Hydro-Morphodynamic Assessment of Raidak River-II in Alipurduar and Coochbehar Districts, West Bengal

A Dissertation Submitted

To

Sikkim University

In Partial Fulfillment of the Requirement for the

Degree of Master of Philosophy

By

Ajit Kumar Singha

Department of Geography

School of Human Sciences

February 2017

Acknowledgements

It's my privilege in having been given this opportunities to carry out this academic research and writing this dissertation. It has been a wonderful experience that will cherish me forever. In fact there are many people to whom I would like to express my gratefulness.

At first, I would like to extend my heartiest gratitude to my supervisor Dr. E. Ishwarjit Singh for his guidance throughout the research process. His all time accessibility, his patient of hearing, his constant material and intellectual support and inspiration helped me to complete this dissertation.

Secondly, I would like to extent my thanks to Dr. Uttam Lal, Dr. Abdul Hanan, Dr. Rafiul Ahamed, Dr. Sohel Firdos, Dr. Vimal Khawas for their continuous encouragement and advices.

Besides, I would like to express my especial thanks to Mr. Tulshi Sharma (Lab Assistant, Department of Geography, Sikkim University) for his guidance in the preparation of difference maps pertaining to my study.

Similarly, I express my gratitude to Dimple Das, Anil Chandra Das, Laxman Ray, Prosun Das for helping me to carry out field survey.

Besides, I would like to express my appreciation to the institutions like, NATMO(Kolkata), Survey of India(Kolkata), Geological Survey of India(Kolkata), Barokodali Farmhouse(Tufanganj, Coochbehar), Kumargram Farmhouse(Kumargram, Alipurduar), Netaji Pathagar(Lataguri, Jalpaiguri) for providing valuable information.

I express my sincere gratitude to Pompi Sarkar (Research Scholar, University of North Bengal) for extending her valuable suggestion at different stage of my research.

Last but not the least, I am indebted to my family for their unconditional love, support and constant source of encouragement.

Ajit Kumar Singha

Table of Contents

List of Figures

List of Tables

List of Plates

1.1. Introduction

Rivers are always fascinating to the humanity for centuries. They are the most important fresh water source for terrestrial ecosystem and also play a vital role on economic, social and political development. The ancient civilizations had been developed along the river valleys. The civilization of Mesopotamia, Egyptian, Indus and Chinese were flourished along the Tigris and Euphrates river valleys in Southwest Asia, the Nile river valley on the north-eastern Africa, the Indus river valley in South Asia, and the Huang He Valley in East Asia respectively. The largest cities around the world have been developed along the rivers. At present the most populous areas are also along fertile river basin due to refreshing fertile soil, irrigation, transport, tourism, industry etc.

Rivers are the most prolific land surface sculptors. Any landform on earth's surface has some imprints of river. Different type of appalling landforms is thus evolved under fluvial processes. Floodplain is one of the most important landform which responds directly and abruptly to the changes whatsoever to the flow regime of the river. Floodplain study is one of the most important to understand river channel morphology. Floodplains are of valuable resource. These are the sites of the settlements and also provide agricultural raw materials for rural industries. Floodplains are capable of preserving records of past climatic change. In addition, any morphological changes in the floodplains due to channel processes have direct bearing on the land and land use pattern thereof (Kumar, 2010).

Floodplain is defined as the smooth strip of land bordering the river channel, embracing the river pattern and inundated at the times of high stage (Gregory and Walling, 1973).

According to Leopold and Wolman "the flood plain consists of channel and overbank deposit". In other words, floodplains are prone to submersion. These are best understood in the context of meandering channel and movement of meander bend, which work over the valley alluvium and erode its outside bends. But deposition of sediments takes place along the bends of the meander. In this way a smooth depositional strip of land is formed along the length of valley (Dury 1969).

Hydro-morpho dynamic of river is also involved in floodplain evolution and modification. Floodplains are geologically ephemeral as they are continuously constructed and destroyed by fluvial processes (Morisawa, 1985). Channel deposition and erosion (or scour and fill), combined with shifting of a channel, bankline and meander are collectively responsible for flood plain morphological change. In the flood plain, river channel gradient is very low, erosional material is deposited on the river bed and start meander flow with bank erosion. Sediments eroded from a concave side of meander tend to get deposited on point bar along the convex side of the next meander downstream. This process is known as lateral breeding. The result of such type of process is a cross-stratified deposit, with a subdued relief of low ridges and intervening swales that may record many episodes of meandering channel migration. Apart from channel deposit, floodplain is produced by over bank deposition i.e. vertical accretion. The suspended sediments are deposited on the floodplain when the river water is out on the plain during floods. In such flood condition, the velocity over bank is very low and the flood waters take long time to recede back into the channel.

The most significant characteristic features of the river is the dynamic nature of both floodplain and channel morphology. Since the floodplains are the product of fluvial process. The changes of channel morphology are one of the important factors for changing the floodplain morphology. This change also affect on human activity along the river banks. The modification and alteration in the floodplains may affect the livelihood and every year damaged huge amount of physical resource and human properties. These modification and alteration in the flood plain due to flood, bank erosion, course change, bank-line shifting, and channel bifurcation around the flood plain area etc. are function of volume of water and gradient grounded in river. Therefore, a detailed survey of these changes and the processes involved is essentially needed. Today, river engineers are still designing the structures of river to draw benefits from the fluvial system for societies.

The foothills[1] of North Bengal, i.e. Duars[2] region have received huge rainfall in the rainy season due to its geographical location and topographical position. The major tributaries of the Brahmaputra System, namely the Teesta, Jaldhaka, Torsa, Raidak, Sankosh, etc. are originated from Sikkim, Bhutan and Darjeeling Himalayan ranges. Very heavy precipitation for long duration in the upper catchments, synchronised with heavy local rainfall in the foothills causes enormous flood discharges in the rivers of Duars region and changes their morphology rapidly and shift channel (Chakraborty et al., 2013).

---

[1]Foothill is geographically defined as gradual increase in elevation at the base of a mountain range, higher hill range or an upland area. https://en.wikipedia.org/wiki/Foothills, accessed on 2016-11-11.

[2] The **Dooars** or **Duars** (Pron: ˌduːˈɑːz) (Bengali: ডুয়ার্স) are the floodplains and foothills of the eastern Himalayas in North-East Indiaaround Bhutan. *Duar* means 'door' in Assamese, Bengali, Nepali, Maithili, Bhojpuri, Magahi and Telugu languages, and the region forms the gateway to Bhutan from India. https://en.wikipedia.org/wiki/Dooars, accessed on 2016-11-12

This study is oriented towards developing a better understanding of the fluvial processes, and the morphological change of the Raidak river-II in Alipurduar and Coochbehar Districts. This includes the study of river channel morphological change such as bar, alluvial island change, bankline shifting, river bifurcation in the floodplain and processes that have brought about changes through sediment deposition, bank erosion, volume of discharge etc.

1.2. Study Area

The Alipurduar district of West Bengal represents a zone between the Himalayan Mountain and Brahmaputra-Gangetic Plain. It displays the typical characteristics of the piedmont alluvial fans of the Himalayan foothills. This part of the foothill which is located to east of Teesta river is known as the duars . The districts of Jalpaiguri and Alipurduar of West Bengal also fall in this region.

The Raidak river originates in Mt. Akungphu at an altitude of 6400 metre of the Himalaya which is located at the boundary between Bhutan and Tibet (Government of West Bengal, 2014). The Raidak debouches into India at 'Bhutan Ghat'(Jalpaiguri district) and it is known as Raidak. In Bhutan the Raidak river known is Wang Chhu or Wong Chhu . At Tiyabari(Jalpaiguri district) the river divided into two branches-Raidak-I and Raidak-II. The Raidak-II flows through Alipurduar and Coochbehar plains and joins with Sankosh river at Bainaguri (Boxirhat, Coochbehar) and finally Sankosh river joins Brahmaputra in Bangladesh as Gangadhar river. The Raidak-I river is flowing through Alipurduar and Coochbehar plain and joined with Torsa river. Kulkuli, and Ghoramara are the main tributaries of Raidak-I river.

The present study concentrates on the lower part of the Raidak river i.e Raidak II from Bhutan Ghat to Bainaguri with a length 50 km. The longitudinal and latitudinal extension of the study area is between 89˚45' E to 89˚ 50' E longitude and 26˚ 20' N to 26˚ 40' N latitude (Figure-1.1). The river Raidak-II mainly covers Kumargram Block of Alipurduar district and Tufanganj-II Block of Coochbehar district.

Figure-1.1 Location Map of the Study area

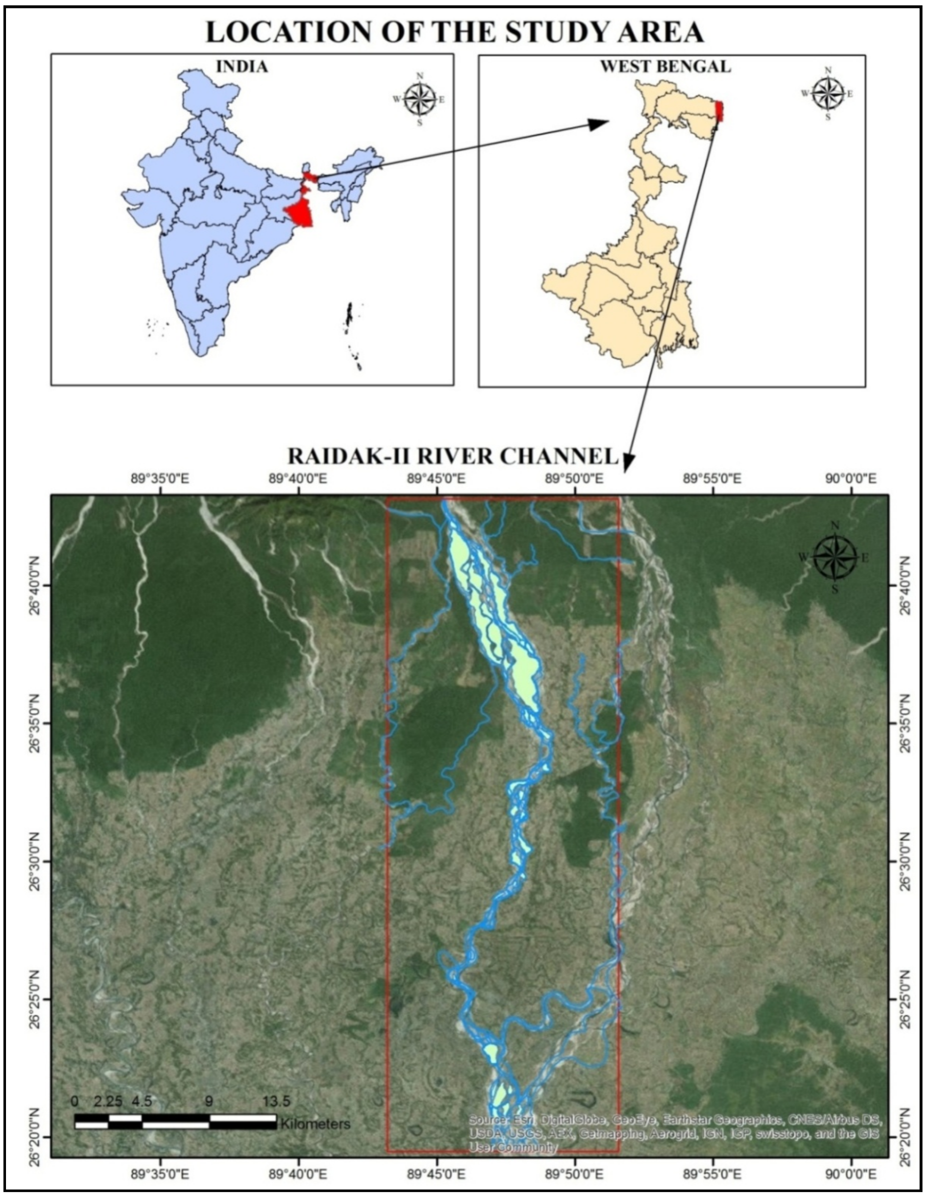
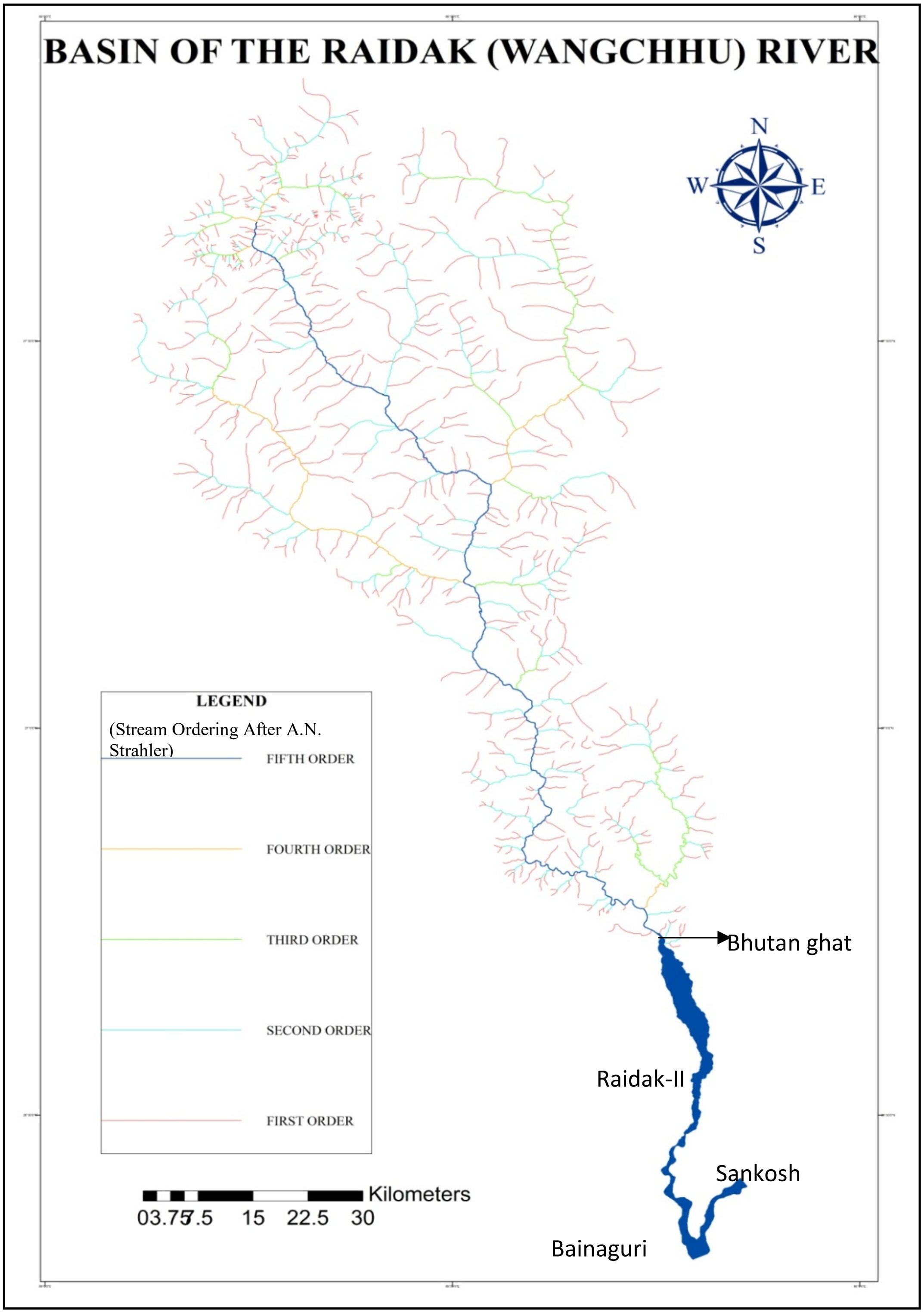


Figure-1.2. Basin Map of The Raidak(Wangchhu) River



Source- Prepared from Google Earth image (12.2.2014)

1.5. Literature Review

The dynamics of river and associated problems like bank erosion, channel morphological change, river course shifting have been studied extensively by scholars since ages all over the world. Physical based research in the area of fluvial geomorphology has pointed out the historical trends in fluvial processes, channel morphology and bank erosion. Objective of the present study was developed upon previous literature on similar lines. Pioneering study in fluvial geomorphology by Leopold and Wolman (1957) is the most noteworthy along with the work of Chorley (1969), Gregory and Walling (1973), Schumm (1977), Brice (1981) Hooke (2006), Morisawa(1987) and David Knighton(1984).The following section deals with the literature survey to streamline the present research.

i) River channel Morphology and Morphodynamic.

Leopold and Wolman (1957) studied on " *River Channel Pattern: Braided, Meandering and Straight*", and grouped the alluvial rivers into braided, straight and meandering on the basis of planform and formulated the characteristics of each of these patterns. Braided river was found to be the one that flows into two or more anastomosing channels around alluvial island, and in a winding course.

Leopold, L.B and Wolman, M.G (1960) worked on "*River Meander"*. In this paper examined the river meander and analysed the form and morphology of the meander. They found that in the sample of 50 rivers the median value is 2.7, mean 3.1, and two-thirds of the cases lie between 1.5 and 4.3. About one quarter of the values lie between 2.0 and 3.0.

Ou-Yang, Z. et al.(2001) studied on " *Between energy dissipation rate and channel morphology in the development of the model braided channel".* This paper focused on the variation of the energy dissipation versus the channel morphology during and after the bed making process of braided channel. The result shows that there exists a good empirical relationship between the energy dissipation rate and channel morphology. They have completed whole work by the experiment. The experiment was carried out in the laboratory of experiment and simulation in river and coast. They also used process-respond model.

Roy, N. G. and Sinha, R. (2005) worked on "*Alluvial geomorphology and confluence dynamics in the Gangetic plains, Farrukhabad–Kannauj area, Uttar Pradesh, India*". Remote sensing images and topographic maps have been used to understand the geomorphic processes in parts of the Gangetic plains of Uttar Pradesh. Detailed geomorphic mapping suggests that the confluences of the Ganga–Ramganga–Garra rivers has moved both upstream and downstream during the last 30 years in response to river capture, local cut-offs and aggradation. There is a remarkable difference in the fluvial dynamics of this region compared to the eastern Gangetic plains from where rapid and frequent channel avulsions have been reported. They do not observe any definite trend in the movement of the confluence points and their work departs from earlier suggestions of regional controls such as choking up of rivers due to sea-level rise or increased erosion in the catchment areas.

Sinha, R. et. al.(2005) studied on *"Geomorphic characterization and diversity of the fluvial systems of the Gangetic Plains"*. In this paper they select two regions of the Gangetic Plains to compare the morphology, hydrology, and fluvial processes. These are the Ganga–Yamuna interfluves in the Western Gangetic Plains (WGP) of Uttar Pradesh and the Gandak–Kosi interfluve in the Eastern Gangetic Plains (EGP) of north Bihar. The Ghaghra–Gandak interfluve region in between the WGP and EGP is named as Transitional Gangetic Plains (TGP). The objective of this paper is to investigate the spatial homogeneity across the plains and to explain any diversity in terms of geomorphic and geologic controls. Additional morphometric data on drainage density and frequency for the rivers of the WGP were computed from the 1:50,000 Survey of India toposheets.

Roy, N. and Sinha, R. (2007) studied on *"Understanding confluence dynamics in the alluvial Ganga–Ramganga valley, India: An integrated approach using geomorphology and hydrology"*. In this paper they have discussed that new confluences have been created during this period and that the confluence points have moved both upstream and downstream on a historical time scale. Apart from major avulsions, other processes that have controlled the confluence movements include river capture, cut-offs and aggradations in the confluence area. Temporal variation of channel position as well as confluence points were analyzed for the last hundred years using two different periods of Survey of India topographic sheets and several repetitive satellite images from Indian Remote Sensing satellite (IRS, LISS III, spatial resolution 23.5 m), Landsat 5 TM (spatial resolution 28.5 m) and Landsat 7 ETM (spatial resolution 14.5 m). Visual interpretation as well as digital image processing techniques such as contrast stretching, edge enhancement, image filtering, false colour composites, principal component analysis, image ratio and image subtraction were applied on the digital data to map the paleo-channels and confluences.

Kusimi, J.M. (2008) studied on *"Stream processes and dynamic in the morphology of the Densu river channel in Ghana"*. In this paper critically analysed the impact of human activities such as farming, lumbering, sand winning, animal grazing, dam construction etc. on change the river channel of Densu river, Ghana. The study examined the current fluvial processes and landforms and the dynamics in the river morphology since the 1960s. This was done by analysing existing survey maps and aerial photographs. This involved aerial photo interpretation and digitizing of old topographic maps which were overlaid on each other to identify changes in the river's course. Topographical maps (1964, 1975, 1976 and 1996), and Aerial Photographs (1975) of the study area were acquired from Survey Department in Accra. These were analysed for morphological changes in the basin channel. Aerial photos were analysed using the mirror stereoscope. The longitudinal profile of the Densu river was drawn from 1975 topographical map.

Siddhartha, K et al, (2012) studied on "*Tectonic controls on the morphodynamics of the Brahmaputra River system in the upper Assam valley, India."* In this paper they have analysed morphodynamic of the Brahmaputra river system in the upper Assam valley, mainly discuss on rate of bankline shifting of the Brahmaputra river. For this study, the IRS-P6 LISS-3 images acquired on 15 December 2005 with a spatial resolution of 23.5 m and older topographic maps of 1:253,440 scale corresponding to 1912–1926 and 1977 (scale: 1:250,000) have been used. Digital image processing of the satellite images obtained from the National Remote Sensing Centre, Hyderabad, India, was carried out to enhance the geomorphic features for mapping. Shuttle Radar Topographic Mission (SRTM) data with spatial resolution of 90m and vertical resolution of 1 m were used to find point elevations and for computing slope. All temporal data were geo-referenced and registered on a common platform for investigating the temporal variability in bankline, channel width, and planform parameters of the Brahmaputra and its tributaries for three different time periods: 1915, 1975, and 2005.

Sarker, M.H. et. al.(2013) worked on *"Morpho-dynamics of the Brahmaputra–Jamuna River, Bangladesh*" This paper draws on all these sources to chronicle the morphological evolution of the Jamuna River since the avulsion that created it about 200 years ago, and to establish temporal trends and spatial patterns in the changes that have characterized process–response mechanisms in this fluvial system since then. The understanding gained from these investigations then supports deeper analyses to explain how historical migration of the river westward has produced significant contrasts between left and right (west) bank material properties; elucidate the relationships between discharge, fluvial processes, anabranch instability and floodplain erosion rates, and; identify causal links between drivers and morphological responses at a different of time and space scales.

Chakraborty, S. and Dutta, K. (2013) worked on *"Causes and consequence of fluvial hazard- A Hydro-Geomorphic analysis in Duars Region, India".* They examined the fluvial hazard in North Bengal Plain and briefly discussed the fluvial hazard in main river system of Duars region. They mainly discussed bank failure, shifting of river courses, Channel widening and resultant loss of land, loss of forest resource and biodiversity.

They identified the main causes of fluvial hazard in Duars region which are frequently flood, heavy rainfall, road bridge construction etc.

Bhuiyan, M. A. H. et.al.(2014) worked on *“Application of remote sensing and GIS for evaluation of the recent morphological characteristics of the lower Brahmaputra-Jamuna River, Bangladesh”.*This paper deals with the morphological changes of the lower Brahmaputra-Jamuna River (BJR) in Bangladesh. The channel behaviour of some of the selected channel segments of the lower braided BJR has been analyzed for 38 years from 1973 to 2011. Satellite imagery of Landsat MSS (1973, 1976, 1980 and 1985) and TM (1992, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2005, 2006, 2009, 2010 and 2011) bands of 18 different year–sets were used for planform analysis. The data used in this study have been sourced from the Centre for Environmental and Geographical Information Services (CEGIS), Dhaka.

Muhammad A. et al. (2016) focused on “*River bank erosion and channel evolution in sand-bed braided reach of River Chenab: role of floods during different flow regimes*”. This paper highlights the bank erosion and channel evolution induced by eleven different flood events in a 7-km long reach of the River Chenab, Pakistan. The impact of floods on river bank erosion and channel evolution is analyzed under low and high flow conditions. Flood-induced changes, for river’s external banks and channel evolution. This worked were assessed by processing Landsat ETM+ images in ArcGIS tool, and their inter-relationship is evaluated through regression analysis.

ii) Channel Bank-Line Shifting and Bank Erosion

Goswami et al., (1999) worked on *"River channel changes of the Subansiri in Assam, India*". They covered sequential changes in the position of bank lines of the Subansiri river using SOI topographic sheets (1920 and 1970) and satellite imageries (1990). The entire reach of the river was divided into 10 equal transverse cross-sections for analysis. The lateral shift in bank line towards east-west direction and the erosion along cross-section was identified and quantified between 1920 and 1990.

Goswami et al. (2007) worked on "*Change of river channel and bank erosion of the Burhi Dihing river (Assam), Assessed using Remote Sensing data and GIS."* This paper has discussed the sequential changes in the position of bankline of the river due to bank erosion with help of topographical map (1934-1972) and digital satellite data of 2001 and 2004 using GIS.

Sarkar, A. et al (2011**)** studied on *"RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India."* They have been quantifying the actual bank erosion/deposition along the Brahmaputra river within India for a period of eighteen years (1990-2008). The channel configuration of the Brahmaputra river has been mapped for the years 1990 and 2008 using IRS 1A LISS-I, and IRS-P6 LISS-III satellite images respectively. The analysis of satellite data has provided not only the information on the channel configuration of the river system on repetitive basis but also has brought out several significant facts about the changes in river morphology, stable and unstable reaches of the river banks and changes in the main channel. The results provide latest and reliable information on the dynamic fluvio-geomorphology of the Brahmaputra river for designing and implementation of drainage development programmes and erosion control schemes in the north eastern region of the country.

Dayal, S and Pattanaik,D.S. (2012**)** worked on *"Assessment of Bankline Changes of River Ganga around Patna City,India, using Multi Temporal Satellite Data*". In this paper they studied the rate of bankline shifting of Ganga river. For this study the Landsat TM imageries of pre-monsoon (April) 1975, 1988, 1999 and 2010 with the band combination 3, 2 and 1 which gives good geomorphic features were used to study the bank-line changes of river Ganga in and around the Patna city. They also employed the Landsat TM data of 1988, 1999 and 2010 with the band combination 7, 4 and 2.

Das, A.K. et al. (2012) worked on "*Bankline change and the facets of riverine hazards in the floodplain of Subansiri–Ranganadi Doab, Brahmaputra Valley, India*". This paper attempts to study the changes in the banklines of two major rivers in the floodplains of the Subansiri–Ranganadi Doab during 1997–2009 in the context of the riverine hazards. It brings to the floodplain dwellers. For delineating the banklines, this study uses the Survey of India toposheet 83 I/4 for the year 1969 and the multi spectral satellite data IRS 1B LISS-II (print format FCC) imagery for the year 1997 and IRS P6 LISS-III (digital FCC) for the year 2009. LANDSAT-TM data for 1990 and ETM for 1999 are used for showing the areas of inundation. Information on location, extent and causes of breaches are available from Annual Flood Report, Assam, published by Department of Flood Control, Government of Assam. Information regarding embankments was also collected from Embankment and Drainage (E&D) Department, Lakhimpur Division, North Lakhimpur, Assam.

Aher, S.P. et al. (2012) studied on “*River Change Detection and Bank Erosion Identification using Topographical and Remote Sensing Data”.* They discussed about the shifting of Pravara river course and controlling of bank erosion. Survey of india topographical map (1974-75) and google map(2006) are used. The SRTM (Shutter Radar Topography Mission) data are also used for understanding the gradient and relating physiographic information.

Dr. Chakraborty, S and Datta, K. (2013) studied on *“Causes and Consequences of Channel Changes – A Spatio- Temporal Analysis Using Remote Sensing and Gis— Jaldhaka-Diana River System (Lower Course)”.* They mainly discussed the morphological change of the river confluence. Base map has been generated with the help of SOI Topographical maps and satellite images of the respective area. For this purpose updated version of ERDAS Imaging is employed as image processing tool for enhancing, merging and to update the spatial information of channel configuration and Arc GIS for final product generation.

Gogoi, C. and Goswami, D.C. (2013) worked on *“A study on bank erosion and bank line migration pattern of the subansiri river in Assam using remote sensing and GIS technology*”. They have identified that every year the hazard of flood and erosion causes severe problem to the people living in the floodplain of the river Subansiri. Bank line migration due to erosion is a common feature in the Subansiri River. A study on bank erosion and bankline migration of the present course of the Subansiri river through the Ghagar nala indicates that the area is currently under active erosion. The satellite image of IRS LISS-III of 1995 and Landsat 5 TM of 2010 are used for this purpose. In the first step, the satellite images of these two years were georeferenced using GIS software ARCGIS 9.3. Bank lines of these two years were digitised from the georeferenced satellite imageries using the same software and then the bank lines are overlaid. The overlaid bank lines give the overall channel migration pattern of the Subansiri River from 1995 to 2010 and the rate of erosion and deposition. Bank line migration was measured taking 17 cross-sections along the present river. Erosion and deposition areas have been estimated through area estimation using GIS software tools for polygon areas with the shifting bank lines in the study period.

Das, S. et al. (2014) studied on *" Hydrodynamic changes of river course of part of Bhagirathi – Hugli in Nadia district - A Geoinformatics appraisal".* This paper is mainly oriented towards the morphometric measurement of river through temporal changes during 1977, 1990, 2010 of LANDSAT MSS and LANDSAT TM satellite data. In this paper an attempt has been made to get the nature of shifting, direction of shifting, erosion and deposition along the river bank, ox-bow lake formation, sinuosity index measurement, meander ratio and cut off of the river channel has also been calculated. Data are analysed from Landsat MSS of 1977, Landsat TM of 1990 & 2010 and block maps of study area. Images are rectified (ERDAS IMAGINE-9.0) after registration (ERDASIMAGINE-9.0). Then all the images have been mosaiced for three years. Then sub setting of images using ERDAS IMAGINE 9.0 & Arc GIS 10 to identify the study area. After that, the river bank line from three images has been digitized and extracted by using Arc GIS 10 software. Next, the extracted layers of three images of different decades have been over lapped on each other. Then RS & GIS approach has been implemented for measurement of length, width, centre line radius, shifting length, shifting direction. The river has been divided into 5 reaches which are identified as Kaliganj, Nakashipara, Krishnanagar- Nabadwip, Shantipur-Ranaghat and Chakdah.

Chatterjee, S. et al,(2013) worked on "*Impact of River Bank Erosion on Human Life: A Case Study in Shantipur Block, Nadia District, West Bengal"*. They discussed about erosion of the river Bhagirathi-Hooghly and thousands of inhabitants are either displaced or suffered huge loss in the form of land, cattle and houses and thrown as destitute. They conducted with an effort on analyzing the impact of erosion on the socio economic lives of the poor villagers, their frequency of displacement, patterns of rehabilitation, their perception about the causes of erosion and the way they continuously try to adapt themselves to this arena.

iii) Channel Bifurcation and Avulsion

Slingerland, R. and N. D. Smith, N.D. (2004) focused on river avulsion and causes and consequence in their paper "*River avulsion and their deposit"*. Avulsion is the natural process by which flow diverts out of an established river channel into a new permanent course on the adjacent floodplain. Avulsions are primarily features of aggrading floodplains. Their recurrence interval varies widely among the few modern rivers for which such data exist, ranging from as low as 28 years for the Kosi River (India) to up to 1400 years for the Mississippi. Avulsions cause loss of life, property damage, destabilization of shipping and irrigation channels, and even coastal erosion as sediment is temporarily sequestered on the floodplain. They are also the main process that builds alluvial stratigraphy. Their causes remain relatively unknown, but stability analyses of bifurcating channels suggest that thresholds in the relative energy slope and shields parameter of the bifurcating channel system are key factors.

