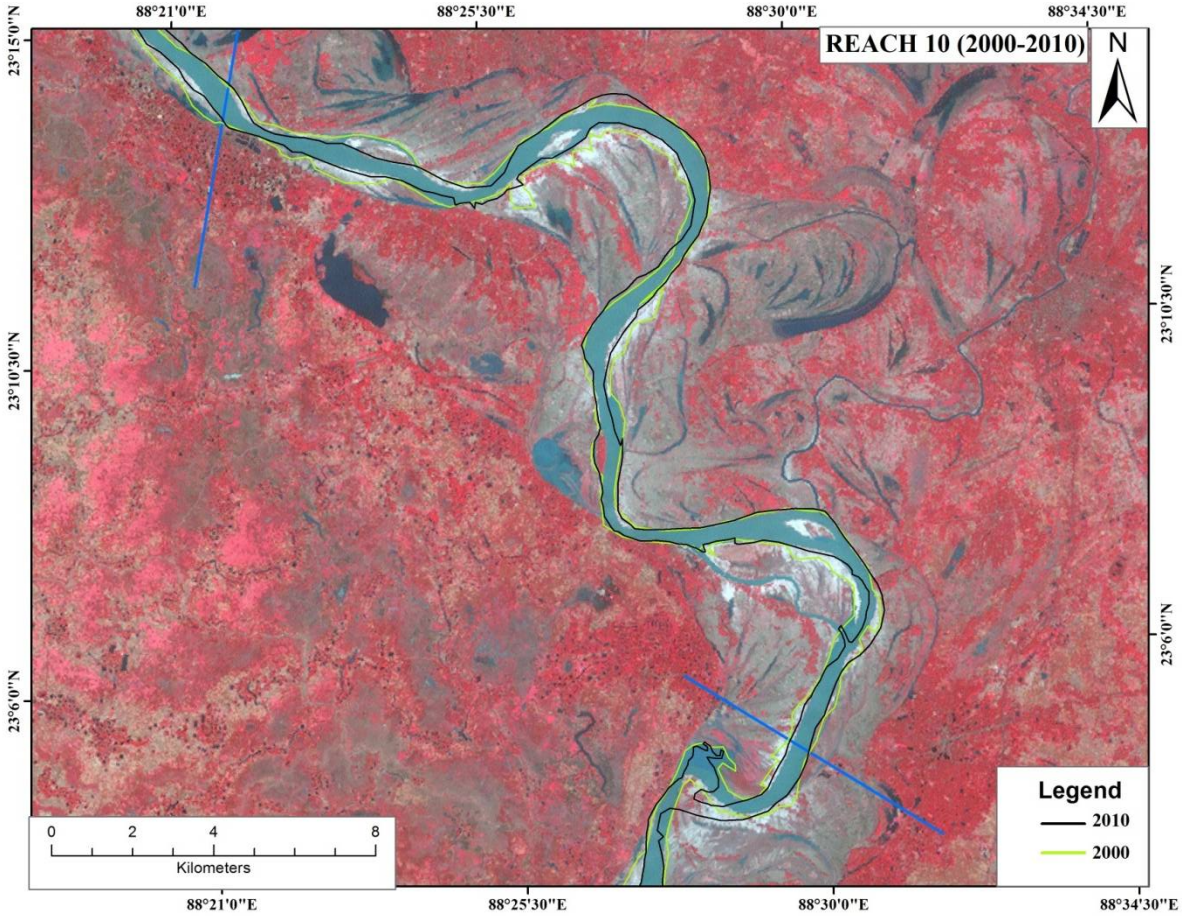


Figure 25.4: Changes in the course of Hooghly River of Year 2000-2010

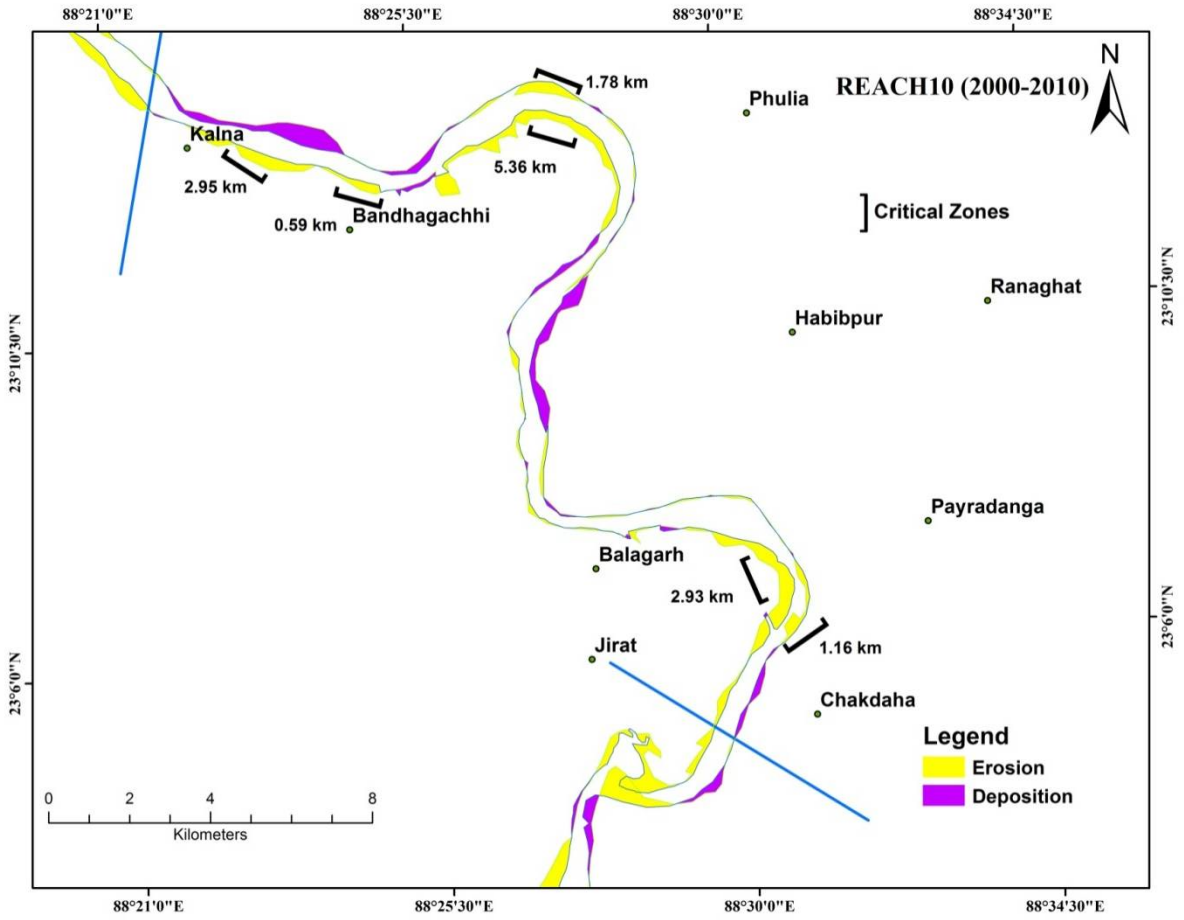


Figure 25.5: Identification of critical zones for Hooghly River of Year 2000-2010