Das, L.M. (2015) examined on *"Channel Avulsion in Jiadhol River of Brahmaputra Basin"*. The focus of this study is to understand the pattern of channel avulsion in the Jiadhol River. For the analysis the data on river planform are collected from the survey of India toposheets 83 I with RF 1:50,000 surveyed between 1963 and 1967 and a number of satellite imageries (LANDSAT MSS-1973, LANDSAT TM-1993, LANDSAT7 ETM-2003, LANDSAT7 ETM-2013, LANDSAT8 ETM-2014).With the help of the mentioned data, different courses of the river Jiya Dhol are digitized in ArcGIS 9.3 Software for analyzing the phenomenon of channel avulsion of the river. The time series of river planform is used to analyze the pattern of channel avulsion. The analysis shows that before 1973, the Jiadhol River had tendency to shift from west to east, from 1973 to 1993 the shift was from east to west and after 1993 till present time the channel avulsions are from west to east. The distance between the new and the old course has reduced over time.

1.6. Research Problems

The river Raidak-II is flashing and shifting in nature. From the upper catchment huge amount of boulders, gravel and silt are carried to downstream with high velocity. When the river enters plains, the velocity is suddenly reduced due to decrease of gradient; the sediments are deposited on the river bed. At this reach the channel bifurcate in different channel and rejoin. This forms braided bar and spread valley extensively. The problem in the hills, where the rivers flow in gorges, vertical erosion is active and associated frequent landslide on hill sides of its course. But the problem in the plains is more acute, due to sedimentation, lateral erosion, bank line migration, avulsion, and inundation of settlement, valuable agricultural lands and damage property both public and private. The morphological change of the river involves in floodplain modification. Avulsion of one river into another, and also a tendency to avulse by way of lateral erosion, wiping out vast stretches of land along with structures thereon, also poses serious problems. The present work tries to understand the morphological change of Raidak-II channel and mapping of different change of the channel morphology.

1.7. Objectives

Two objectives have been taken in this study. They are as follows

1. To assess the channel morphology and morphodynamic of the river Raidak-II .
2. To study rate and nature of bankline shifting of Raidak-II.

1.8. Data Base

Table-1.1 Secondary Data was Collected

Types of data	Sources of data
Geological map	Geological survey of India, Govt. Of India
Topographical map(78F/14,15),1980-81	Survey of India, Govt. Of India
LANDSAT IMAGERY(1978-2016)	http://earthexplorer.usgs.gov
Landuse and landcover Thematic map (2011-2012)	http://bhuvan.nrsc.gov.in
Rainfall data(2004 to 2016)	Kumargram farmhouse and Barokodali Farmhouse
Soil data	National Bureau of soil survey and Land use planning, govt of India
Basin map	Google Earth(12.2.2014)

1.9. Methodology

The mixed method which is amalgam of quantitative and qualitative method had been adopted in this study. Field visit is one of the most important sources of any study. The changes of the channel morphology have been mapped by the collected data from the field and with secondary data.

(i) Quantitative Method:

For physical setup data has collected from different sources. Soil map have prepared from NBSS and LUP soil map of Jalpaiguri and Coochbehar districts. For vegetation map and landuse/cover map, themetic map from Bhuvan are used. Geological map, relief map, slope map, etc. have been prepared from mainly Geological Survey of India and Survey of India topographical map. Geomorphological map of the study area has been prepared from Bhuvan thematic map of geomorphology (2005-2006). Rainfall data of the study area was collected from Kumargram and Barokodali farm house, that data was calculate in MS excel sheet.

Channel morphology, Channel dynamic, channel type and channel pattern changes from1980 to 2016, had been studied by using topographical maps surveyed and published by Survey of India (SOI), and satellite imagery(LANDSAT IMAGE, MSS, TM, ETM,) obtained from USGS. Satellite Imageries, which had been used in this study, are listed in the Table-1.2.

Table-1.2. Satellite Images

Agency	Year	Date of acquisition	Scale	Band combination
LANDSAT-2 MSS	1978	22.02.1978	60M	2,3,4
LANDSAT-5 TM	1990	14.11.1990	28.5M	1,2,3
LANDSAT-7 ETM+	2001	20.11.2001	28.5M	1,2,3
LANDSAT-8 ETM	2016	20.10.2016	28.5M	5,6,7

All these maps are digitized in ArcGIS software version 10.2 and final thematic map was prepared. The bar change and island change thematic maps was also prepared from Google earth from 2007 to 2014. At first channel bar and island were digitized from

Google earth and created kml file. All the kml file inputs were prepared in ArcGIS 10.2 version to prepare thematic map.

Rate of channel bankline shifting had been measured from satellite images (LANDSAT) since 1978 till 2016 with an interval of around 10-15 years. The LANDSAT TM data of pre-monsoon 1978 and after-monsoon 1990, 2001, and 2016 were used to study the bankline changes of Raidak-II. The LANDSAT TM of 1978 and 1990 with the band combination of 2, 3, 4 and 1, 2, 3 gave good geomorphic features. Similarly, the LANDSAT ETM+ data of 2001 and 2016 with the band combination 1, 2, 3 and 5, 6, 7 provided distinct geomorphic features.

The visual interpretation of the bankline was done based on the ton, texture and color. The bankline of 1978, 1990, 2001 and 2016 were generated in the GIS platform using ArcGIS 10.2. The rate of bankline shift were obtained, which helped in thematic mapping of the bankline changes on 1:300000 scale.

To study the shift of bankline, the 50 kilometers stretches of the rivers was divided into 20 sections at average 2.5 kilometer interval. The nature of bankline changes were studies at each sections on both right and left bankline.

The bankline of river Raidak-II for the year 1978 was taken as based map. The bankline of year 1990 was over laid on base map of 1978 to assess the shifting rate and direction. The shift on bankline was measured with respect to change in bankline of 1978. Since, the river Raidak-II is flowing North to South and the right and left bank are on the West and East respectively. Therefore any shift in bankline was measured with respect to the West and East shift of the bankline. The bankline shift in 1990- 2001 and 2001- 2016 were measured in similar manner.

Six Corss-section sites have been taken to understand the channel width, depth, shape, size, barformation and channel bifurcation for field observation. Each six cross sections has specific features. They are-

(i) Bhutan ghat, foothill region and starting point of Raidak-II

(ii) Joydebpur, extensive braided site

(iii) Hemaguri, confluence site of many sub-channel

(iv) Chokchoka, narrowest channel width

(v) Takuamari, meandering channel

(vi) Bainaguri, bifurcate many subchannel and fall in Sankosh river.

All the cross-sections' profiles have been measured in the month of May, 2016 with help of Rise fall method. The velocity was measured in monsoon season (16, 17, 18 July 2016) and post monsoon season (10, 12, 13 December, 2016). SPSS software, version-20 was also used to understand co-relationship between width and depth of Raidak-II channel.

The SRTM (Shutter Rader Topography Mission) DEM was also used for understanding the elevation and gradient etc.

(ii) Qualitative Method:

For discussion, 5 people (ages 55-60) were selected from each 6 sites and discussed with irrigation official staff.

2.1. Introduction

The physical setup of the study area is responsible for the dynamic of channel. The river system in area is the reflection of existing relief, topography, litho-logical characteristics, type and depth of soil, prevailing climate, vegetation etc. All these factors are indicator and multidimensional mirror which the environmental indicators particularly the geomorphic environment is reflected (Bhattacharyya, 2013). In fact the hydro-geomorphologic conditions are independent variables which are controlling the channel behaviour and the physical nature of the valley. The present study discuss about the physical setup of the study area including those factors (geomorphology, climate, vegetation, soil, geology) which are responsible for the changing characters of the river channel morphology.

This section emphasizes on geomorphology, elevation, geology, slope, vegetation, climate, soil status etc. Here the deliberation has been made on the lower part of the Raidak river which is known as Raidak-II. The physical configuration of the Raidak-II is largely depending on its geological structure, being the controlling factor in evolution of the landforms. The resultant physical environment in the region is due to different geomorphic processes, each of which has developed its own characteristic assemblage of it.

This study includes two districts of west Bengal, namely Alipurduar and Coochbehar through which Raidak-II passes through these two districts these areas are further characterised by floodplain which is deposited by Raidak-II.

2.2. Geomorphology of the Raidak-II River

Geomorphologically the study area is a part of Raidak and Sankosh river interfluves[1]. Geomorphology of the study area differences from Bhutan Ghat to mouth due to depositional and erosional activity of the Raidak-II river. The lower course of the Raidak river consisted of wide open gently sloping plain where the river of the Raidak drainage system have deposited huge amount of eroded materials which carry from the upper course. In the lower course are effected by different exogenesis process and fault. The northern part of the study area are mainly characterised by the alluvial fan, braided and this gradually graded into alluvial plain further south. The study area is divided different geomorphic unit (figure-2.1) on the basis of Bhuvan Geomorphology map of West Bengal (2005-2006). This are-

(i) Fluvial origin younger alluvial plain

(ii) Fluvial origin older flood plain

(iii) Fluvial origin active flood plain

(iv) Fluvial origin piedmont alluvial plain

(v) Structural origin.

(i) **Fluvial Origin Younger Alluvial Plain**

Fluvial origin younger alluvial plain is found in the lower part of the study area. Takuamari, Salbari and Bainaguri mainly covered by younger alluvial plain. This

[1] Interfluves are areas of relatively high ground that lie between adjacent valleys in a drainage basin. In its most literal sense of land 'between rivers', the term interfluves refers to undissected ridges that lie between streams. Encyclopedia of Geomorphology, Volume 1, Edited by A.S. Goudie, p-572

geomorphic unit mainly characterised by every year deposition of eroded material. In this unit mainly fine grain size partical are found.

(ii) Fluvial Origin Older Alluvial Plain

The older flood plain is mainly found left bank of the Sankosh river at Boro Laukuti. This geomorphic unit mainly characterised by the alluvial soil and far from the river channel.

(iii) Fluvial Origin Active Alluvial Plain

The active flood plain is characterised by the unconsodited material which deposited every year within the river channel and beside the natural levee. Alluvial island at Joydebpur, Hemaguri and Bainaguri is mainly cover by active flood plain.

(iv) Fluvial Origin Piedmont Alluvial Plain

The upper part of the study area is covered by piedmond alluvial plain. From Barobisha to Bhutan Ghat is mainly covered by piedmont alluvial plain. According to the geomorphological map of the study area mainly covered by piedmond alluvial plain, 271 sq/km area covered by piedmont alluvial pian among the total area.

(v) Structural Origin Plain

Near bhutan boarder a few portion only 2 sq/km cover by structural origin plain.

Table -2.1. Total Area of Different Geomorphic Unit

Geomorphic unit	Area in sq/km
Fluvial origin younger alluvial plain	143
Fluvial origin older flood plain.	20
Fluvial origin active flood plain	55
Fluvial origin piedmond alluvial plain	271
Structural origin.	2
Water bodies	64
Total	567

Source: Prepared from Bhuvan Geomorphological map(2005-2006)

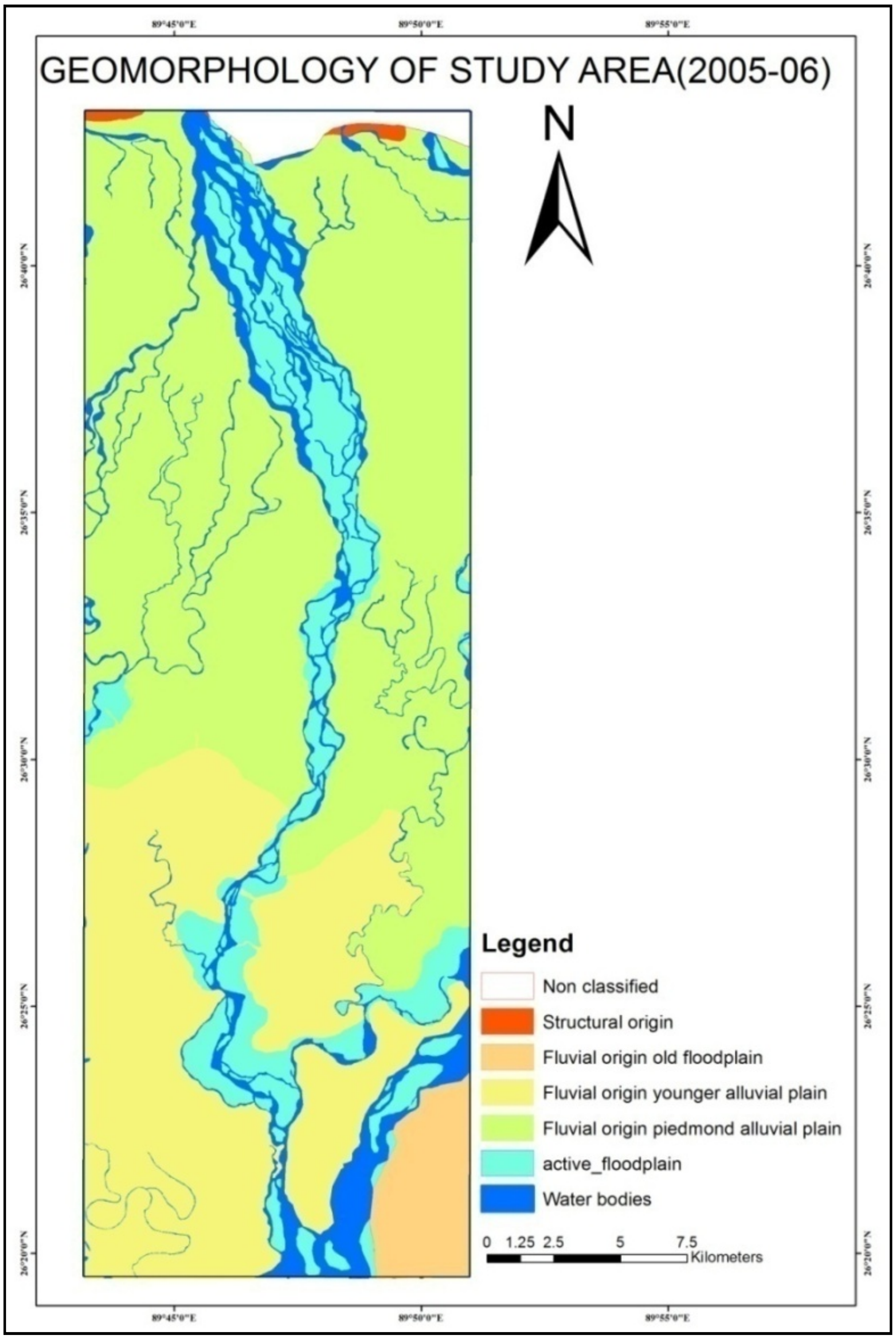
2.3. Geology of the Study Area

The Raidak-II river and surrounding areas are almost entirely covered with alluvium[2] except that narrow portion of hard rock's is exposed along the northern border (Niladri, 2008). On the basis of geological map of Jalpaiguri and Coochbehar district, the study area is covered with different geological formation (Figure-2.2). In the upper part, the two geological formations the Sub-Himalayan and Chalsa formation are found. These two formations are confined within the Himalayan arc. This formation is mainly characterised by alluvial fan geology, brown colour topsoil, and yellow coloured sediment weathering zone. The geological age of this formation is Early Holocene to Late Pliestocene. Large part of the study area from Joydebpur to mouth is covered by

[2] **Alluvium** (from the Latin, *alluvius*, from *alluere*, "to wash against") is loose, unconsolidated (not cemented together into a solid rock) soilor sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting. Alluvium is typically made up of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. When this loose alluvial material is deposited or cemented into a lithological unit, or lithified, it is called an alluvial deposit. https://en.wikipedia.org/wiki/Alluvium, accessed on 2016-11-12.

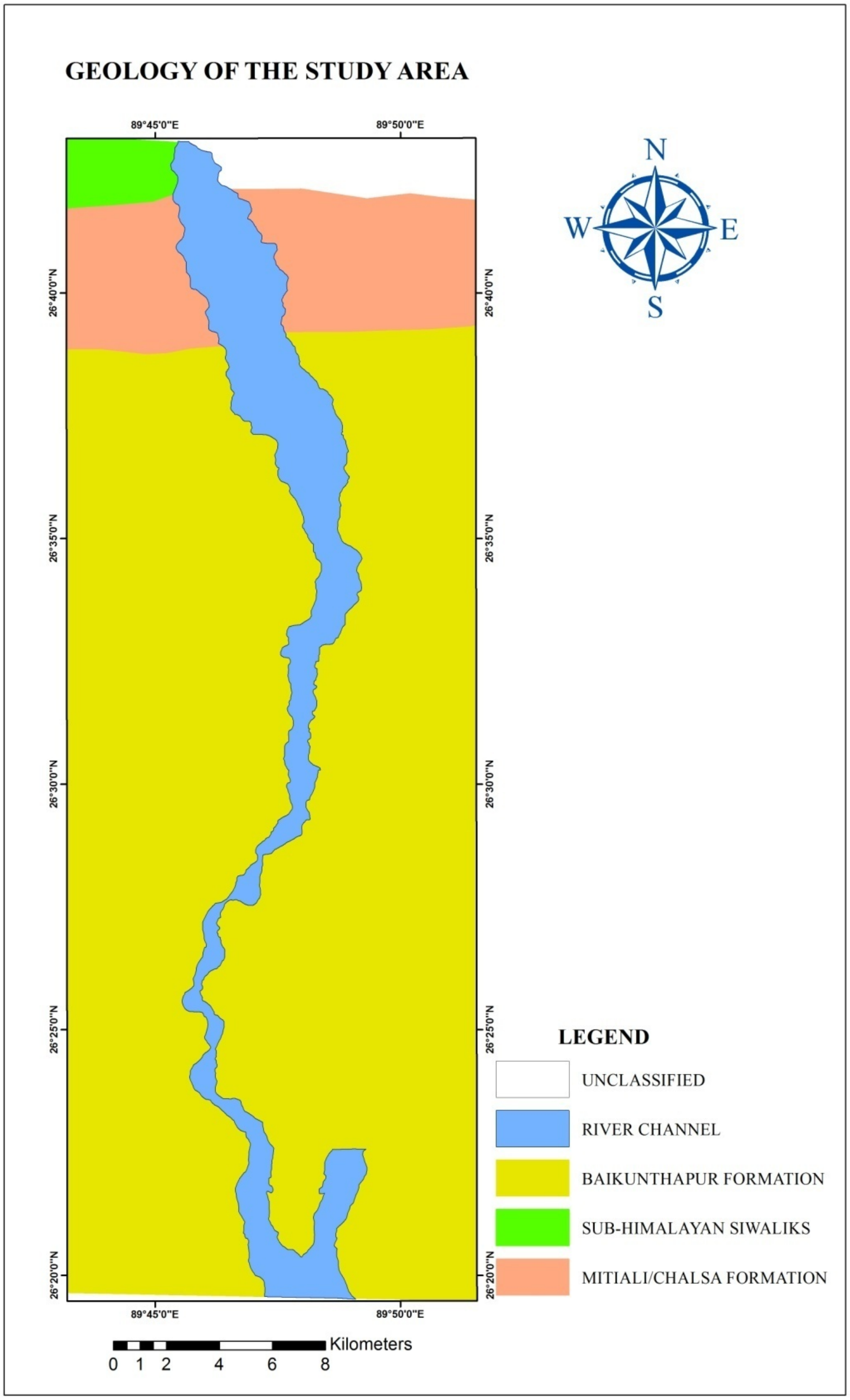
Baikunthapur formation. This formation is mainly characterised by alluvial fan material geology, black soil cover and unoxidized.

Figure- 2.1. Geomorphology of The Study Area.



Source –Prepared from ISRO,Bhuvan Geomorphology map(2005-06)

Figure-2.2. Geological Map Of The Study Area



Source- Prepared from Geological survey of India map.

Table-2.2. Morphostratigraphic Units of West Bengal (GSI unpublished report)

Quaternary landforms	Geology	Colour of topsoil	Weathering zone	Geological age	Year B.P
Shaugaon formation	Alluvial material	No soil colour	Unoxidized	Present day to Late Holocene	0.11 million to present
Erosional unconformity					
Baikunthapur formation	Alluvial fan material	Black soil cover	Unoxidized	Late to Middle Holocene	
Chalsa formation	Alluvial fan material	Brown soil cover	Yellow coloured sediment	Early Holocene to Late Pliestocene	
Upliftment and erosion					1.8 million to 0.126 million
Mitiali formation	Alluvial fan material	Red soil cover	Orange coloured sediment	Early Holocene to Late Pliestocene	
Upliftment and erosion					
Samsing taljhora formation	Alluvial fan material	Choklate soil cover	Red coloured sediment	Middle to Early Pliestocene	

Source-Niladri, 2008

2.4.Relief of the Study Area

The study area is mainly a plain region. The plain of Alipurduar is part of the piedmont plain situated at the foothill of the Himalaya. On the basis of alitude, the study area has been divided into different relief zones ranging between less then 50 metre to above 150 metre (Figure-2.3). They are –

(i) Below 50 in lower part of the Raidak-II river from Salbari to mouth.

(ii) 50-100 metre which is extended from Salbari to Hemaguri.

(iii) 100- 150 metre relief zone is extended from Hemaguri to Maynarghat

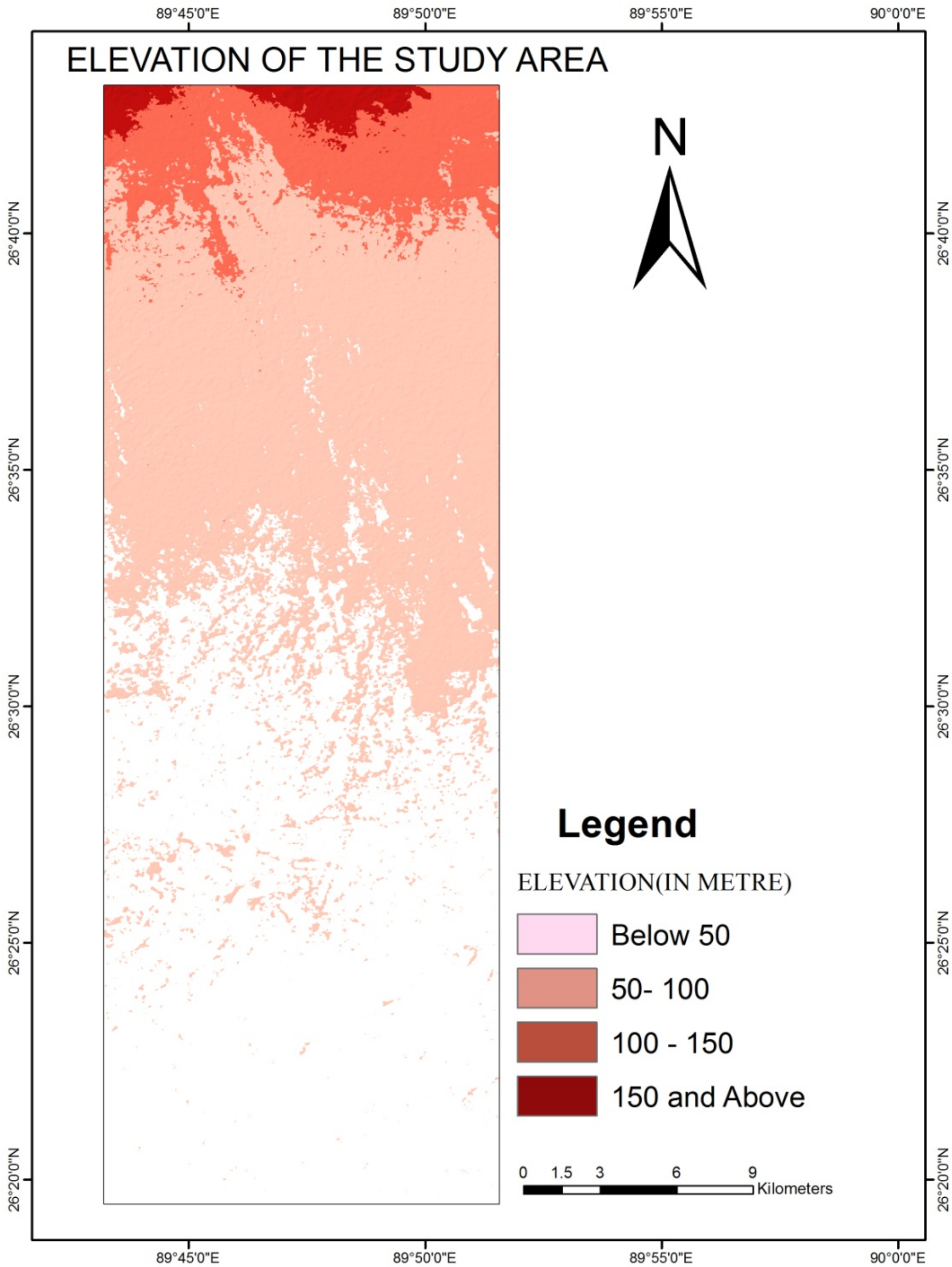
(iv) 150 and above relief zone is mainly found near Bhutan boarder.

The relief of the study area is mainly decrease from north to south direction.

2.5. Average Slope of the Study Area

Slope is one of the most important aspects of basin geomorphology. It is the result of both endogenetic and exogenetic forces. Slope which develops due to endogenetic forces is called primary slope. Secondary slope, on the other hand, is the result of exogenetic forces. Besides the earth movements there are many factors, viz. structure, process, geologic history, climatic events, relief etc. responsible for the development of slope. The lower part of the Raidak river is undulating foothill area called duars. The slope of the study area is very low. The average slope of the study area is .7 %. The upper part of the study area belong a high slope range from 10% to 20%. The slope direction is north to south and the slope continuously decreases from north to south. Near mouth the slope is very (.1%) low.

Figure -2.3. Elevation of the Study Area



Source-Prepared from USGS SRTM DEM(2011)

2.6. Soils of the study area

The Raidak-II river flow through Alipurduar and Coochbehar district plain. The soils in the area are partly developed and show beginning of profile development. The soils have been in the process of developing in young alluvium. These are formed in shallow to moderately. The deep soil are characterized by medium to fine in texture and classified as Fluventic Dystrochrepts, Fluventic Eutrochrepts and Aeric Haplaquepts. They are strongly to moderately acid while at places neutral and mildly alkaline (NBSS and LUP, 1992)[3].

The river causes flood every year and directly affects soil condition of the surrounding area. Nature of soil properties of the study area frequently changed due to sediment form. Some mining activities in Bhutan effects on soil condition of the lower part of the river basin. Soils are mostly sandy, highly acidic, heavily leached and poor in base and plant nutrients**.** The study area divided different soil zone on the basis of NBSS and LUP soil map (Figure-2.4).

(i)Fine loamy-Coarse loamy

(ii) Coarse loamy

(iii) Coarse- loamy-Fine loamy

[3] Soils of West Bengal for optimizing land use(1992), National Bureau of Soil Survey and Landuse Planning(NBSS & LUP),p-38

(i) **Fine Loamy-Coarse Loamy**

The upper portion and lower part of the study area is covered by fine loamy-coarse loamy soil. 212 sq/km area is covered by that type of soil.

(ii) **Coarse Loamy**

The middle part and north-western corner is covered by coarse loamy soil and 150 sq/km area covered by this soil.

(iii) **Coarse- Loamy-Fine Loamy**

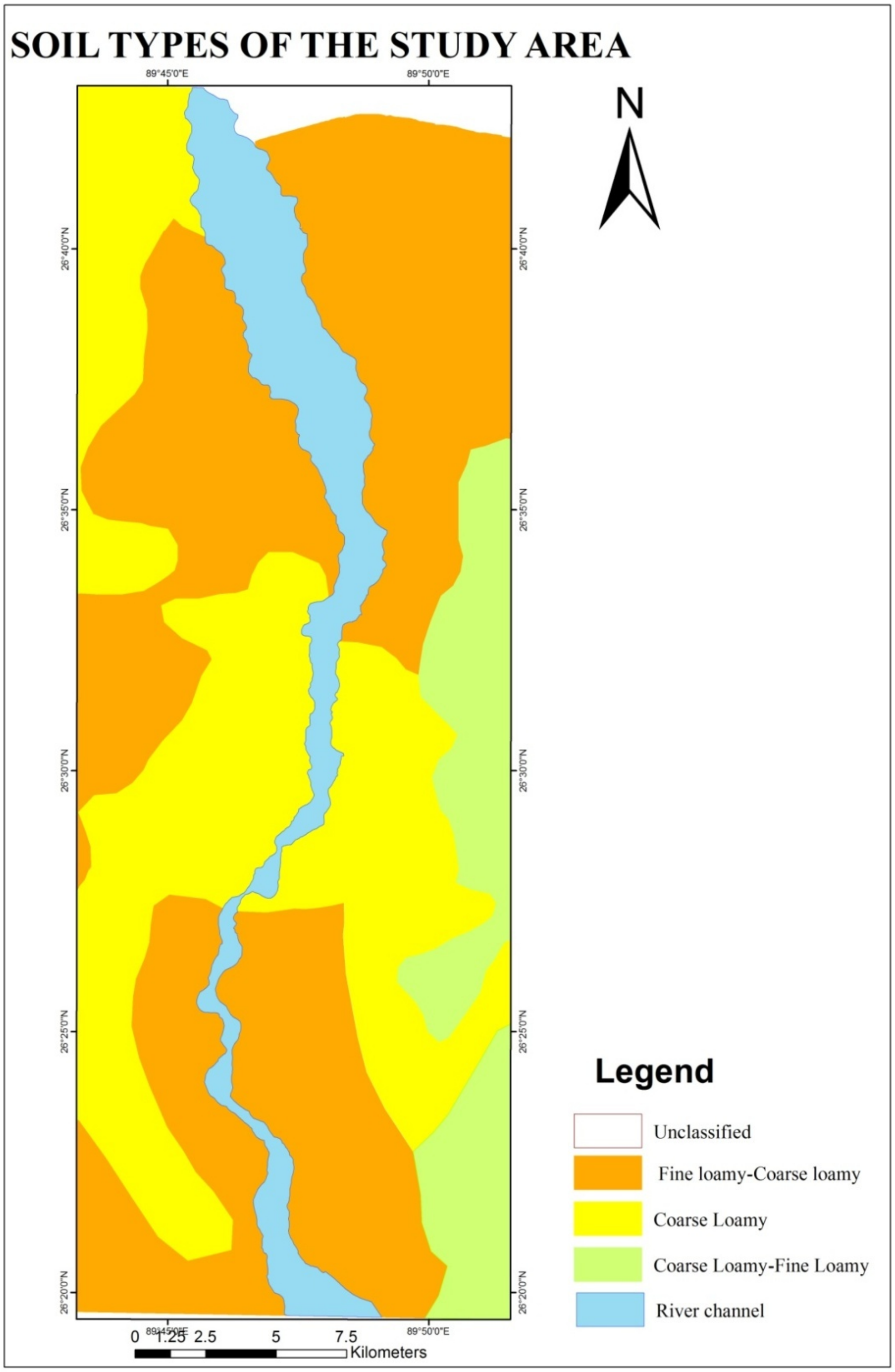
A narrow part of the eastern portion of the sutdy is covered by coarse loamy-fine loamy soil and around 47 sq/km area covered by this soil.

Table-2.3. Total Area of Different Soil Types

Soil type	Area in sq/km
Coarse loamy-fine loamy	47
Coarse loamy	150
Fine loamy-coarse loamy	212
Unclassified	12

Source: Prepared from Geological Survey of India map

Figure -2.4. Soil Map of the Study Area



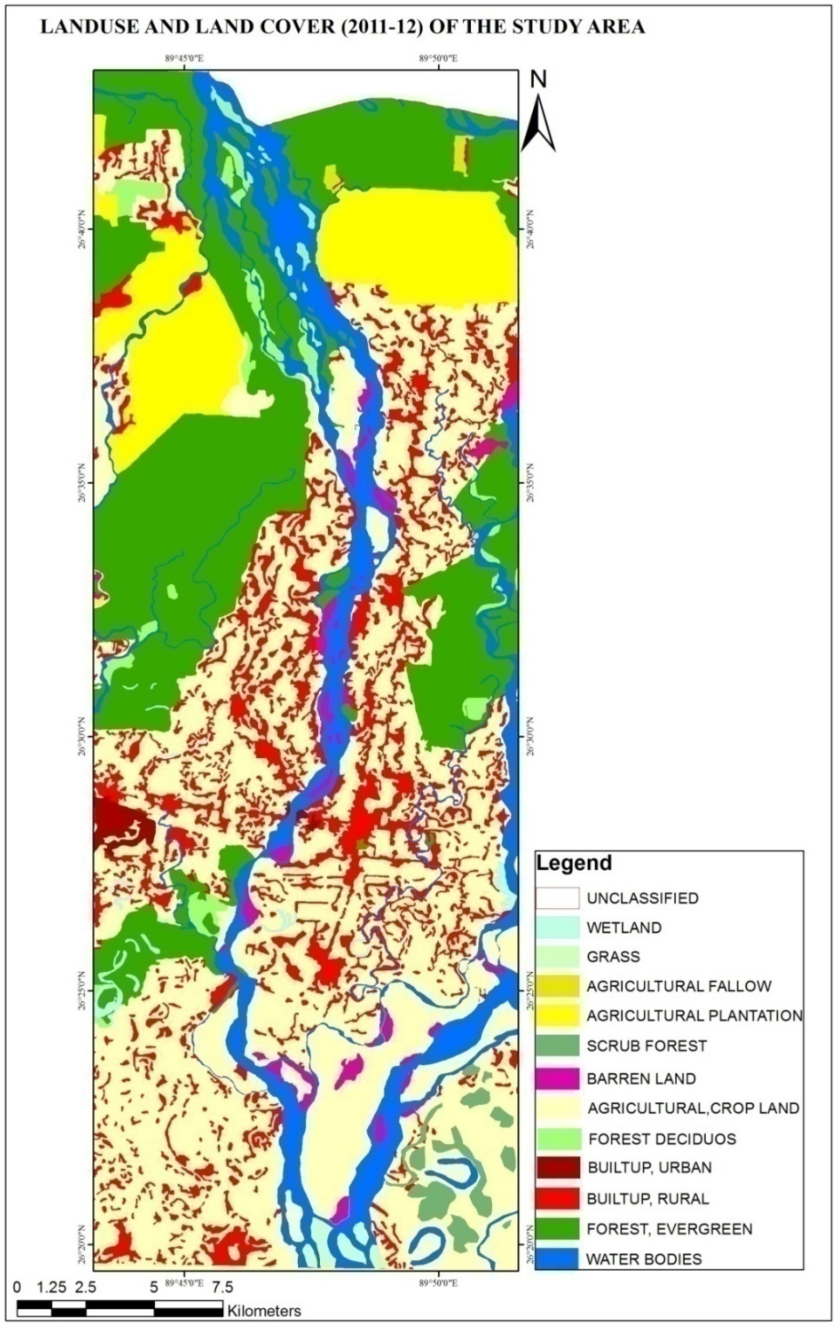
Source-Prepared from NBSS and LUP soil map.

2.7. Natural Vegetation of the Study Area

A major part of Alipurduar district is covered by forests. Even today this area remains one of the most prominent wildlife areas of the state and bears the best Sal forest in West Bengal. The forests of the area can be broadly categorized into riverine forests, plains forests, hill forests and Savannah forests. The most striking feature of classification is the abrupt merger of the riverine forests into mixed type and sal forests. The plains forests have many distinct types, viz., scattered sal and wet mixed forests, mature sal forests, dry mixed type and wet mixed type. Near the streams and moist area (rainfall), occur a type of evergreen forests known as North Bengal Tropical Evergreen Forests harbouring species like Aesculus assamica, Eugenia formosa, Dillenia indica, Eschinocarpus sterculiacells, Castanopsis species, Talalma hodgsoni, Pinanga gracilis, Artocarplts chapasa and Myriitica species (Forest Survey of India, 1999)

The study area is mainly covered by beautiful moist tropical forests. From the field visit it was observed that the area covered by reserved forest and mixed vegetation and different forest area commuted into tea garden. Raidak reserved forest is found in the right bank of the Raidak-II river where mainly found good quality of sal. Major predominant tea garden are also found in this area they are Raidak tea garden, Turturi tea garden,and Kohinoor tea garden(right bank of the Raidak-II river) and Sankosh tea garden and Newland tea garden (left bank of the Raidak-II river). In some mixed forest, the main species are sal, segun, bamboo etc. The Land Use –Landcover map(Figure-2.5) shows that the upper part of the Raidak-II river is mainly covered by tea garden and dense forest but the lower and middle part mainly covered by settlement and open mixed jungle.

Figure-2.5. Landuse and Landcover Map



Source- Prepared from Bhuvan thematic map(2011-12)

2.8. Climatic Characteristic of the Study Area

The lower part of the Raidak-II river comprises of part of Bhutan hill region and section of the adjacent plains of Alipurduar and Coochbehar district. The area is covered by the Raidak R.F, Sanchaphu R.F, Boxa R.F. A great deal of diversity in climate has been brought by the latitudinal extension as well as altitudinal variation. There is a marked differences in rainfall and temperature between upper part and lower part of Raidak-II due to altitude variation (Table 2.4,2.5, 2.6 and 2.7). An analysis of the temperature and rainfall data helps in bringing about a clear understanding of the climatic diversities and their impact on the river. The mean annual temperature of the area is about 20.94˚C. The region experiences hot and humid summer with extending 28˚C of moisture in winter temperature less is than 16˚C. Alipurduar district received highest rain fall (more than 4000mm) in west Bengal. Boxa area expenses highest rain fall Alipurduar district. Highest rainfall in Raidak and Turturi exceed about 1300mm usually during the month of July and August but in winter rainfall in minimum.

2.9. Seasons

The areas experiences four dominant seasons with altitudinal variations both in duration and extent. The important seasons are as follows:

(i). Summer Season (May to September)

(ii). Autumn Season (October to November)

(iii). Winter Season (December to February) (iv). Spring Season (March to April)

(i) Summer Season

Temperature goes up daily this season with humidity. The mean daily maximum temperature in the hottest month is 21˚C. The maximum temperature recorded in this season is more than 35˚C. The air humidity fluctuated from 87% to 58% in the lowland while the northern uplands; humidity is mostly high due to excessive cloudiness. The highest temperature is recorded in the month of March to May. This season also marked by South-West monsoon which bring maximum rainfall due to its location near foothill, the area expressing heavy rainfall 85% of rainfall falls plain during this season. The area received high rainfall in the month of June to July which the area 700mm. The upper part (Kumargram farmhouse) and lower part (Barokoli farmhouse) rainfall variation is showed in figure no 2.6.

(ii) Autumn Season

During this season rainfall decreases drastically and also temperature. Some time cyclonic rainfall brings heavy rainfall. In the beginning of this season marks high temperature but end temperature falls down.

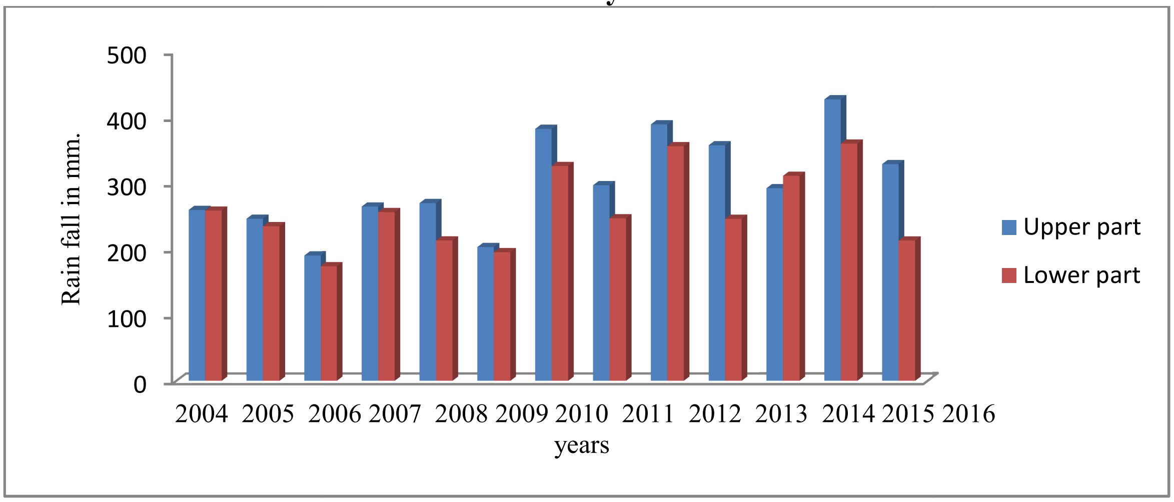
(iii) Winter Season

Minimum temperature is recorded in this season. Most of time foggy and dry. Temperature reached upto 10˚C and mean goes up 20˚C. Hardly these are no rainfall during in this season but cyclonic condition brings rainfall some time.

(iv) Spring Season

This season is mainly month of raise in temperature and still dry. Temperature raises upto 30˚C during mid season. This is very pleasant.

Figure-2.6. Annual Monthly Average Rainfall Variation in Upper and Lower Part of the Study Area



Source- Prepared from Kumargram and Barokodali Farmhouse rainfall data

Table-2.4 Monthly Average Temperature of Jalpaiguri and Coochbehar District (2010)

Months	Monthly average temperature in ◦c	
	Jalpaiguri	Coochbehar
January	15	17
February	19	19
March	25	24
April	27	26
May	27	27
June	27	28
July	28	29
August	28	29
September	28	28
October	26	26
November	24	24
December	19	18

Source-State forest report,2011-2012

Table-2.5. Year wise monthly average raifall of upper part

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL RAINFALL IN(MM)
2004	nil	Nil	nil	nil	nil	581.2	1579	192.8	628	128	2.6	6.4	3118
2005	6.6	6.4	143	171	264.9	614.1	703.8	622.4	142.2	251	26.6	nil	2951.3
2006	nil	15	2.6	127	344.8	538.8	472.6	142.4	507.2	115	12.8	4.2	2282.6
2007	nil	51.5	15.2	209	198.8	579.2	790.2	548.4	720.6	55	1.2	nil	3168.7
2008	11	3.2	52.6	190	233.3	450.7	879.2	1070	256.8	75.8	nil	9.8	3231.7
2009	6.4	Nil	16.4	145	242	458.2	601.2	643.8	139.8	178	nil	1.6	2432
2010	nil	0.6	151	553	481.4	933.6	827.4	1027	536.8	55	14.2	nil	4580.2
2011	1.2	15	138	146	211.8	656.2	1235	690.6	418.2	32.8	nil	11.4	3555.6
2012	4.6	18.4	2.8	135	414.2	1868	1134	448	510	128	nil	nil	4662.2
2013	nil	17.6	9.8	239	464.2	696	1233	539.6	848.8	234	nil	Nil	4282.4
2014	nil	30.4	14.4	110	598.2	737.8	434.4	959.6	566.4	51	nil	nil	3502.6
2015	24.8	2.8	28.6	153	665	1328	768.8	1501	515	83.4	40.2	7.2	5117.6
2016	8	3.4	45	200	539	1052	929.4	166.2	715.8	277	nil	4.4	3940.3

Source-Kumargram Farm House, Kumar Gram, Alipurduar,2016

Table-2.6 Year wise monthly average rain fall in lower part

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL RAIN FALL IN (MM)
2004	nil	0.9	nil	nil	5.2	562	1559	196	620	126	27	3	3099.1
2005	5.1	6.3	120	151	248	600.2	695.9	600.2	140.3	225	22.3	nil	2814.8
2006	nil	10	2.1	125	334.8	535.8	460.6	141.4	503.2	100	10.8	3.2	2227.1
2007	nil	50.5	15.2	211	197.8	477.2	791.2	542.4	725.6	55.3	1.3	nil	3067.1
2008	7.2	2.2	50.6	183	230.3	440.7	882.2	1009	209.8	78.8	nil	9.8	3102.9
2009	5.1	Nil	15.9	145	243.1	458.9	560.2	600.8	139.8	169	nil	1.6	2339.25
2010	Nil	nil	42.8	143	489.4	933	1131	659.9	467.4	36.6	3.8	Nil	3906.18
2011	5	4.6	108	158	383	467.8	834.9	629.1	315.8	45.8	2.4	0.2	2954.3
2012	2.4	13.6	4.2	169	412.2	1400	801.8	414.2	681.2	367	nil	Nil	4265.4
2013	nil	15.4	12.3	187	422	398.4	711	467.3	520	210	1.2	Nil	2945.4
2014	nil	26.2	8.8	22.9	636.6	802.6	222.2	938.8	1024	41.8	nil	2.8	3726.9
2015	20	4.4	57.6	172	452	1365	237.5	1288	594.1	113	10.4	nil	4313.4
2016	6.2	Nil	61	171	452.6	865.2	854.4	374	325.4	304	nil	3.2	3417.32

Source- Barokodali Farmhouse, Tufanganj, Coochbehar,2016

2.7. Monthly max. and min teperature of lower part

Months	Temperature (^{o}c)2012			Temperature (^{o}c)2013		
	Max.	Min.	Mean	Max.	Min.	Mean
January	22	9	15.5	22	8	15
February	28	12	20	27	12	19.5
March	31	16	23.5	31	18	24.5
April	31	20	25.5	32	20	26
May	32	23	27.5	33	24	28.5
June	33	25	29	33	26	29.5
July	31	26	28.5	31	26	28.5
August	33	26	29.5	33	26	29.5
September	33	25	29	33	25	29
October	33	22	27.5	33	22	27.5
November	29	15	22	29	15	22
December	26	12	19	26	12	19

Source-_Source: Sub-divisional Irrigation Office, Tufanganj,2015

2.9. Summary

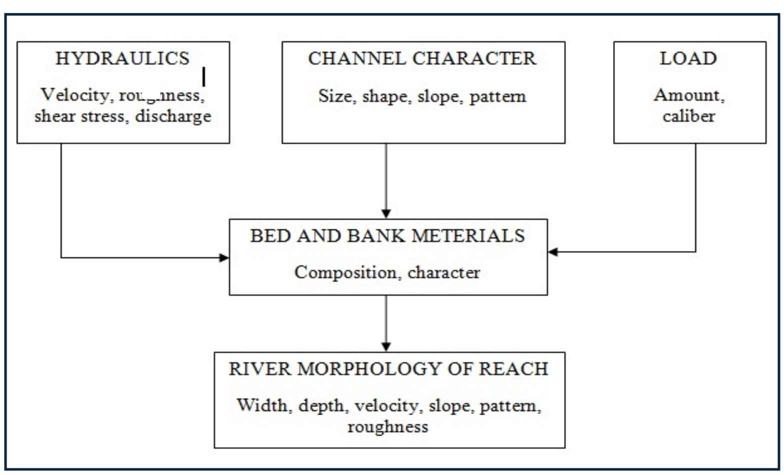
The physical characteristics of the study area reveals that it is geologically young and fragile region. the upper part of the study area is characterised alluvial fan and the lower part is floodplain region. Large part of the study area is covered by piedmont alluvial plain. Mainly three types of soil are found. The upper part of the study area is mainly covered by evergreen forest and some tea garden. The lower part of the study area is cover by settlement and agricultural practice. This is also mentioned different in temperatur and rain fall in upper and lower part.

3.1.Introduction

The hydro-morphology of a river channel is intimately linked with the form and behaviour of the river channels along with volume of water that shape them. It is very dynamic because channel forms are quite changeable. Various processes of deposition, reworking and erosion are involved in the formation and development of channel morphology. Sediment deposits on floodplain surfaces by various processes of accretion, the main ones being vertical, lateral and braided bar.

River channel morphology is the shape or form of a river along its length and across its width. Transported materials are used in deposited river bed and thus shaping its morphology. The transported materials are deposited either temporarily or permanently along the course of a river when it can no longer be transported. The shape of a stream channel at any point in the channel network is a result of a balance between the erosive force of moving water and the material over or through which the water is moving (Tamang, 2013). In reach the channel morphology is also controlled by dependent and independent variable (Figure-3.1).

Figure- 3.1 Controls of River Reach



Source- Morisawa, 1985

As the Raidak river debouches onto the Alipurduar and Coochbehar plain, the fall in gradient and incompetence force to carry material, provides greater scope for the water to spread laterally. Thus, along the lower course, the river attains the braided pattern with several bars and islands developed from irregular deposition and also successive divisions and rejoining of flows within the main braided channel which has increased the size of bars downstream. Such bars are unstable and change their size, shape and location due to varied channel erosion both during high flows (monsoon months) and also due to anthropogenic impacts (mostly boulder lifting activities). This chapter mainly focus on the channel morphology and it's dynamic of the Raidak-II channel. It mainly discusses on bar and island change in upper part, bar change in middle part, meandering channel change in lower part, confluence change and bankline shifting.

3.2. Morphological Features of the Raidak-II

Different morphological features are found in the Raidak-II channel. These feature are of two types erosional and depositional features. The features of a river channel can be listed as follows in the table-3.1.

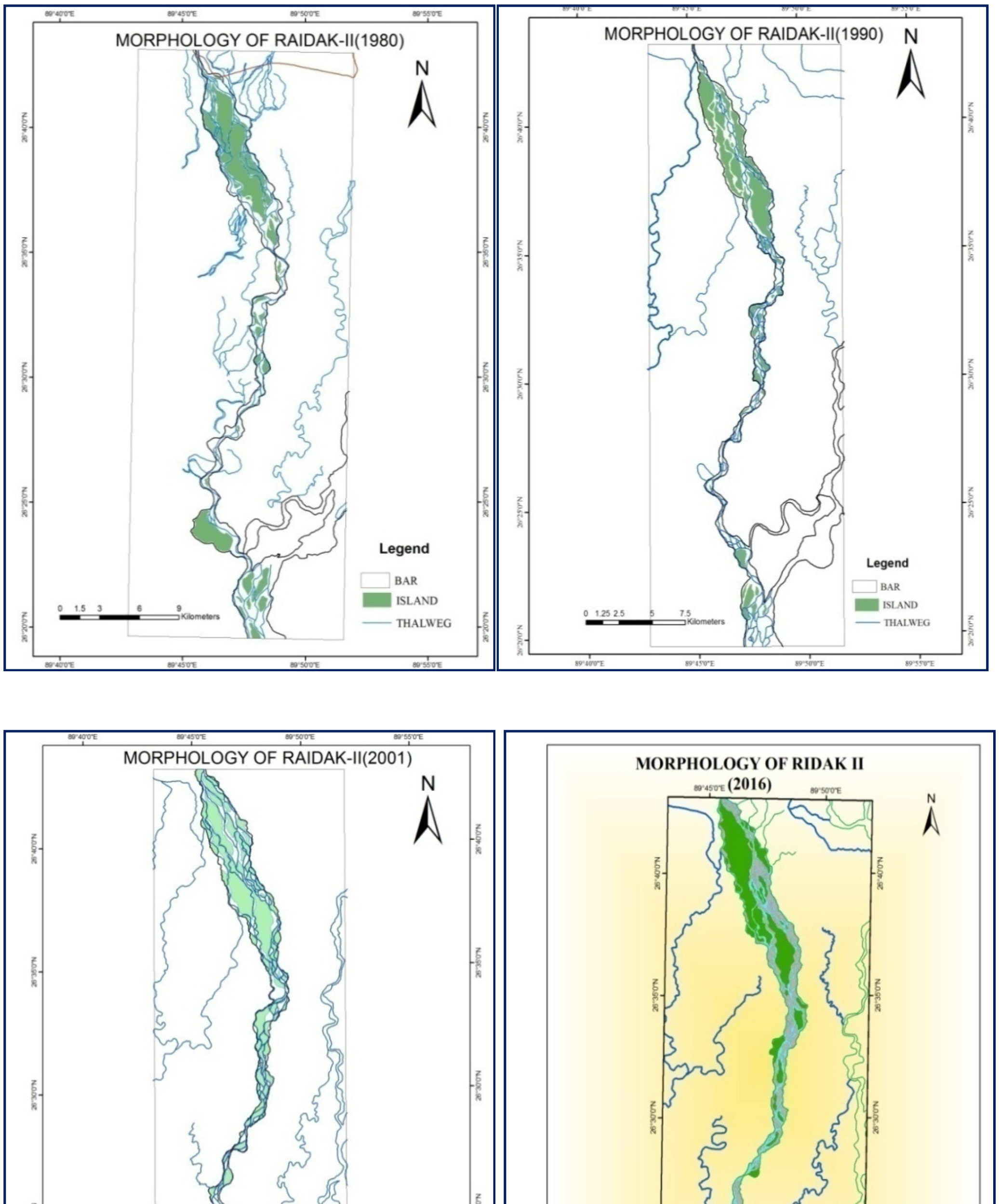
The morphology of Raidak-II river was studied from topographical map, Google earth and satellite images. The major features of the river channel morphology listed in the Table-3.1 and these features are also found in Raidak-II with same mechanism through different size and extension.

Table-3.1. Flood plain features (After Gregory and Walling ,1973)

Lateral accretion	• Point bars • Channel bars	Features developed by the deposition of materials at the margins of the channel or within channel.
Intermediate features	• Cutoff channel • Channel fill	New channel developed along a swale in a bar or abandon meander loop.
Overbank features	• Levees • Crevasse splays • Flood basin	Wedge shaped ridges of sediment bordering stream channel A system of distributing channel on the levee slope when water escapes through low section of bank or natural levee Back swamps which are poorly drained flat features.
Ancillary features	• Lake • Deferred tributary • Alluvial ridge	Depression with water in it. Form by cutoff, abandon channel, meander scrolls or where a tributary is blocked. Where tributary flour parallel to main rivers for some distance because of an aggraded alluvial ridges. An aggraded meander belt above the general flood plain.

Source- Das, (2000)

Figure -3.2. Channel morphology of Different Year



Source: - Prepared from SOI, Topographical map (1980) and USGS, LANDSAT image (1990,2001,2016)

The Raidak-II river channel is mainly characterized by the highly depositional features. Channel bar and alluvial island is the common features of this river channel. From Bhutan Ghat to mouth different sizes of island and bars are found. Some of these are large size. They are transient in nature and subjected to low flow deposition and high flow removal. The alluvial channel island is mainly covered by grass and some open mixed jungle. In Joydebpur region, island mainly covered by Raidak reserved forest and open mixed jungle. Alluvial island of Salbari and Bainaguri is mainly covered by all grasses and some trees. Now a days, some island are covered by settlement and agricultural practice. Some of these are in Joydebpur, Hemaguri, Bainaguri which are used for settlement. Channel cutoff is one of the most important morphological features. In the lower part, there are many cutoff, which can easily observed from Google earth image (Figure-3.3) and also assessed them in field visit.

In order to have a proper understanding of such morphological features in detail, Raidak-II course divided into three parts.

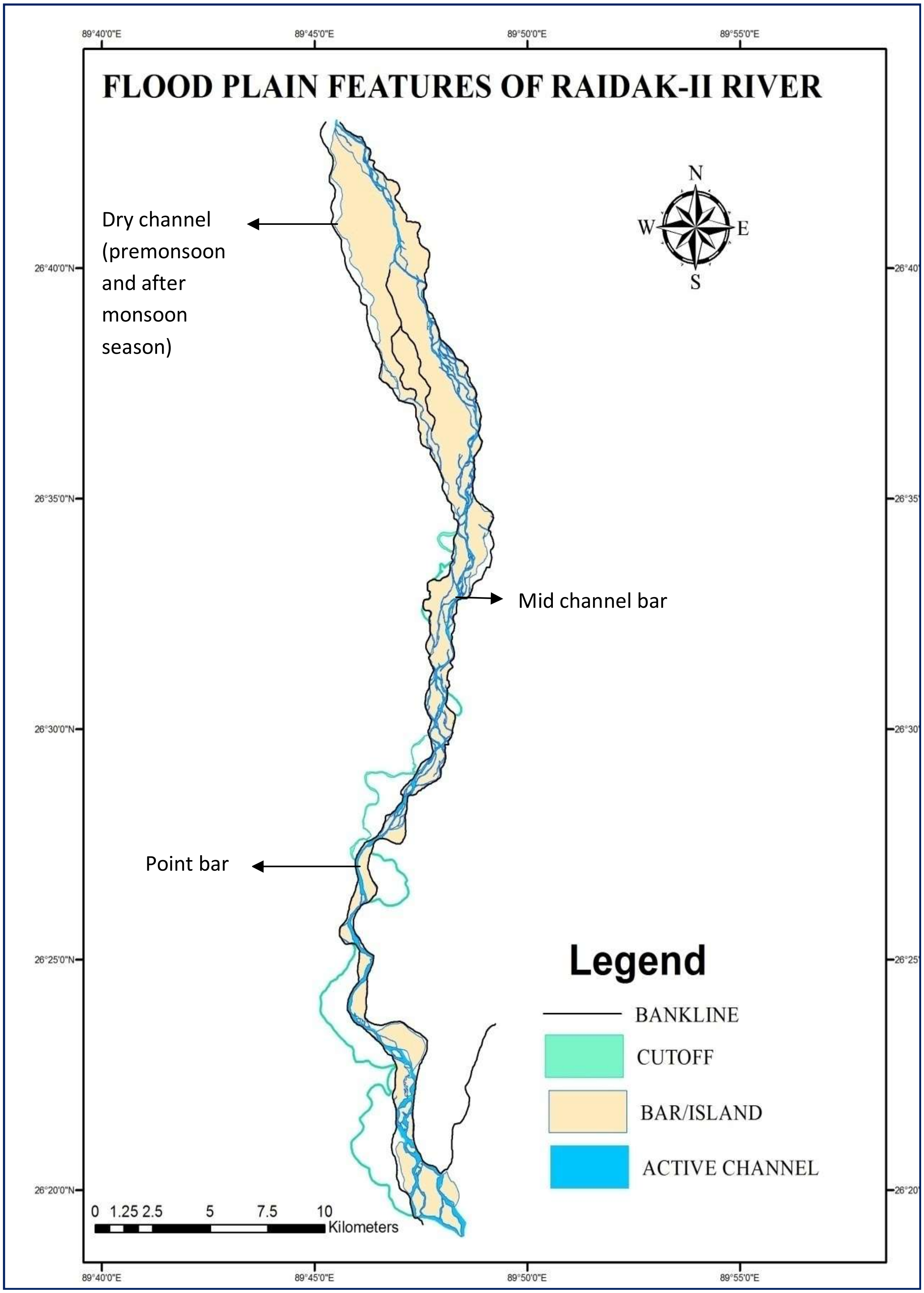
The three division of the course Raidak-II was divided on the basis of its distinct morphological features (figure-3.4). Each division has quite different morphological features (table-3.2). The three divisions are

(i) Upper part (Bhutan Ghat to Joydebpur)

(ii) Middle part (Joydebpur to Chokchoka)

(iii) Lower part (Chokchoka to Bainaguri)

Figure-3.3. Morphological Features of Raidak-II River,



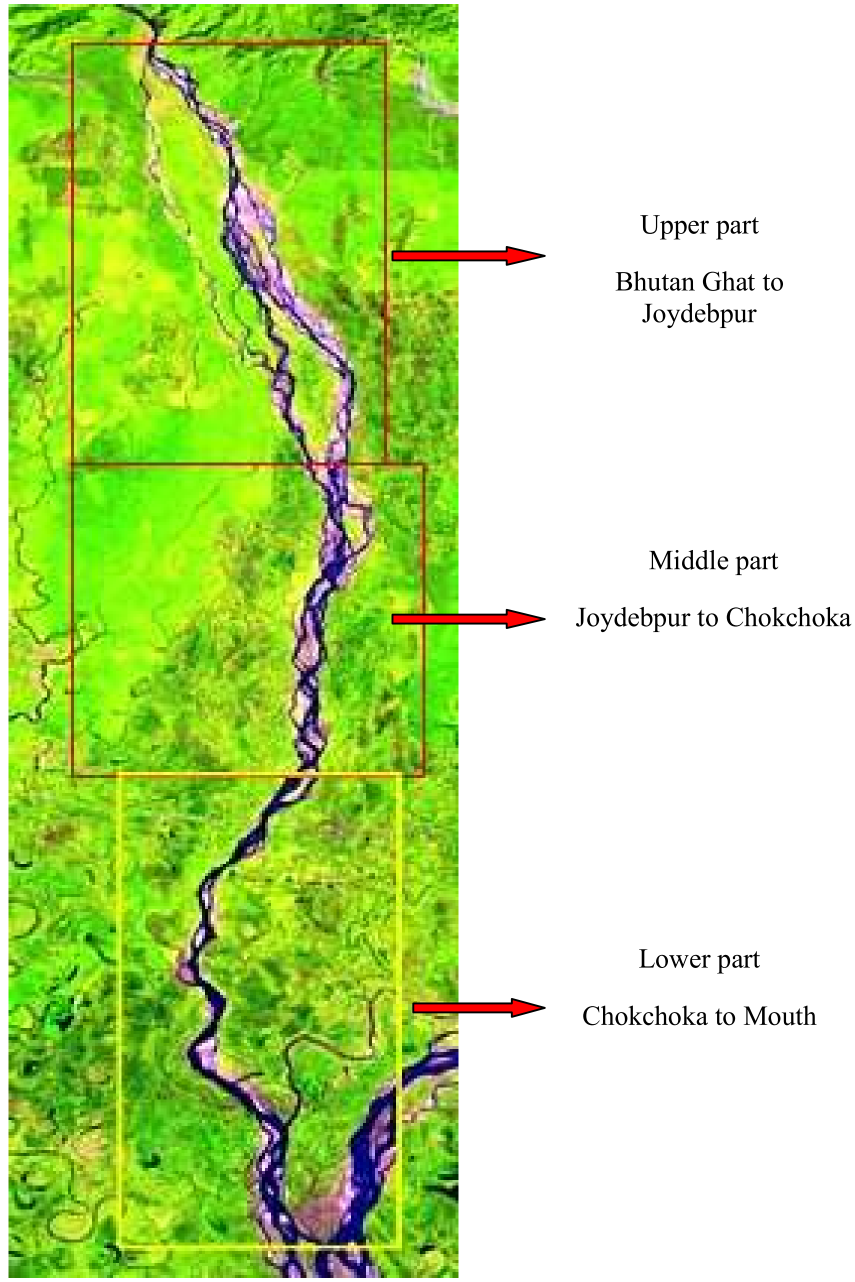
Source: -Prepared from Google Earth, 2014

Table-3.2. Morphology of the Different Parts

Parameters	Upper part	Middle part	Lower part
Special extent	Bhutan Ghat to Joydebpur	Joydebpur to Chokchoka	Chokchoka to Bainaguri
Reach length (in km.)	19	15	18
Channel sinuosity	1	1.2	1.5
Channel type	Mixed and bed rock	Alluvial	Alluvial
Active channel width (in meter)	2000	1200	620
Number of secondary channel	4	2	1
Dominant bed materials	Grabbles and boulders	Sand and pebbles	Sand and silt
Morphological appearance	Anabranching/ Braided	Anabranching/ Braided	Meandering
Stream gradient(in degree)	.6-.9%	0.8 to -1%	0.6 to -1%
Average valley width(in metre)	1900	1100	550
Annual monthly average rainfall(in mm)	350	350	350

Source- Prepared from field study and USGS, LANDSAT-8 image 2016.