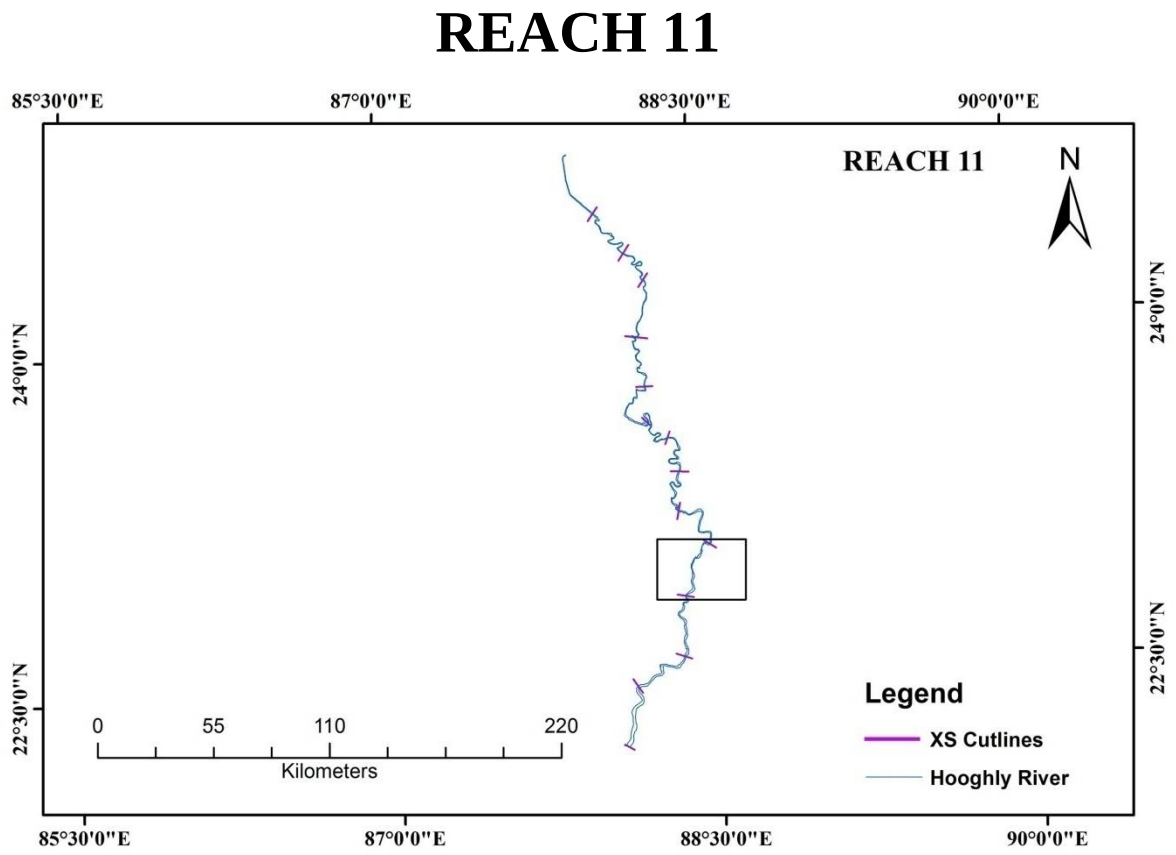


Figure 26: Location of reach number 11 in the Hooghly river

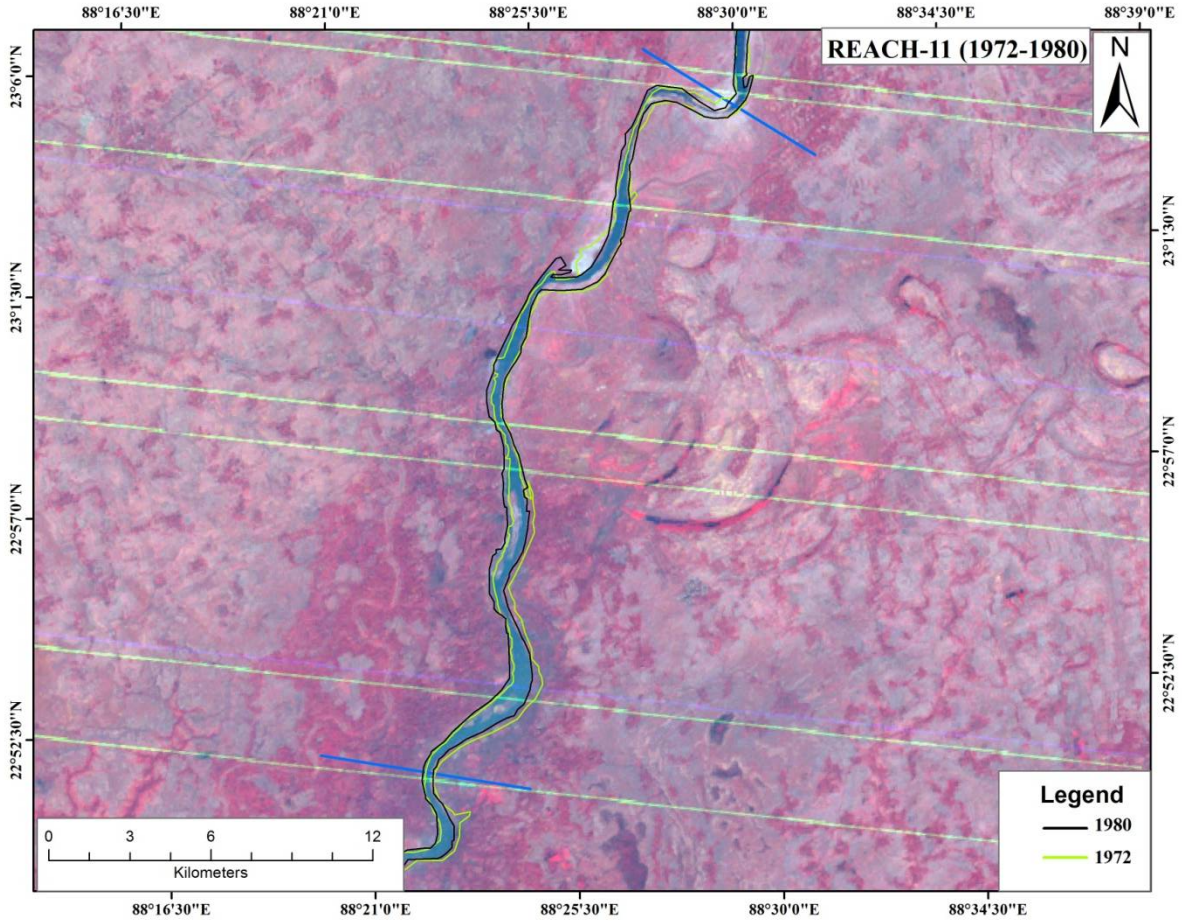


Figure 26.1: Changes in the course of Hooghly River of Year 1972-1980

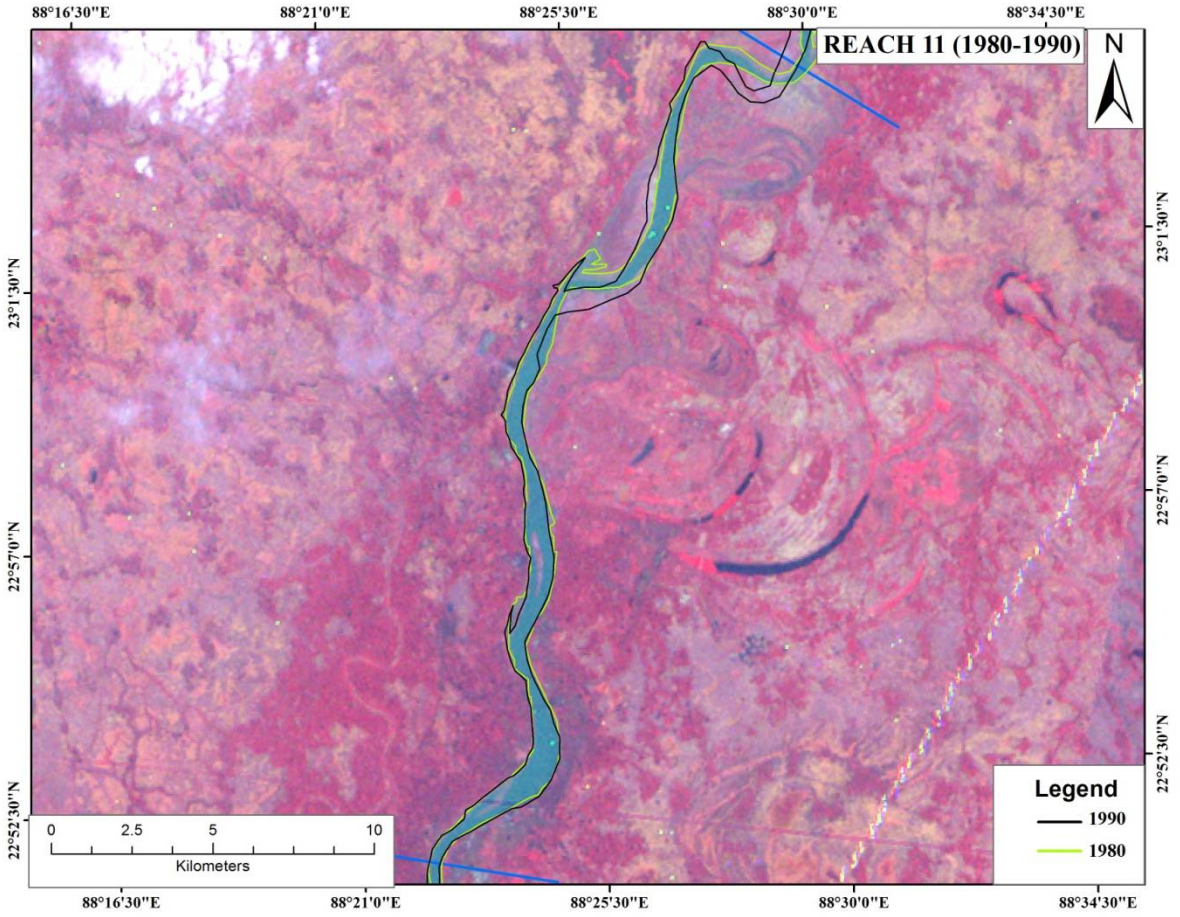


Figure 26.2: Changes in the course of Hooghly River of Year 1980-1990

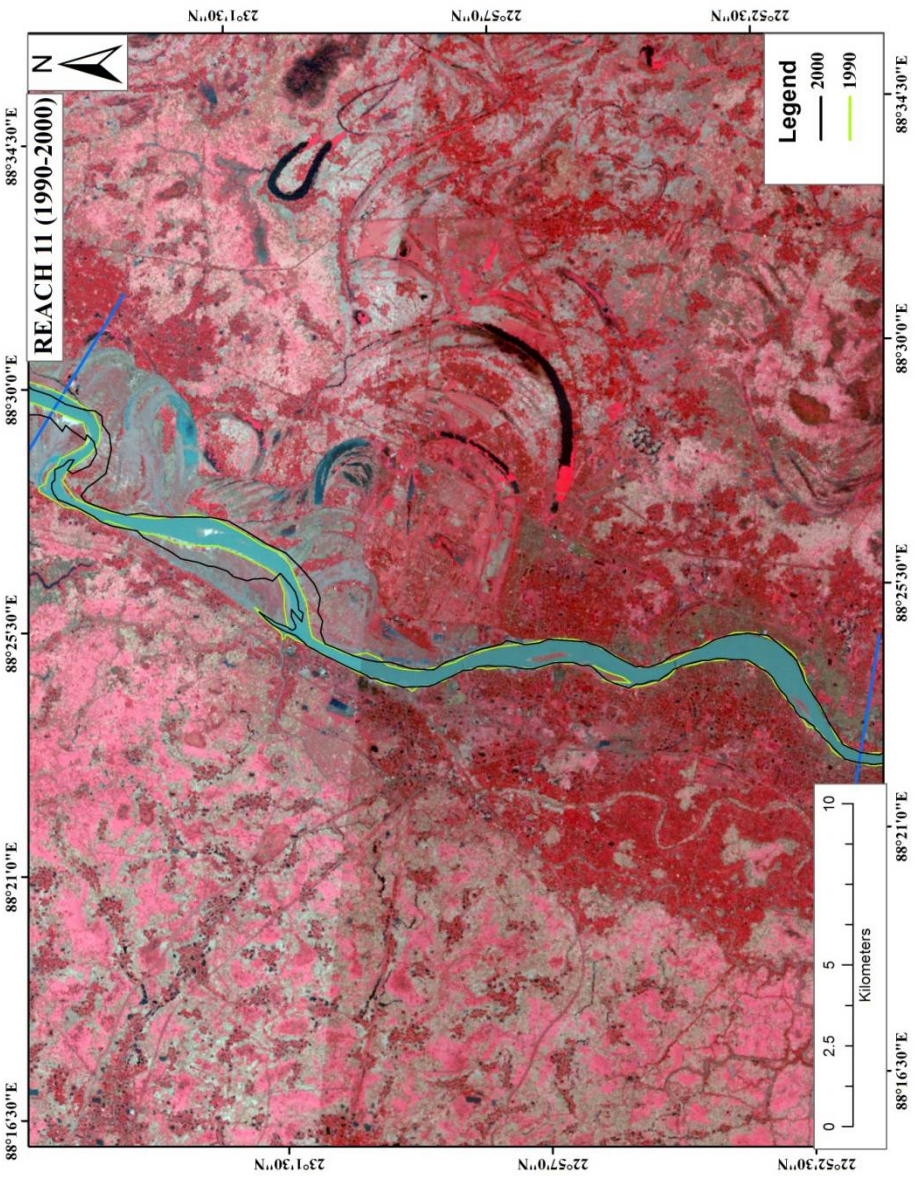


Figure 26.3: Changes in the course of Hooghly River of Year 1990-2000

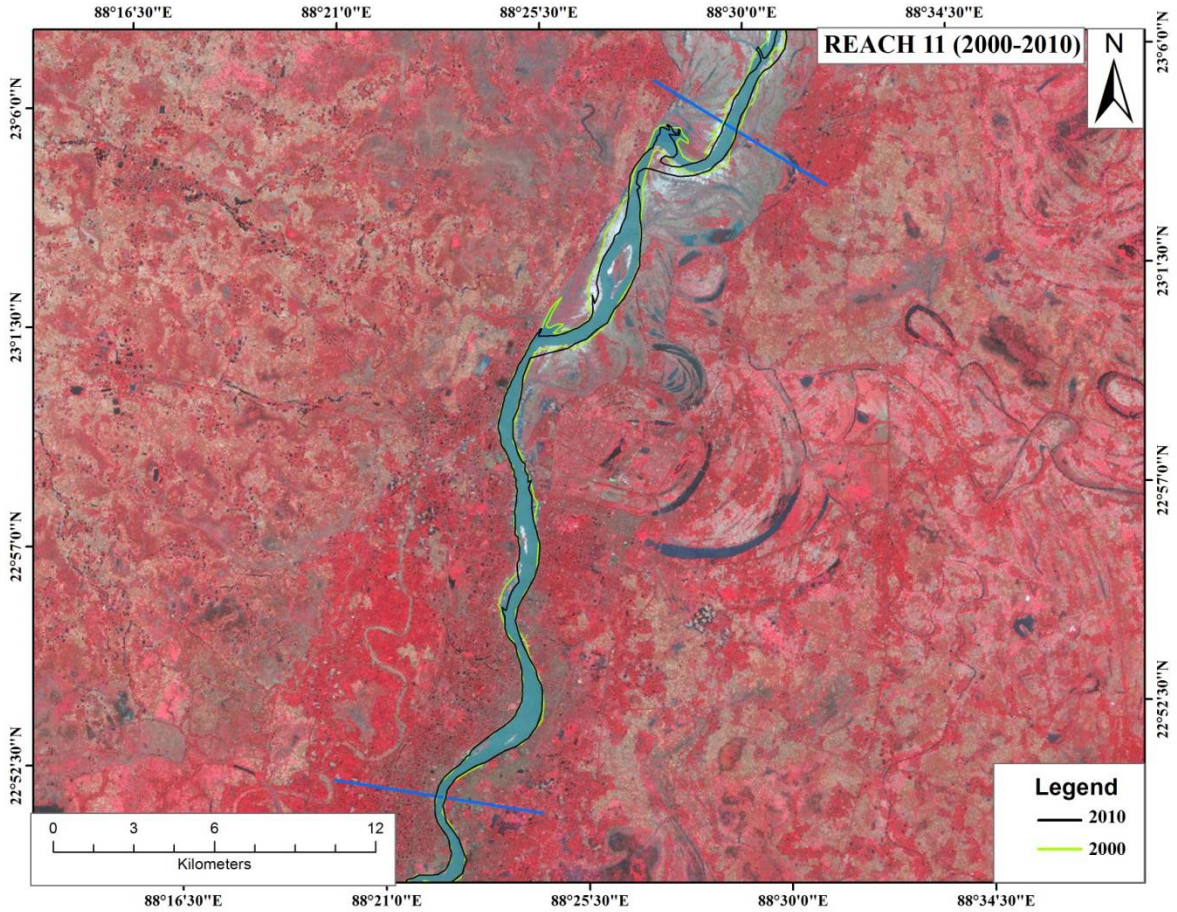


Figure 26.4: Changes in the course of Hooghly River of Year 2000-2010

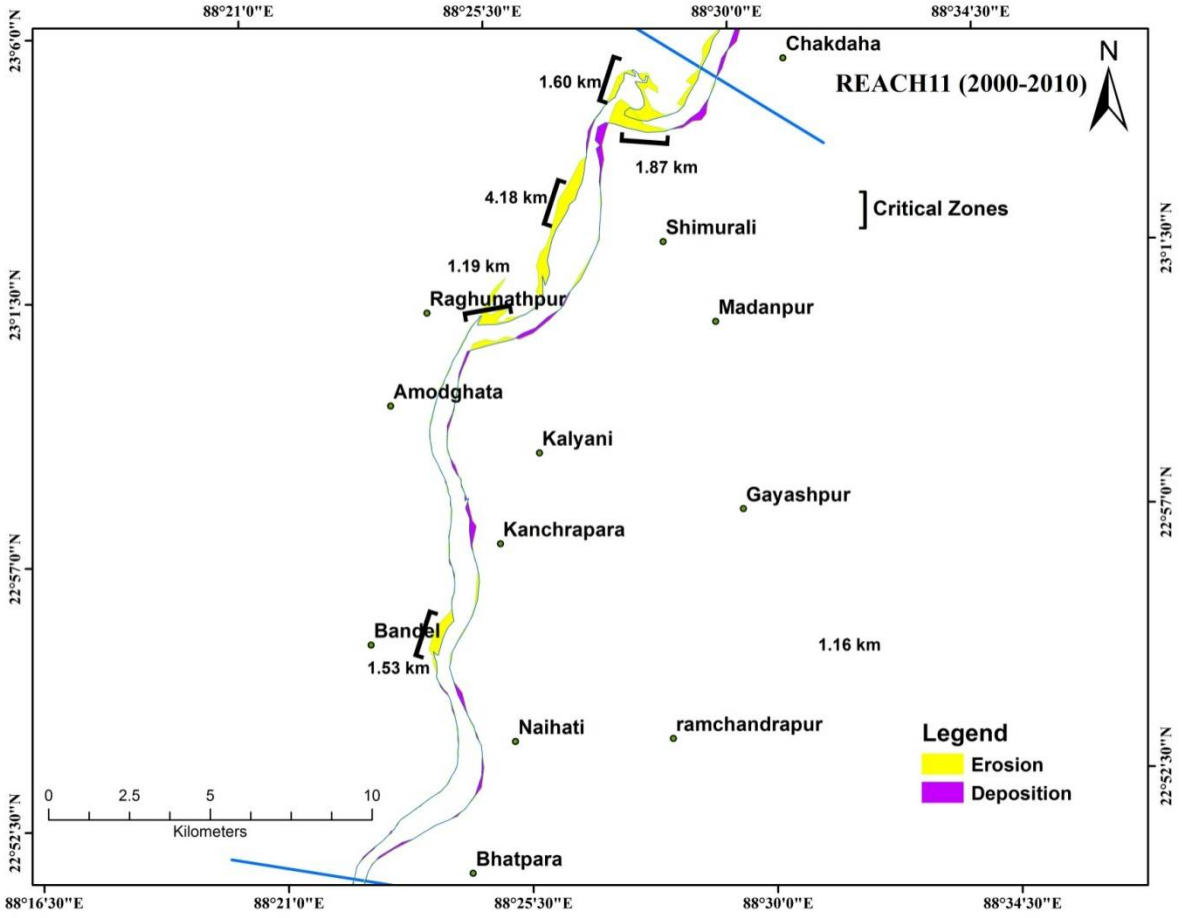


Figure 26.5: Identification of critical zones for Hooghly River of Year 2000-2010