Figure-3.4.Three Part of the Raidak-II River



Source-Prepared from USGS, LANDSAT-8 ETM+ image, 2016

(i) Upper Part of the Raidak-II River

The upper part of the Raidak-II river is extented from Bhutan ghat to Joydebpur and total length of the upper part is 19km. The average slope of this part is 0.6-0.9 percent. The average valley width is 950 metre and average depth is 1.4 metre(pre-monsoon/post monsoon). The sinuosity index of this part is 1.2. The upper part is bearing some morphological characteristic which are different from middle and lower part. In this part the river bifurcate in different channel due to huge amount of deposition. Different sizes of alluvial island are found in this region. Near Bhutan many tributaries have joined with to upper part of the Raidak-II channel and this tributaries supply huge amount of erosional material and water in the rainy season and change the morphology of this part. Of this part, the erosive behaviour of the channel is valley widenning due to sudden fall in gradient of river course, the large volume of water start lateral spreading and depositional bevaviour is agradation sediment carried by river gets deposited in the course itself and form mid channel bar. In this part the bed matrials are mainly boulder and grabbles. The channel bars/islands are more or less parmannt. Grasses and vegetation are grown on it. Some of bars / islands of this part are under reserved forest. The river attained alluvial braided stage but due to permanency of bars and island, they are anastomoshing. Many small tributary also are bifurcated and later join to main stream. But actually large number of joining take place in this part. It was observed in field visit in premonsoon and after monsoon at this part the active channel mainly found in the left side.

(ii) Middle Part of the Raidak-II River

The middle part of the Raidak-II river is extented from Joydebpur to Chokchoka. It bears distinct characteristic from other parts. The lotal length of this part is 15 km and the sinuosity index is 1.2 . The average slope of this part is 0.6-0.8 percent. The average width of this part is 900 metre and average depth is 1 metre(pre-monsoon/post monsoon). In this part the river flow two or more channels with bars and small island. In this part, still maintain valley widenring due to erosive behaviour of the channel and depositional bevaviour is performed by agradation and mid channel bar formation also taking place. In this part the bed material are mainly sand and pebbles. Diffent types of bars are found in this part that are mid channel bar, point channel bar, newly form bar, old bar deposit. All channel bars are transient in nature becuase of changing their size and shape due to high flow in the monsoon season and also by human activity.

In this part, all bifurcated tributeries are coming together to the main channel. Though due to some remaining fine sediment get deposited in the channel itself again and course bifurcation also observed but not extensive and join to main channel which forms anabranching. It also maintains characteristics of braided as bars and island form but not permanent.

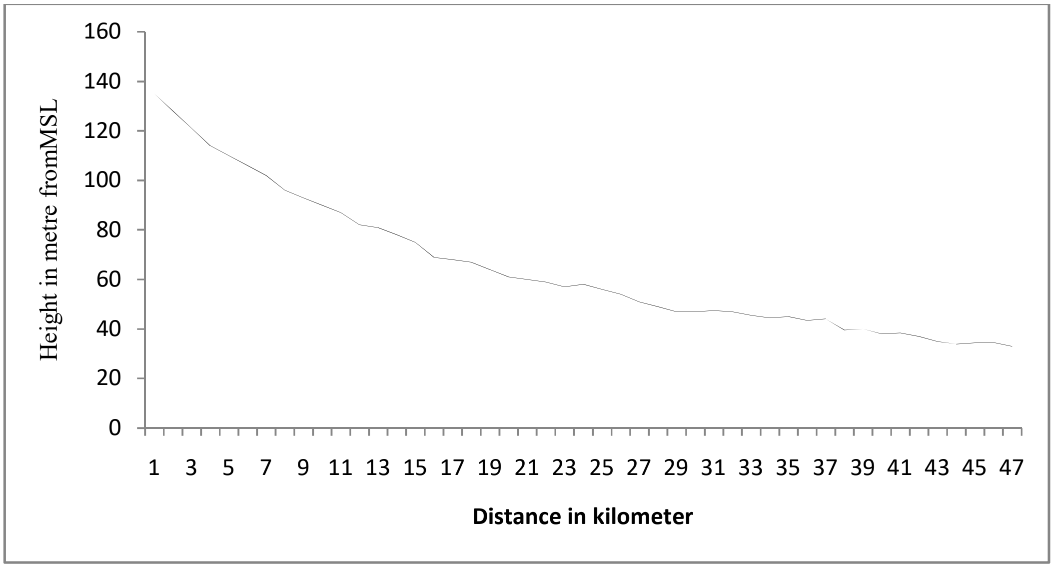
(iii) Lower Part of the Raidak-II River

Lower part of the Raidak-II river is extent from Chokchoka to mouth. The total length of this part is 20 km and sinousity index is 1.5. The average slope of this part is 0.6-0.1 percent. The average channel width of this part is 600 metre and average depth is 1.1 metre . The river flow through this part a single channel with different bend and bifurcate in different channels at confluence of Sankosh. In this part the point bar is main depositional features. The bed materials are mainly sand and silt. At the confluence some island are formed which are now used for settlement and agriculture. Deposition of transportational meterials are taking place on the side of bank that is known as point bar. Channel pattern mainly characterised by pool and riffle sequence. Due to anabranching channel to main channel increase volume of water cause lateral erosion. The depositional activity also very less in the channel because sediment contain in river water also very less. River becomes very sluggish by which lateral erosion is active. Due to lateral erosion the course of river stands bounding and form meander channel.

3.3. Longitudinal Profile of the Raidak-II

River long profile are an important element of drainage basin geomorphology in that together with the channel network, they fixed the boundary condition for hillslope process(Knighton, 1998). The long profile of a river channel is a way of displaying the channel gradient of river along its entire course(source to mouth). Therefore the long profile showing a river channel gradient decrease from source to mouth. Generally the longitudinal profile of a river channel is concave with a steep. For the analysis of the longitudinal profile of the Raidak-II river channel, image from Google Earth has been used. Here mainly showing the long profile of Raidak-II river from Bhutan Ghat to mouth(Bainaguri). The long profile's gradient is generally decreasing from Bhutan Ghat to mouth with the direction of North to South. Elevation of the long profiles are 60 to 140 metre between Bhutan Ghat to Joydebpur, 60 to 40 metre is between Joydebpur to Chokchoka and less than 40 metre is Chokchoka to mouth(Bainaguri) (Figure-3.5).

Figure-3.5. Long Proflie of the Raidak-II river from Bhutan Ghat to Mouth



Source- Prepared from Google Earth, 2014

3.4. Channel Type

River channel are conduits for varying amounts of water discharge and sediment and solid loads and as such have fascinated scientist, engeneers with their self forming geometry and their response to change both natural and human induced(He Qing Huang,1969). River channel is mainly divided into two types on the basis of lithological characteristic of the region through which the river has developed its course. They are bed rock channel and alluvial channel.

Bedrock channel mainly developed in the mountain region where river perform active vertical erosion and alluvial channel developed in the plain region. The Raidak-II channel is alluvial channel type. Raidak-II bears all characteristics of alluvial channel. The upper part of the Raidak river mainly flow through the eastern Himalaya, for this the upper part of the Raidak river is bedrock channel type. From

Bhutan Ghat to mouth the river channel mainly flow through the plain of Alipurduar and Coochbehar district and this part of the channel activity is more or less characterised by deposition.

The depositional character of sediment in the course of river varies from one part to another. In the upper part /foothill, depositional material are mainly boulder, pebble and medium size grain. Most of them are bedload materials. Middle part of river course sediment are characterised by fine boulder to suspended material, but dominated by bedload sediment. In the lower part mostly suspended material but due to tributeries which join this part bring madium size materials sometime. So, the river in the lower part is characterised by dominant suspension materials.These are characteristics of alluvial channel.

3.5. Channel Pattern

Channel pattern is spatial distribution of channel network. It may be straight, meandering and braided. River channels exhibit great range of plan form or pattern due to range of variation in quantity of sediment carried , flow and topographic characteristic, gradient, volume of water, geological structure etc.

The alluvial channel pattern of a river is usually considered as straight, meandering or braided(Morisawa, 1985). Alluvial channel patterns has been classified into different category by different geomorphologist. Leopold and wolman(1957) have classified river channel into three types on the basis of sinuosity index, these are (i) straight channel (sinuosity index is <1.05) (ii) sinuous channel (sinuosity index is between 1.05-1.50) (iii) meandering channel (sinuosity index is >1.5) . The formula of sinuosity index is-

$$SI = Lc/Lv$$

Where, SI is sinuosity index, Lc is channel thalweg length and Lv is valley length.

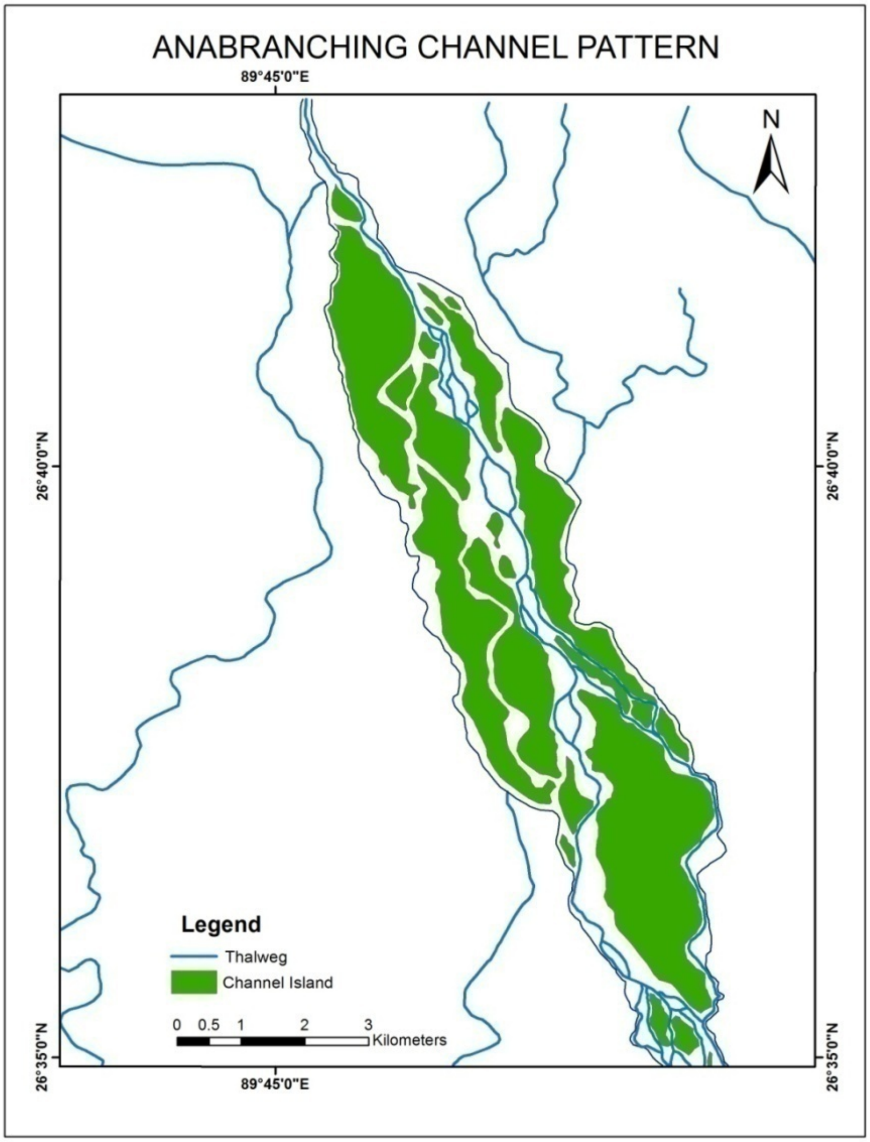
According to A.D. Mial (1985) have divided alluvial channel into five major categories on the basis of geomorphic characteristics, sinuosity index, sediment load type and erosional and depositional behaviour. They are (i)straight channel (ii) sinuous channel (iii) meandering channel (iv) braided channel and (v) anabranching channel.

The Raidak-II river flows through the plain of Alipurduar and Coochbehar district in different channel pattern. According to above formula of channel pattern classification, the Raidak-II channel can be divided in two channel pattern (i)anabranching/braided and (ii)meandering channel pattern. Anbranching/braided channel is developed in the upper part and in the middle part. The meandering channel pattern is developed in the down stream of Barobisha. At the confluence the river channel again bifurcates one and more channel and join with Sankosh river.

(i) Anabranching/ Braided Channel Pattern

Anabranching channel are multi thread channels in which individual channel are seperated by vegetated bar (Figure-3.6) or otherwise stable bars and island that are broad and long and divided flows upto bankfull(Nanson,2013). The Raidak-II river from Bhutan Ghat to Joydebpur is anabranching/braided channel pattern. In this reach the river channel bifurcates in many sub channels due to huge amount of deposition and develop bar and island and after few kilometer that some channels join with the main channel. In this region many stable bars and island are found and all island are covered by vegetation.

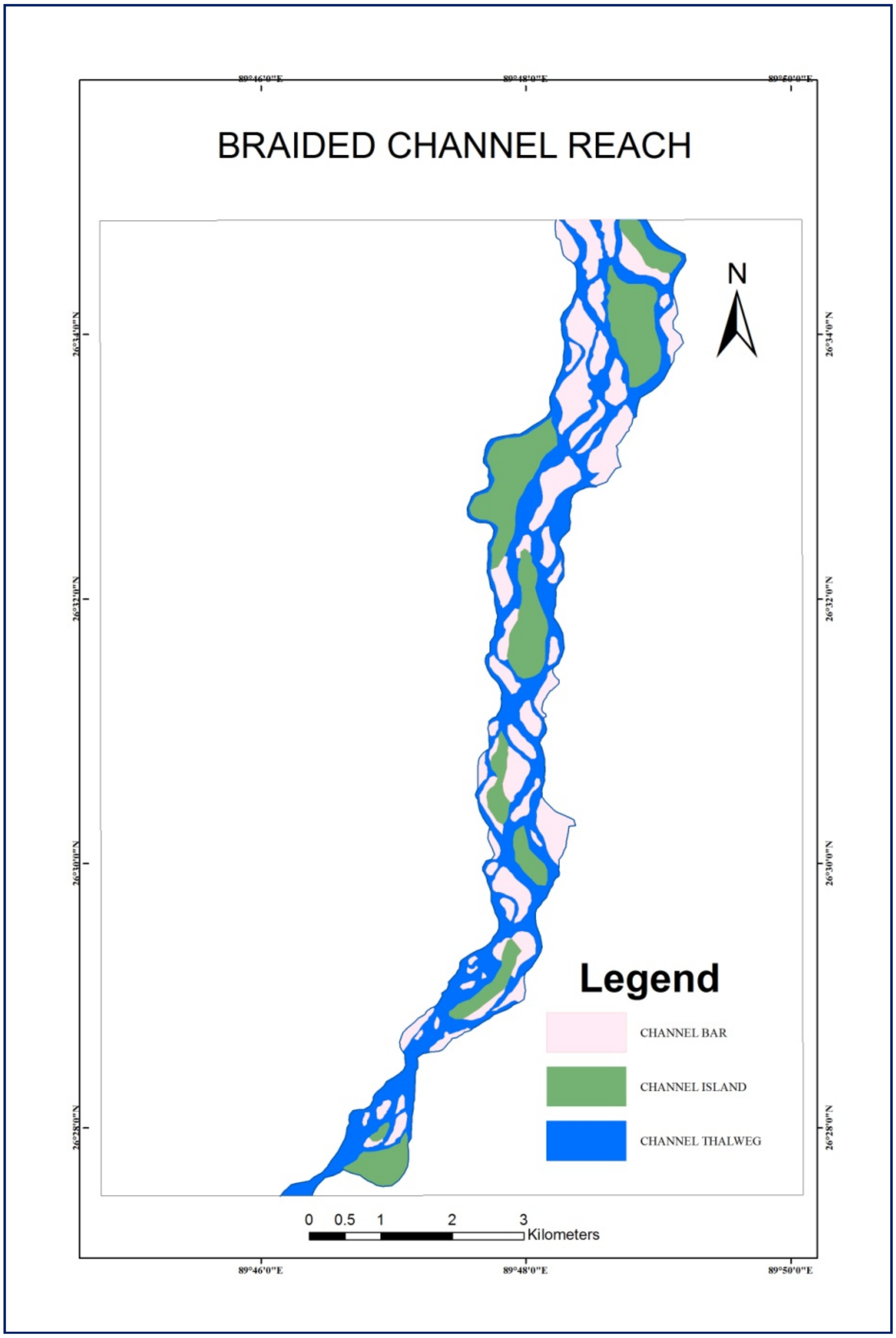
Figure-3.6. Anabranching/Anastomoshing channel



Sourcce:- LANDSAT Image ETM+ 2016

A braided channel pattern is mainly characterised by multiple channels(Figure- 3.6 &3.7), they are divided by different bars and alluvial island. The characteristics features of braided channel pattern include unstable bars and island. The bars and island temporarily change their shape and size, also change their location. According to Morisawa(1968) “ a braided stream is characterized by the general instability of the bars and channel ways and by caving of the channel walls”.

Figure-3.7. Braided Channel



source-Prepared from LANDSAT image ETM +, 2016

The braided channel pattern contains bars and island and the degree of braiding can be express by the percentage of reach length that is divided by one or more island or bars(Chorley, et al. 1985). J. C. Brice(1964) has devised a braiding index to determine the degree of braiding(Singh, 1998)

Braiding Index= 2(sum of the length of bar or island)/Length of the reach

Raidak-II river channel exhibits braided characteristics at many points where it flow anastomosing channel arround bars and island of various sizes. Braiding is best example in the short reach upstream of N.H.-31 road crossing at Barobisha. In this reach different sizes bars are developed and the channel thalweg seperated by them. During the field visit, it has been observed that these channel bars are transient in nature. They are subjected to submergence during high flow and changes shape and size.

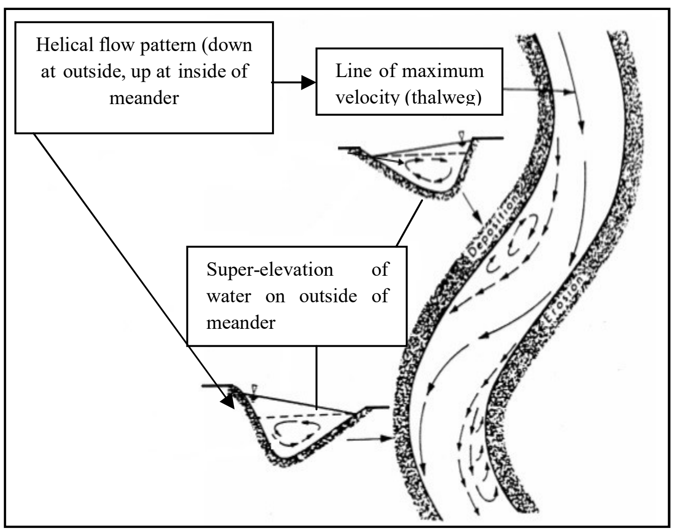
(ii) Meandering Channel Pattern

A meandering channel pattern is a common pattern which is found in every alluvial channel. A channel having sinuosity index more then 1.5 is called as meandering channel pattern. Meandering channel pattern mainly charcterised by pools at the bend and riffles at the crossovers of the river course.

In the Raidak-II, the meandering channel pattern observed in the downstream from Barobisha to mouth. In this reach the river channel flows a single or more less channel with bend in different point. In this part the river channel deposited transportational meterials in the side of bank, that known as point bar and flow resistence is greater at riffles than at pool[1] which means velocity of water is less at riffle[2]. In this part the channel meandering is mainly occured for helicalflow[3]. According to Marie Morisawa "helicalflow is often advanced as the basic cause of meandering"(figure-3.8). The main factors of meandering in this part is of low gradient. The slope ranges from 0.6% to 0.1 % in this part. So, river gets sluggish and more active in lateral erosion. The sinuosity index of this part is 1.5.

In eastern loop of meander from the top to bottom in this part, the length of the 1st meander loop is 2.48km, second is 2.99km whereas western side first is 3.07km and last one is 6.99 km.

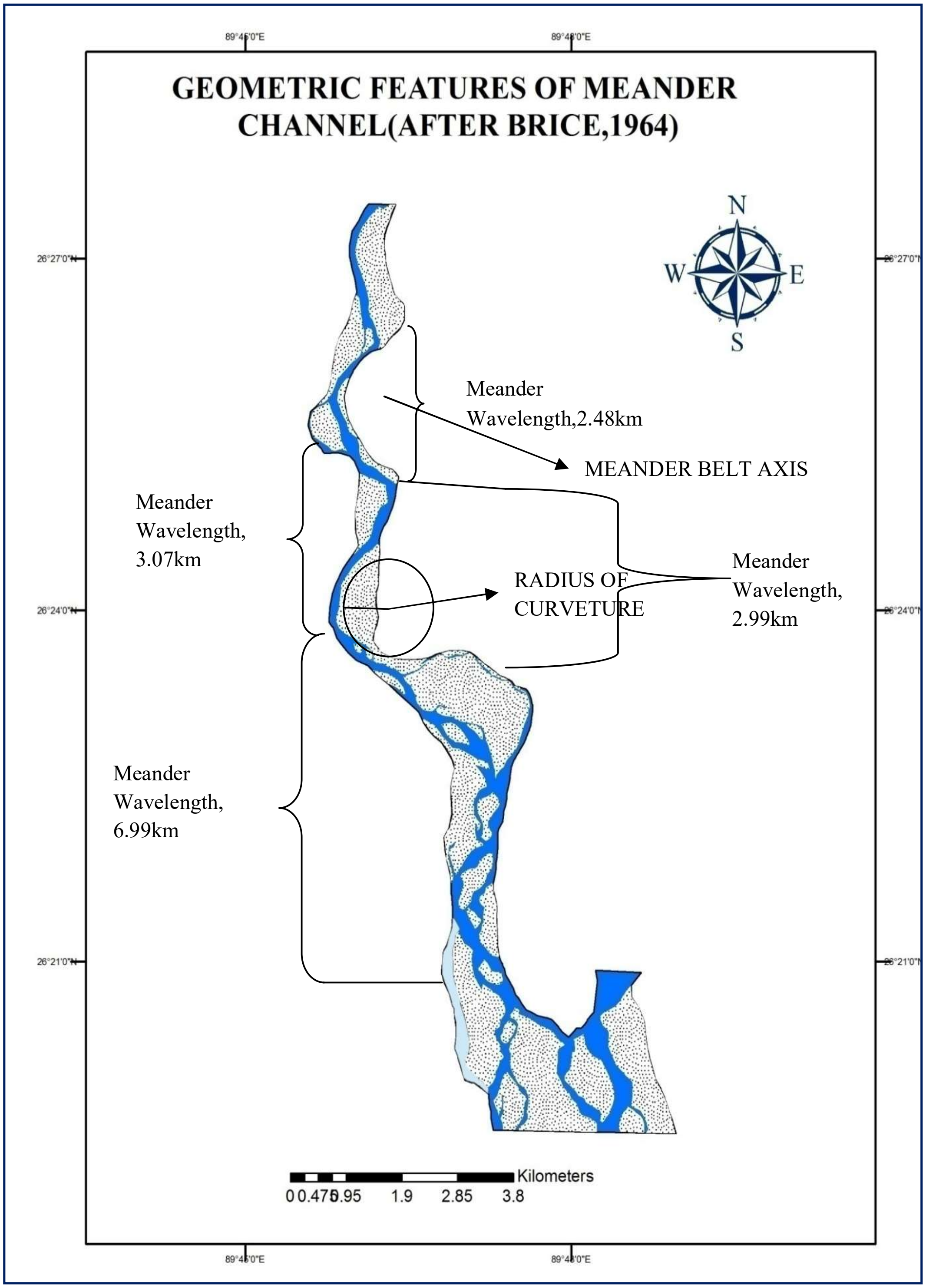
Figure-3.8. Flow Component of Meander



Source- Morisawa,1968

[1] Depression produced by erosional activity.
[2] Riffle deposition of sediment on the river bed.
[3] Helicalflow is a contributing factor to the formation of slip-off slopes and river cliffs in a meandering section of the river. The helical motion of the flow aids the processes of hydraulic action and corrasion on the outside of the meander, and sweeps sediment across the floor of the meander towards the inside of the meander, forming point bar deposits. https://en.wikipedia.org/wiki/Helicoidal flow access on 21.2.2016

Figure:3.9 Geometric Features of Meander ,



Source- Prepared from Google earth, 2014

3.6. **Hydraulic geometry**

Channel hydraulic geometry is the combination of discharge, velocity, channel shape, sediment load, channel width, channel depth, channel slope etc. while the relationship between these component is called hydraulic geometry of the channel. The channel morphology also depends on the hydraulic geometry of the river channel. Generally , if the channel slope is increased water velocity will increase and also increase channel depth whereas channel width will be decrease and vice versa.

L.B. leopold and T. Maddak(1953) describe hydraulic geometry by the process of channel form as power function of discharge as follows-

$$W=aQb$$

$$d=cQf$$

$$v= kQm$$

where W= channle width, d= channel depth, v= channel velocity(mean)

a,c,k, =constant and b,f,m=exponent

$$a \times c \times k=1.0$$

$$b+f+m=1$$

The present study discuss the hydraulic geometry of the Raidak-II channel. For this velocity, depth, width of the channel in differrent point have been measured. Six cross-sections have been taken along the river course. The selection of these six cross-sections were done on the basis of specific characteristic feature of the sites to show the relationship between width, depth, velocity and bed load transport.

3.6.1. Cross Profile Analysis

The shape of the cross-section profile is described through the ratio of the channel width to depth. The flow in channel is directly propotional to the force which the water exerts on the bed and to its ability to transport sediment (Leopold and Wolman,1957). The Raidak-II channel is typically braided type with a number of water covered channels that are separated by sandbar, alluvial vegetated covers island and bars. Here mainly discuss Six cross-sections which were taken for analysis. Field observation was done in different season, pre-monsoon, monsoon and post monsoon are at Bhutan ghat, Joydebpur, Hemaguri, Chokachoka, Takuamary and Bainnaguri. In the monsoon most of the place were under water, except few places. Cross sections' width and depth were measured during, May 2016.