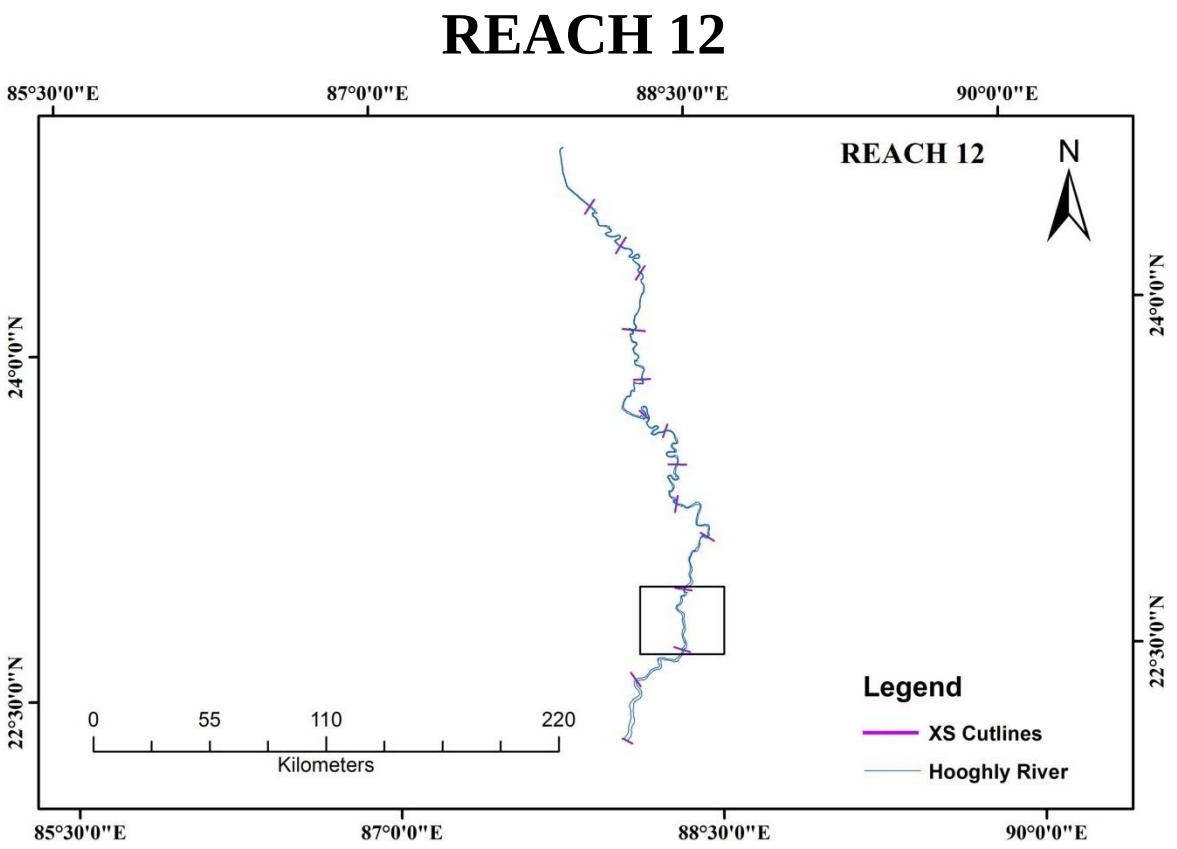


Figure 27: Location of reach number 12 in the Hooghly river

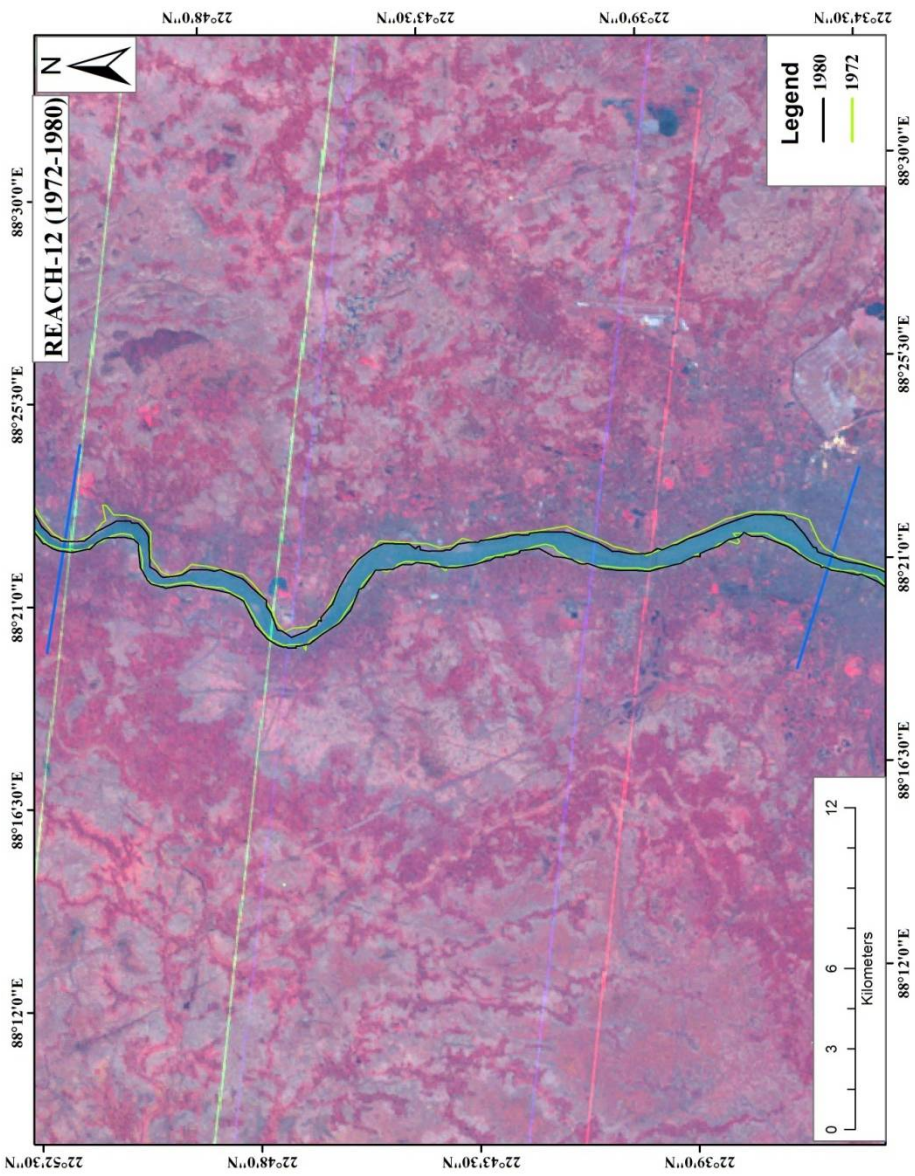


Figure 27.1: Changes in the course of Hooghly River of Year 1972-1980

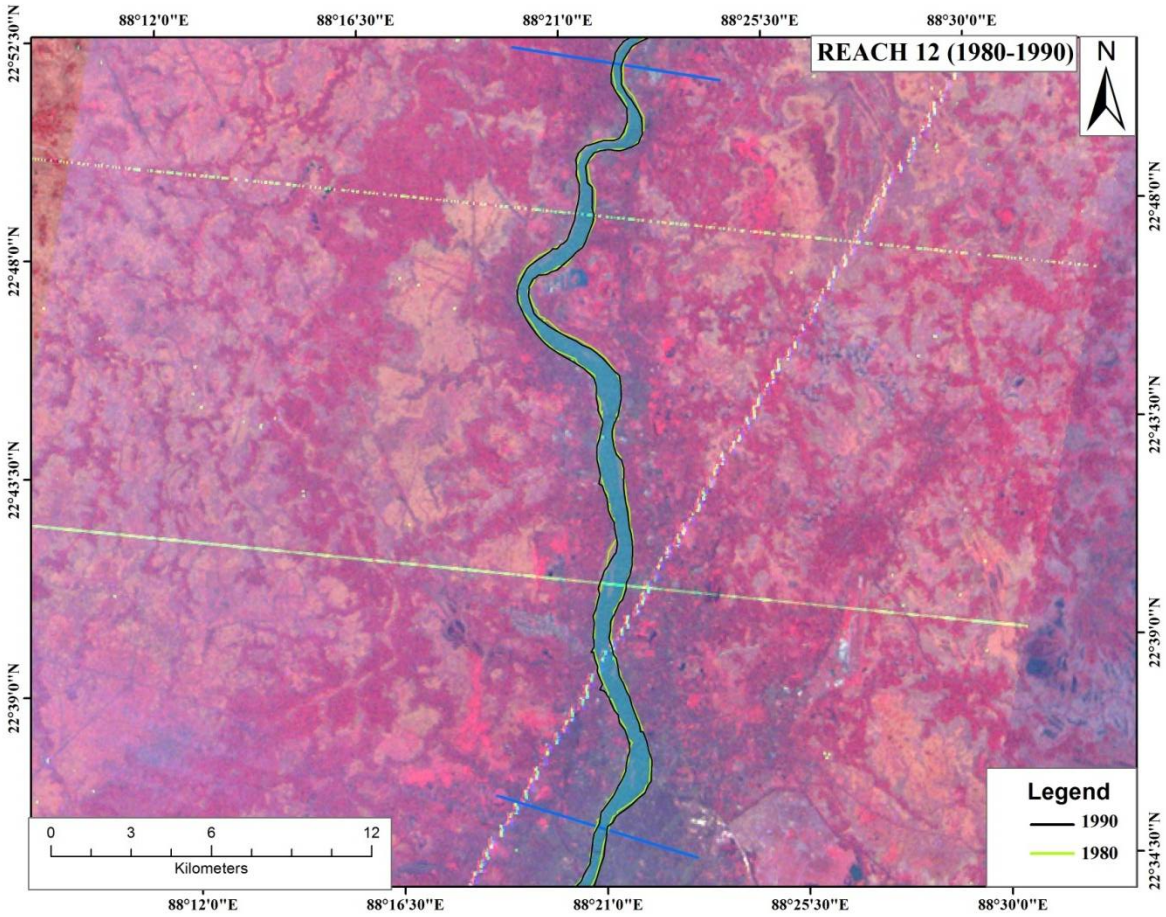


Figure 27.2: Changes in the course of Hooghly River of Year 1980-1990

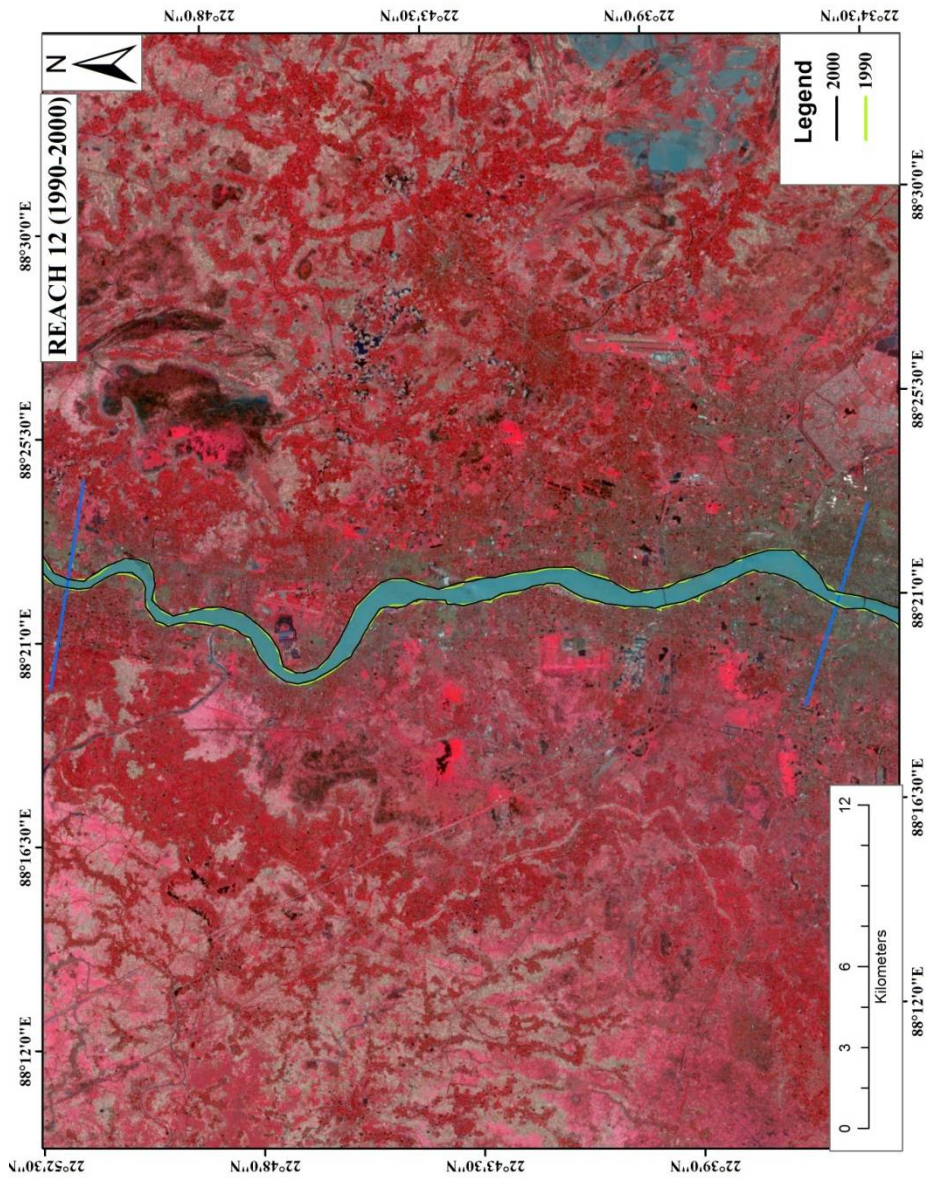


Figure 27.3: Changes in the course of Hooghly River of Year 1990-2000

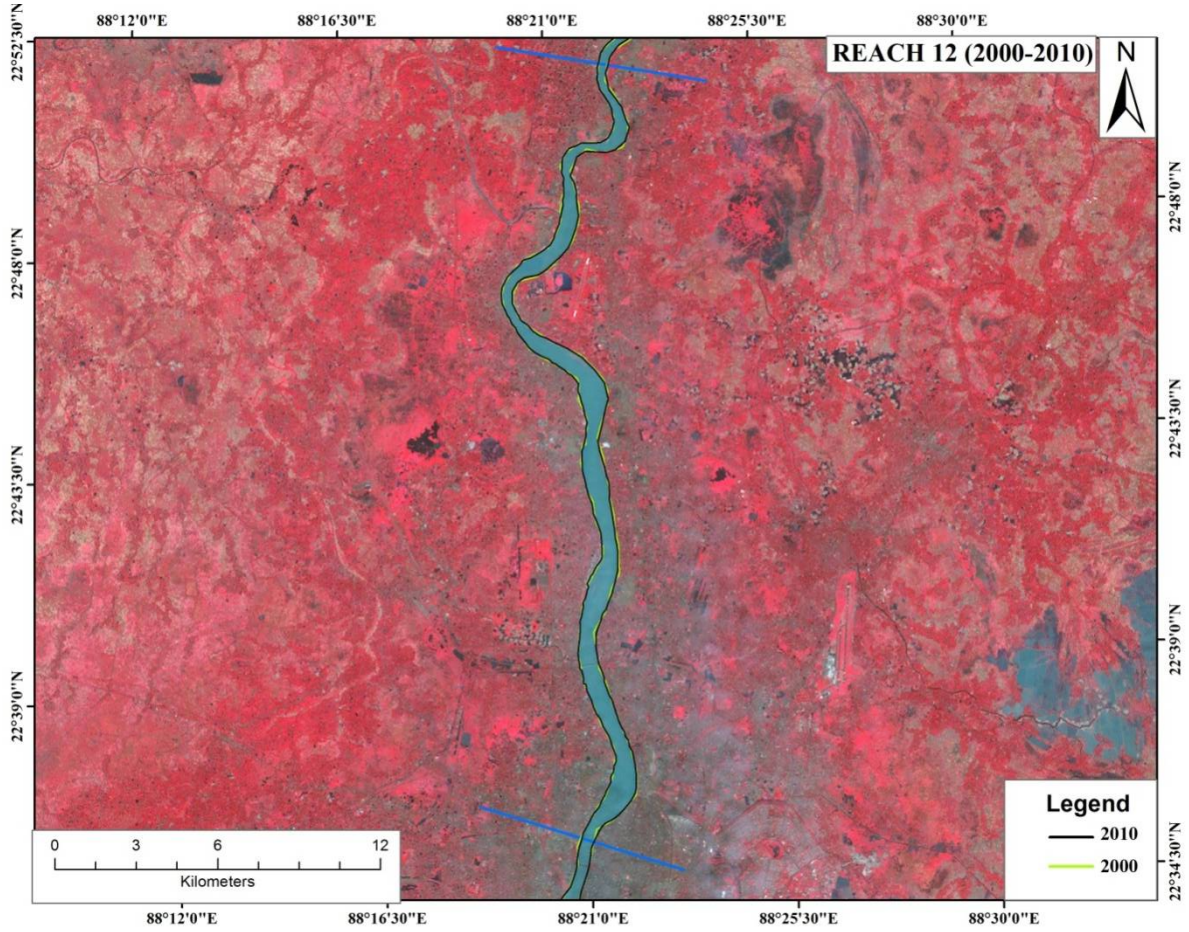


Figure 27.4: Changes in the course of Hooghly River of Year 2000-2010

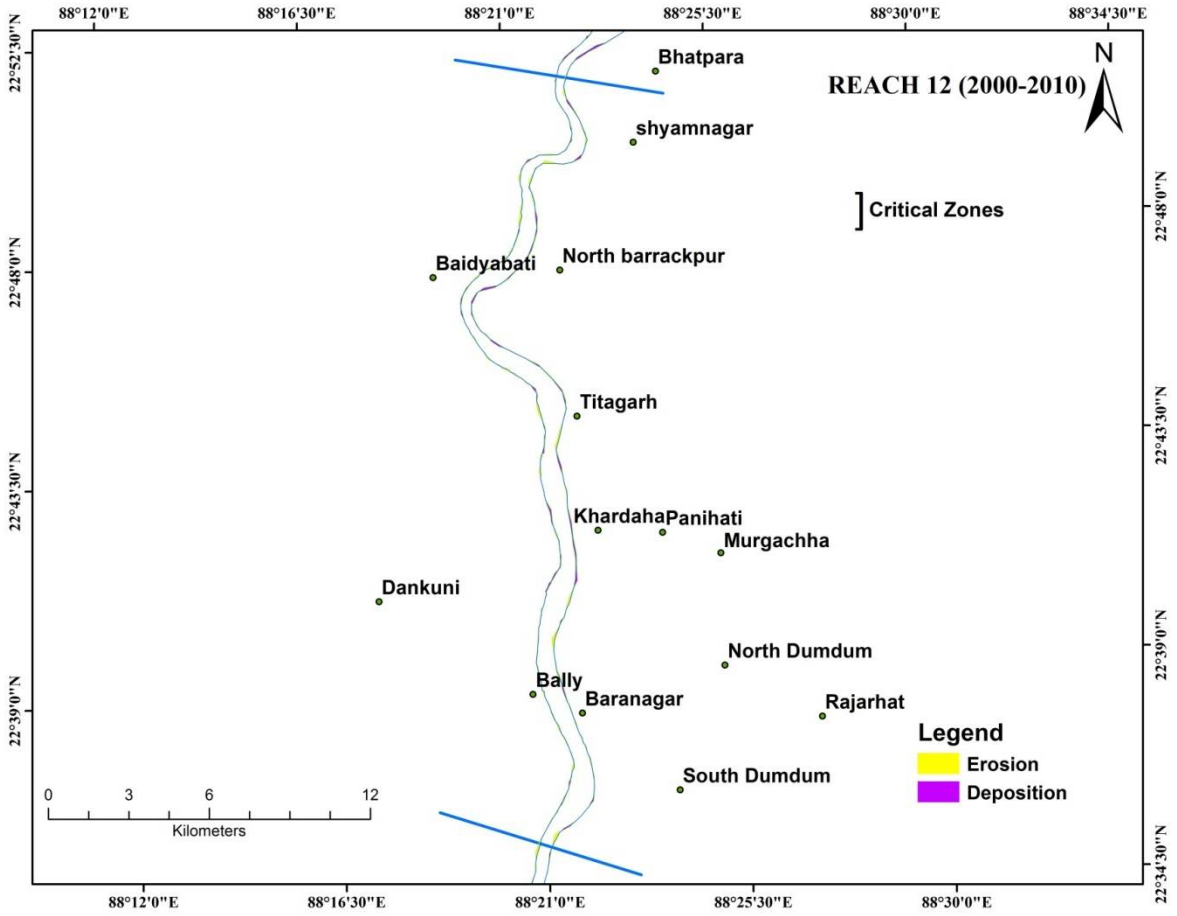


Figure 27.5: Identification of critical zones for Hooghly River of Year 2000-2010

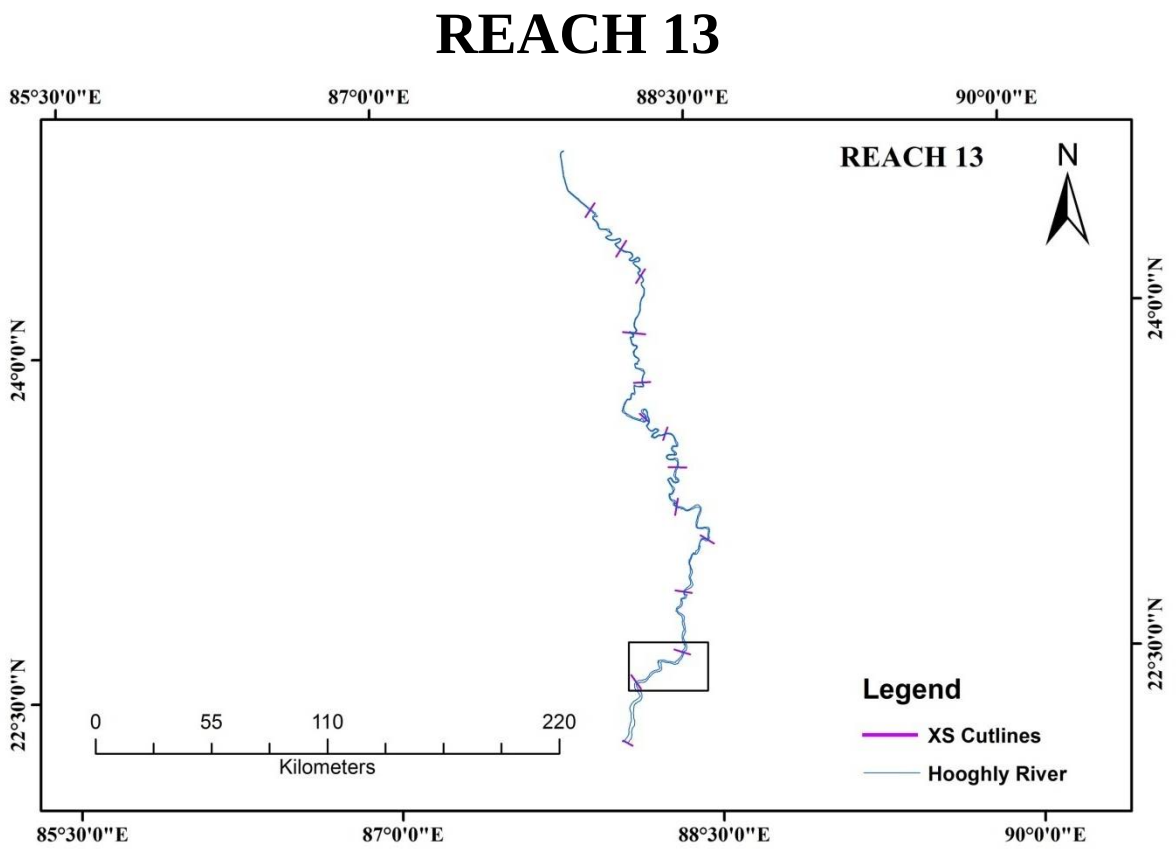


Figure 28: Location of reach number 13 in the Hooghly river

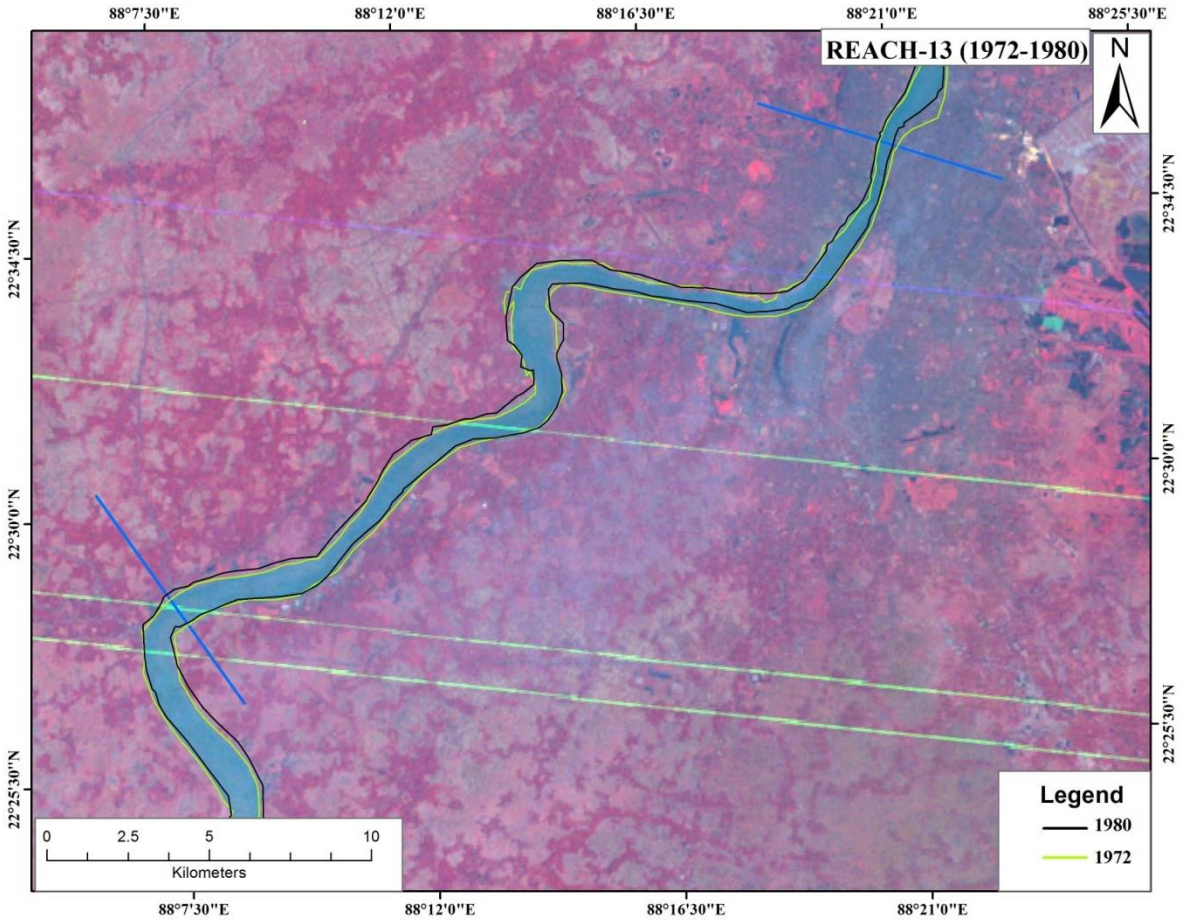


Figure 28.1: Changes in the course of Hooghly River of Year 1972-1980

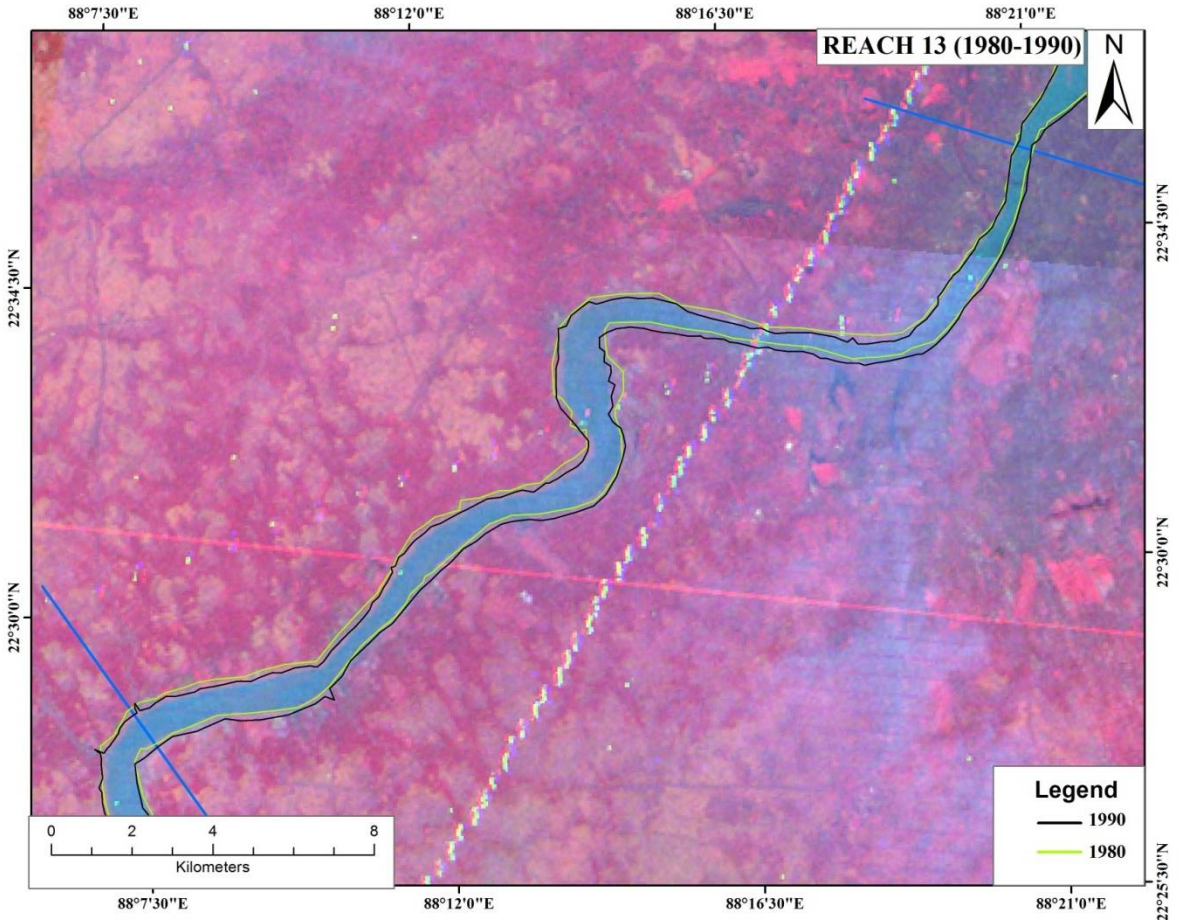


Figure 28.2: Changes in the course of Hooghly River of Year 1980-1990

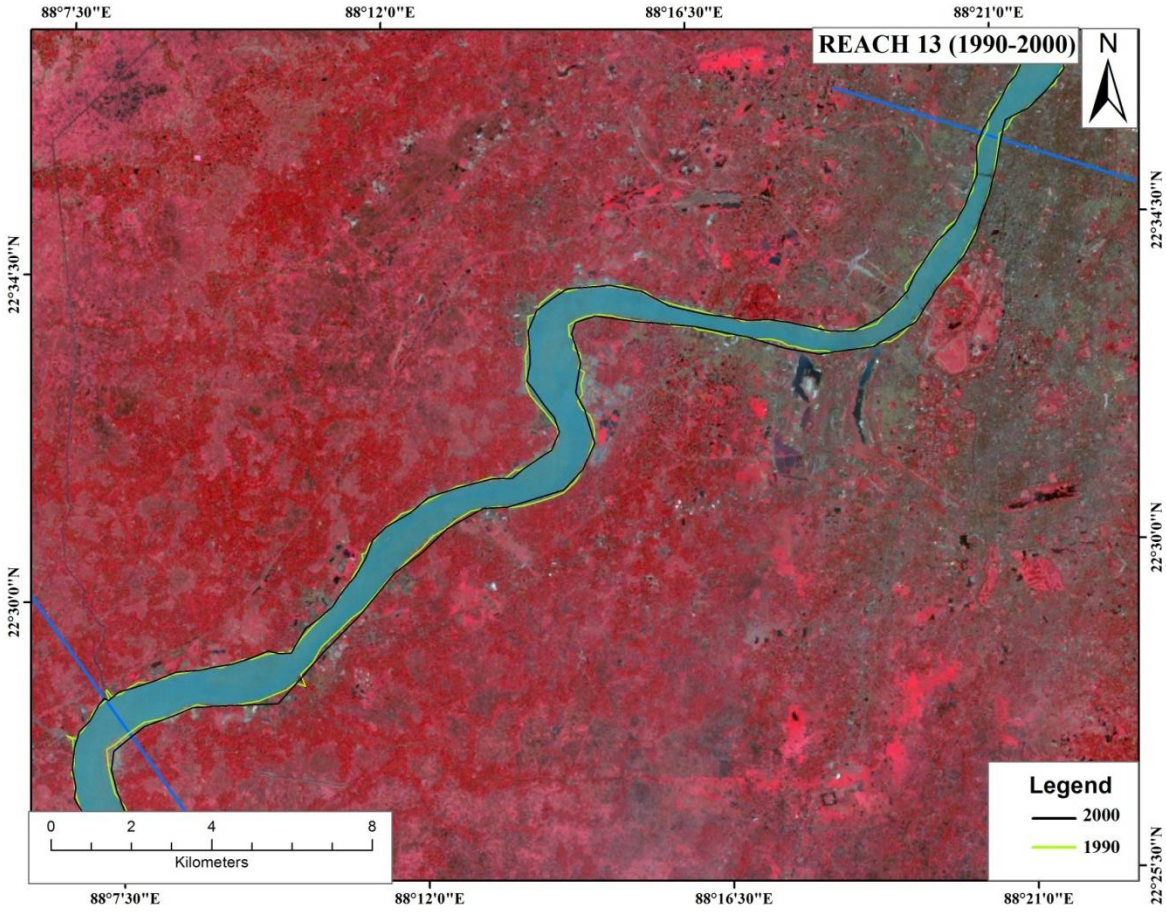


Figure 28.3: Changes in the course of Hooghly River of Year 1990-2000

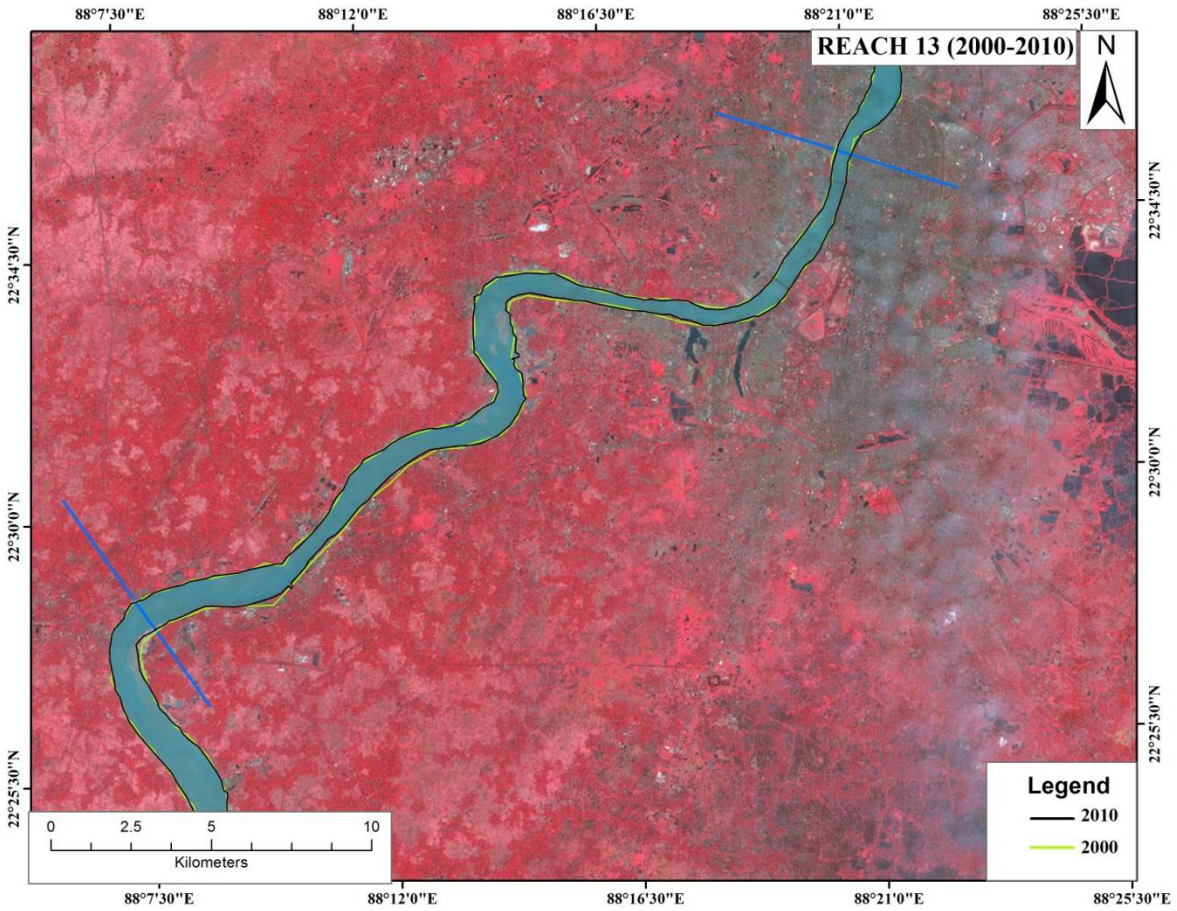


Figure 28.4: Changes in the course of Hooghly River of Year 2000-2010

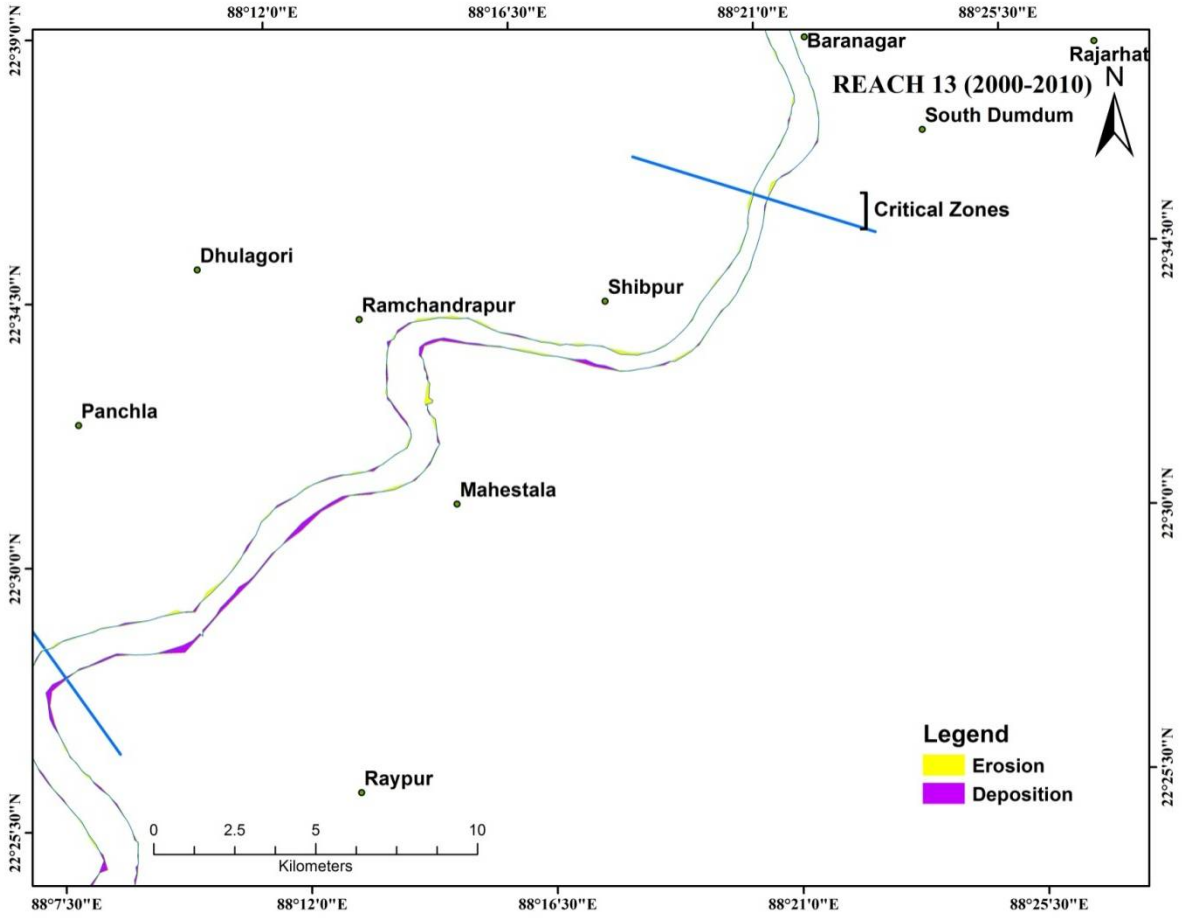


Figure 28.5: Identification of critical zones for Hooghly River of Year 2000-2010

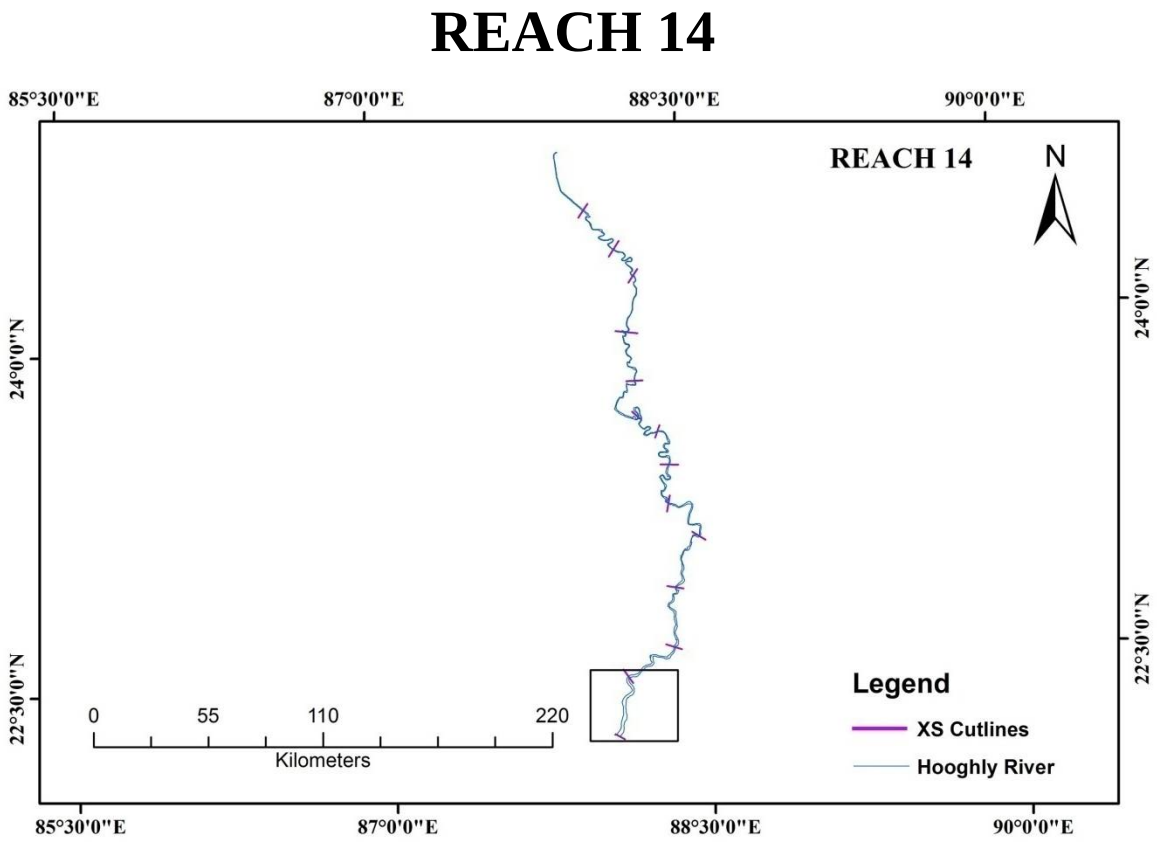


Figure 29: Location of reach number 14 in the Hooghly river

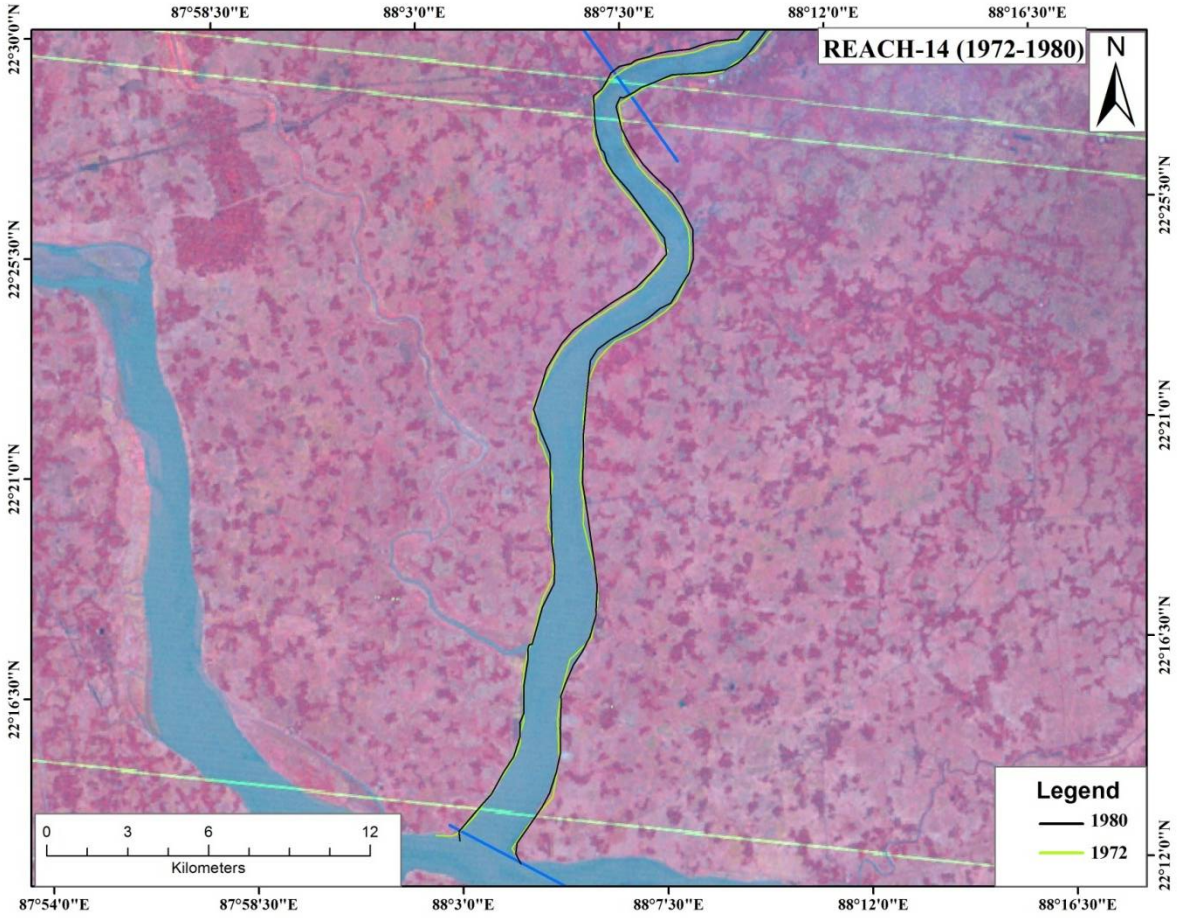


Figure 29.1: Changes in the course of Hooghly River of Year 1972-1980

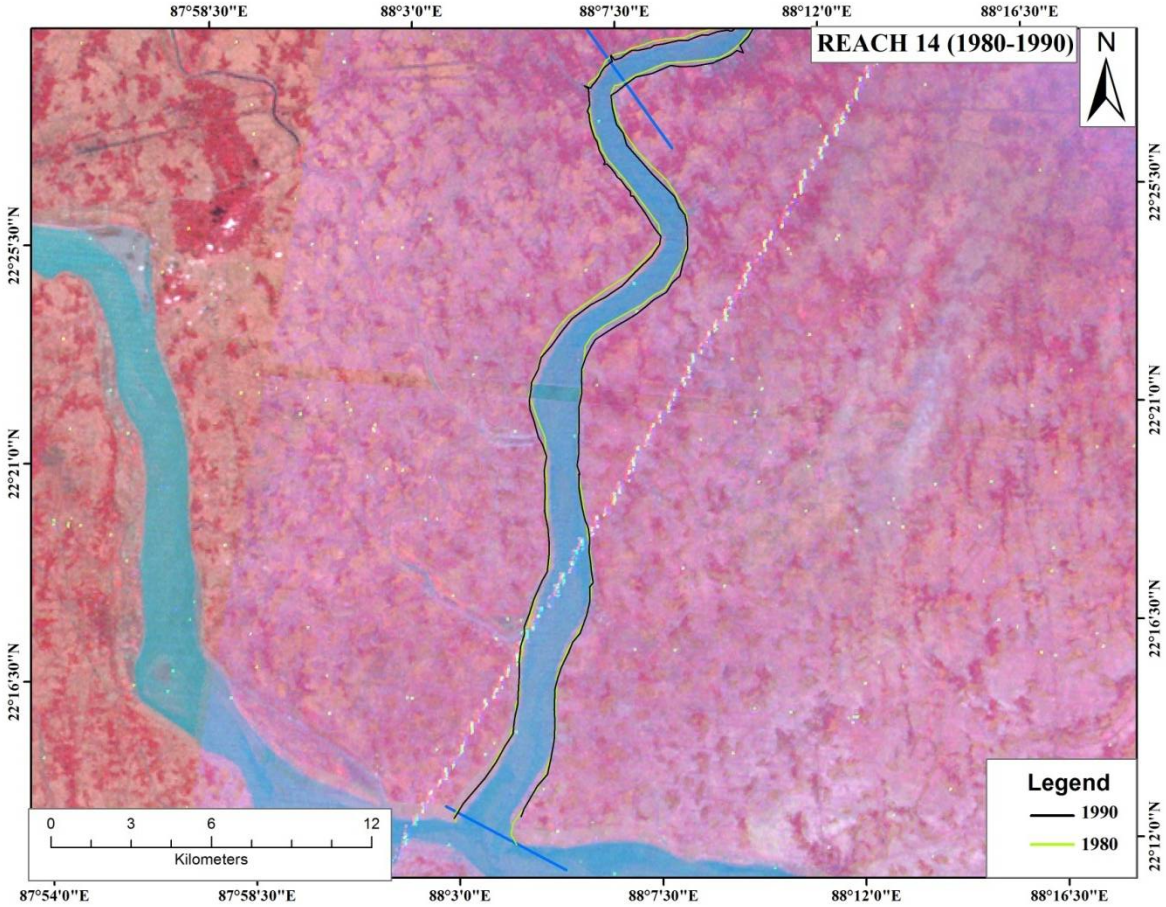


Figure 29.2: Changes in the course of Hooghly River of Year 1980-1990

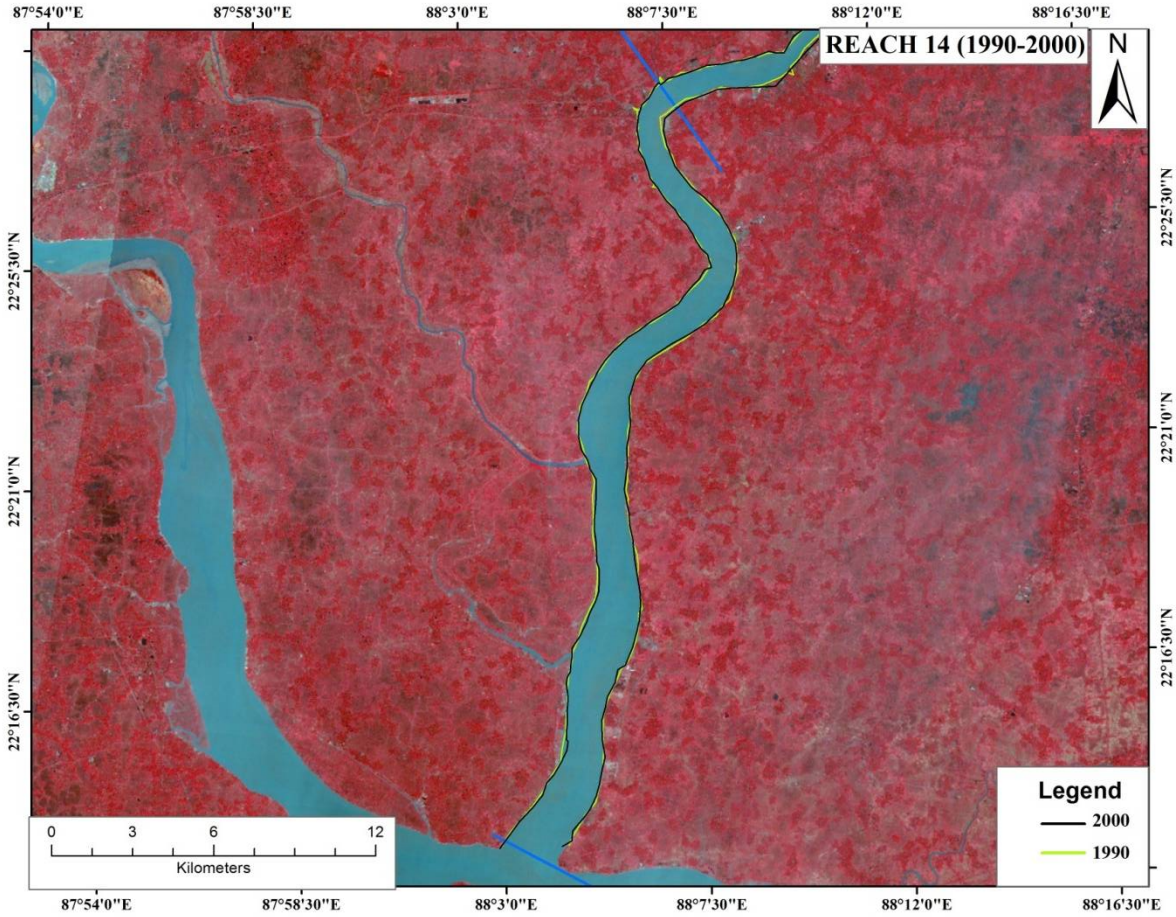


Figure 29.3: Changes in the course of Hooghly River of Year 1990-2000

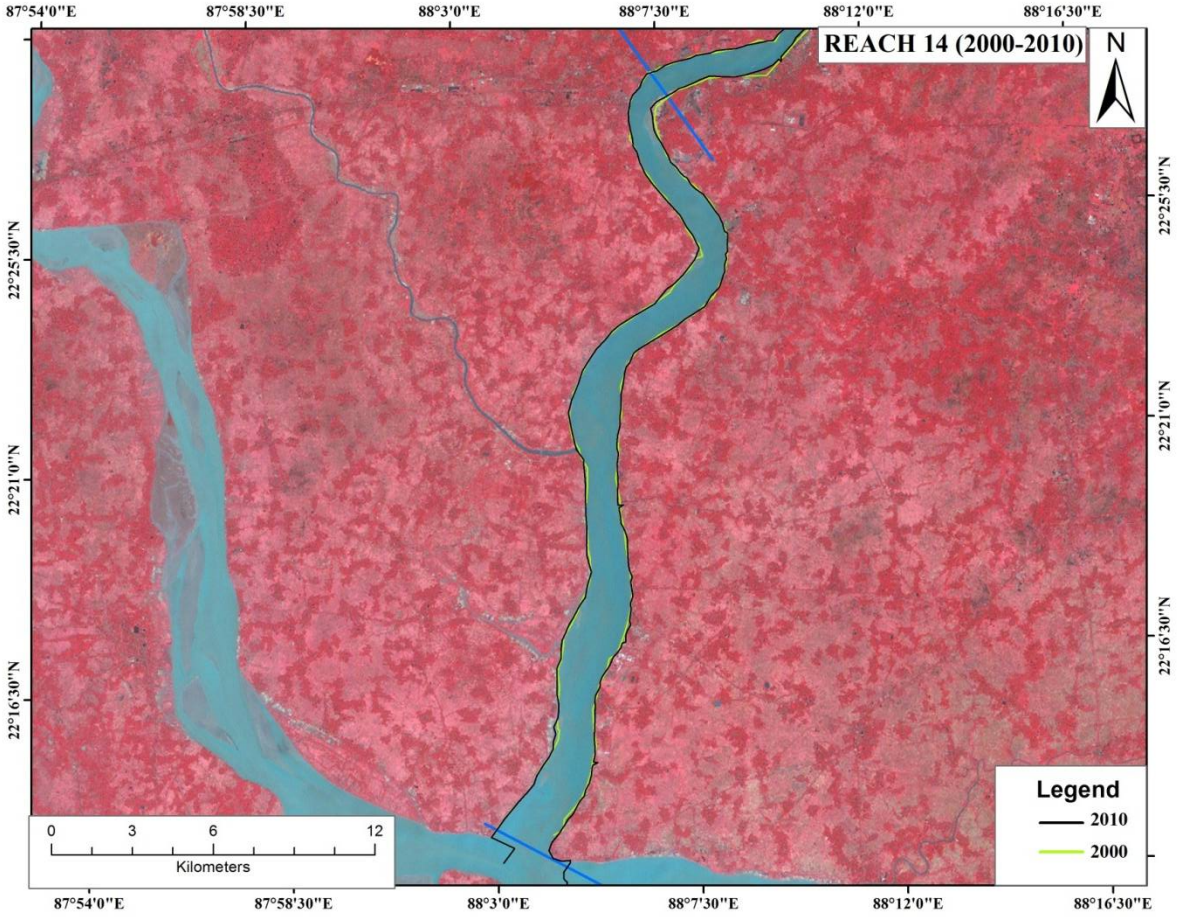


Figure 29.4: Changes in the course of Hooghly River of Year 2000-2010

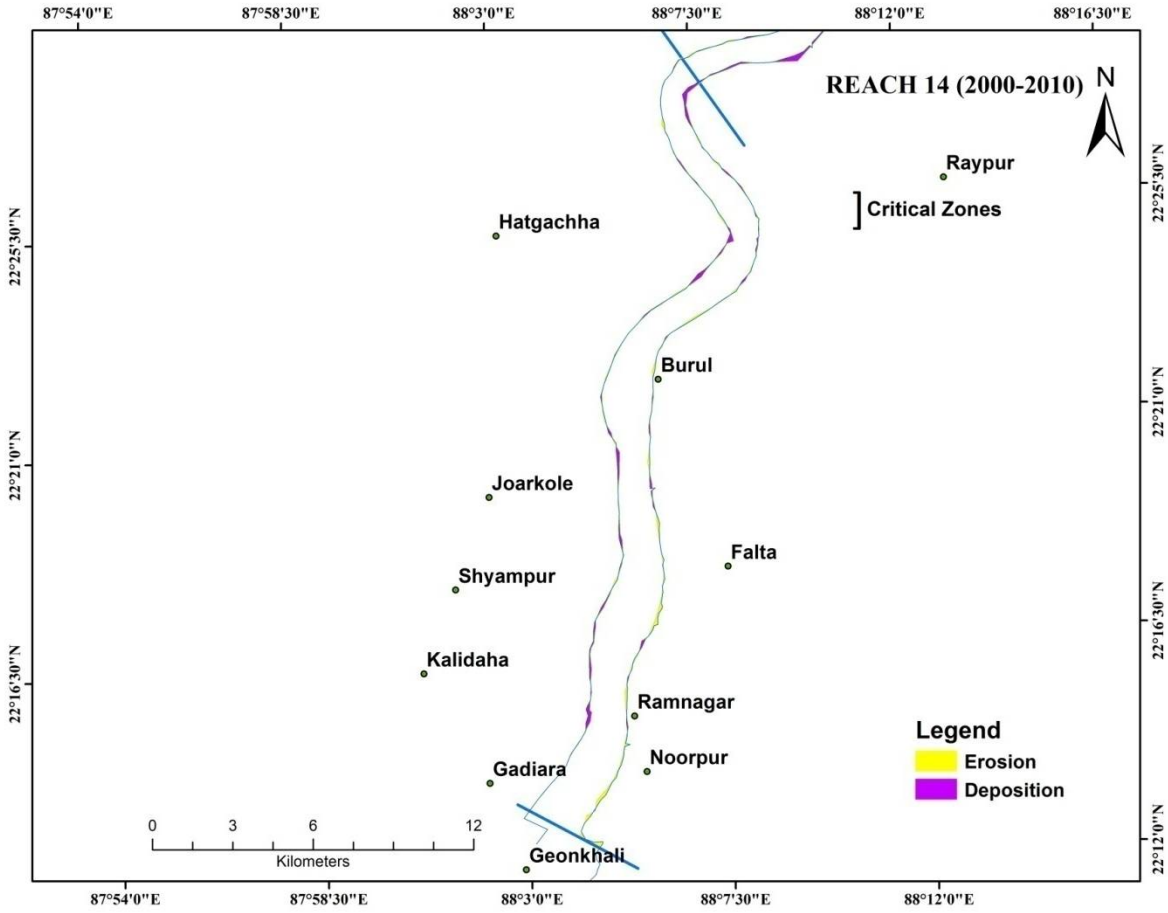


Figure 29.5: Identification of critical zones for Hooghly River of Year 2000-2010

5.11.Critical Reaches of Ganga (Farakka to Lalgola)

In section 5.10, the stretch of the river Hooghly (actually, Bhagirathi-Hooghly, as per local nomenclature) was analysed for critical reaches for the distributary of the river Ganga offtaking at Farakka and ending up towards its confluence with the Bay of Bengal near the Sagar Island. In this section, the stretch of the main river Ganga flowing down from the Farakka Barrage upto the international border with Bangladesh is analysed for any critical reaches. The methodology adopted, of course, is similar to that followed in section 5.10

Ganga river (Farakka to Lalgola) in Murshidabad and Malda district the lower portion of the river under Lalgola, Maia, Putia, Teghari, Jangipur, Rameswarpur, Ramkantapur, Sajinipara, Aurangha, Dhunsari and Suti blocks are observed to be in the highly critical zone. In this area of the river bank erosion is within high-risk zone and flood affected. Detailed information of reaches is shown in Figure 30 to 30.5.