Table: 3.3 Element of Hydraulic Geometry

Station	Depth(in metre)	Width (in metre)	Velocity(metre/second), July-2016	Velocity(metre/second), December-2016	Bed materials
Bhutan ghat	1.35	530	2.5	1.67	Grabbles and boulders
Joydebpur	.95	1355	1.3	0.95	Grabbles and boulders
Hemaguri	1.01	1360	1.1	0.72	Sand and pebbles
Chokchoka	1.52	430	.95	0.48	Sand and pebbles
Takuamary	1.33	495	.65	0.35	Sand and silt
Bainaguri	.8	1600	.46	0.26	Sand and silt

Source-Prepared from field survey

Figure: 3.10 Cross-Section at Bhutan Ghat

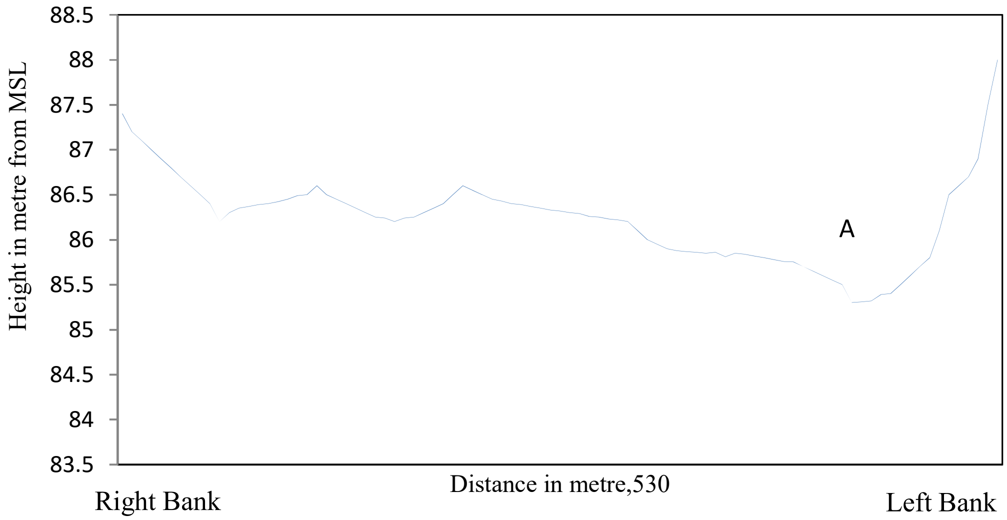


Plate:3.1 Channel Bed on Cross-Section at Bhutan Ghat

Source- Photograph in the time of field visit, December-2016

Figure:3.11. Cross-Section at Joydebpur

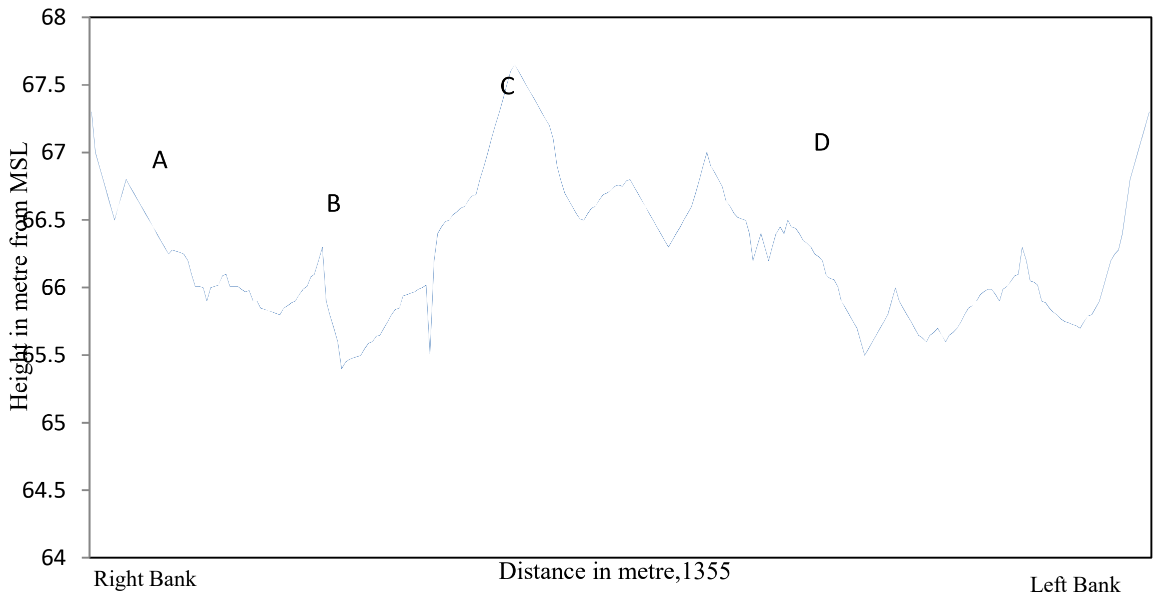


Plate-3.2. Channel Bed on Cross-section at Joydebpur

Source- Photograph in the time of field visit, May-2016

Figure-3.12. Cross-section at Hemaguri

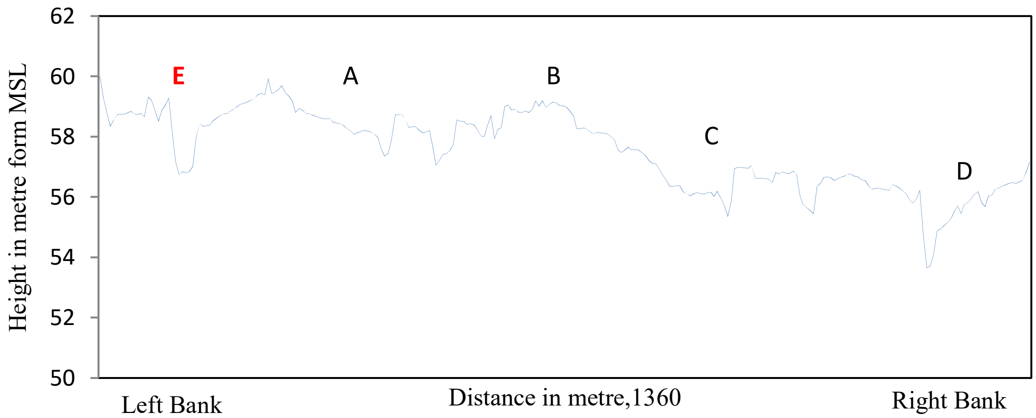


Plate-3.3. Channel Bed on Cross-section at Hemaguri

A,B,C,D- In Pre-monsoon (May 2016)

E- In monsoon (July 2016)

Source- photograph in the time of field visit

Figure-3.13. Cross-section at Chokchoka

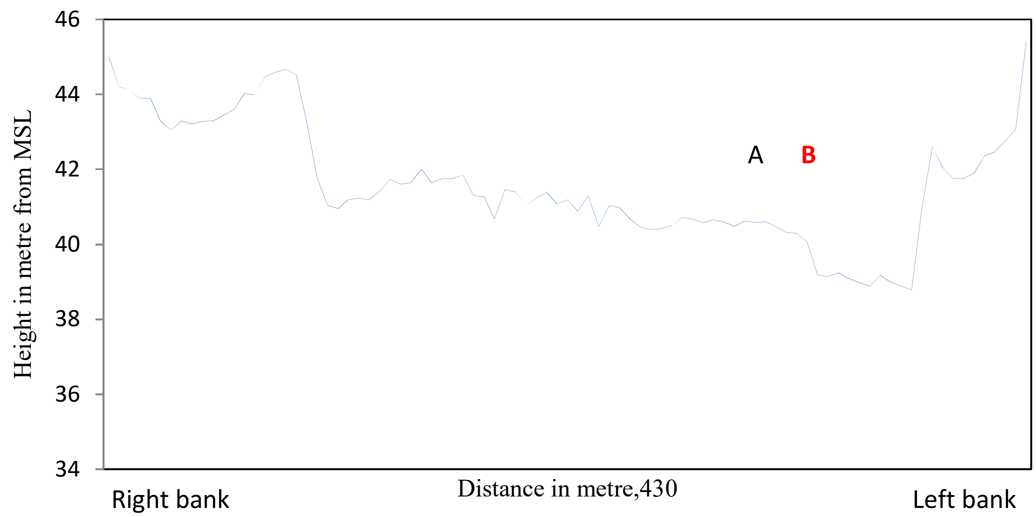


Plate-3.4. Channel Bed on Cross-section at Chokchoka

A-In pre-monsoon (May, 2016)

B-In monsoon (July, 2016)

Source- photograph in the time of field visit

Figure-3.14. Cross-section at Takuamari

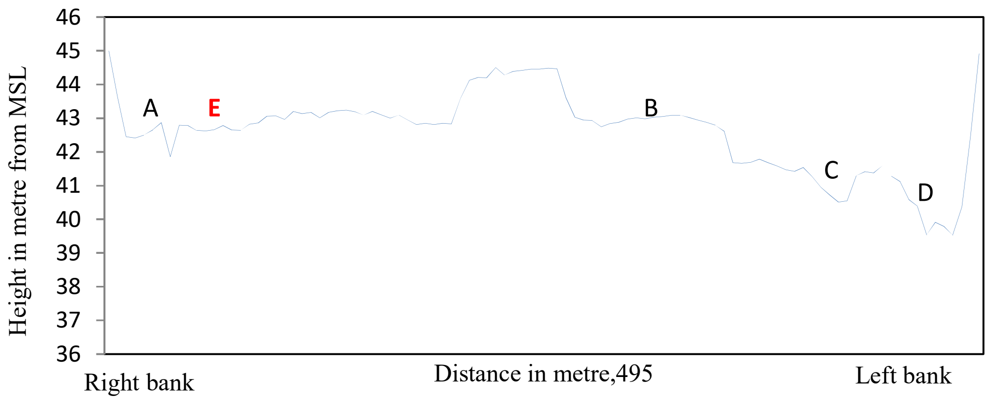


Plate-3.5. Channel bed on Cross-section at Takuamari

A, B, C, D- In pre-monsoon (May, 2016)

E-In monsoon (July, 2016)

Source- Photograph in the time of field visit

Figure-3.15. Cross-section at Bainaguri

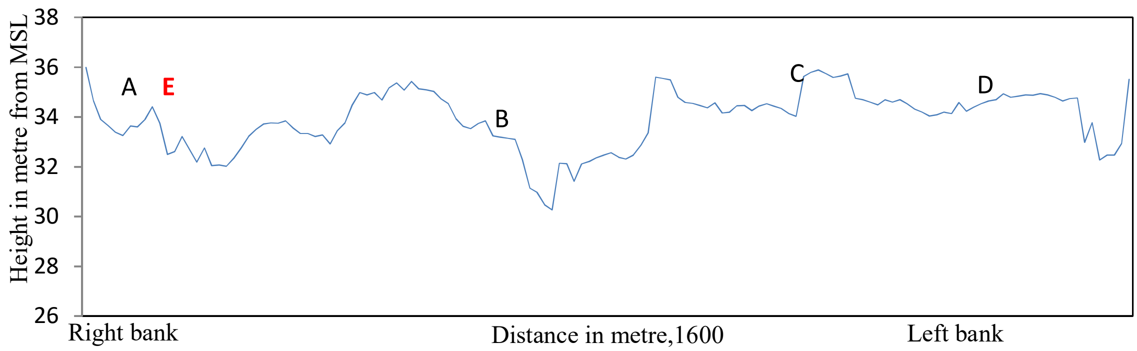


Plate-3.6. Channel bed on Cross-section at Bainaguri

A,B,C,D- In pre-monsoon (May, 2016)

E- In monsoon (July, 2016)

Source- Photograph in the time of field visit

At Bhutan Ghat the cross-section width is 530 metre and the average depth is 1.35 metre. The velocity is 2.5 metre per second(table-3.3). In the cross-section showing highest depth in the left bank of the channel(figure-3.10). In the time of the field visit it was observed that the main flow in left side. This section shows that erosional activity in active on left bank and shifting of bankline is also on left side. The bed material are mostly pebble,sand and boulders(plate-3.7).

At Joydebpur the cross-sectional width(1355 metre) is higher than Bhutan Ghat. At this section the river channel are bifurcated into many sub channel with separated by vegetated island and mid channel bars. In this cross-section depth of the channel veries in different point, average depth is 0.9 metre and highest depth is found on right and left side of the channel. Average velocity at this point is 1.3 metre per second. The bed materials are also more or less similar with bed material of Bhutan Ghat(plate-3.7).

At Hemaguri the shape of the cross-section is same as Joydepur, at this point the channel is highly braided. The channel is bifurcated in different channel which are separated by channel bars. Average depth of the channel is 1.01 metre and average velocity is 1.1 metre per second. At this point the channel width is 1360 metre. At this section onward the bed materials are mainly sand and pebble(plate-3.7).

The shape of the cross-section at Chokchoka is different from others cross-section. At this point the channel depth is high and channel width is narrow. Average depth is 1.52 metre and average velocity is .95 metre per second. At this point channel width is 430 metre. Bed material of this section also sand and pebble(plate-3.7).

At Takuamari the cross-sectional width is 495 metre and average depth is 1.33 metre. At this point the channel depth is high on right bank. Average velocity is 0.65 metre per second. Sand and silt are main bedload at this section(plate-3.7).

At Bainaguri the cross-sectional width i.e 1600 mts is high among others cross-section. The channel depth at this cross-section is different at different point. In this cross-section average depth is 0.8 metre and average velocity is 0.46 metre per second. The bed load of this section is sand and silt(plate-3.7).

3.6.2. Interrelationship of Channel Width and Depth

Width of a river channel at any point is represented by cross-sectional distance of channel which shows the channel stage erosional and depositional character and evolutional character. Channel width is absulate measure by bank to bank crossover distance at any point of a channel. Channel width is changed when channel bankline shifting occured which mainly done by lateral erosion.

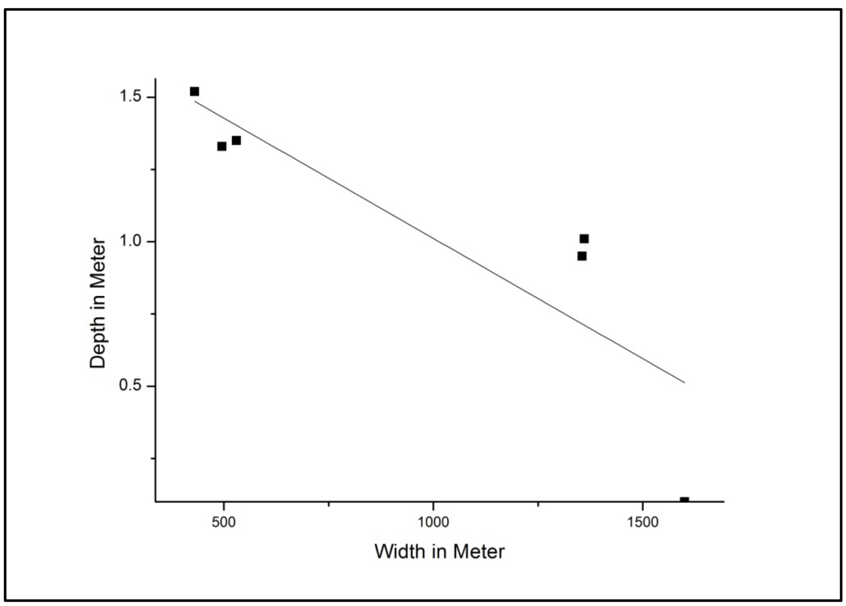
Channel depth is a vertical distance between water level and channel bed. Channel depth is changed by the process of bar/island deposition and channel thalweg bifurcation, vertical erosion/pool formation etc. Generally when channel width is increased channel depth is decrease. The present study shows the same relation. Six selected point from Bhutan ghat to mouth where channel width and depth were measured. That result shows the relation between channel width is increased,channel depth is decreased and vice versa. The channel width and depth correlation is significant at the 0.01 level(2-tailed).

Table-3.4. Correlation Between Width and Depth

Correlations			
		Depth(in metre),	Width(in metre),
Depth(in metre),	Pearson Correlation	1	-.977**
	Sig. (2-tailed)		.001
	N	6	6
Width(in metre),	Pearson Correlation	-.977**	1
	Sig. (2-tailed)	.001	
	N	6	6
**. Correlation is significant at the 0.01 level (2-tailed).			

Source-Computed by reseacher

Figure-3.16.Linear Relationship Between Channel Depth and Width.

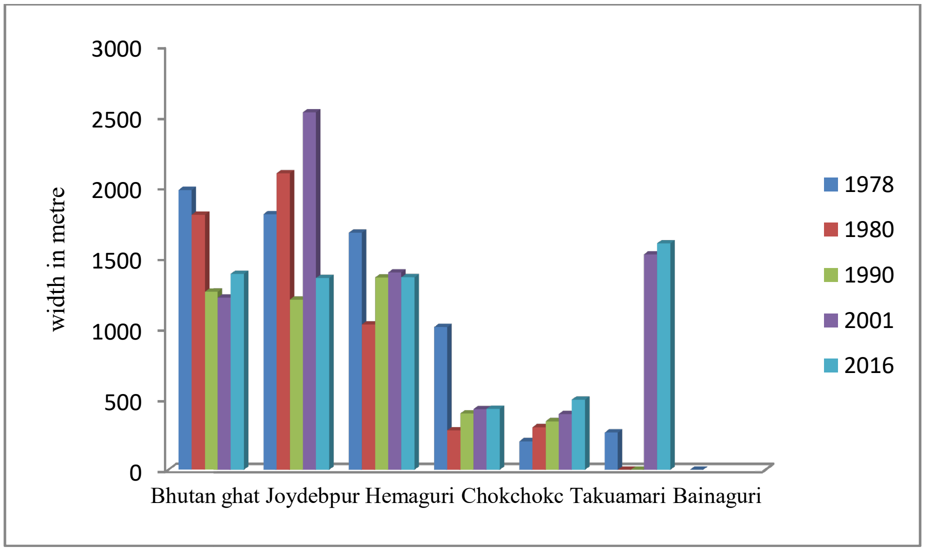


Source-Computed by Reseacher

3.6.3. Channel Width Change

It is also observed that the average width of the Raidak-II river channel is changing. From 1978 to 2016 the channel width increase and decrease at different point. Channel width change is the most important indicator of bankline shifting. The present study has shown the channel width of Raidak-II channel at six point where the data were collected from topographical map, LANDSATE image and GPS survey.

Figure-3.17. Channel Width in different years



Source-Prepared from topographical map, LANDSAT image and field survey

Table-3.5.Channel width change in selected point in different year

Section	Channel width in different years(in metre)				
	1978	1980	1990	2001	2016
A (Bhutanghat)	1806	1803	1258	1216	1384
B(Joydebpur)	1675	2095	1202	2526	1355
C(Hemaguri)	1008	1027	1358	1394	1360
D(Chokchoka)	200.83	278.9	397.23	427.85	430
E(Takuamari)	262.7	300.36	341.88	393.35	495
F(Hainaguri)	-	-	-	1522	1600

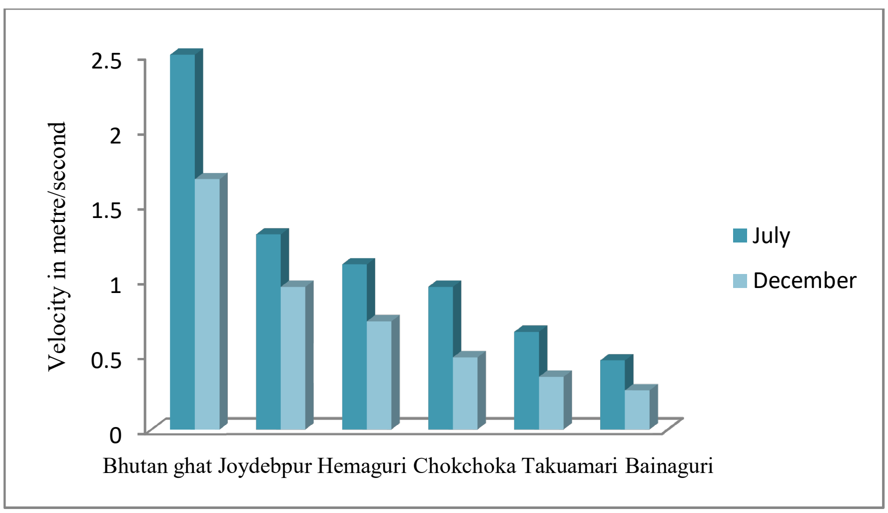
Source- Prepared from Topographical Map (1980-81), LANDSAT Image (1978,1990,2001) and GPS Survey, May,2016

3.7. Flow velocity

Theoretical principle says that velocity of channel gradually decrease downstream. In the Raidak-II the pattern of velocity both during monsoon and aftermonsoon is very fluctuating in nature. The velocity of Raidak-II were measured at six selected point(Bhutan ghat, Joydebpur, Hemaguri, Chokchoka, Takuamari and Bainaguri) in the period of monsoon(July,2016) and after monsoon(December,2016). According to this velocity data, we can see that the velocity frequently decrease from upper part to lower part due to decrease of gradient of the channel.

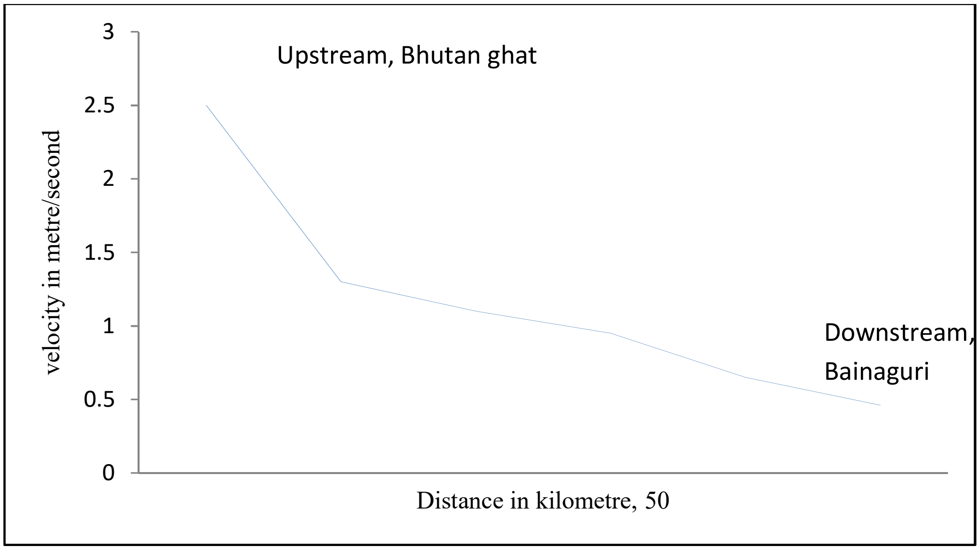
In monsoon season, observation from six cross-section at Bhutan Ghat, joydebpur, Hemaguri, Chokchoka, Takumari and Bainaguri. The rate of velocity(metre/second) are found 2.5,1.3,1.1,.95,.65, and .46(July, 2016) and 1.67, .95, .72, .48, .35, .26(December, 2016) respectively.

Figure- 3.18.Velocity in Monsoon and Aftermonsoon



Source-Field survey data

Figure-3.19. Velocity Gradient



Source-Prepared from field Survey 2016

3.8. Interrelationship Slope, Width, Depth, and Bed Materials

Channel morphology also depend on channel slope, width, depth, and bed material and these are interrelated to each other.

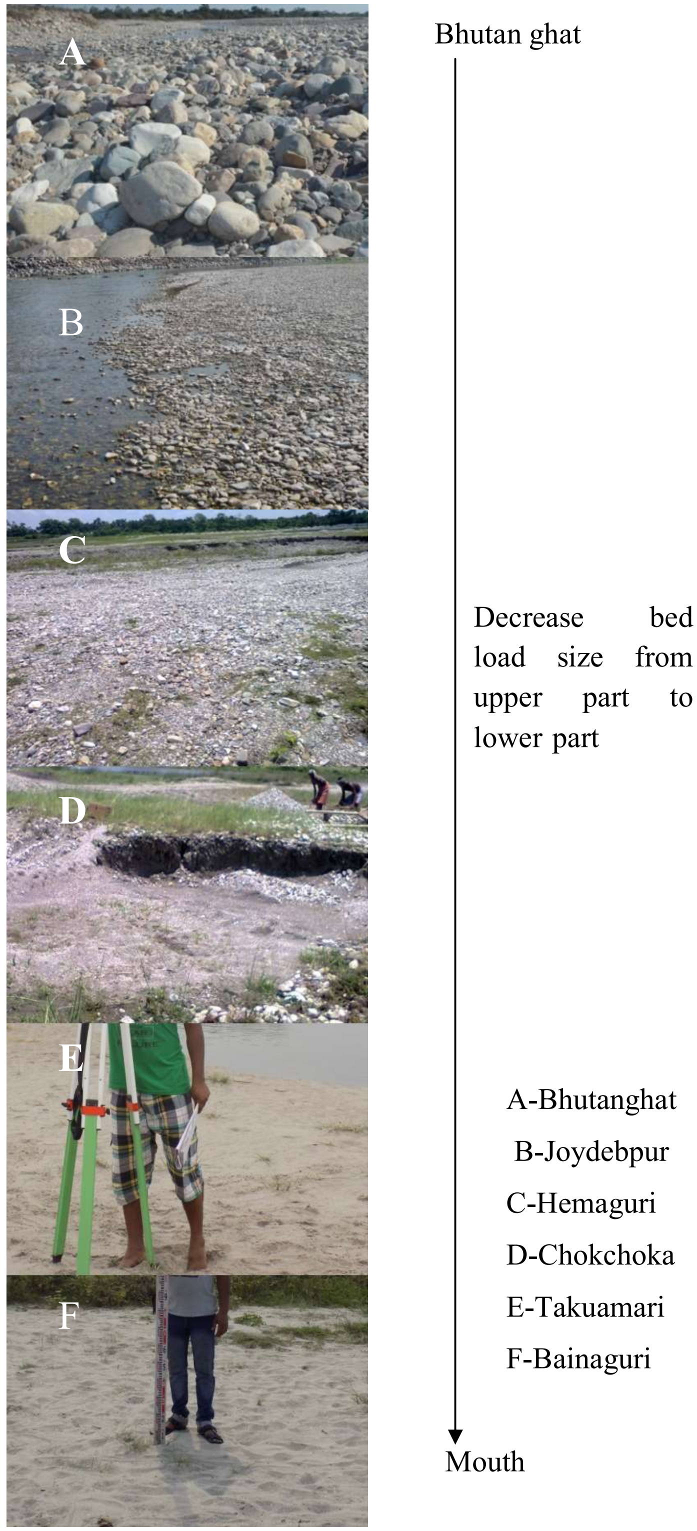
As channel slope decrease, channel width also increase simultaneously. Similarly happen in Raidak-II from Bhutan Ghat to Hemaguri. But Hemaguri to Takuamari shows different picture(figure-3.18). The channel slope at Joydeb pur and Hemaguri is higher than Takuamri and Chokchoka, but at this point channel width is very narrow than Joydebpur and Hemaguri. At this reach anabranching are joined with main channel. At this point , mainly railway and road way bridges are constructed , and concrete enbankment also intensified. These are factors for this reverse relation.

Generally when channel width increases channel depth is decreased. The present study shows the same relation. Six selected stations from Bhutan Ghat to mouth where channel width and depth where measured, that result showsthat station where channel width is increased channel depth decreases and vice versa.

The distribution of channel bed material is also depend on the channel slope. The erosional transportation of bed materials are also depending on channel velocity. The bed metarial size of the Raidak-II varies from upper to lower part. The size of bed materials continuously decrease from upper part to lower part that was observed during the field visit(plate-3.7).

The size of materials which form the bank due to deposition of the river clearly shows the channel gradient(plate-3.8)

Plate-3.7. Bed Material Size Upper to Lower



Source-Photograph in the time of field visit, May 2016

Plate-3.8. Channel Bank Material in Different Place

Source- Photograph in the time of field visit, May 2016

A-Bhutan ghat, B-Joydebpur, C- Hemaguri, D-Bainaguri

Plate-3.9. Stable Bank at Chokchoka and Takuamary

Source-Photograph in the time of field visit, July and May,2016

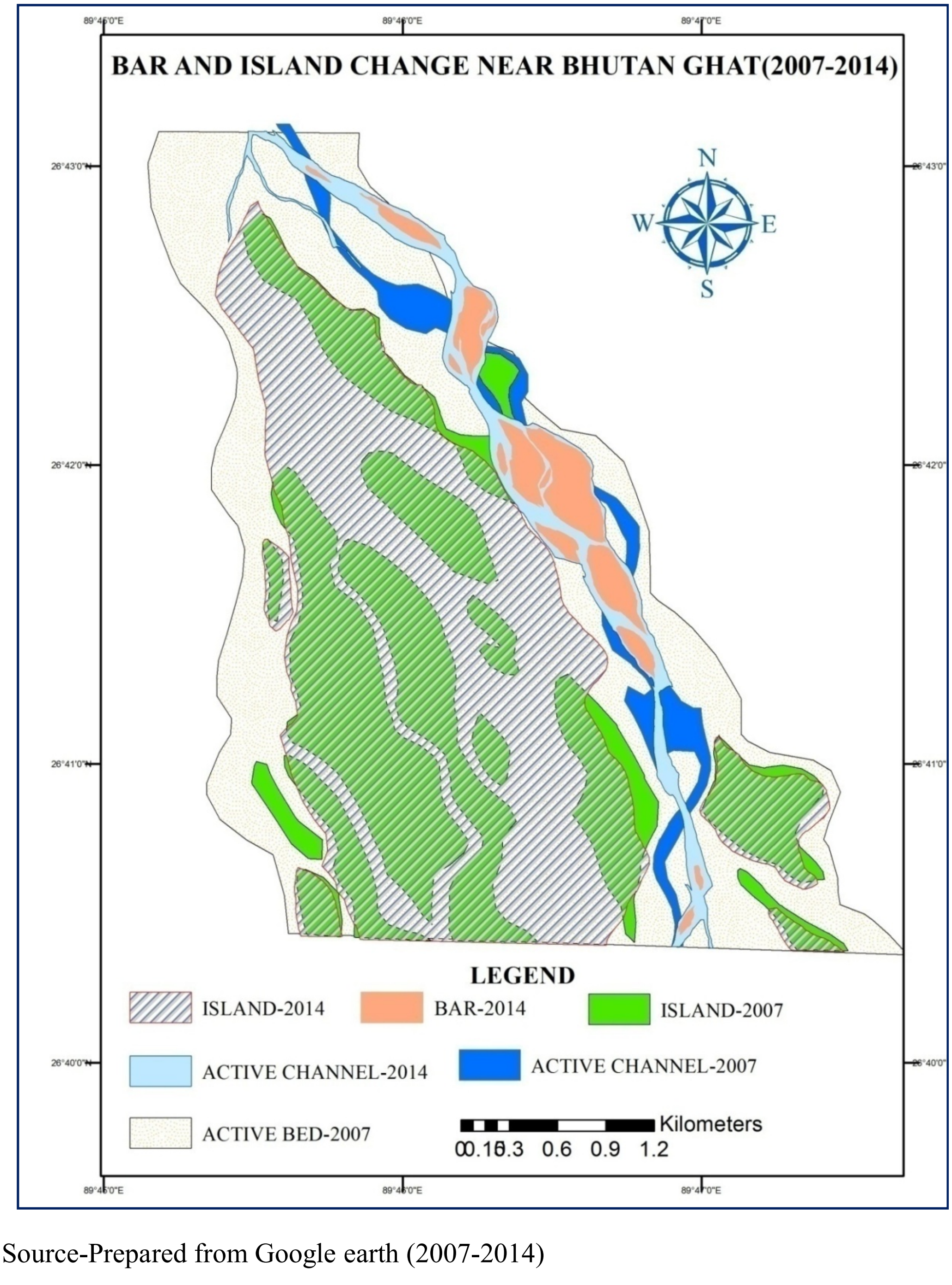
3.9.Bar and Island change of Raidak-II

3.9.1 Bar and Island change in the Upper part

To understand the change bar and island in the upper part is divided into three sub part. The upper part of the Raidak-II is characterised by morphology change continuously. In this part some particular changes are found. Channel bar of the Raidak-II in upper part mainly found on the left side. In this part of channel every year form a new bar and eroded channel bars. It was found large and small size alluvial island and they change their shape and size every year. In the rainy season islands are affected by over flow. Alluvial island are mainly affected by the process of lateral migration and over flow in monsoon season. River bars changes shown from 2007 to 2014 on the basis of Google image. Channel thalweg is also changed with its location. According to the Figure-3.20,3.21 and 3.22, it is observed that there is change of the channel island and channel bars. The figure 3.20 is showing that the island of the year 2007, there has nine islands but in the year 2014 same place we can see only one big island. The channel thalweg also changed the shape and location.