REACH

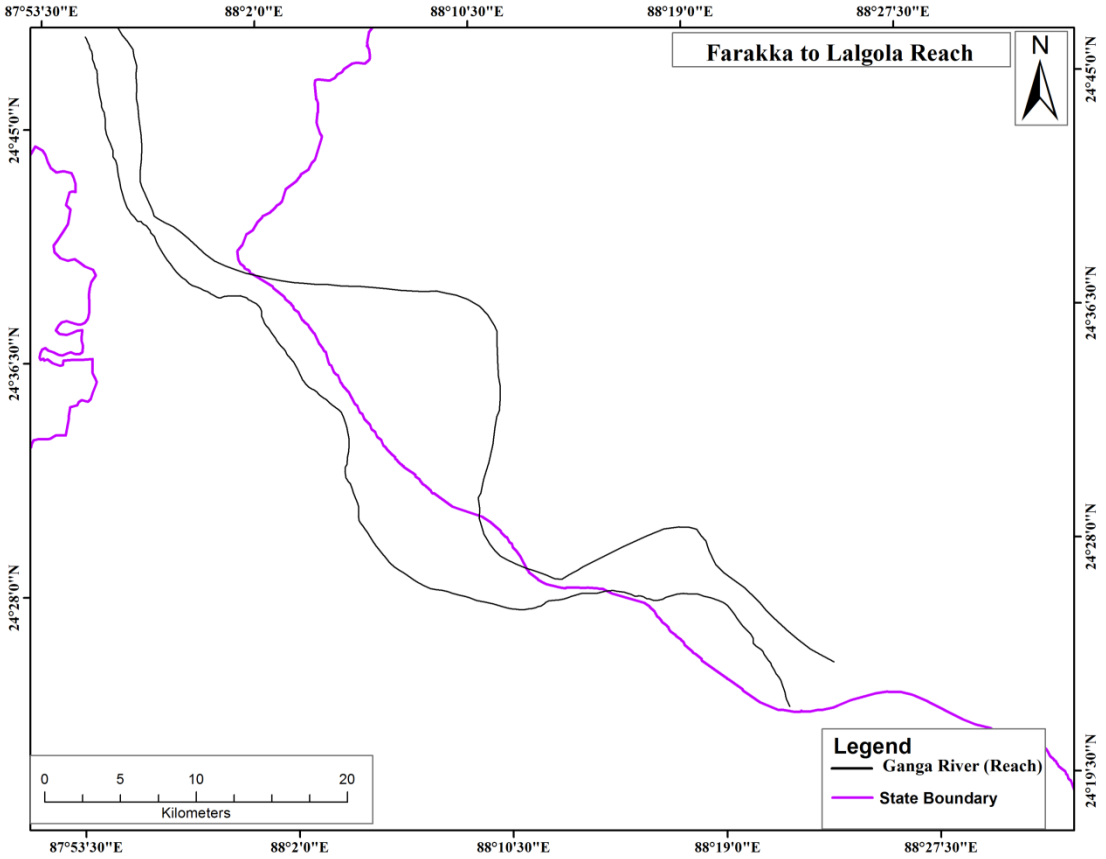


Figure 30: Location of reach in the Ganga river

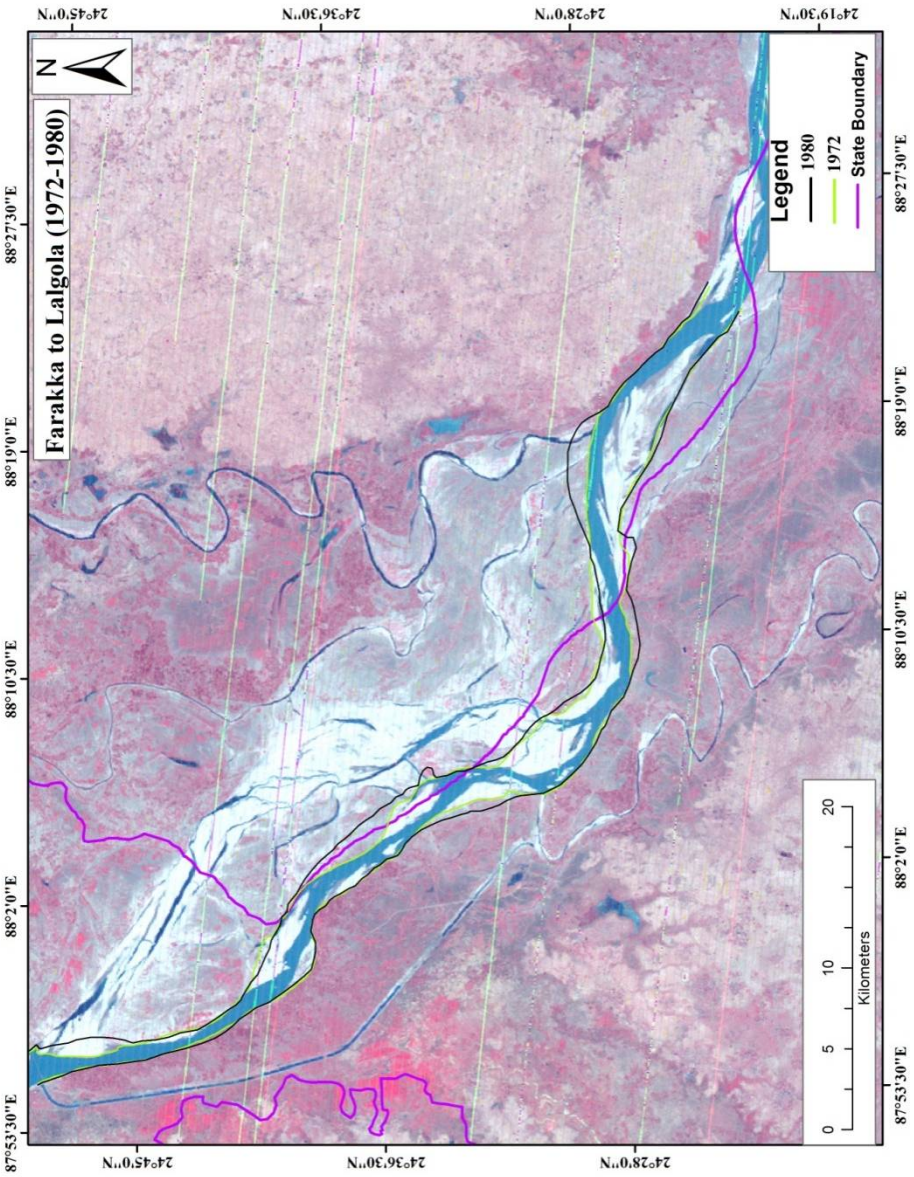


Figure 30.1: Changes in the course of Ganga River of Year 1972-1980

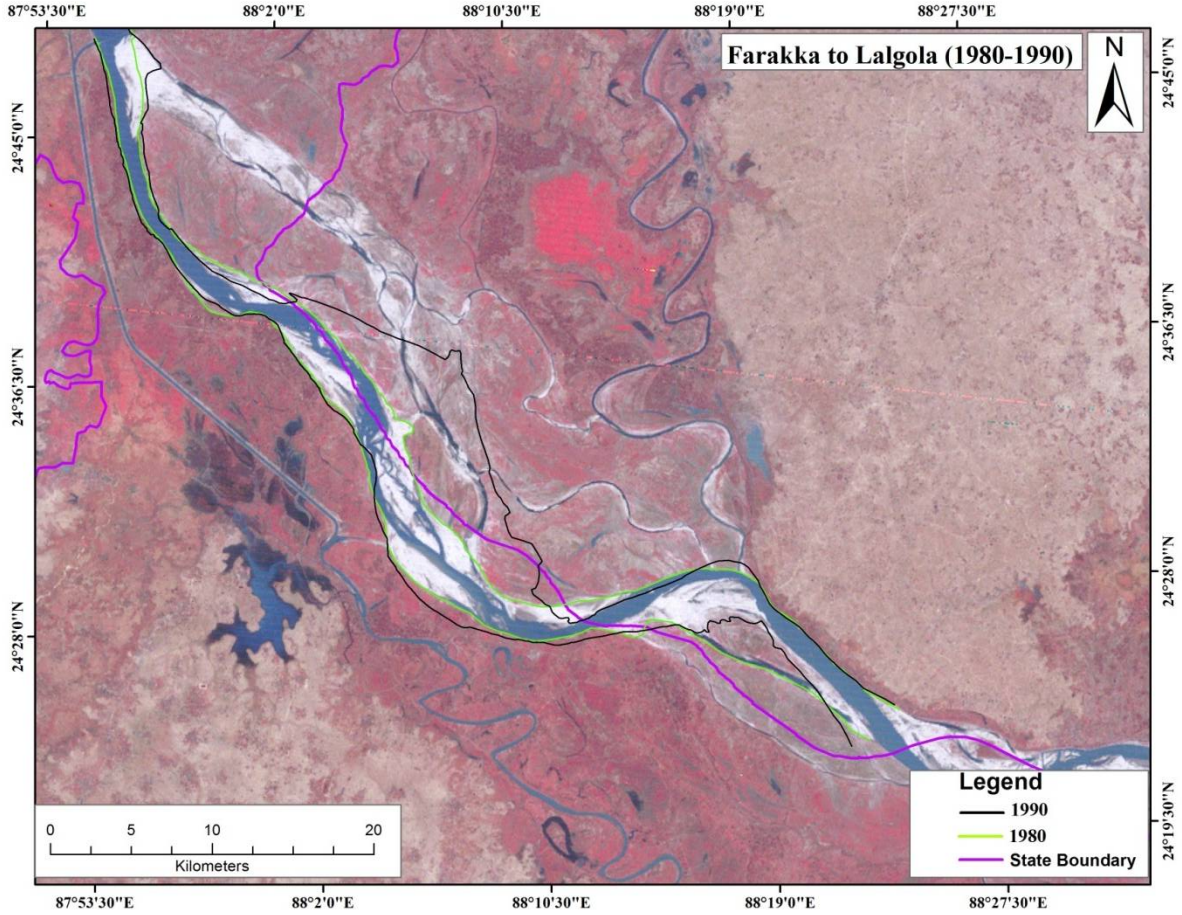


Figure 30.2: Changes in the course of Ganga River of Year 1980-1990

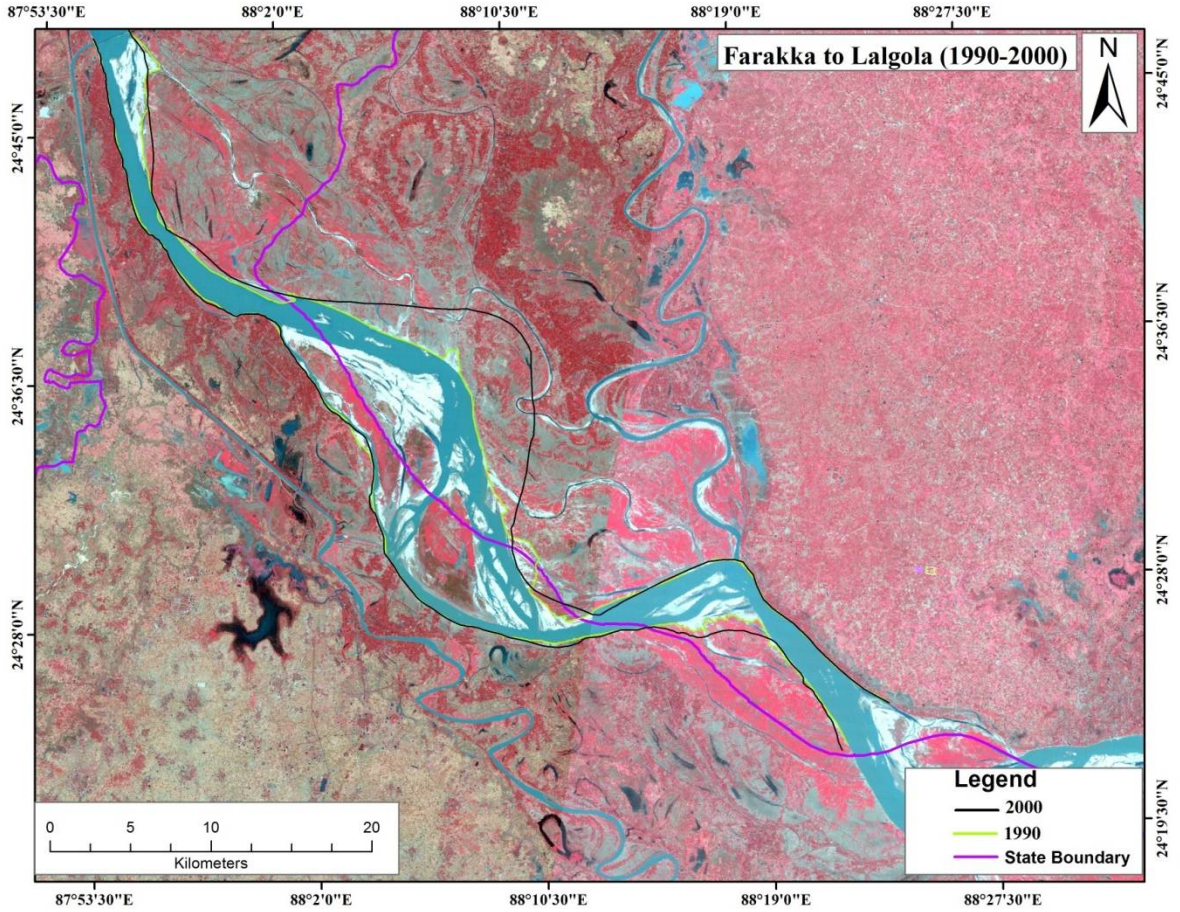


Figure 30.3: Changes in the course of Ganga River of Year 1990-2000

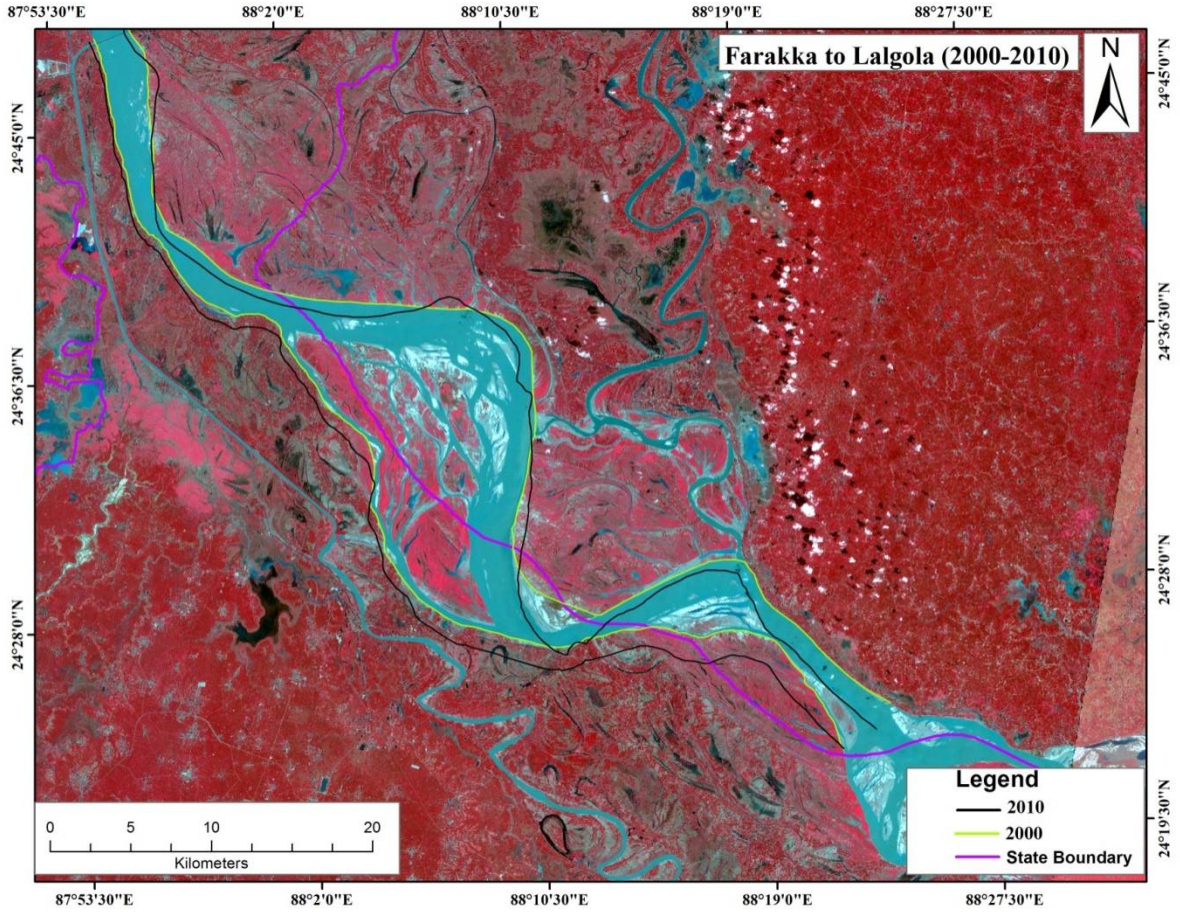


Figure 30.4: Changes in the course of Ganga River of Year 2000-2010

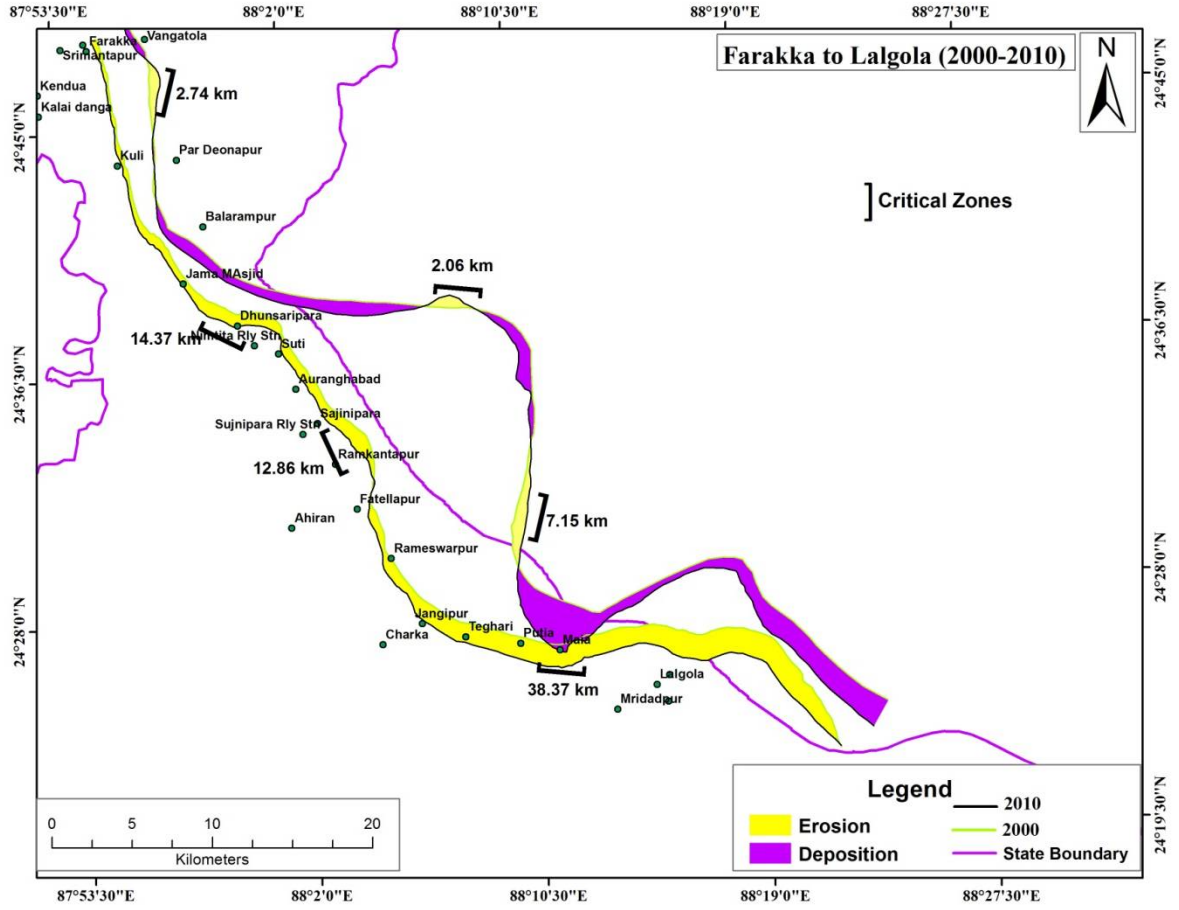


Figure 30.5: Identification of critical zones for Ganga River of Year 2000-2010

5.12. Site suitability for river sand mining:

Sand mining is an anthropogenic activity referring to the process of the excavation and removal of sand from the foreshore including rivers, streams and lakes. Sand is mined from beaches and inland dunes and dredged from ocean beds and river beds. A related process is the mining of mineral sands, such as mineral deposits like diamond, gold and silver. These minerals typically occur combined with ordinary sand. The sand is dug up, the valuable minerals are separated in water by using their different density, and the remaining ordinary sand is re-deposited.

Excessive in-stream sand-and-gravel mining causes the degradation of rivers. In-stream mining lowers the stream bottom, which may lead to bank erosion. Depletion of sand in the stream bed and along coastal areas causes the deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets. It may also lead to saline-water intrusion from the nearby sea. The effect of mining is compounded by the effect of sea level rise. Any volume of sand exported from stream beds and coastal areas is a loss to the system. It is also a threat to bridges, river banks and nearby structures. Sand mining also affects the adjoining groundwater system and the uses that local people make on the river.

In the morphological study of the Hooghly River, covering a total of 14 reaches were also analyzed for sand mining activities. The Hooghly River in the districts of Murshidabad, Nadia, Hooghly, and Braddhaman in the middle portion of the river covering the Blocks of Raghunathganj, Kasiadanga, Sujapur, Satui, Bazarsaw, Sompara, Naliapur, Katwa, Dhramatala, Agradwip, Patuli, Mayapur, Hastimla, Kina, Balagarh and Raghunathpur are seen to be highly susceptible to river sand mining (Figures 31.1 to 31.14). Field-based observations are also carried out to ascertain first hand the sand mining activities at certain chosen locations.

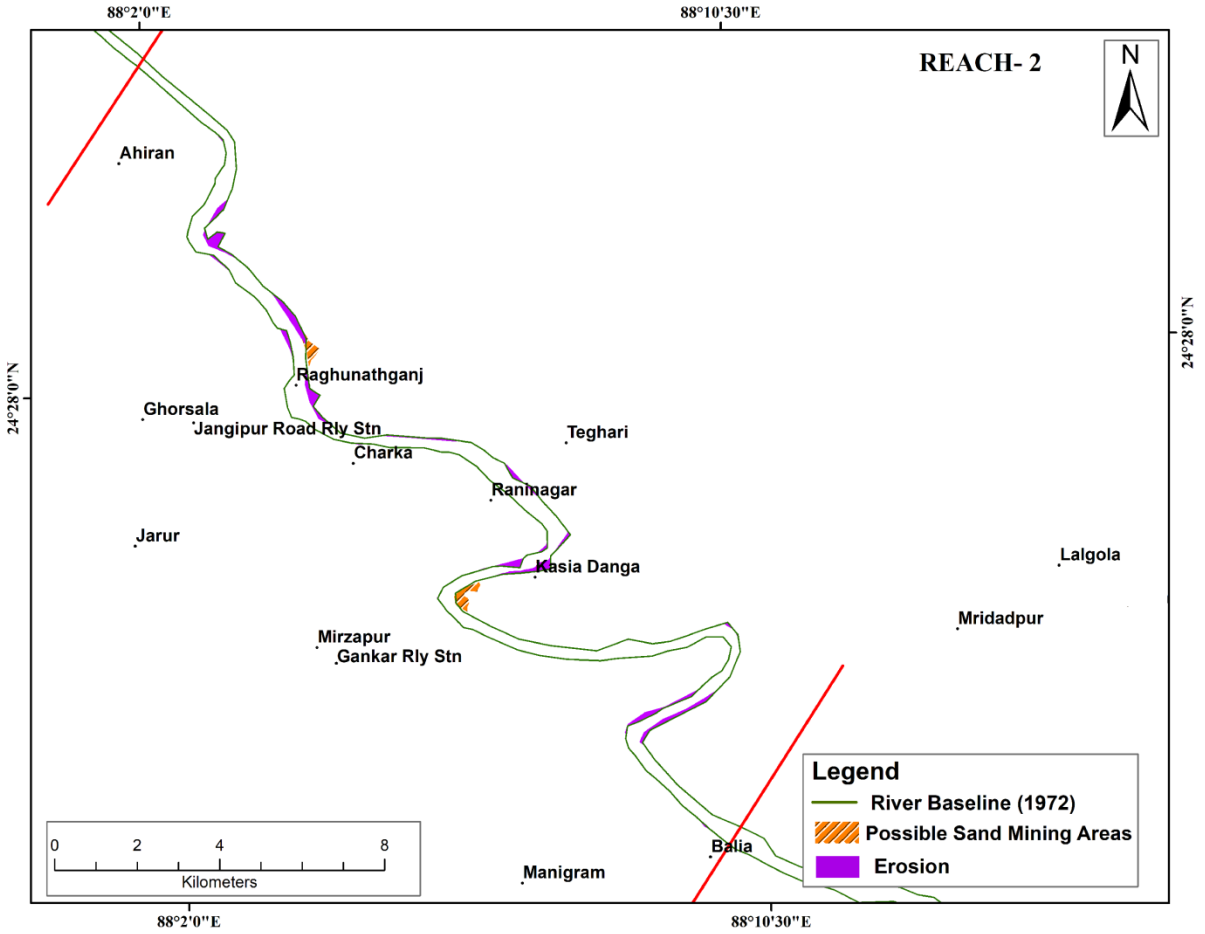


Figure 31.1: Identification of Posssible sand mining for Hooghl River Reach-2

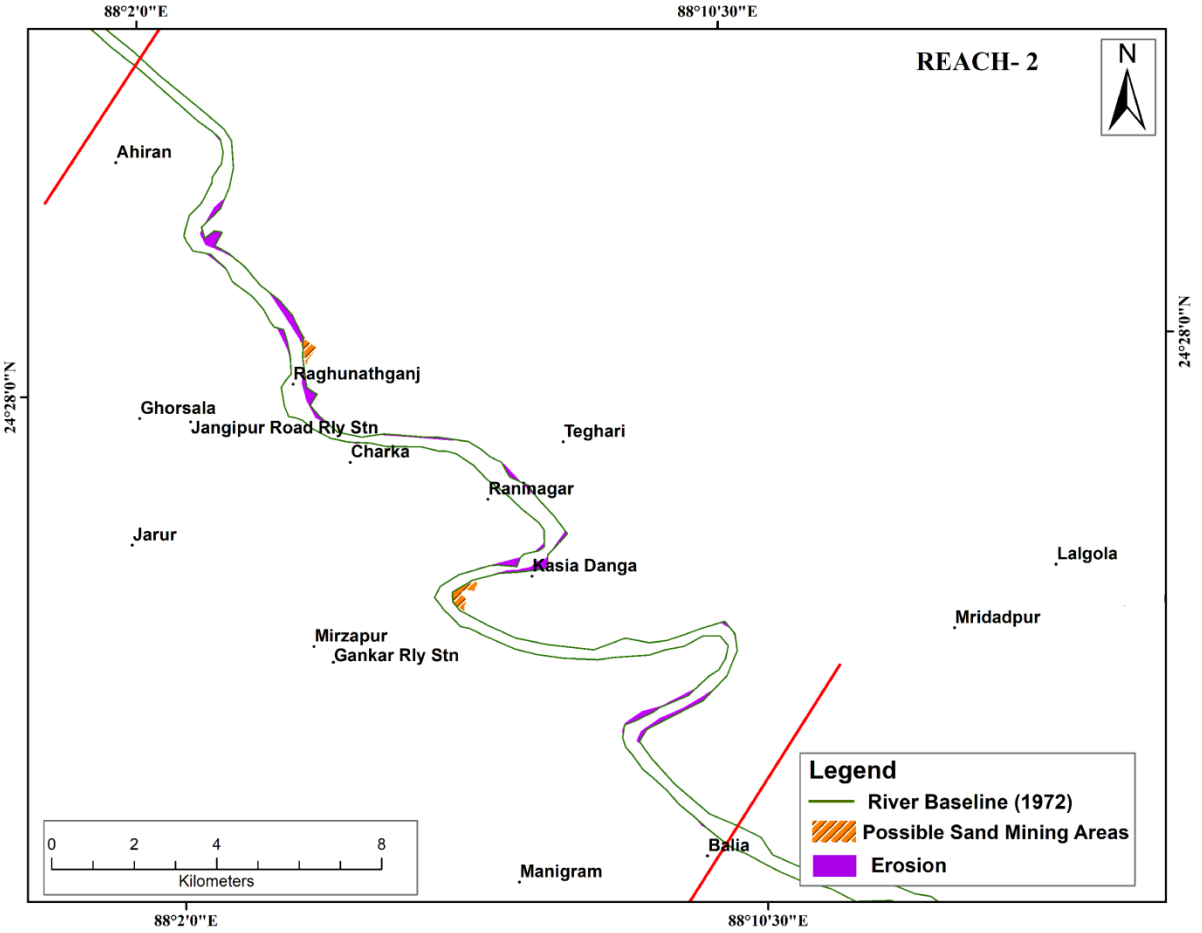


Figure 31.2: Identification of Posssible sand mining for Hooghl River Reach-2

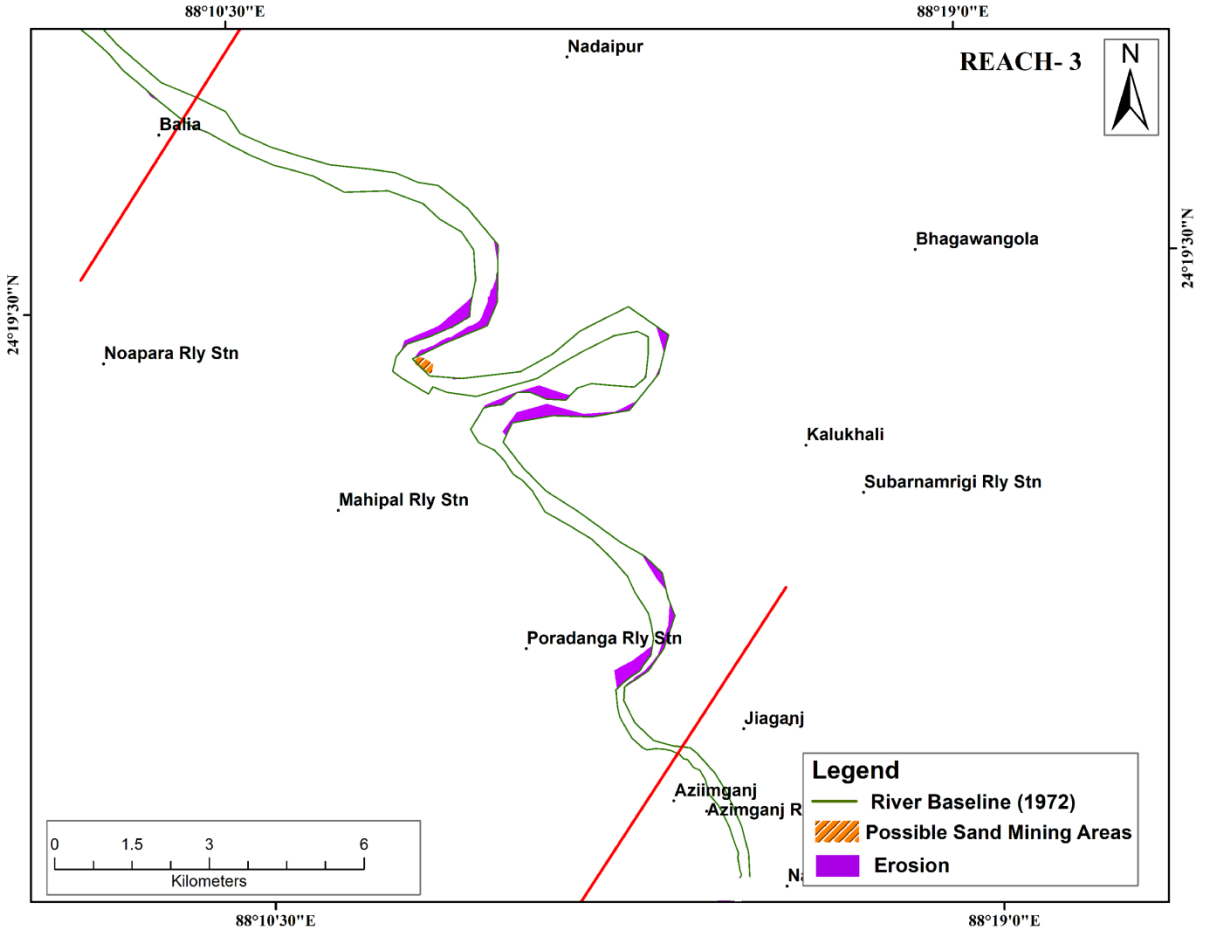


Figure 31.3: Identification of Posssible sand mining for Hooghl River Reach-3

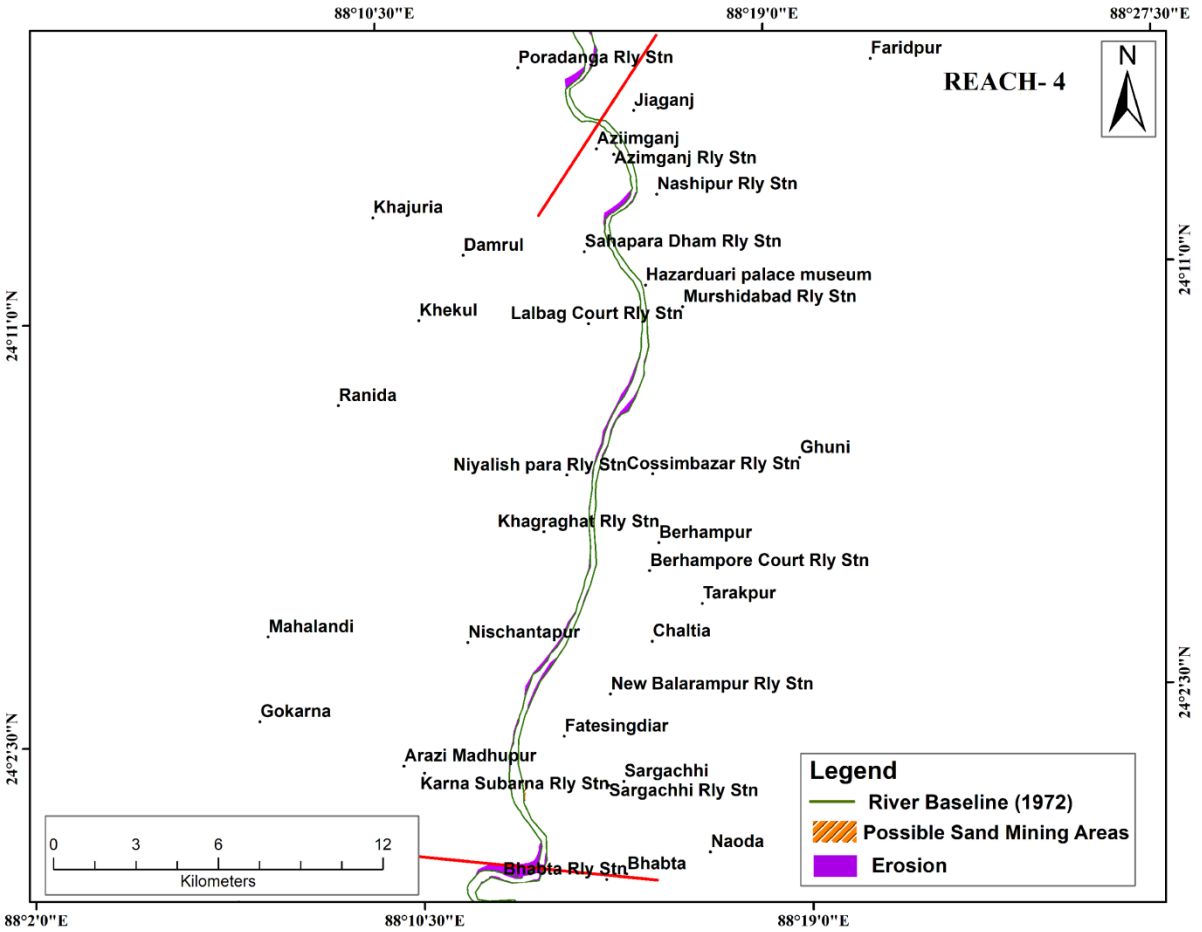


Figure 31.4: Identification of Posssible sand mining for Hooghl River Reach-4

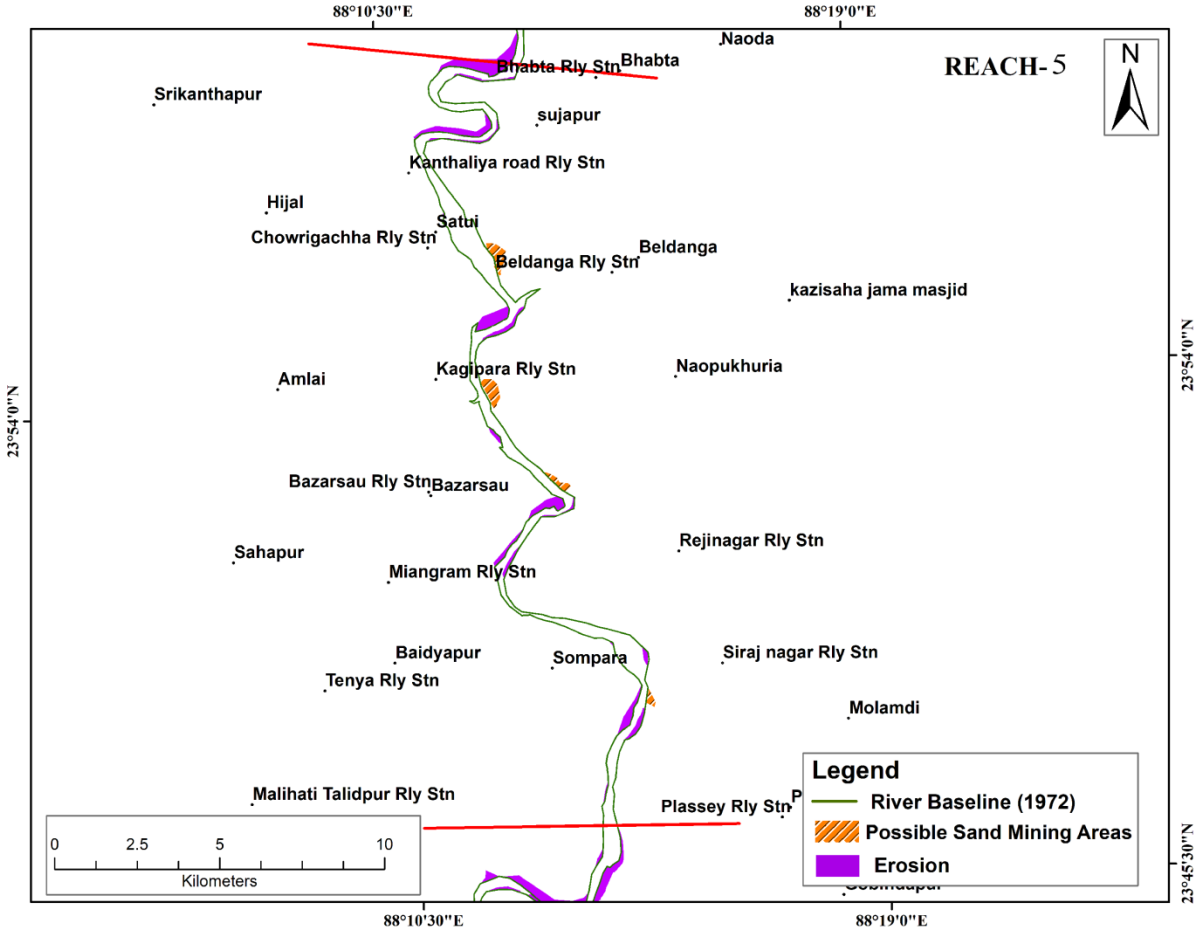


Figure 31.5: Identification of Posssible sand mining for Hooghl River Reach-5

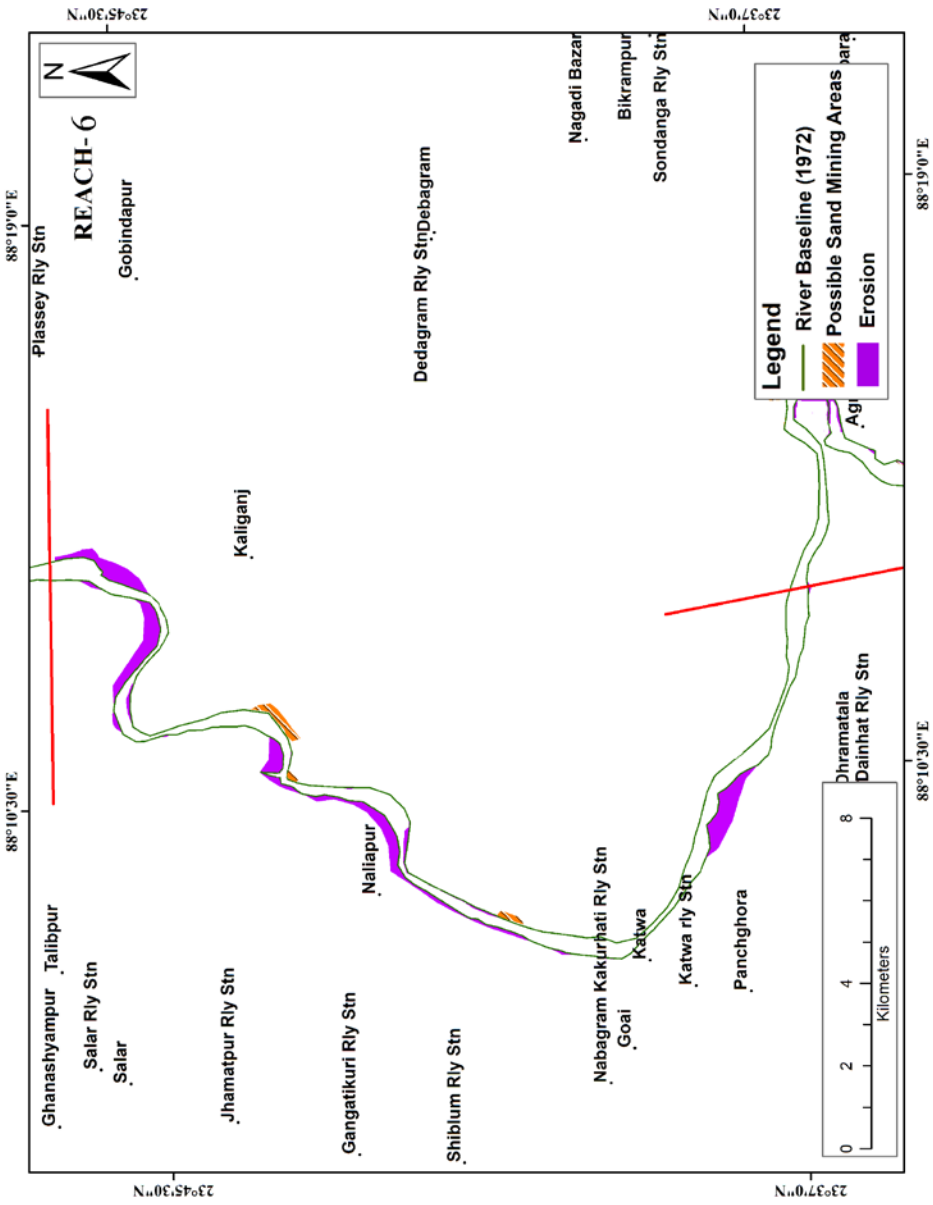


Figure 31.6: Identification of Possible sand mining for Hooghl River Reach-6

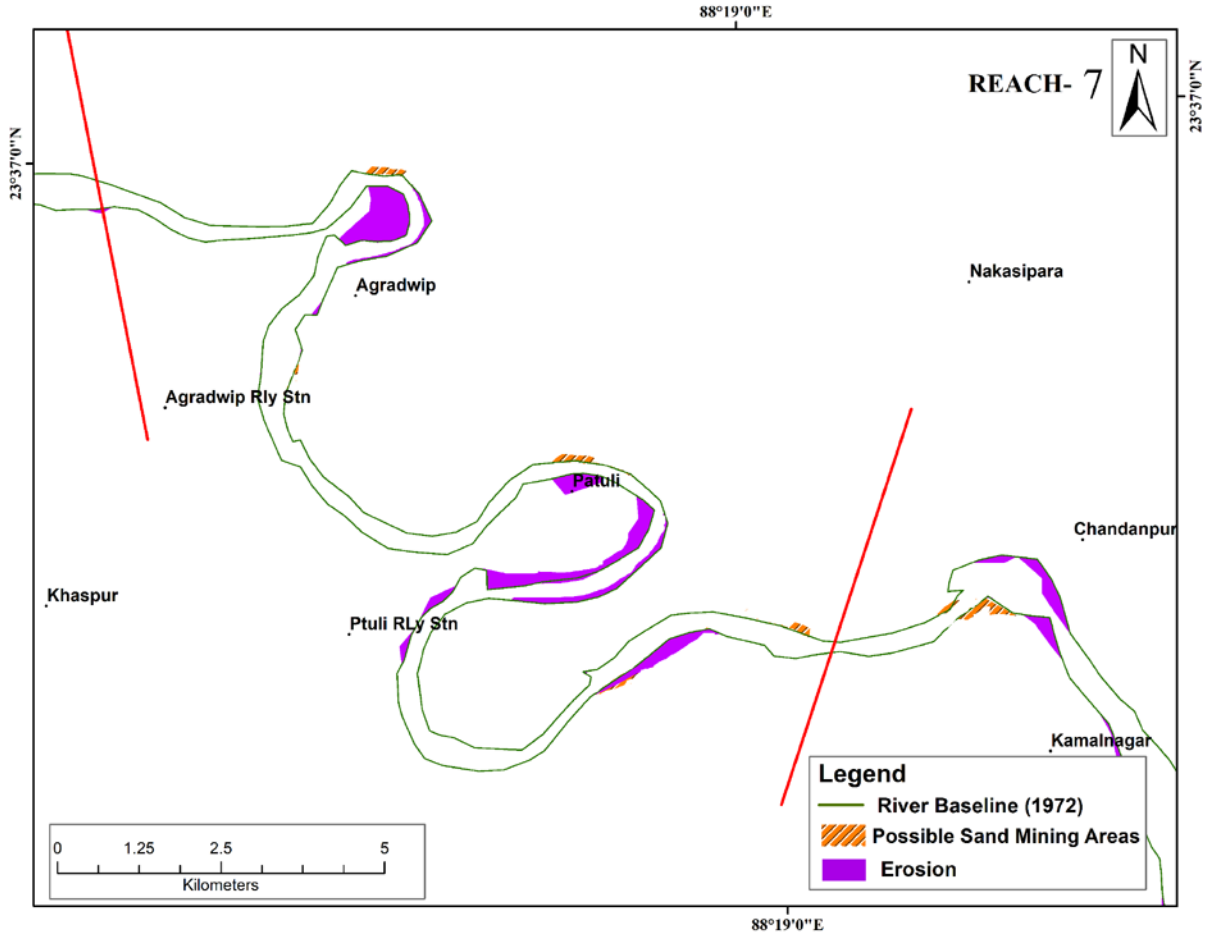


Figure 31.7: Identification of Posssible sand mining for Hooghl River Reach-7

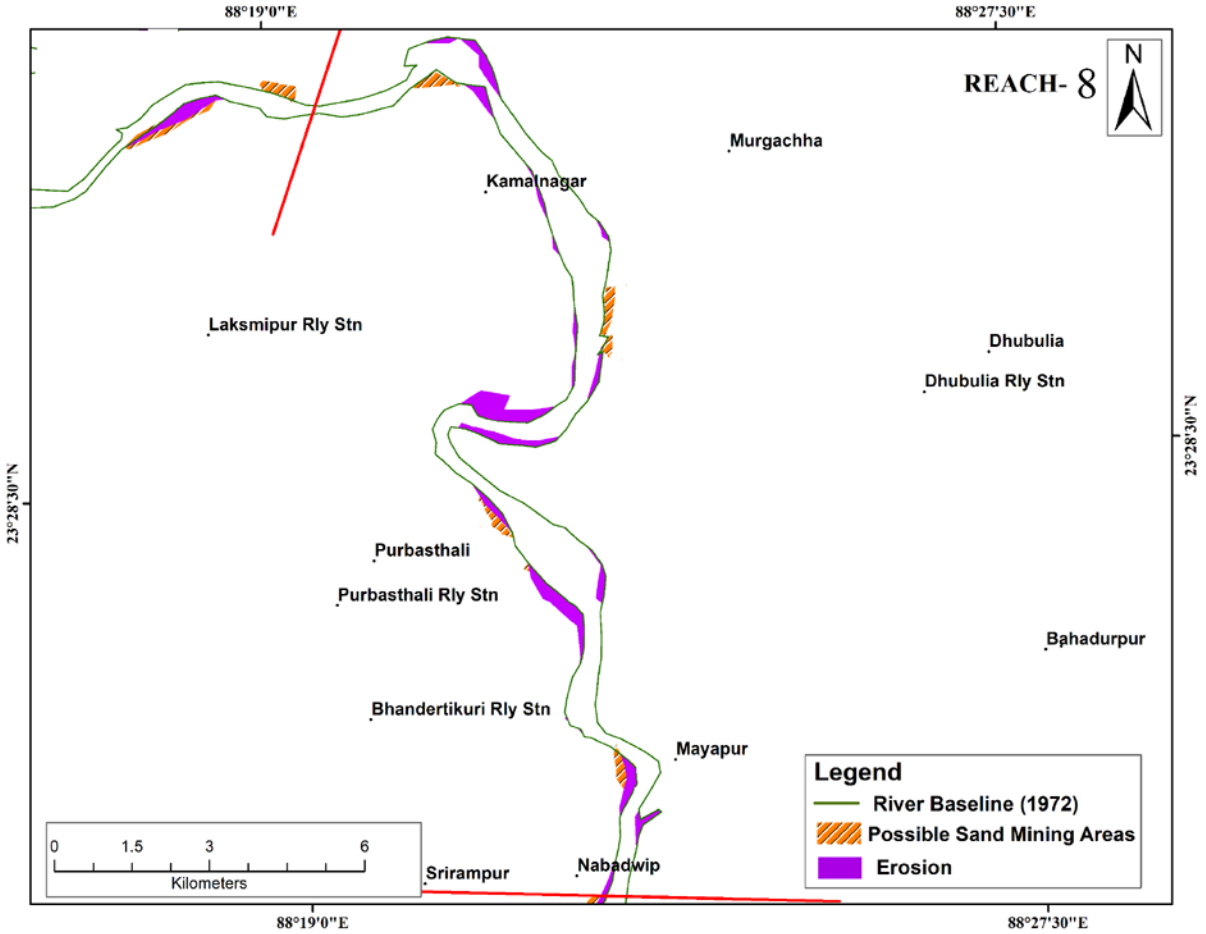


Figure 31.8: Identification of Posssible sand mining for Hooghl River Reach-8

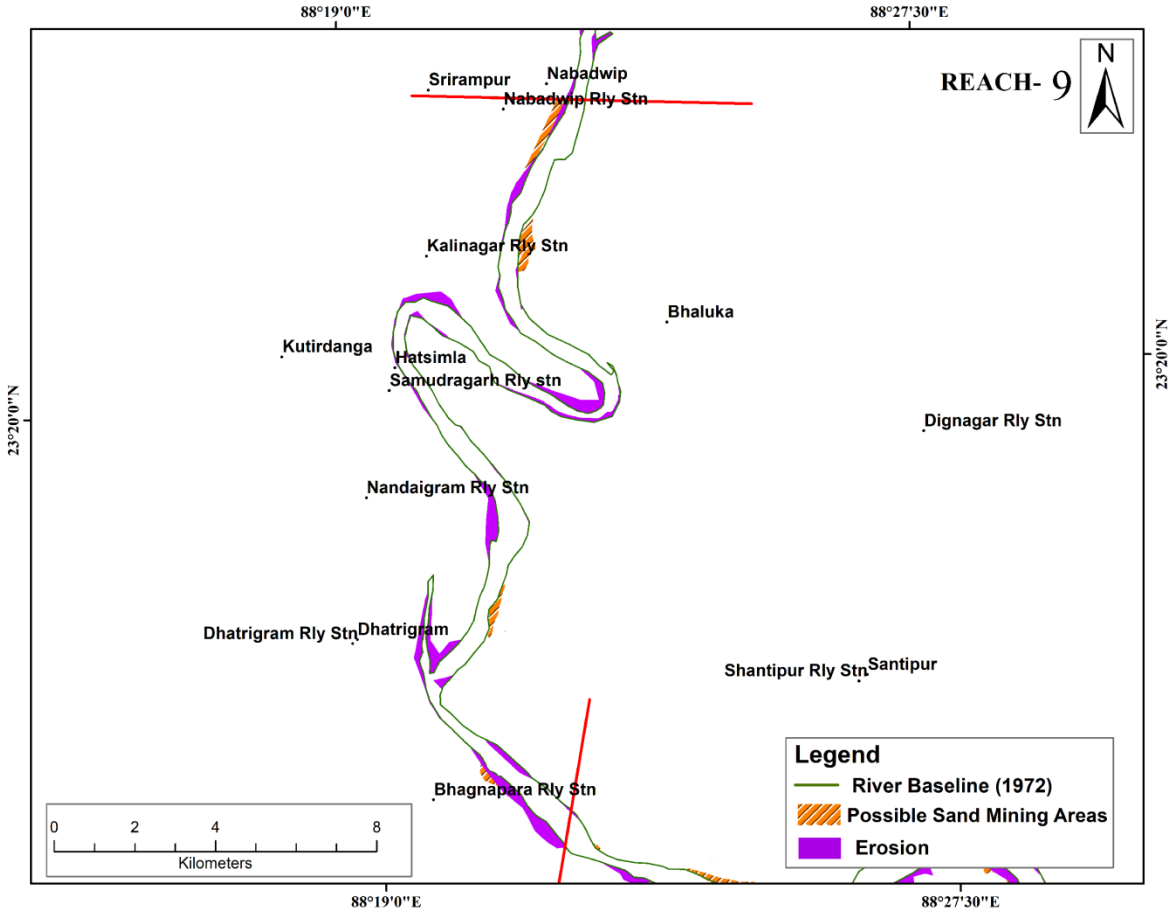


Figure 31.9: Identification of Posssible sand mining for Hooghl River Reach-9

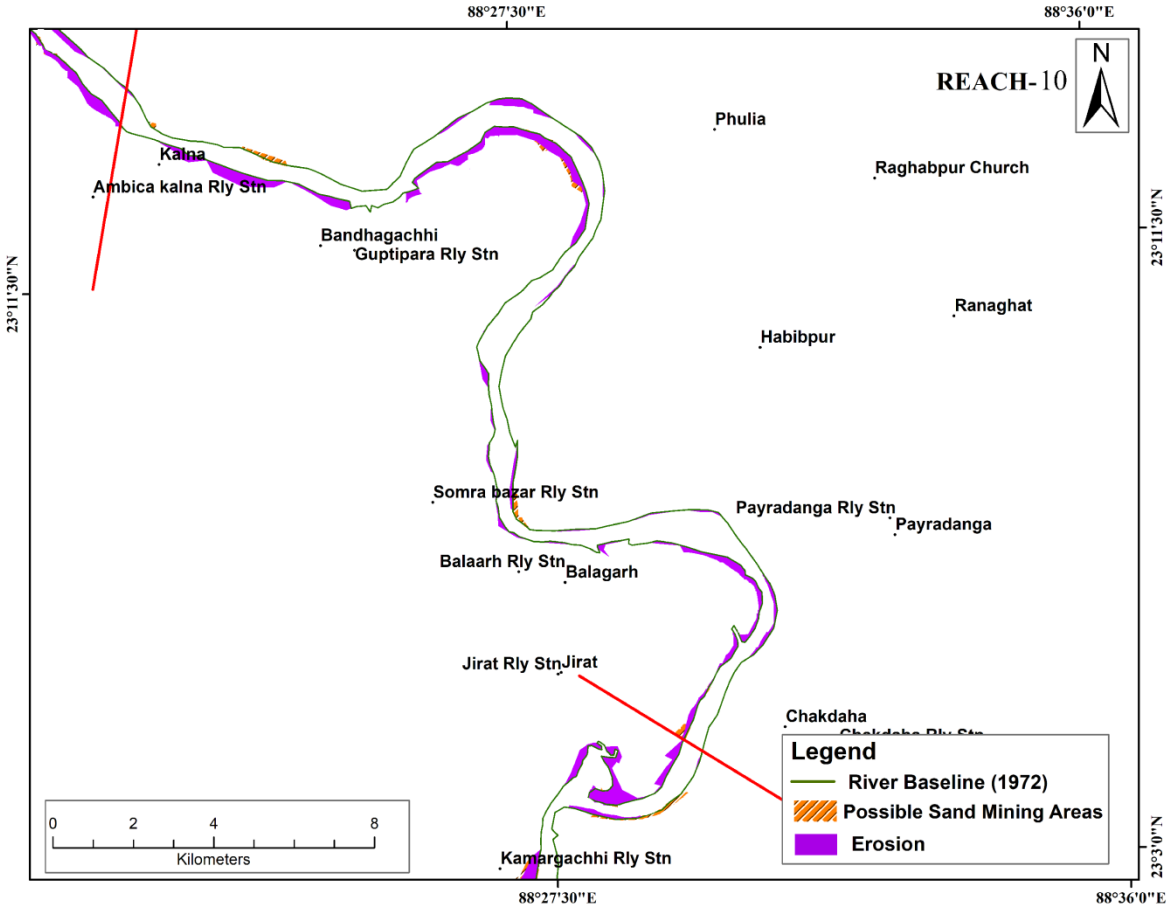


Figure 31.10: Identification of Posssible sand mining for Hooghl River Reach-10

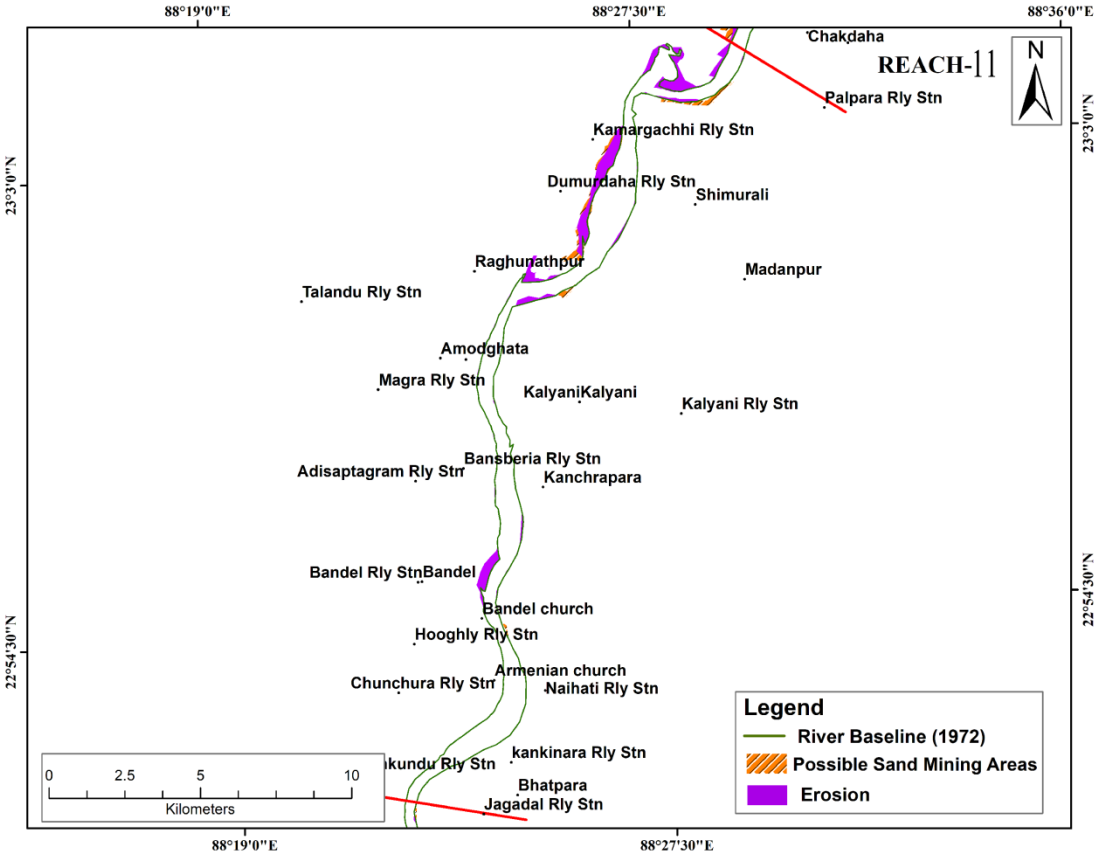


Figure 31.11: Identification of Posssible sand mining for Hooghl River Reach-11

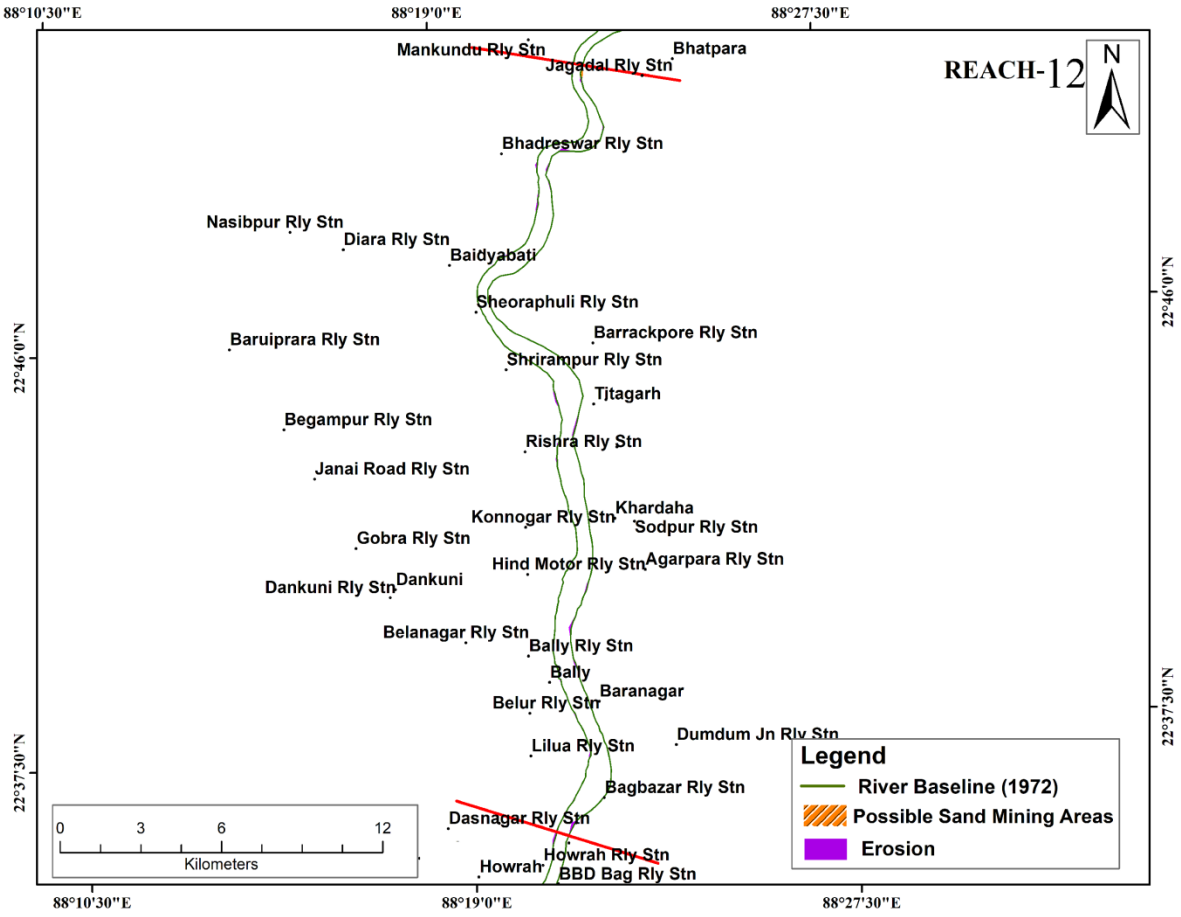


Figure 31.12: Identification of Posssible sand mining for Hooghl River Reach-12

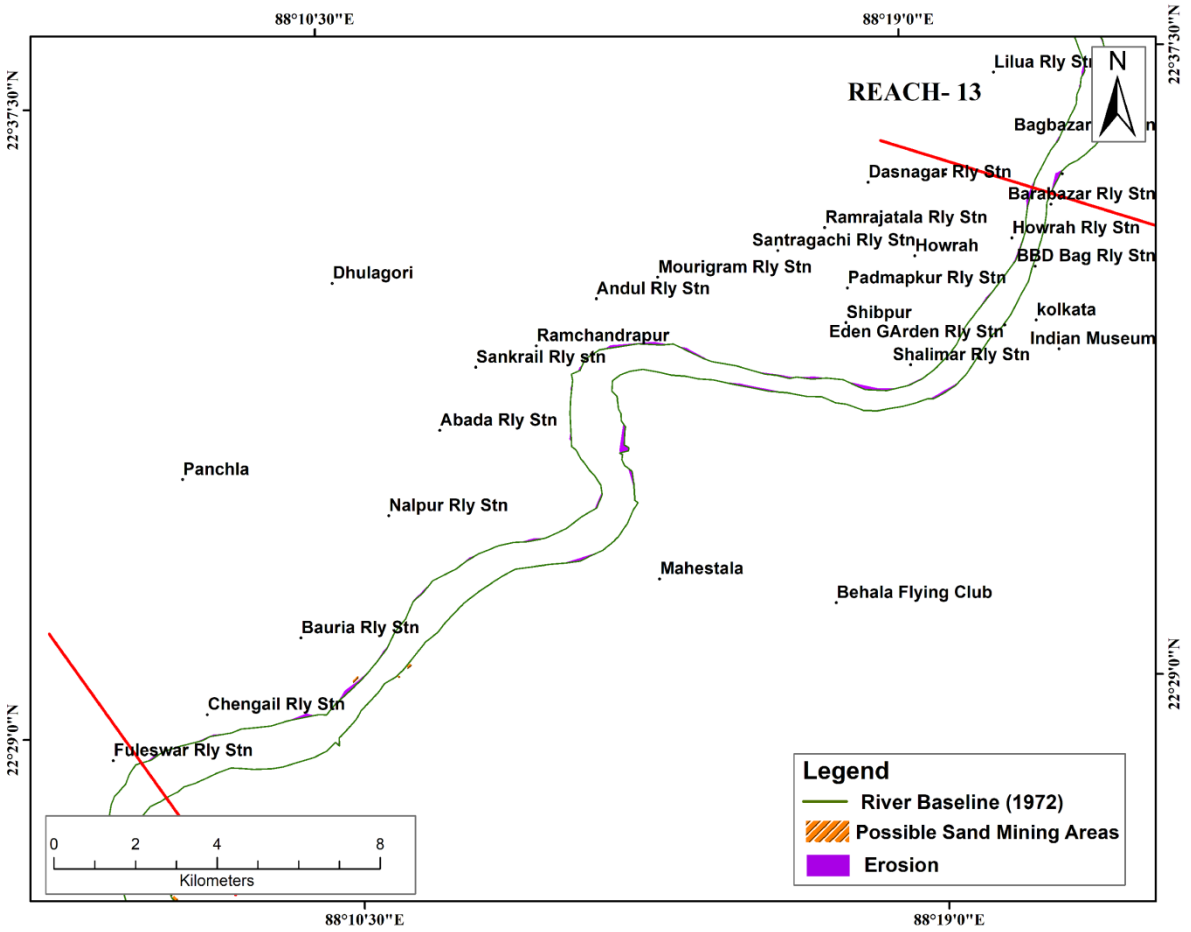


Figure 31.13: Identification of Posssible sand mining for Hooghl River Reach-13

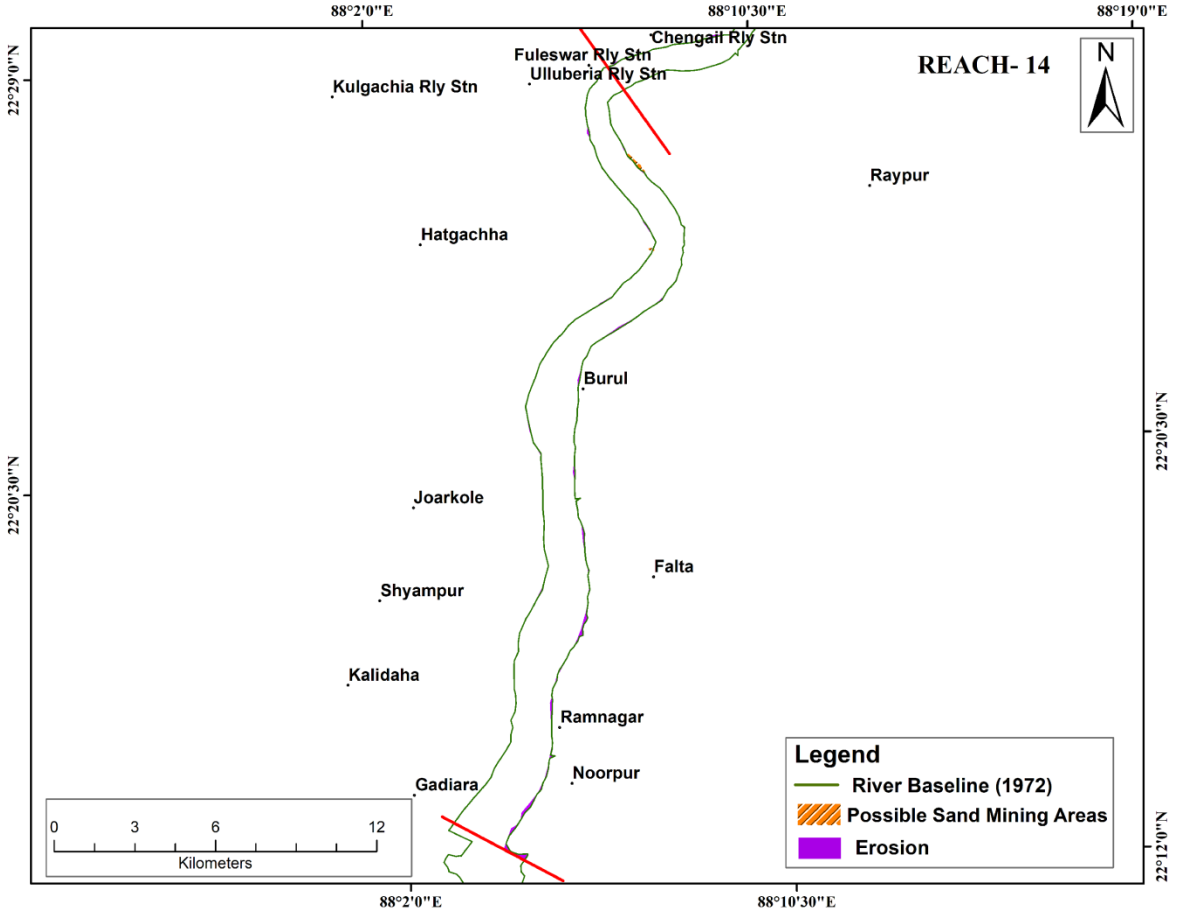


Figure 31.14: Identification of Posssible sand mining for Hooghl River Reach-14

5.13 Possibility of gainful utilization of river sand

The river sand mined at different places are used for many purposes. However, the sand's suitability to a particular use is very much dependent upon its grain size and gradation. As a part of this study, suitable sand mining areas have been identified using common deposition area of a riverbank, and materials collected from those different sand mining areas for laboratory testing of grain size analysis. For the Hooghly river,which is at the lower part of the Ganga river, the deposited materials have collected from suitable sand mining areas near Katwa, Nabadwip, Shantipur, Kalna etc (Figure 32). After analysis in the laboratory, it is found that the materials collected from these locations contain a lot of silt. The grain size of the materials is also very fine. The results of the laboratory experiment are presented in the below Table 18.

Table- 18 Laboratory experiment of gainful utilization of river sand

Sample Point	Latitude	Longitude	Location	Fineness modulus of sand
1	23°39'27.19"N	88° 8'6.54"E	Katwa	0.80
2	23°38'15.42"N	88° 9'17.77"E	Gobindapur	1.67
3	23°36'26.07"N	88°14'1.04"E	Kabrajpur	1.66
4	23°27'58.63"N	88°21'33.15"E	Chupi	0.91
5	23°23'37.09"N	88°22'9.04"E	Nabadwip	0.98
6	23°25'11.59"N	88°22'51.72"E	Nabadwip Ranirchara	0.95
7	23°17'1.39"N	88°20'50.26"E	Gramkalna	0.94
8	23°13'49.43"N	88°27'35.20"E	Shantipur	0.95
9	23° 4'53.82"N	88°29'41.91"E	Raninagar	0.92

Standard fineness modulus for sand using in construction work varies from 2.2 to 3.2. As per IS 383. (1970), sand is divided into four zones (Zone I, Zone II, Zone III and Zone IV) depending on the grain size. Sand falling under Zone IV is considered to be very fine. Materials which are collected from the Hooghly riverbed, is finer than the minimum limit of usable sand. Also, the sand contains lots of silt. So, these materials can be used only for landfilling purposes and not suitable as a mix in concrete that is used for construction.