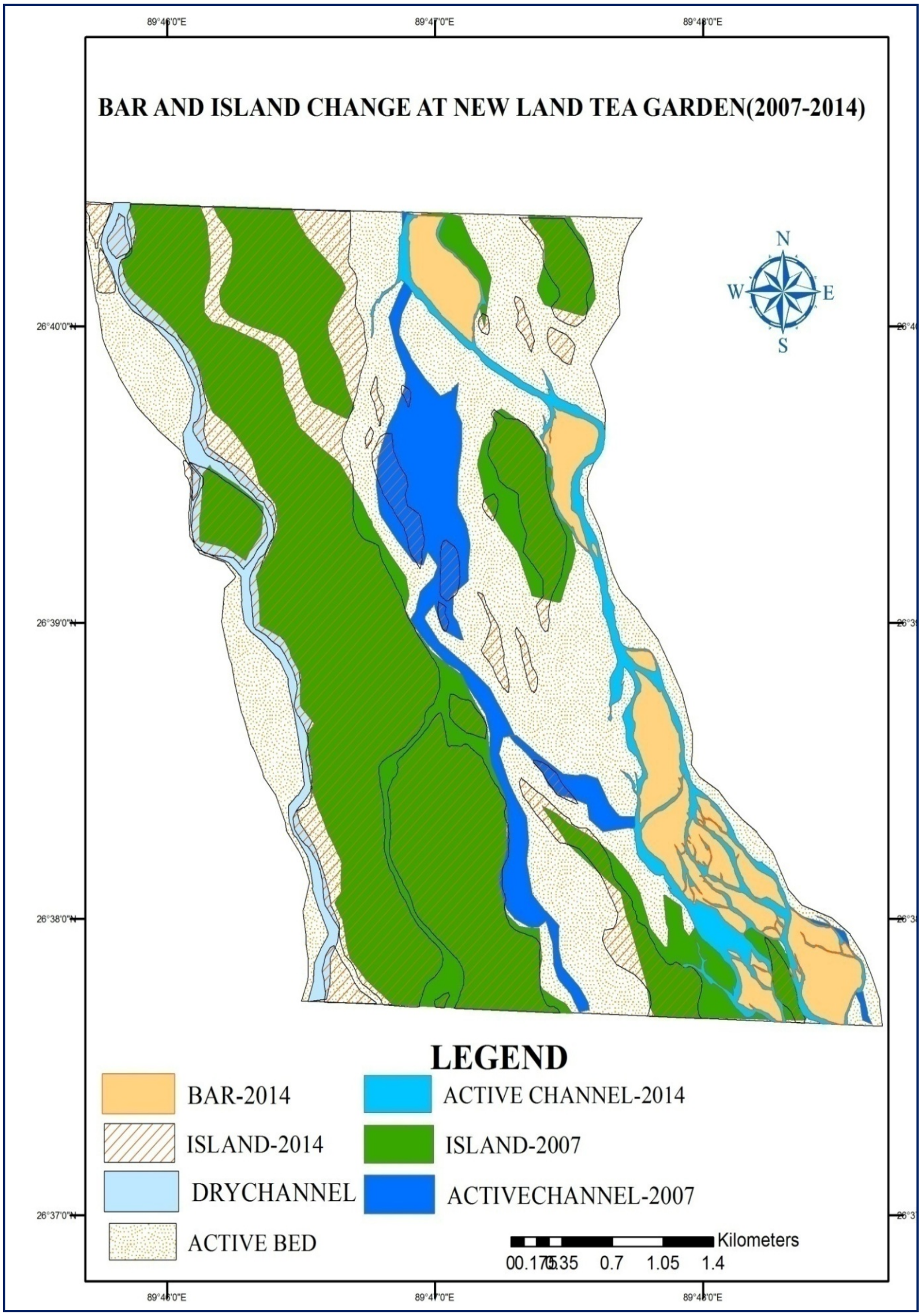
The channel pattern of the Raidak-II in the upper part is changing. The channel pattern of the Raidak-II mainly is changing due to bar formation and lateral migration. At Present day the channel get a new planform in the upper part. The active channel on left side in 2007 had been changed in 2014. Figure no. 3.21, it is observed that bar/island which were formed in 2007 are decreasing the size on the left side of river whereas on right side extension and expension of bars/islands are taking place in 2014. Active channel was also shifted from 2007 to 2014 and right side of bank(Figure-3.20). Most of the island which were formed in 2007 were bifurcated in 2014. It is observed that huge bar formation took place in 2014. The active channel had been shifted toward the left bank in 2014(Figure-3.20)

Figure-3.20. Bar and Island Changes near Bhutan Ghat



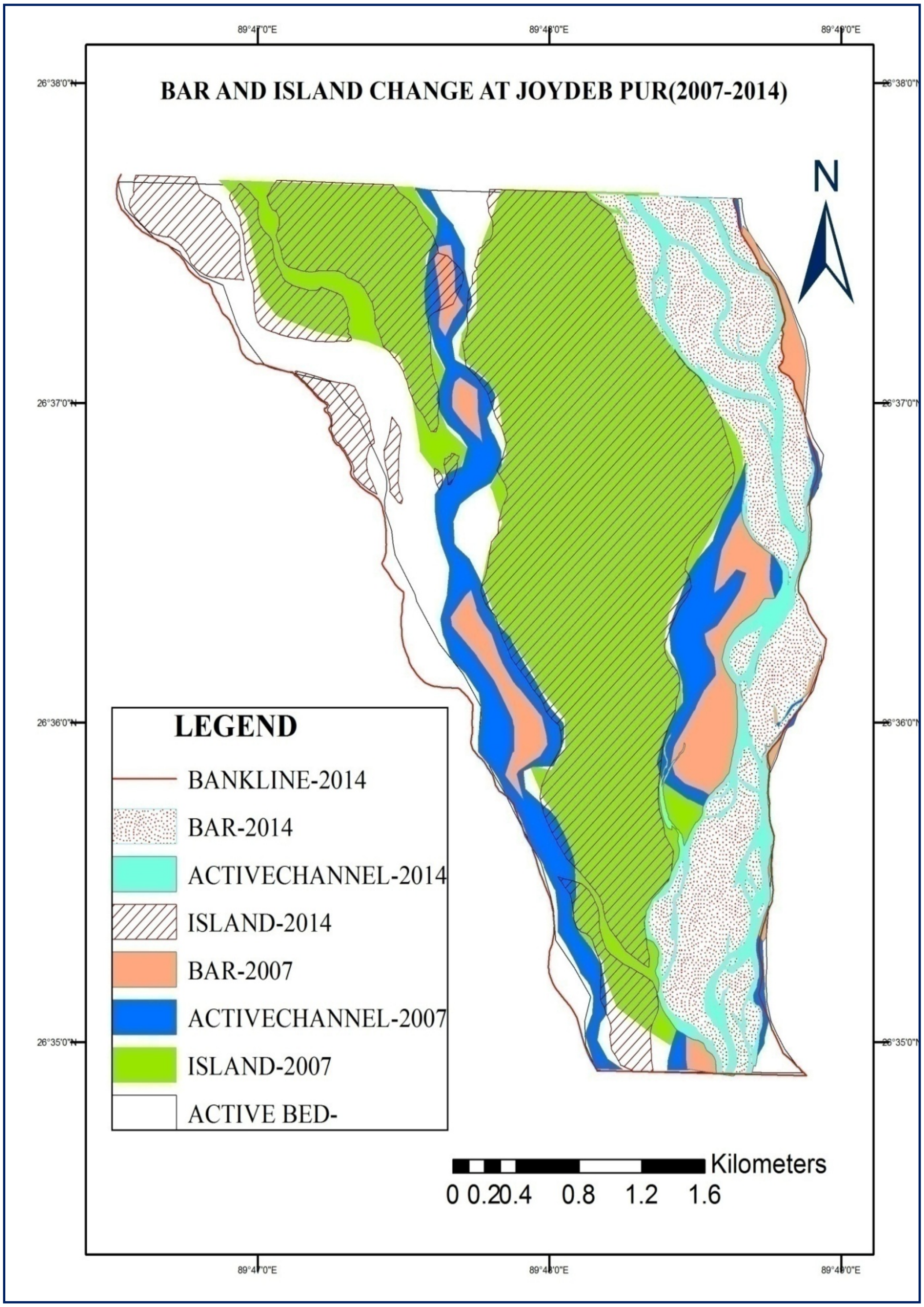
Source-Prepared from Google earth (2007-2014)

Figure-3.21. Bar and Island Change at New Land Tea Garden,



Source- Prepared from Google earth (2007-2014)

Figure-3.22. Bar and Island change at Joydebpur,



Source- Prepared from Google image (2007-2014)

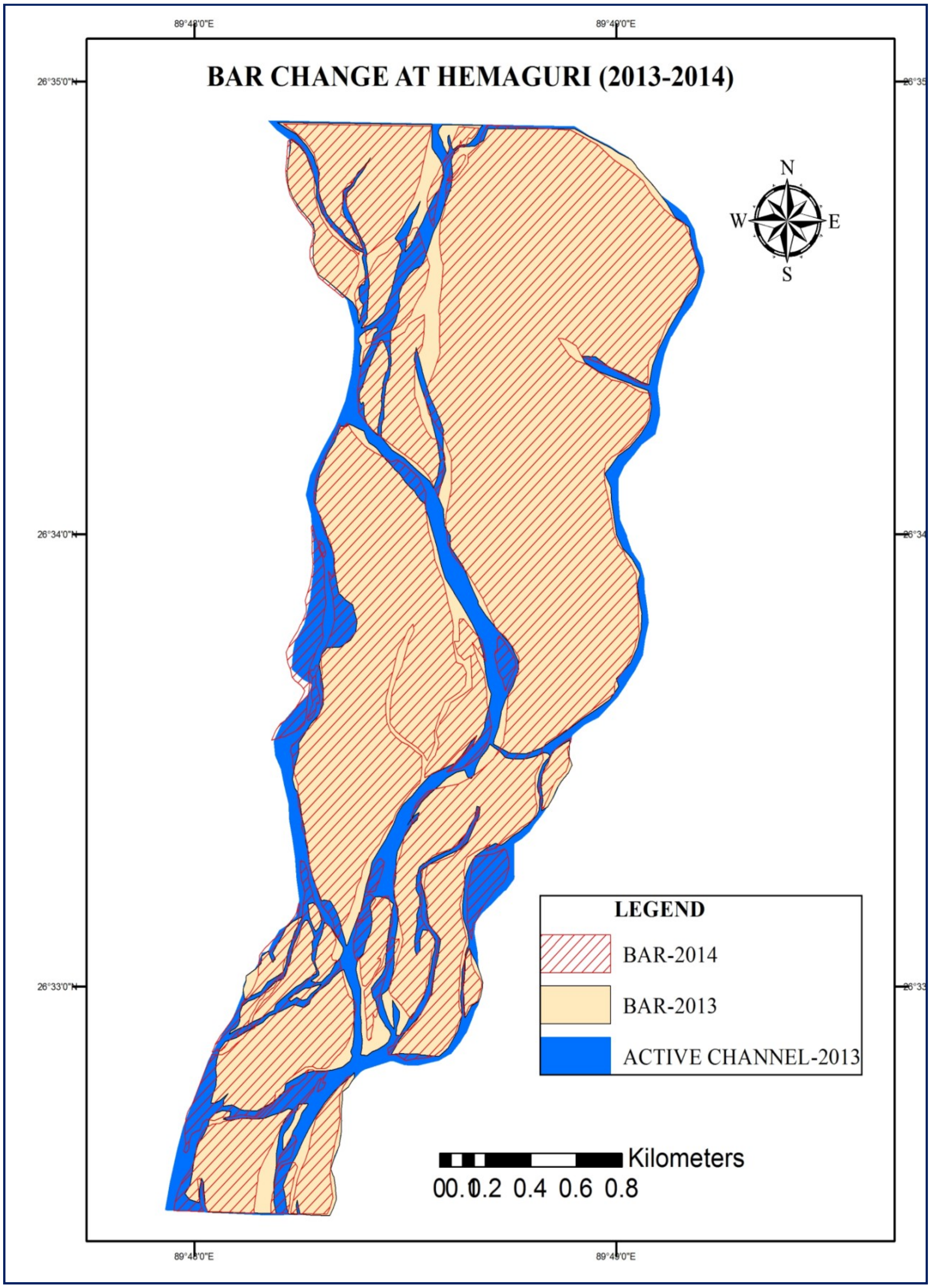
3.9.2. Bar and Island change in the Middle part

The middle part also divided into three sub divisions to find more accurate changes. In this part of river channel morphology is mainly characterised by different middle and side channel bar. Different channel bars are formed every year. In the monsoon season all bars are under water and also subjected to erosion due to high flow. In this part, mainly showing the bars change from 2013-2014 with the help of Google earth image. The bar changes are shown in the figure 3.23.On the image it is observed that the channel bar of 2013 have changed their shape and size. Some channel bar size is increasing and some bars size decreasing. In the 2014 some new channel bar formation are shown. In the 2013 map where there was channel thalweg and active channel are showed at Hemaguri area but in the 2014 map showing new channel bar. Comparatively middle portion is more stable than upper part. The changes in bar/island formation and shifting of active channel are also less which can be observed around Hemaguri, Chengmari and Chokchoka(Figure-3.23, 3.24,3.25)

3.9.3. Bar and Island Changes in the Lower Part

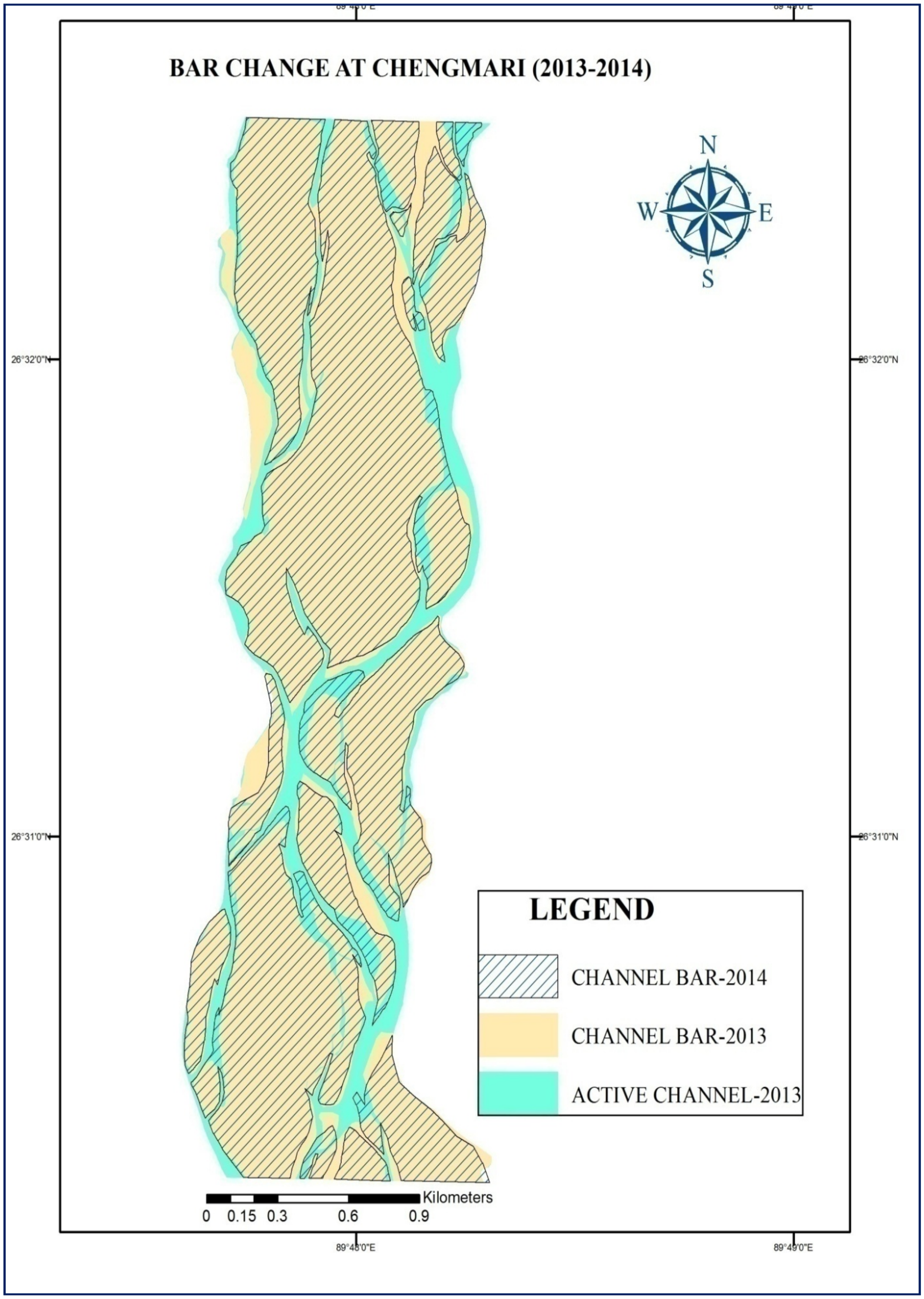
In this part the river channel mainly characterised by meandering channel, point bar with pool and riffle. The lower part of the Raidak-II bed load is mainly fine sand. The changes is different from the upper part. The changes like point bar change, meander bar change, cut-off etc. is found. The meander channel change is mainly shows in the year of 2007 to 2012 , 2012 to 2014 and 2007 to2014(Figure-3.26,3.27 and 3.28). According to the figure, it is found that the change of the meander channel, mainly change the channel point bar and channel thalweg. Channel bends also change. That change is mainly occurred by the process of deposition and erosion of riffle and pool.

Figure-3.23. Bar Change at Hemaguri,



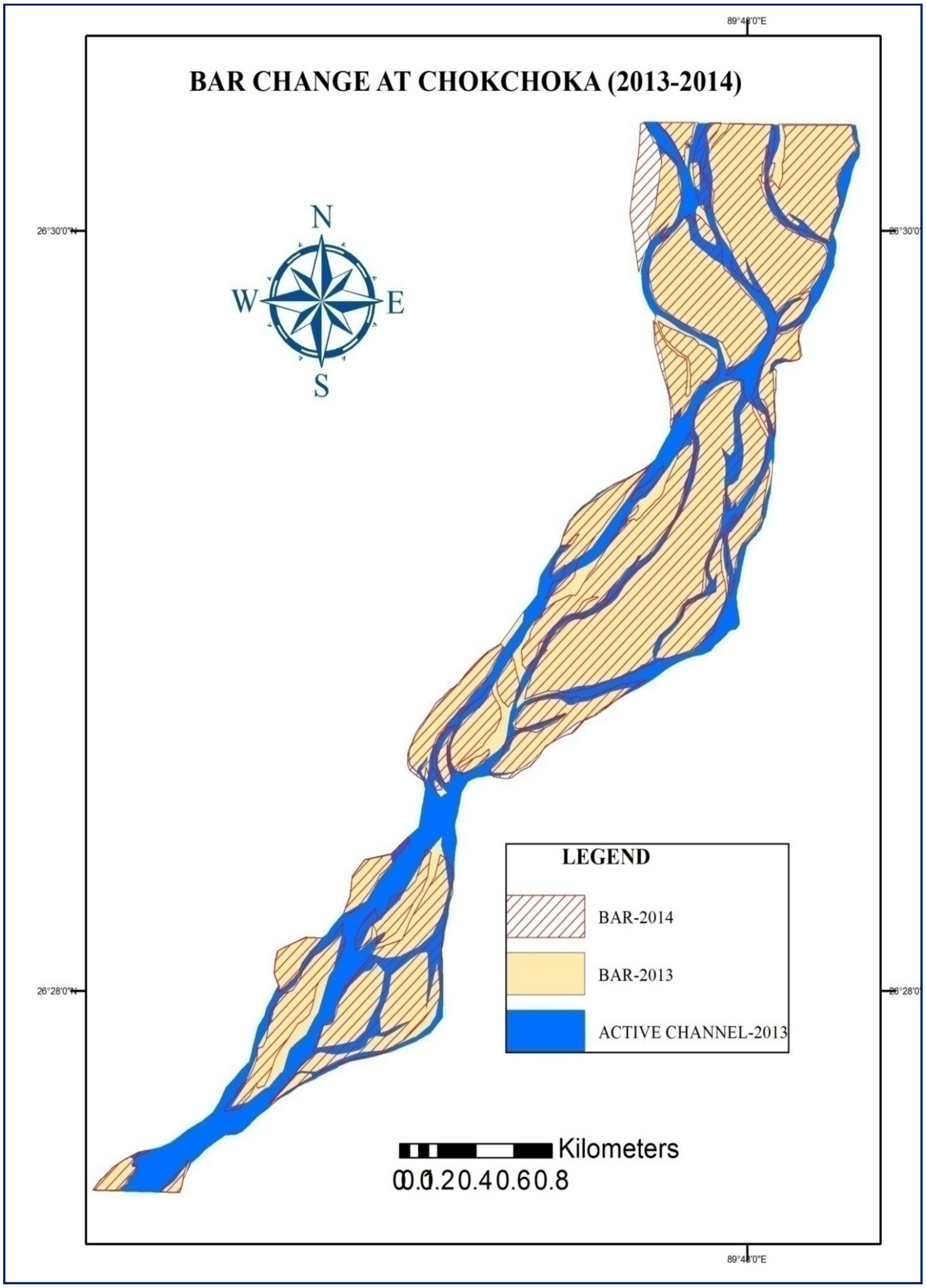
Source- Prepared from Google Earth (2013-2004)

Figure-3.24. Bar Change at Chengmari,



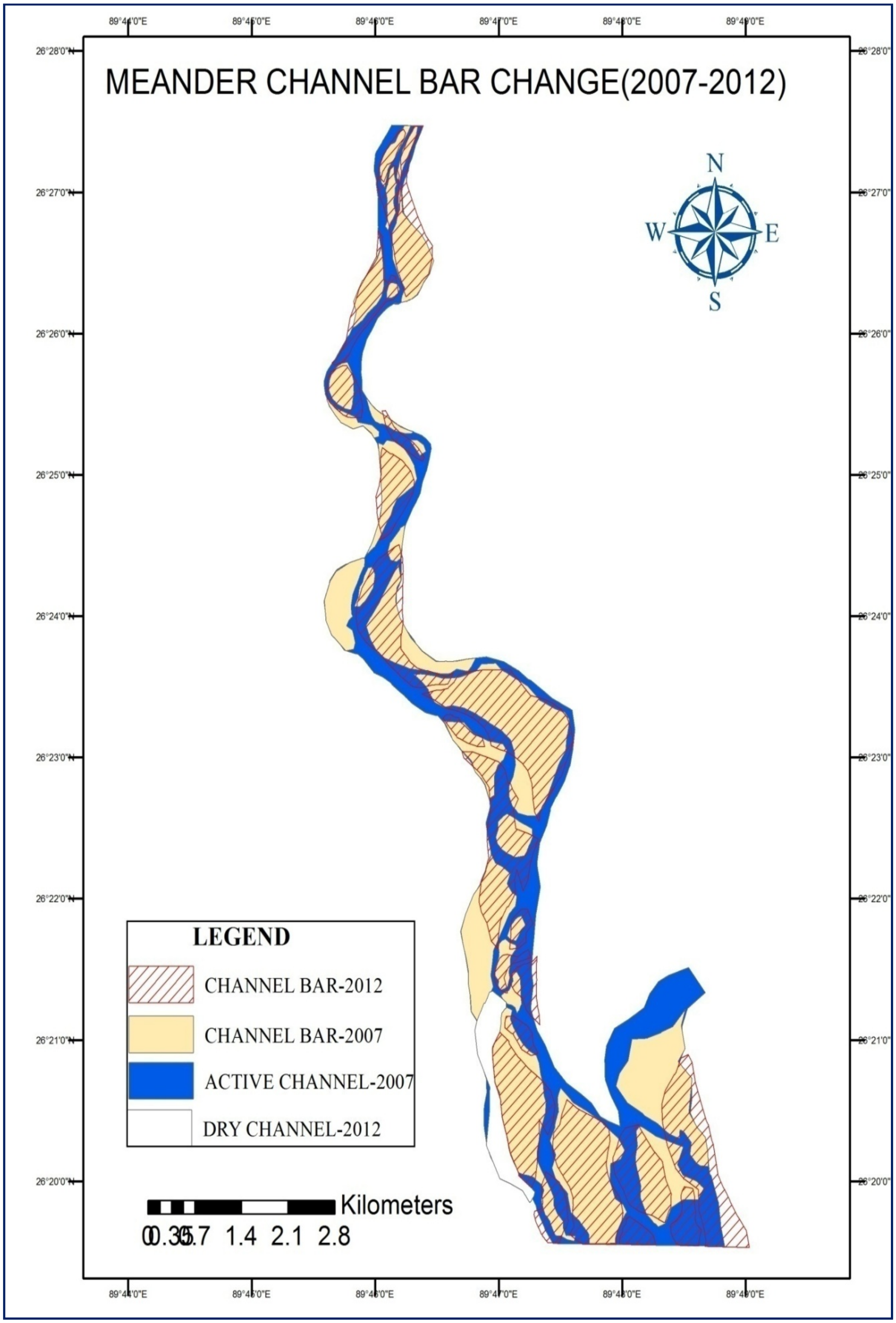
Source- Prepared from Google image (2013-2004)

Figure-3.25. Bar Change at Chokchoka,



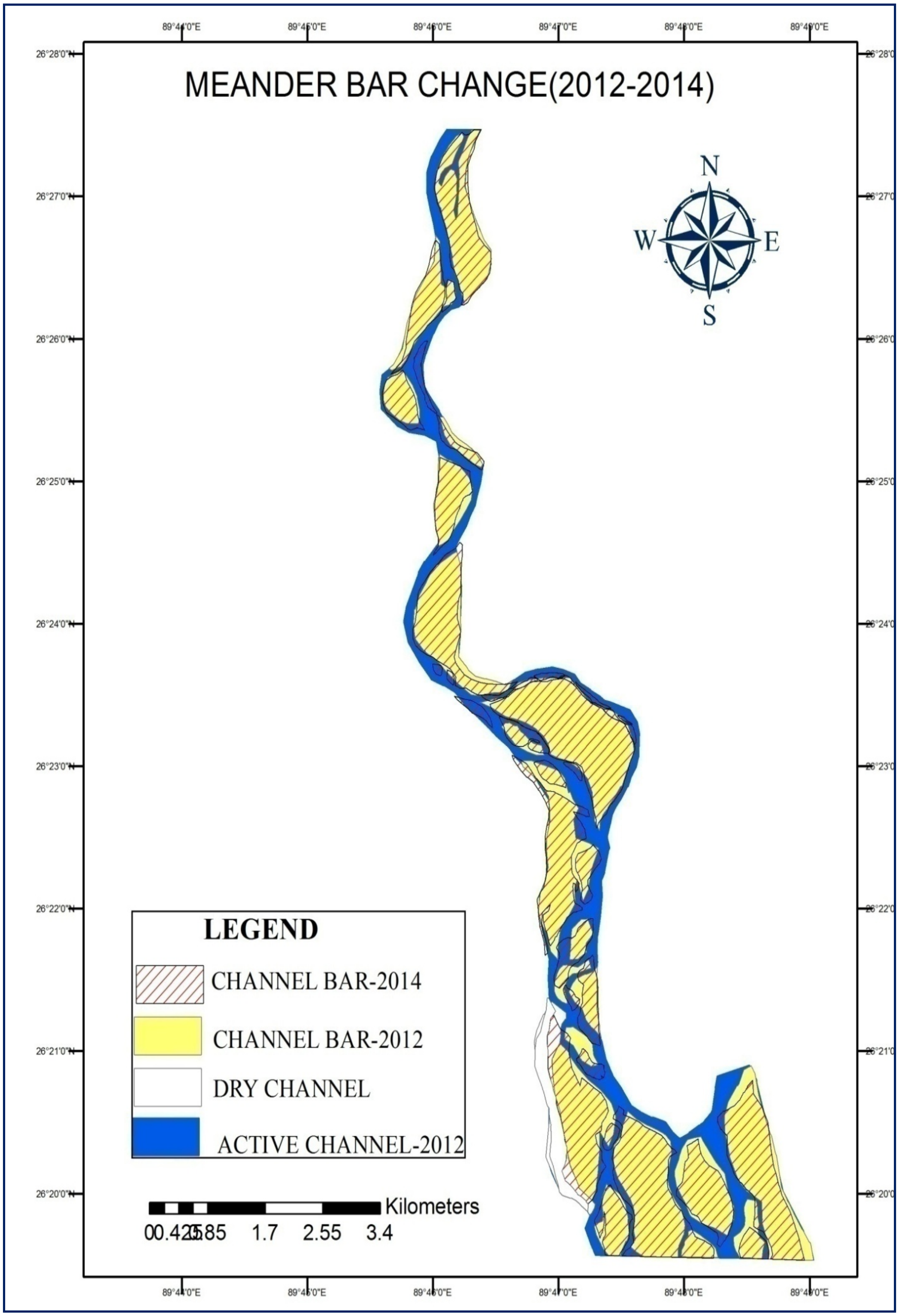
Source- Prepared from Google earth (2013-2014).

Figure-3.26. Meander Channel Bar Change (2007-2012).



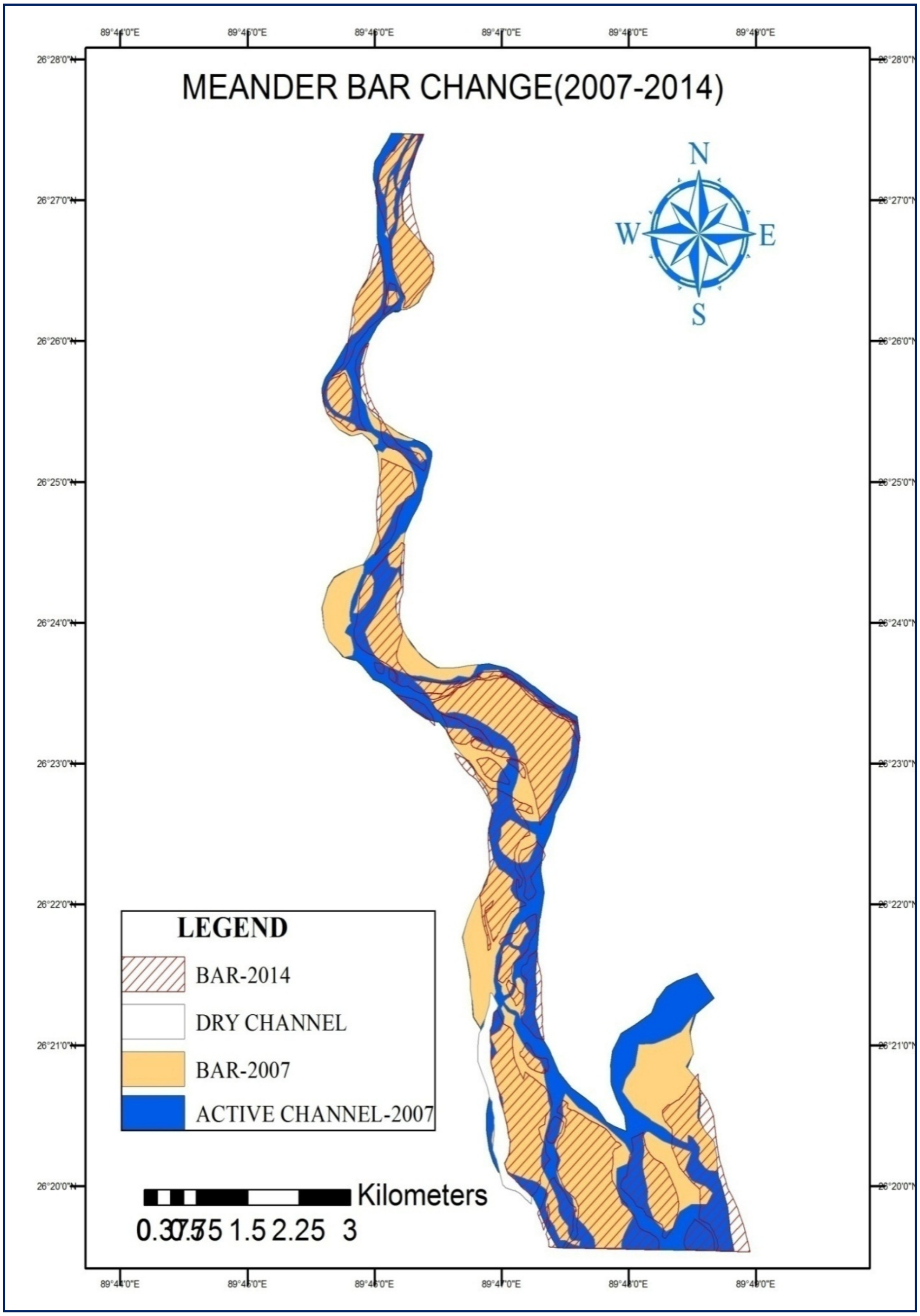
Source- Prepared from Google Earth (2007-2012).

Figure-3.27. Meander Channel Bar Change (2012-2014)



Source- Prepared from Google Earth (2012-2014).

Figure-3.28. Meander Channel Bar Change (2007-2014),



Source- Prepared from Google Earth (2007-2014).