Figure-32 Sand Mining field photo of Hooghly river

Figure-32 (continued): Sand Mining field photo of Hooghly river

Figure-32 (continued): Sand Mining field photo of Hooghly river

Figure-32 (continued): Sand Mining field photo of Hooghly river

5.14. Field Observation and Verification

Erosion/deposition, bed conditions and sand mining activities are verified in the field using GPS and other instruments. The field photographs clearly describe the location, activities and condition of the river bed and bank areas with flood prone areas. Erosion and deposition locations are captured along with the sand mining activities during the field observation. Images from site visits are presented in Figures -33.1 to 33.4.

Figure 33.1: Field photo of Hooghly river reaches

Figure 33.2: Field photo of Hooghly river reaches

Figure 33.3: Field photo of Hooghly river reaches

Figure 33.4: Field photo of Hooghly river reaches

CHAPTER 6

CONCLUSIONS

This report gives a complete understanding of the different geomorphological aspects specific to the Bhagirathi-Hooghly river system and provides references to its water resource management. It also provides a compilation of the information about the river bank shifting and erosion-deposition study from 1972 upto 2010 on the river. Land use/land cover for the year 1972, 1980, 1990 and 2000 are also identified. The probability of exceedance and recurrence intervals of peak discharge in the river is also calculated. Soil erosion scenario within a corridor of 2 km on both sides of the river is also estimated. The facts and data about the morphology of the basin have been gathered from different sources like satellite remote sensing data and field observation data by concerned agencies and our own practical (field) observations of specific locations. From an analysis of the basin, it is observed that it suffers from drought in its central region and is more prone to floods and cyclones near the eastern coast due to its geographic location. Sand mining, bank erosion, channel deepening are also carefully focussed and classified. The report is an attempt to give an insight to all important aspects which directly or indirectly decides the changes in physical properties of the river and is hoped to be helpful for further morphological studies of the river in future.

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ANNEXURE I

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Bazarsau (1958-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
1	1218.42	59.00	1.69
2	1079.42	29.50	3.38
3	1028.00	19.66	5.08
4	1000.00	14.75	6.77
5	960.49	11.80	8.47
6	943.00	9.83	10.16
7	923.49	8.42	11.86
8	920.00	7.37	13.55
9	916.00	6.55	15.25
10	910.00	5.90	16.94
11	907.50	5.36	18.64
12	905.17	4.91	20.33
13	894.15	4.53	22.03
14	885.55	4.21	23.72
15	885.00	3.93	25.42
16	848.64	3.68	27.11
17	839.19	3.47	28.81
18	825.00	3.27	30.50
19	780.50	3.10	32.20
20	774.20	2.95	33.89
21	773.55	2.80	35.59
22	757.70	2.68	37.28
23	727.70	2.56	38.98
24	727.02	2.45	40.67
25	722.08	2.36	42.37
26	711.00	2.26	44.06
27	709.05	2.18	45.76
28	680.80	2.10	47.45
29	647.53	2.03	49.15
30	640.82	1.96	50.84
31	631.37	1.90	52.54
32	621.61	1.84	54.23
33	606.25	1.78	55.93
34	605.00	1.73	57.62
35	604.57	1.68	59.32
36	604.09	1.63	61.01
37	563.80	1.59	62.71

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Bazarsau (1958-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
38	560.30	1.55	64.40
39	550.00	1.51	66.10
40	549.22	1.47	67.79
41	543.03	1.43	69.49
42	536.06	1.40	71.18
43	536.04	1.37	72.88
44	534.39	1.34	74.57
45	533.12	1.31	76.27
46	527.84	1.28	77.96
47	521.20	1.25	79.66
48	479.80	1.22	81.35
49	476.28	1.20	83.05
50	474.69	1.18	84.74
51	472.24	1.15	86.44
52	468.05	1.13	88.13
53	464.97	1.11	89.83
54	438.47	1.09	91.52
55	404.42	1.07	93.22
56	303.47	1.05	94.91
57	276.62	1.03	96.61
58	244.50	1.01	98.30
Berharmpore (1968-2015)			
1	3361.56	49.00	2.04
2	3050.00	24.50	4.08
3	2257.15	16.33	6.12
4	2040.35	12.25	8.16
5	1877.67	9.80	10.20
6	1809.73	8.16	12.24
7	1785.60	7.00	14.28
8	1777.91	6.12	16.32
9	1769.24	5.44	18.36
10	1766.00	4.90	20.40
11	1745.95	4.45	22.44
12	1721.28	4.08	24.48
13	1693.42	3.76	26.53
14	1665.10	3.50	28.57
15	1629.28	3.26	30.61
16	1614.17	3.06	32.65

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Berharmpore (1968-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
17	1592.20	2.88	34.69
18	1564.70	2.72	36.73
19	1556.04	2.57	38.77
20	1522.18	2.45	40.81
21	1519.22	2.33	42.85
22	1512.55	2.22	44.89
23	1506.27	2.13	46.93
24	1480.56	2.04	48.97
25	1474.03	1.96	51.02
26	1455.26	1.88	53.06
27	1436.26	1.81	55.10
28	1433.08	1.75	57.14
29	1414.00	1.68	59.18
30	1395.45	1.63	61.22
31	1382.67	1.58	63.26
32	1379.34	1.53	65.30
33	1374.43	1.48	67.34
34	1371.08	1.44	69.38
35	1370.11	1.40	71.42
36	1362.57	1.36	73.46
37	1351.58	1.32	75.51
38	1340.55	1.28	77.55
39	1336.53	1.25	79.59
40	1329.36	1.22	81.63
41	1320.00	1.19	83.67
42	1294.18	1.16	85.71
43	1265.37	1.13	87.75
44	1262.00	1.11	89.79
45	1261.36	1.08	91.83
46	1259.54	1.06	93.87
47	1189.71	1.04	95.91
48	1159.54	1.02	97.95
HR Farakha Feeder (1975-2015)			
1	1928.40	42.00	2.38
2	1408.44	21.00	4.76
3	1381.03	14.00	7.14
4	1331.04	10.50	9.52

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

HR Farakha Feeder (1975-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
5	1290.84	8.40	11.90
6	1289.05	7.00	14.28
7	1286.31	6.00	16.66
8	1285.45	5.25	19.04
9	1284.06	4.66	21.42
10	1281.19	4.20	23.80
11	1271.57	3.81	26.19
12	1266.36	3.50	28.57
13	1264.92	3.23	30.95
14	1254.75	3.00	33.33
15	1253.51	2.80	35.71
16	1251.17	2.62	38.09
17	1247.83	2.47	40.47
18	1239.69	2.33	42.85
19	1221.46	2.21	45.23
20	1218.02	2.10	47.61
21	1215.31	2.00	50.00
22	1214.64	1.90	52.38
23	1214.30	1.82	54.76
24	1213.87	1.75	57.14
25	1212.29	1.68	59.52
26	1211.60	1.61	61.90
27	1211.60	1.55	64.28
28	1211.45	1.50	66.66
29	1208.16	1.44	69.04
30	1207.01	1.40	71.42
31	1201.30	1.35	73.80
32	1196.00	1.31	76.19
33	1183.32	1.27	78.57
34	1180.87	1.23	80.95
35	1177.53	1.20	83.33
36	1174.16	1.16	85.71
37	1171.55	1.13	88.09
38	1165.06	1.10	90.47
39	1148.54	1.07	92.85
40	1146.88	1.05	95.23
41	1136.39	1.02	97.61
Kalna EBB (1956-2015)			
1	8800.00	60.00	1.66
2	8450.00	30.00	3.33
3	7695.85	20.00	5.00
4	7427.60	15.00	6.66

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Kalna EBB (1956-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
5	7075.08	12.00	8.33
6	6650.00	10.00	10.00
7	6129.80	8.57	11.66
8	5710.88	7.50	13.33
9	5593.93	6.66	15.00
10	5346.85	6.00	16.6
11	5040.74	5.45	18.33
12	4884.50	5.00	20.00
13	4878.52	4.61	21.66
14	4745.56	4.28	23.33
15	4424.86	4.00	25.00
16	4341.46	3.75	26.66
17	4215.95	3.52	28.33
18	4183.98	3.33	30.00
19	4168.86	3.15	31.66
20	4113.60	3.00	33.33
21	4104.96	2.85	35.00
22	4103.72	2.72	36.66
23	4062.50	2.60	38.33
24	4001.54	2.50	40.00
25	3998.54	2.40	41.66
26	3979.60	2.30	43.33
27	3849.00	2.22	45.00
28	3848.70	2.14	46.66
29	3798.48	2.06	48.33
30	3795.78	2.00	50.00
31	3777.37	1.93	51.66
32	3744.51	1.87	53.33
33	3720.43	1.81	55.00
34	3655.50	1.76	56.66
35	3608.02	1.71	58.33
36	3594.78	1.66	60.00
37	3538.67	1.62	61.66
38	3508.69	1.57	63.33
39	3498.05	1.53	65.00
40	3412.40	1.50	66.66
41	3404.86	1.46	68.33
42	3381.03	1.42	70.00
43	3366.00	1.39	71.66
44	3339.09	1.36	73.33
45	3334.04	1.33	75.00
46	3279.37	1.30	76.66
47	3270.59	1.27	78.33

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
Kalna EBB (1956-2015)			
48	3153.03	1.25	80.00
49	3096.94	1.22	81.66
50	3018.52	1.20	83.33
51	2837.04	1.17	85.00
52	2833.50	1.15	86.66
53	2735.40	1.13	88.33
54	2678.24	1.11	90.00
55	2541.52	1.09	91.66
56	2394.30	1.07	93.33
57	2245.87	1.05	95.00
58	2235.24	1.03	96.66
59	2197.80	1.016	98.33
Kalna Flow (1957-2014)			
1	7745.00	59.00	1.69
2	7500.00	29.50	3.38
3	6870.00	19.66	5.08
4	5373.33	14.75	6.77
5	5034.30	11.80	8.47
6	4868.00	9.83	10.16
7	4861.23	8.42	11.86
8	4840.57	7.37	13.55
9	4812.42	6.55	15.25
10	4625.18	5.90	16.94
11	4584.75	5.36	18.64
12	4543.06	4.91	20.33
13	4446.00	4.53	22.03
14	4440.00	4.21	23.72
15	4217.00	3.93	25.42
16	4159.97	3.68	27.11
17	4107.86	3.47	28.81
18	4106.30	3.27	30.50
19	4106.00	3.10	32.20
20	3979.12	2.95	33.89
21	3955.00	2.80	35.59
22	3955.00	2.68	37.28
23	3888.12	2.56	38.98
24	3865.15	2.45	40.67
25	3863.28	2.36	42.37
26	3816.30	2.26	44.06
27	3812.02	2.18	45.76
28	3786.58	2.10	47.45
29	3780.00	2.03	49.15

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Kalna Flow (1957-2014)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
30	3756.16	1.96	50.84
31	3699.89	1.90	52.54
32	3658.50	1.84	54.23
33	3644.00	1.78	55.93
34	3640.00	1.73	57.62
35	3590.26	1.68	59.32
36	3577.81	1.63	61.01
37	3577.70	1.59	62.71
38	3389.24	1.55	64.40
39	3350.68	1.51	66.10
40	3302.44	1.47	67.79
41	3292.87	1.43	69.49
42	3271.84	1.40	71.18
43	3265.94	1.37	72.88
44	3218.00	1.34	74.57
45	2899.00	1.31	76.27
46	2788.58	1.28	77.96
47	2785.93	1.25	79.66
48	2658.32	1.22	81.35
49	2635.44	1.20	83.05
50	2598.53	1.18	84.74
51	2477.00	1.15	86.44
52	2316.45	1.13	88.13
53	2265.80	1.11	89.83
54	2242.86	1.09	91.52
55	2219.06	1.07	93.22
56	2171.32	1.05	94.91
57	1238.01	1.03	96.61
58	497.10	1.01	98.30
Katwa (1991-2015)			
1	6084.00	26.00	3.84
2	5636.73	13.00	7.69
3	5120.00	8.66	11.53
4	5100.00	6.50	15.38
5	4996.44	5.20	19.23
6	4556.60	4.33	23.07
7	4100.00	3.71	26.92
8	4073.32	3.25	30.76
9	4029.86	2.88	34.61

ANX-I (continued) : Station wise probability of exceedence and recurrence interval

Katwa (1991-2015)			
Rank	Peak Discharge (m^3/s)	Probability of Exceedence(Px)=r/(n+1)	Recurrence Interval (RI) =1/Px
10	4023.91	2.60	38.46
11	3895.50	2.36	42.30
12	3789.39	2.16	46.15
13	3763.50	2.00	50.00
14	3683.91	1.85	53.84
15	3338.88	1.73	57.69
16	3190.43	1.62	61.53
17	2924.08	1.52	65.38
18	2879.40	1.44	69.23
19	2665.00	1.36	73.07
20	2268.53	1.30	76.92
21	2182.46	1.23	80.76
22	2054.56	1.18	84.61
23	1987.26	1.13	88.46
24	1949.30	1.08	92.30
25	1901.20	1.04	96.15