3.10. Shifting of Confluence Point of Raidak-II to Sankosh River

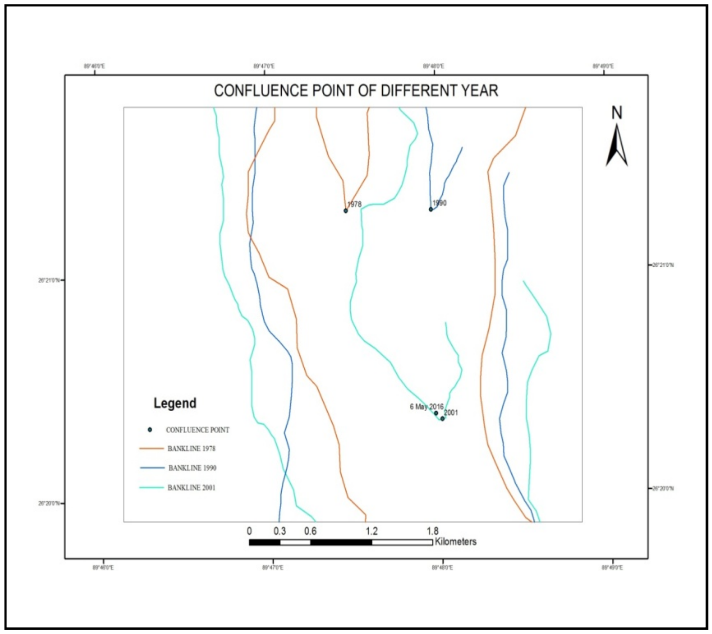
River confluence is one of the most important element of a river channel. Confluence is a junction of tributary and main river at a point. River channel confluence is critical interfaces where intense changes in physical process are occurred. These changes affect both the local and downstream characteristic of the river flow and of the bed. The confluence of the Raidak-II is highly dynamic. Deposition, erosion and bifurcation are common phenomena which occur every year at the confluence point. The confluence point Raidak II changes in different years is shown by in figure no 3.29 and rate and direction are shown in table no. 3.5. At the confluence point channel island, bars are highly dynamic. Here Confluence Island, bars change is showing in the figure 3.30 and 3.31. According to the figure we can see that the change of bar and island.

Table-3.5 Shifting and Direction of Confluence Point in Different Years

Sl. No.	Year	Migration rate (in metre)	Direction
01	1978-1990	12.336	North-east
02	1978-2001	1722	South-east
03	1978-2016	1674	South-east
04	1990-2001	1721	South-east
05	1990-2016	1674	South-east
06	2001-2016	47.15	North-west

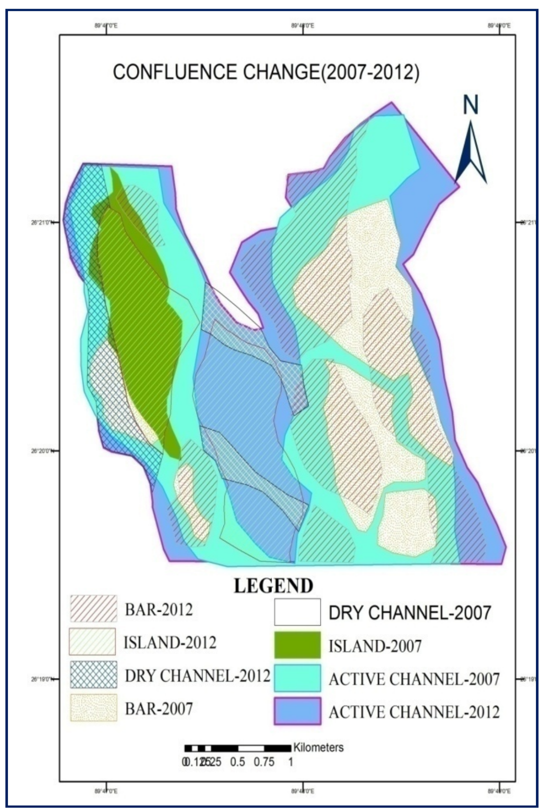
Source-Prepared LANDSAT image and GPS survey

Figure-3.29. Confluence point in different years,



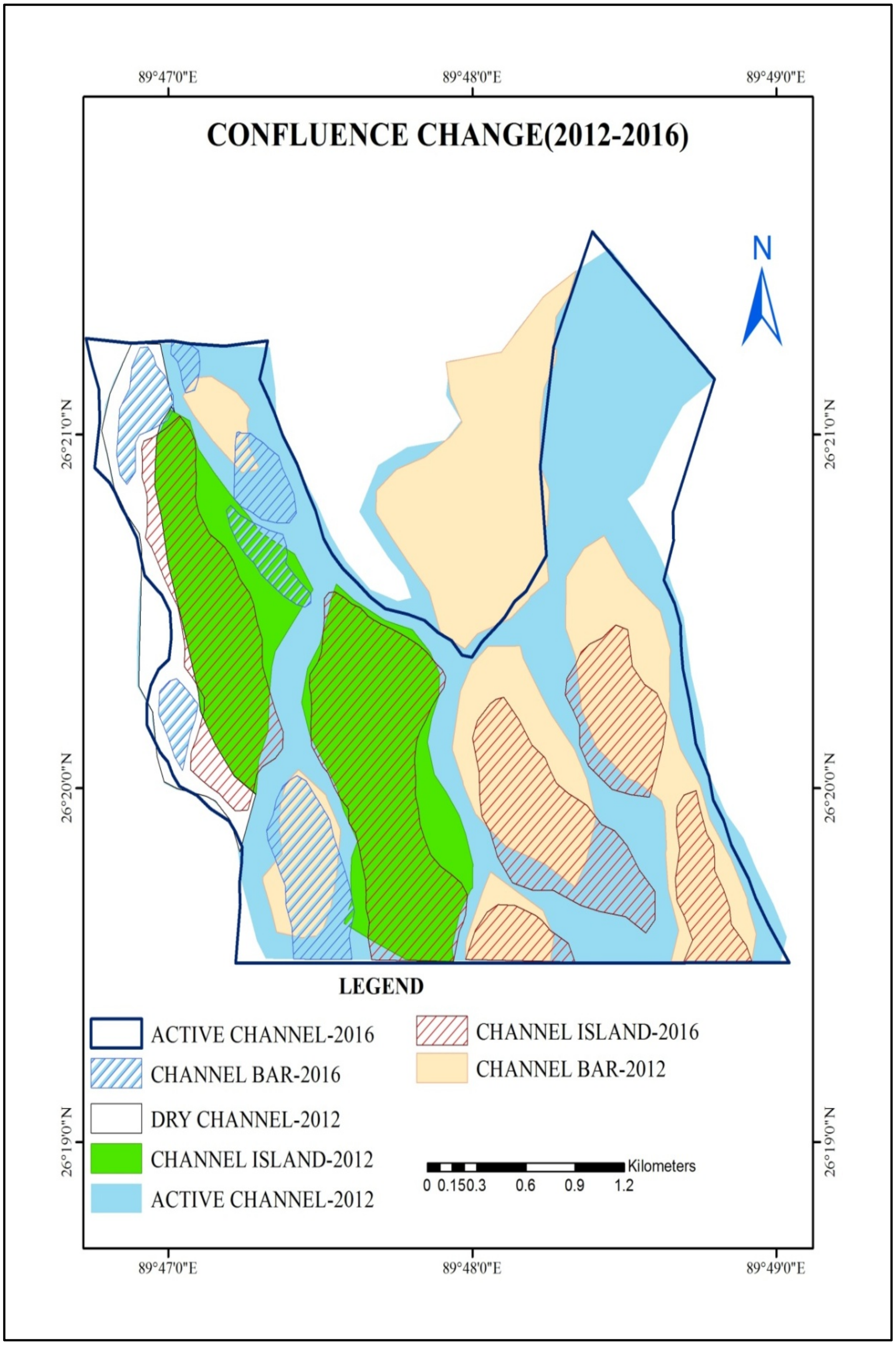
source:- Prepared from LANDSAT image and GPS survey.

Figure-3.30. Changes of bar and island at confluence Point,2007-2012



Source- Prepared from Google earth (2007-2012).

Figure-3.31. Changes of Bar and Island at Confluence Point, 2012-2016



Source- prepared from Google earth (2012) and LANDSAT ETM+ image (2016).

3.11. Bankline shifting of Raidak-II

River bankline migration is perhap a very common hydro-morphologic phenomena in a alluvial channel. In general sense, channel bankline migration is simply lateral movement of a bankline across its flood plain across a time frame.

From scientific point of view, the migration of river channel bankline with respect to space and time is an expression of response by river channel to its natural and anthropogenic drivers. This response manifested the change in the physical form of a river channel owing to action of the various drivers. Keeping these very basic of channel bankline migration is studied.

The present study has attempted to enquire the ongoing fluvial and hydromorphological process along the Bhutanese Himalaya piedmont region(Alipurduar and Coochbehar district plain) that encompasses the historical movement of the Raidak-II in term of its unstable bankline and shifting for a period of 40 years(1978-2016) based on multi temporal data base, field observation and numeric assertation. The present study mainly discuss about the rate and direction of bankline shifting in three section i.e, 1978to1990, 1990 to2001 and 2001 to 2016. In order to find minutes shifting, 20 cross section have been drawn along river from Bhutan Ghat to mouth and assess the shifting of bankline on 20 cross section(figure-3.33,3.35,3.37). Since river is flowing from north to south, left bank is an east and right bank is on west of river.

3.11.1. Bankline shifting 1978-1990

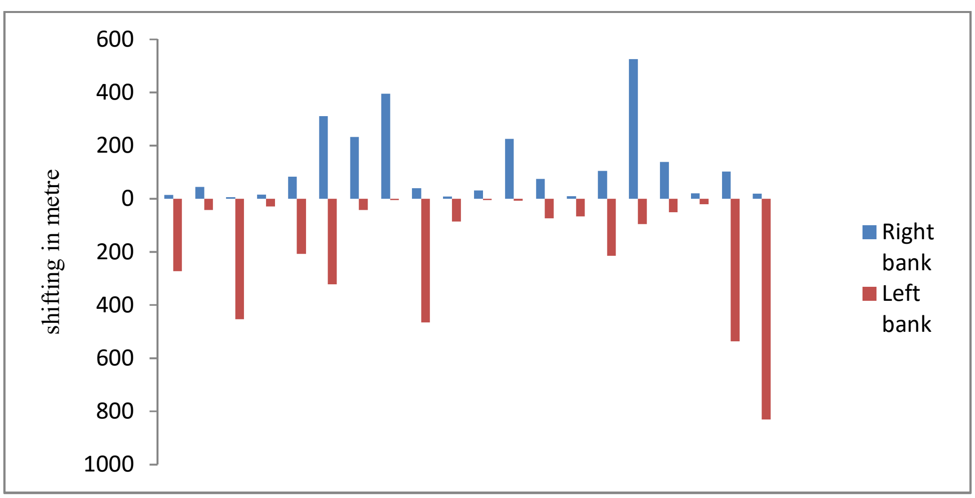
In this period the bankline shifting rate and direction is different at different selection point. Map of 1978 is base map and the rate and direction of bankline migration of 1990 is calculated on the basis of bankline 1978.

Maximum shifting rate is found at upper and lower part of the river channel. The maximum shifting rate of the right bank is found cross-section 6,7,8,12 and 16 where the shifting rate is more than 300 metre (figure-3.32).

The right bankline mainly shifting on right direction and in some points the right bankline shifting on left direction. Left direction mainly found at the section of 16,17 and 18(figure-3.35).The left bankline shifting rate is more than 250 metre at selection points 1,3,5,6,9,15,19 and 20 (figure no 3.32). The left bankline mainly shift on left direction and the section 10 and 11 the bankline shift on right direction (figure-3.38).

The rate of bankline shifting on both left and right direction are shown in table no. 3.7

Figure-3.32. Bankline shifting 1978-1990



Source-Prepared from landsat image(1978-1990)

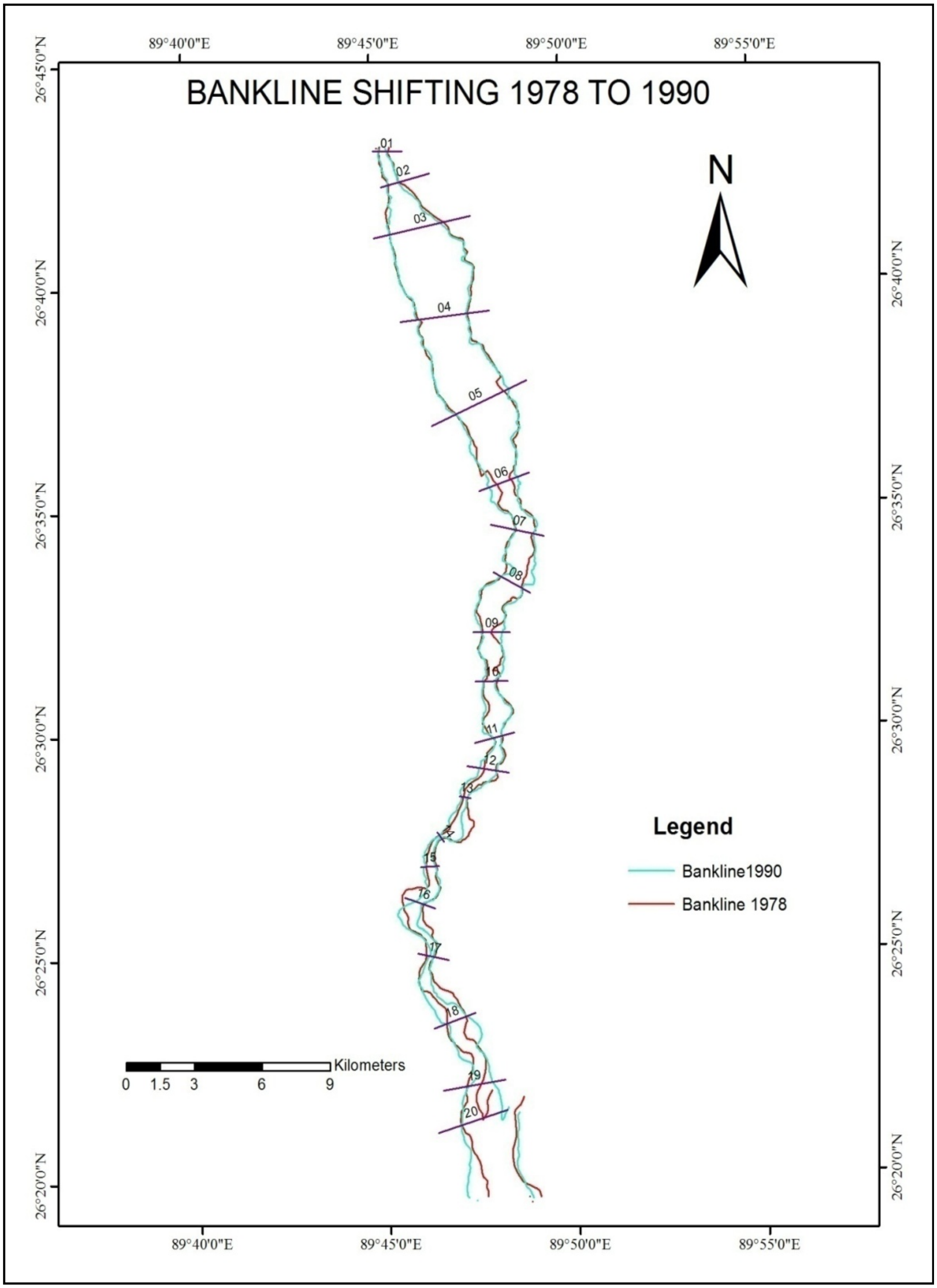
Table-3.7. Bankline Shifting Rate and Direction-1978-1990

Loction no.	Right bank shift(in metre)	Direction	Left bank shift(in metre)	Direction
01	14.25	R	272.95	L
02	44.9	R	41.05	L
03	6.62	R	452.44	L
04	16.86	R	29.43	L
05	83.79	R	207.13	L
06	310.8	R	321.5	L
07	232.4	R	41.101	L
08	396.65	R	4.92	L
09	40.2	R	465.5	L
10	8.84	R	82.11	R
11	30.95	R	5.486	R
12	226.04	R	7.286	L
13	74.93	R	75.15	L
14	9.63	R	66.29	L
15	104.62	R	215.03	L
16	526.34	L	74.711	L
17	139.32	L	50.535	L
18	21.06	R	19.878	L
19	102.16	L	536.92	L
20	19.53	R	829.85	L

Source-prepared from LANDSAT image (1978, 1990)

R-Right, L-Left

Figure-3.33. Bankline Shifting,1978-1990



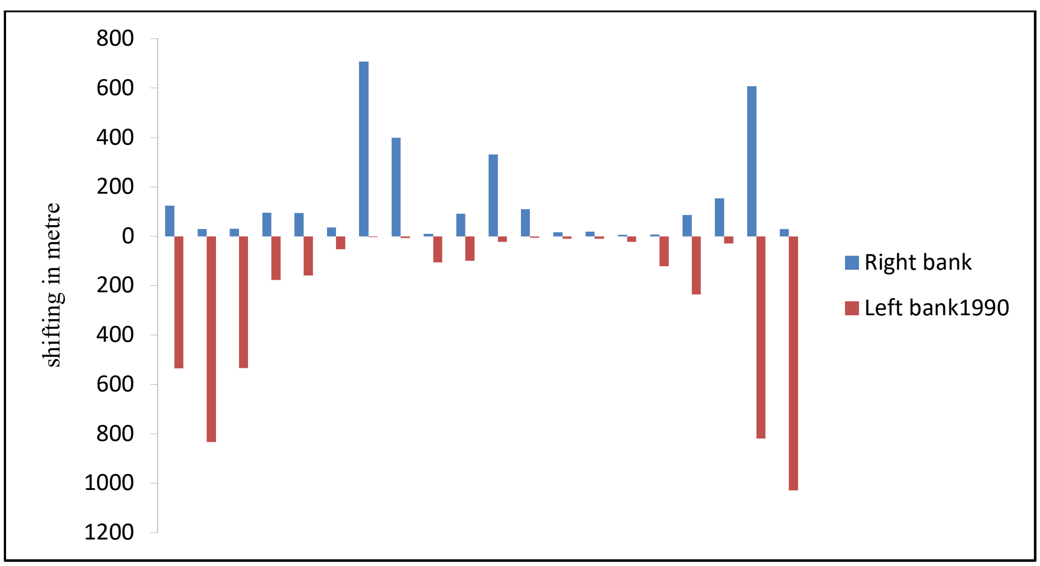
source- Prepared from LANDSAT image (1978-1990)

3.11.2. Bankline Shifting 1990-2001

In this period the bankline shift in different scale. The right bankline shifting rate and direction is different. The right bankline shifting is high at points 7,8, 11 and 19(figure-3.34). The right bankline mainly shift on right direction and at points 2,13,15 and 16(3.34) the bankline shift are on left direction. The maximum shifting rate of the left bankline is mainly found at upper and lower part of channel, where the shifting rate is more than 300 metre. The left bankline mainly shift on left direction and only at three section (8,19 and 20) the bankline shift on right direction(figure-3.38).

The rate of bankline shifting on both left and right direction are shown in table no. 3.8

Figure-3.34. Bankline Shifting 1990-2001



Source-Prepared from LANDSAT image(1990-2001)

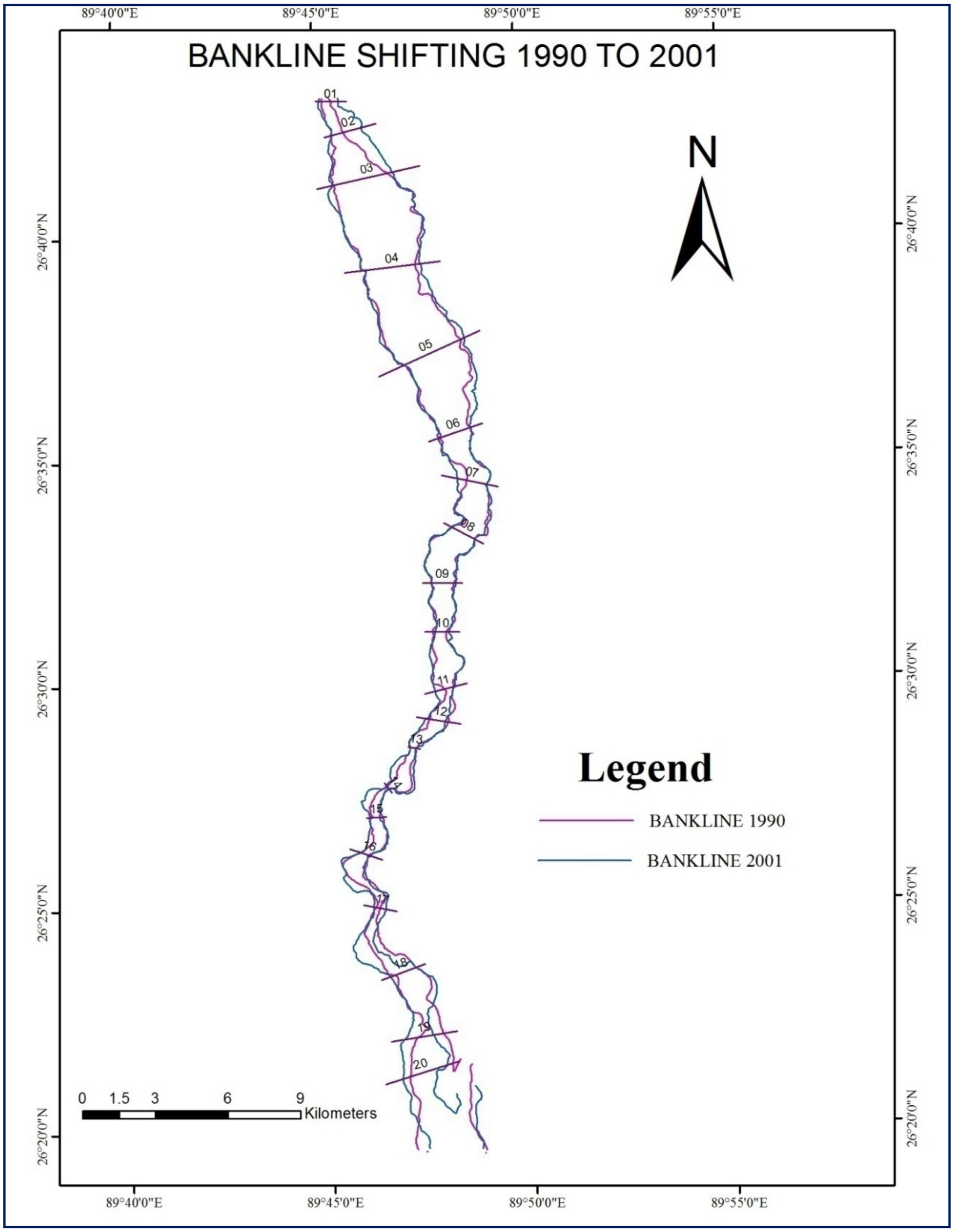
Table-3.8. Bankline shifting rate and direction-1990-2001

Loction no.	Right bank shift(in metre)	Direction	Left bank shift(in metre)	Direction
01	123.88	R	534.35	L
02	29.262	L	834.09	L
03	31.566	R	533.43	L
04	96.16	R	176.88	L
05	94.696	R	158.58	L
06	35.77	R	53.11	L
07	708.05	R	2.89	L
08	400.28	R	6.072	R
09	9.981	L	104.98	L
10	91.95	L	99.74	L
11	331.15	R	22.71	L
12	109.4	R	4.98	L
13	17.06	L	10.438	L
14	18.54	R	9.82	L
15	5.96	L	22.58	L
16	6.73	L	121.12	L
17	86.506	R	235.57	L
18	154.53	R	28.32	L
19	608.32	R	819.66	R
20	281.38	R	1030.6	R

Source-Prepared from LANDSAT image (1990,2001)

R-Right, L-Left

Figure-3.35. Bankline Shifting, 1990-2001,



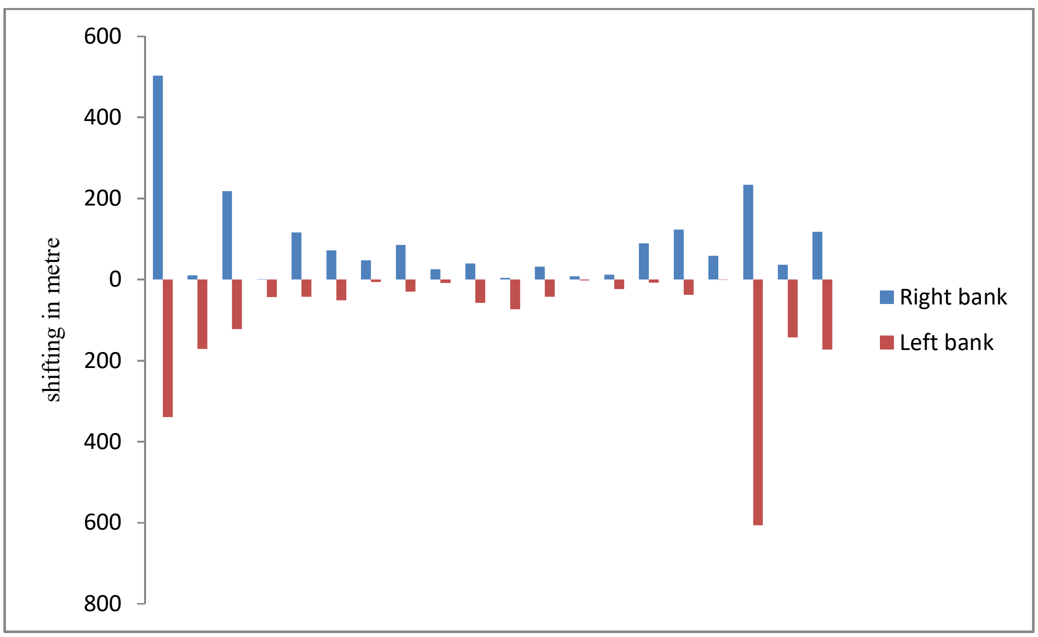
Source- Prepared from LANDSAT image (1990-2001)

3.11.3. Bankline shifting 2001-2016

In this period bankline shifting rate is measured on the basis of bankline 2001. The maximum bankline shifting rate is occured in the upper part of the channel at points 1,2, 3 and 18(figure-3.36). On the left bank shifting is taking at points 1,2,3,18,19 and 20(figure-3.36). The right and left bankline shifting on right and left direction is show in figure-3.38.

The rate of bankline shifting on nature both left and right direction are shown in table no. 3.9

Figure-3.36.Bankline Shifting 2001-2016



Source-Prepared from LANDSAT image(2001-2016)

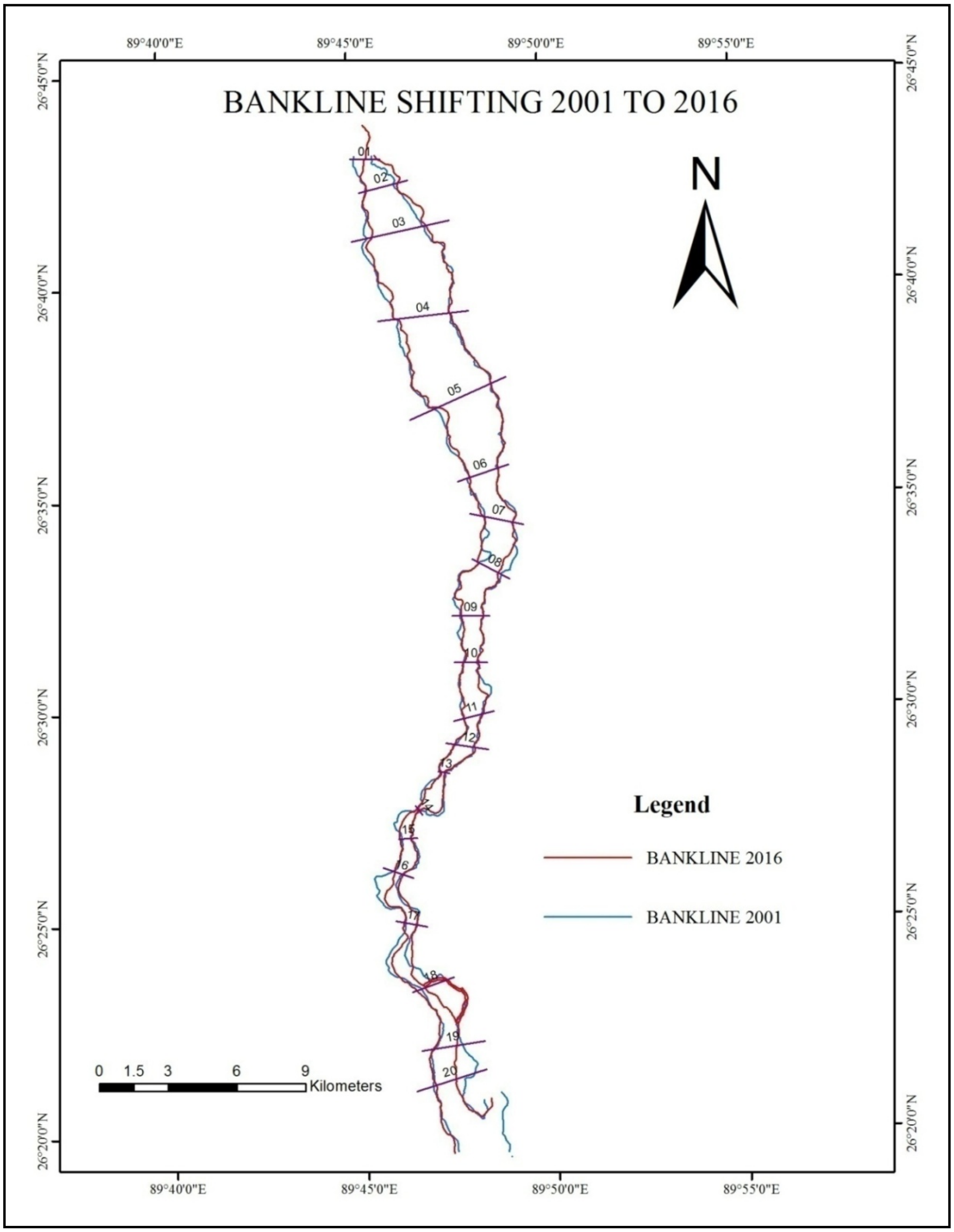
Table-3.9. Bankline shifting rate and direction-2001-2016

Loction no.	Right bank shift (in metre)	Direction	Left bank shift(in metre)	Direction
01	503.16	L	338.68	L
02	10.634	L	171.32	L
03	218.1	L	122.15	L
04	0.851	R	43.259	L
05	115.86	L	42.154	L
06	71.903	L	50.921	L
07	47.716	R	6.326	R
08	85.604	R	29.759	L
09	25.37	L	8.641	R
10	39.902	R	57.667	L
11	4.214	R	73.209	L
12	32.405	R	41.85	R
13	8.73	L	2.123	R
14	12.291	L	23.55	R
15	89.068	R	7.945	L
16	123.64	L	37.543	L
17	58.93	R	0.0098	R
18	234.1	R	606.09	R
19	36.915	R	142.28	L
20	117.8	L	172.64	L

Source-Prepared from LANDSAT image (2001, 2016)

R-Right, L-Left

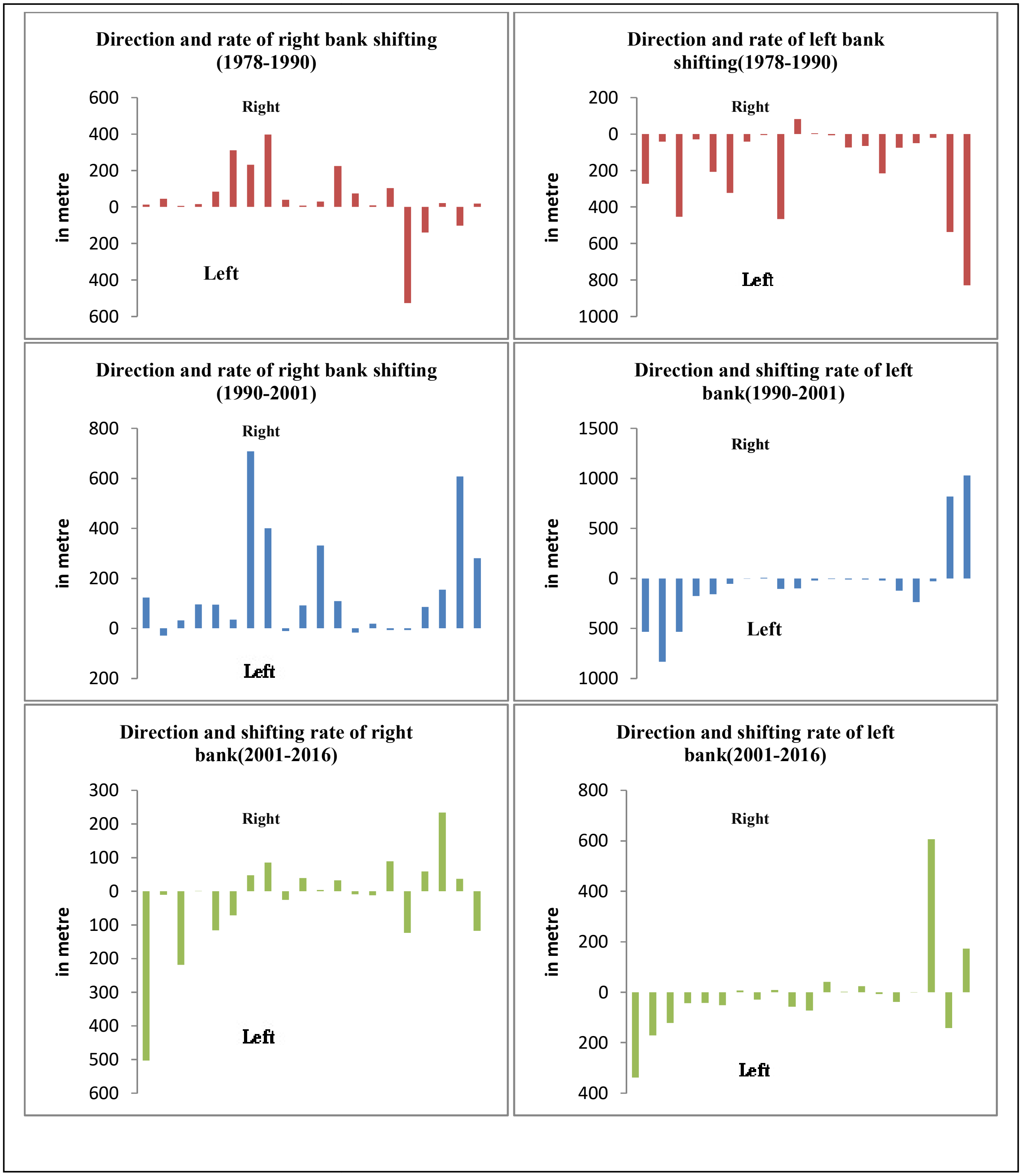
Figure-3.37. Bankline Shifting, 2001-2016,



Source- Prepared from LANDSAT image (2001-2016)

The Raidak-II channel bankline shifting rate of three period is different from each other. According to the table and diagram, in period of 1978 to 1990 the bankline shifting has found in upper, middle and lower part. But in the period of 1990 to 2001 and 2001 to 2016 the bankline shifting is mainly found in upper and lower part.

Figure- 3.38.Right and Left Bankline Shifting Rate and Direction



Source-Prepared from LANDSAT image (1978,1990,2001 and 2016)

3.12. Morphological change of Raidak-II

Channel morphology changes with respect to time and space play an important role in stream flow dynamic.The Raidak-II change its morphology in different scale due to different factors. Different morphological changes has identify of Raidak-II river channel from different sources, these are topographical map, Landsate image, google earth and field visit. Some of these changes analysis in three part(upper, middle and lower). These changes are alluvial island change, bar change, pattern change,confluence change and bankline shifting etc. The morphololological change of Raidak-II which was divided in three sections for better understanding are showing different pattern changes from each other.

3.12.1. Causes of Morphological Change of Raidak-II

Different factors are responsible for changing the morphology of a river channel. According to M. Morisawa(1985) "the morphology and dynamics of rivers are not only related to each other but are also depending upon environmental variables such as climate, lithology, topography, landuse and vegetation". All these variables interact to each other and make a specific fluvial system. Now a day one of the most important factors is human to change the morphology of a channel by their different activity. According to Schum(1998), "the changes of river channel form may be caused by natural and human activity. It may be stable at one extreme or in the process of total change as part of metamorphosis at the others".

The channel morphology of the Raidak-II river has been change by different factors. They are (i). Frequent flood, (ii). Decrease of gradient, (iii). Huge amount of deposition, (iv). Humann activity etc.

(i) Frequently Flood

Frequently flood is one of the most important factor to change the river channel in lower part. The Raidak-II is associated with frequent floods every year.Due to flood, the channel island, bars and bankline has been changed its location, size and shape. The main cause of flood in this region is heavy rainfall in the rainy season and recieved huge amount of discharge from upper catchment.

(ii) Decrease of Channel Gradient

Channel gradient is the main factors for erosional and depositional activity. The decrease in channel gradient at the outlet from the mountain causes decrease in transport capacity and extensive deposition of erosional material transported from the upper part. The Raidak river gradient is highly variable. The Raidak river debouches in to india at Bhutan ghat and flow through the plain of Alipurduar and Coochbehar. At this reach the channel gradient suddenly decrease and deposited huge amount of erosional materials. Leteral expansion of channel is also taking place and the channel bankline migrated west and east direction. Mid channel deposition of materials form bars and island which is accentuated in rainy season.

(iii) Huge Amount Deposition

The lower part of the Raidak river is mainly deposited erosional material which transported from upper part. The main source of the erosional material is landslide in the upper part. In the lower part, deposition of erosional material is taking in mid channel which cause widening of channel and bifurcation.

(iv) Human Activity

Present day channel morphology also change by human activity. The Raidak-II channel morphology is changed by some human activity mainly boulder lifting and agriculture(plate- 3.10). Huge amount of boulder have been collected by local people in the pre-monsoon and post monsoon season. In the time of field survey it was ovserved that huge amount of boulder are collected from Maynar ghat, Joydebpur, Hemaguri, Chokchoka. In the lower part huge amount of sand are collected from the river bed.

3.22.Summary

The changes in the morphology and the pattern of Raidak-II include overbank avulsion, downstream meander migration and bar change. The changes also due to agricultural practice mainly at Hemaguri to confluence zone.

The most significant morphodynamic changes of the Raidak-II river channel are channel bars, island and bankline shifting. Channel bars continuously change their location, shape and size. The alluvial island also change size and shape due to lateral erosion during the period of high flow.

All of these changes are unpredictable change. Considering the morphological characteristic of river channel as well as flood plain. The Raidak-II river recieves huge amount of sediment during heavy rainfall in the rainy season(mainly June to August). There is mark difference between the high flow and low flow. All these factors make the river channel subjected to both long and short term changes.

The three part of the Raidak-II river bear different characteristic from each other and their changes pattern is different. The Raidak-II river channel is a alluvial channel type. Most of the alluvial channel adjust their courses to these variables. Most importantly to the size and quantity of the sediment it carry and to the fluctuation of the flow. The bank width are also increased in the different point.

The downstream migration of meanders are performed through bank retreat. The channel pattern characteristic such as wandering thalwegs and alternating point bars have favoured bank erosion at its bends. Formation of such bars protect and exposes alternate banks. Erosion takes place in the concave side of the meander bends.

The conluence point have changes by the process of erosion and deposition of the both Raidak-II and Sankosh river.

The bankline shifting of the Raidak-II river channel in the period of 1978 to 2016 is highly variable. Among this the channel bankline shifting rate is more high at upper and lower part of the channel (Bhutan ghat and Bainaguri). In the period of 1978-1990 and 1990-2001 the right and left bankline mainly shift in right and left direction. In the period of 2001-2016 the right and left bankline shifting direction is very variable. The upper and lower part of the channel banklines both are shifted mainly on left direction.

The hydro-morphodynamic of the river is influenced by of both natural and man induced.

Plate3.10.-Human activity on channel morphology change

A-boulder lifting at Maynar ghat
B-boulder lifting at Chokchoka
C-sand lifting at bainaguri
D,E-teporari embankment on channel bed
F-watermelon cultivation on newly form bar at Bainaguri
G-maize cultivation on channel stable island at Bainaguri

Source-Photograph in the time of field visit

4.1 Findings

The majors findings of the study can be summarised as follows

1. The river Raidak called Wangchhu in Bhutan and the lower part of the river (Bhutan Ghat to mouth)is known as Raidak-II. The total length of the Raidak- II is 50 kilometer.
2. Based on the interpretation of Bhuvan image, the study area is divided into five geomorphological unit, viz- Fluvial origin younger alluvial plain, fluvial origin older flood plain, fluvial origin active flood plain, fluvial origin piedmont alluvial plain and structural origin.
3. On the basis of stream ordering (Strahler) the Raidak-II channel is a 5th order stream of Raidak river system.
4. Average depth of the channel is 1.16 metre and the channel width is different, at Jaydebpur, Hemaguri and Bainaguri channel width is more than 1350 metre and at Bhutanghat, Chokchoka and Takuamari channel width is less than 500 metre.
5. Two channel patterns have identified on the basis of sinuosity index such as Anabranching/Braided and meandering
6. The Raidak-II river is characterized by wide variation of deposition and erosional work.
7. Three type of banklines migration are observed (i) lateral migration (ii)straightenting of the river courses by meander cut-off and (iii) progressive changes of meander bends. Among these mainly lateral migration are observed.
8. Channel bar/island formation and its changes are one of the important hydrodynamic characteristic of the Raidak –II.

9. Middle and lower part of the Raidak-II channel is covered by settlement and agricultural practice.
10. Present day the bankline shifting occurred profoundly only near Bhutan border and mouth. Bankline in the middle part of the channel is stable due to embankment. Different type of embankment has constructed, that are concrete, earth material and traditional.
11. Some place of the channel bank erosion mainly protected by local tradition by using bamboo and planting trees.
12. Channel water velocity decreases from upper part to lower part.
13. The channel width of the Raidak-II is different, maximum channel width is found in the upper portion and at the mouth. Channel width in the middle part is narrow. The maximum width in upper portion is formed due to sudden drop of gradient and deposition which form large bars/island and channels are bifurcated. At the mouth of river gradient is very low and spreading channel due to deposition of fine sediment in valley itself.
14. The river is narrow in middle part because all distributaries are joined in main channel but deposition in channel and small bar formation has formed braided character also.
15. The lower portion is characterised by meander where sediment in water less and gradient is also very low that's why lateral erosion cause meander condition.
16. The size of sediment and bedload also varies in different part of the channel. In the upper part boulder and pebbles and lower part is of sand and silt.

17. It is also found that where there is maximum formation of bar the maximum width of the river.
18. The maximum transformation of bar and island is taking in upper part.
19. Maximum bankline shifting falling on left bank in 1978-1990. The direction of shifting of left bankline also on left side. The right bankline shifting was mainly taking in middle portion.
20. In 1990-2001 the bankline shifting is maximum on right bank and rate of shifting is also high on right side. The left bankilne was also shifting in upper and lower portion.
21. In 2001-2016, both left and right bankline were shifted. On right bankline maximum shifting was observed at upper and lower part. The rate of shifting was also highest toward left direction. The left bankline was shifted most in upper and lower part. The rate of shifting of left bankline is highest on lower part in right direction.
22. It is cleared from the observation, the morphology of the river depend on volume and velocity of water which is partially governed by geology, soil, climate of the area.

4.2 Conclusion

Raidak-II is located in the eastern part of Alipurduar and Coochbehar district. It is the lower course of Raidak river (Wangchhu in Bhutan). In the north, it is bordered by Bhutan Himalaya and the Sankosh in the south and east. The study area is mainly covered by the bainkunthapur geological formation; in the upper part is covered Sub-Himalayan Shiwalic formation.

The study area is well drained by Raidak-II river and its tribituries. Loose surface soil, heavy rainfall in monsoon season, braided river course and flateness make this plain a unique geographical unit. The area has received 3000 mm rainfall annually. Most part of the study area is populated; mainly Joydebpur to mouth is highly populated. The upper part is mainly covered by evergreen forest and deciduous forest.

Raidak-II river channel is mainly characterised by different sizes of bar and island. Sandbars are developed within the channel as well as in the convex side of the meander. The upper part of the river mainly characterised by alluvial island some of them are permanent and some are unstable and mainly covered by vegetation. The alluvial island of the upper part mainly changed by the process of lateral erosion in the period of over flow during rainy season. At this part the river channel mainly active on the left side where new mid channel bars are also developed. The middle part is mainly characterised by braided channel. At this part different bars are found and channel bars continuously change their size, shape and location due to over flow in the rainy season. In lower part river flows through a single channel with many bends. At this part the main activity is lateral erosion. At mouth river island are mainly covered by grass and some are used for settlement and agricultural practice.

The size of bedload is decrease from upper part to lower part. In upper part mainly boulder and pebbles whereas in the lower part are dominated by sand and silt.

In the rainy season most of the bars and island except few of which are used for settlement are under water. Most of them have been transformed in rainy season.

River channel bankline mainly shift in the right and left direction. The confluence of the Raidak and Sankosh river is changing. The observation at confluence point in year 1978-1990 was turned north-east with distance of 12.3 metre, in 1990-2001 was on south-east with 1721 metre whereas 2001-2016 was on north-west direction with 47.15 metre. The confluence point is changing its location every year.

The morphodynamic of river are mainly influenced by various factors such changing volume of water in different season, rate of deposition and erosion, gradient of channel besides anthropogenic factors. The rate of morphodynamic of the river Raidak II need to monitored in order to reduce the damage of property which take place every year.

References

Aher, S.P. et al., (2012), “River change detection and bank erosion identification using topographical and remote sensing data”. *International journal of applied information system,* vol.2, pp. 1-7

Bhuiyan, A. H. M. et al., (2014), “Application of remote sensing and GIS for evaluation of the recent morphological characteristic of the lower Brahmaputra – Jamuna river, Bangladesh”. *Earth science inform*, 8:551-568,DOI 10.1007/s12145-014-0180-4

Bhattacharyya, A. (2013), “Evaluation Of Hydro-Geonomic Characteristics of Flood in the Mayurakshi River Basin Of Eastern India” PhD thesis, Visva-Bharati, Santiniketan, West Bengal India

Chakraborty, S. et al., (2013), “Causes and consequence of fluvial hazards: A hydrogeomorphic analysis in Duars region, India’. *Indian streams research journal,* vol.2, no.12, pp.1-7

Chatterjee, S. et al., (2013), “Impact of River Bank Erosion on Human Life: A Case Study in Shantipur Block, Nadia District, West Bengal”. *International Journal of Humanities and Social Science Invention,* vol.2, no.8, pp.108-111

Chakraborty, S. et al.,(2015), “ An assessment on the nature of channel migration of river Diana of the sub- Himalayan West Bengal using field and GIS techniques”. *Arab J geosci*, 8:5649-5661, DOI 10.1007/s12517-014-1594-5

Das, A. K. et al., (2012), “Bankline change and the facets of riverine hazards in the floodplain of Subansiri–Ranganadi Doab, Brahmaputra Valley, India”. *Nat Hazards*, vol.64,pp.1015–1028, DOI 10.1007/s11069-012-0283-5

Das, S. et al.,(2014),“Hydrodynamic changes of river course part of Bhagirathi-hugli in nadia district; a geoinformatics appraisal”. *International jouran of Geomatics and Geosciences,* vol.5, no.2, pp. 284-299

Das, L. M, (2015), “Channel avulsion in Jiadhol river of Brahmaputra basin”. *International journal of scientific research,* vol.4, pp.274-276.

Dayal, S. et al., (2012), “Assessment bankline of change of river ganga around patna city, india, using multi temporal satellite data. “*International journal of earth science and engineering,* vol.05, no-03, pp.442-450

Dury, G. H., (1969), "Relation of Morphometry to Runoff Frequency", in *Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography,* edited by R.J., Chorley, Methuen & Co Ltd., London, p. 425.

Gogoi, C. et al.,(2013) ,“A study on bank erosion and bankline migration pattern of the Subansiri river in Assam using remote sensing and GIS technology”. *The international journal of engineering and science,* vol. 9, pp.01-06

Goswami, U. et al., (1999), “ River channel changes of the subansiri in Assam, India”. *Geomorphology*, vol. 30, pp.227-244

Gregory, K. J. and Walling, D. E., (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London.

Gupta,N. (2008) " Geoinformatic for Inter Basin Water Transfer Assessment : A Study in Part Of Ganga – Brahmaputra Basin, Eatern India" Master Of Science, Thesis, International Institute for Geo-Information Science and Earth Observation(ITC), The Netherland.

Government of West Bengal.(2014) Annual flood report of 2013, Irrigation and waterways directorate,

Kusimi, J.M. (2008), " Stream processes and dynamic in the morphology of the Densu river channel in Ghana". *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXVII, pp.1177-1182

Kumar, R., (2010), "Fluvial process in lower Rapti river basin: A case study of impact on arable land" PhD thesis,Jawaharlal Nehru University, India

Knighton,D.(1998) "*Fluvial Form And Process: A Newperspective*" Arnold, an Imprint Of Hodder Education, Great Britain.

Lahiri, S. K et al.,(2012), "Tectonic control on the morphodynamic of the Brahmaputra river system in the upper Assam valley, India". *Geomorphology* DOI:10,1016/5.geomorph.2012.04.012

Leopold L. B., Wolman M. G. and Miller, J. P., (1963), *"Fluvial Geomorphology",* Dover Publication, INC., New York.

Leopold, L. B., (1960), “Rivers Meanders”, *geological society of America bulletin,* vol.71,pp.769-794

Leopold, L. B., (1973), “River channel change with time: An example”, *Geological society of American Bulletin,* vol.84, pp.1845-1860

Morisawa, M., (1985), “*Rivers: Form and Process*”, Longman Group Limited.

Morisawa, M., (1968), “*Streams: their dynamic and morphology*” McGrow-Hill Book Company

Muhammad, A. et al., (2016), “River bank erosion and channel evolution in sand-bed braided reach of river Chenab: role of flood during different flow regime.” *Arab J geosci,* 9;140, DOI 10.1007/s125-015-2114-y

Nanson, G.C.(2013) “Anabranching and Anastomosing rivers in E wohl, ed, treatise on fluvial geomorphology” *Elsevier Amsterdam*, pp-33-344

Ou-yang, Z. et al., (2001), “Relationship between energy dissipation rate and channel morphology in the development of the model braided channel’”. *Journal of geographical science,* vol.11, no.3, pp. 291-296

Roy, N. et al.,(2007) “Understanding confluence dynamic in the Ganga- Ramganga valley, India: an integrated approach using geomorphology and hydrology.”*Geomorphology,* vol. 92, pp.182-197

Sarkar, A. et al., (2011) studied on "RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India." *Journal of Water Resource and Protection*, vol. 4, pp. 63-72

Sinha, R. et al.,(2005), "Geomorphic characterization and diversity of the fluvial system of the Gangetic plains". *Geomorphology*, vol.70, pp. 207-225

Sarker, M. H, et al., (2013) "Morphodynamic of the Brahmaputra-Jamuna river, Bangledesh" *Geomorphology*, http://dx:doi.org/10.1016/j.geomorph.201307.025

Sarma, J. N. et al., (2007), "Change of river channel and bank erosion of the burhi dihing river (Assam): Assessed using remote sensing data and GIS". *Journal of the Indian Society of Remote Sensing,* vol. *35,* no.1, pp. 93-100

Slingerland, R. and Smith, N. D., (2004), "River avulsion and their deposit". *Annual Reviews, Earth Planet Science,* pp.32:257–285, doi: 10.1146/annurev.earth.32.101802.120201

Singh, S.(1998) "*Geomorphology*" Prayag Pustak Bhawan,Allahabad

State Forest Report (2011-2012), Govt. of West Bengal

Tamang, L. (2013) "Effect Of Boulder Lifting on The Fluvial Characteristics of Lower Balason Basin in Darjeeling District, West Bengal" PhD thesis, university of north Bengal.pp31

Imagaries downloaded from following sites:

Landsat image- http://earthexplorer.usgs.gov/

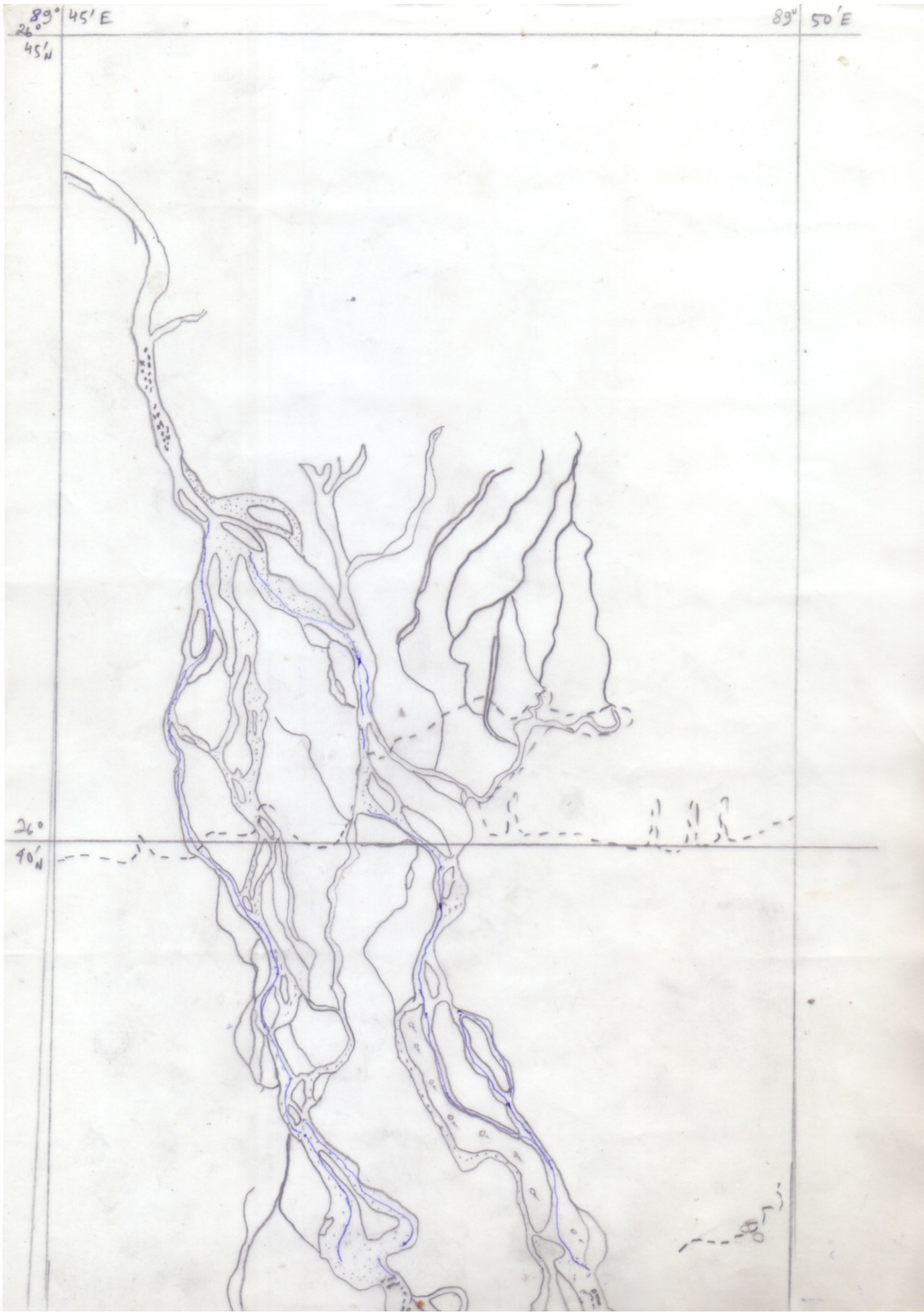
Geomorphology thematic map- http://bhuvan.nrsc.gov.in/

Landuse-landcover map- http://bhuvan.nrsc.gov.in/

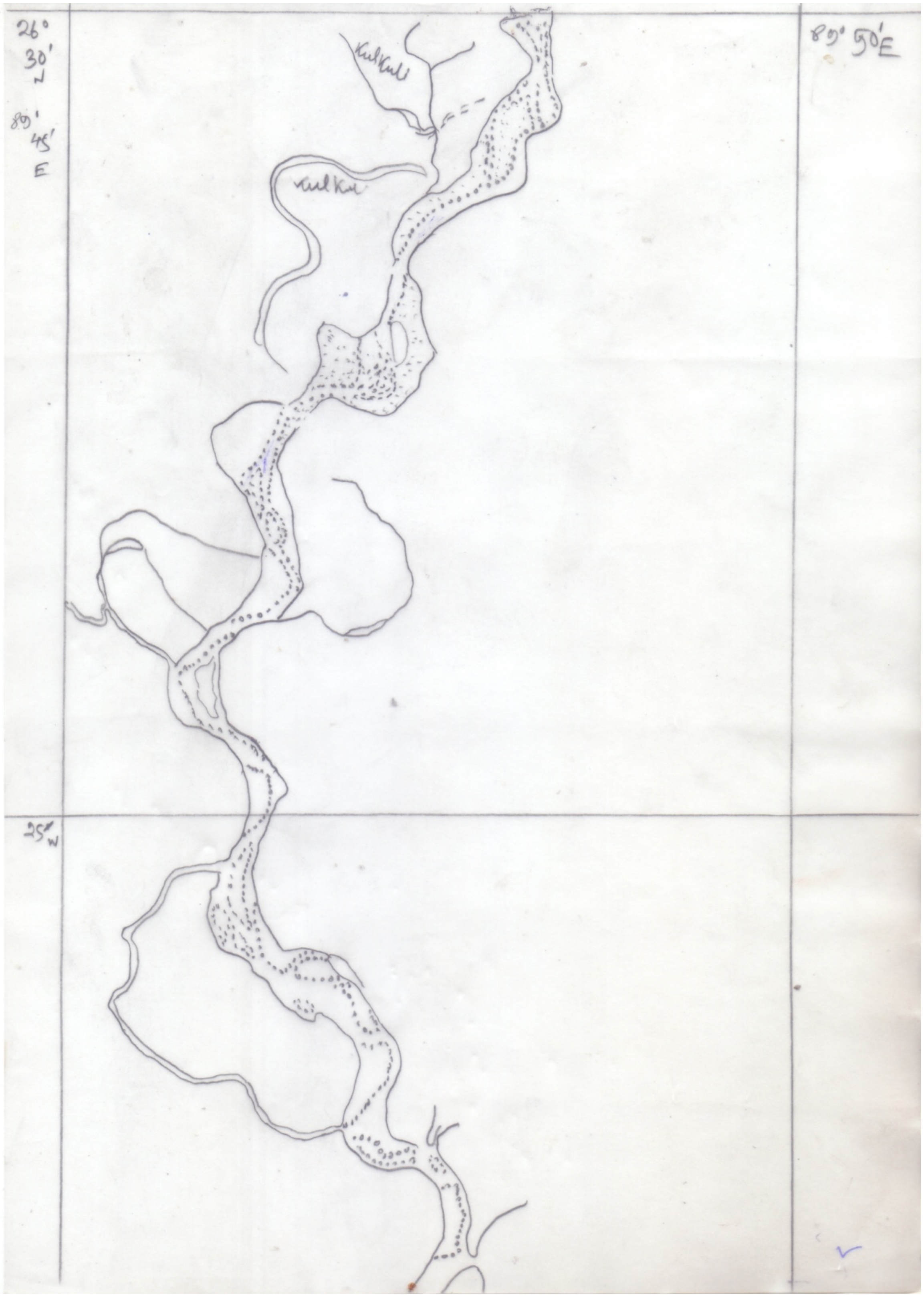
Appendices

Appendix - I

SOI Topo sheet 78F/14,15




26°
35' N
60 mt.
Kali Jhora
Ghoramara N
Tenamari N
Giladonga N
26°
30' N



Source - Tracing from NATMO, Kolkata

Appendix - II

Elevation for long profile

Distance(in kilometre)	Height(metre)
0	135
1	128
2	121
3	114
4	110
5	106
6	102
7	96
8	93
9	90
10	87
11	82
12	81
13	78
14	75
15	69
16	68
17	67
18	64
19	61
20	60
21	59
22	57
23	58

Distance(in kilometre)	Height(metre)
24	56
25	54
26	51
27	49
28	47
29	47
30	47.5
31	47
32	45.5
33	44.5
34	45
35	43.5
36	44
37	39.5
38	40
39	38
40	38.5
41	37
42	35
43	34
44	34.5
45	34.6
46	33

Source- Google earth Image, 2014

Apendix - III

Table-sample field sheet used for the cross-section survey

Cross-section No…………………………………………Date-……………………

Station	Distance	Readings			Rise	Fall	Reduced Level	Remarks
		BS	IS	FS				

Appendix - IV

Calculation sheet of cross-section

RL at Bainaguri	RL at Takuamari	RL at Chokchoka	RL at Hemaguri	RL at Joydebpur	RL at Bhutan ghat
Premonsoon	Premonsoon	Premonsoon	Premonsoon	Premonsoon	Premonsoon
36	45	45	60	68	88
34.65	43.64	44.205	59.27	67	87.2
33.9	42.45	44.115	58.78	66.9	87.1
33.65	42.42	43.89	58.35	66.8	87
33.38	42.51	43.9	58.57	66.7	86.9
33.25	42.66	43.27	58.725	66.6	86.8
33.64	42.87	43.05	58.74	66.5	86.7
33.6	41.86	43.29	58.73	66.6	86.6
33.9	42.79	43.21	58.79	66.7	86.5
34.41	42.78	43.28	58.84	66.8	86.4
33.75	42.64	43.29	58.75	66.75	86.2
32.49	42.625	43.43	58.73	66.7	86.3
32.61	42.67	43.59	58.77	66.65	86.35
33.22	42.78	44.03	58.65	66.6	86.37
32.69	42.66	43.99	59.31	66.55	86.39
32.19	42.645	44.47	59.21	66.5	86.4
32.76	42.83	44.59	58.9	66.45	86.42
32.04	42.86	44.67	58.51	66.4	86.45
32.06	43.06	44.525	58.87	66.35	86.49
32.019	43.07	43.24	59.03	66.3	86.5
32.34	42.97	41.77	59.28	66.25	86.6
32.75	43.2	41.03	58.25	66.28	86.5
33.21	43.14	40.95	57.2	66.27	86.45
33.5	43.175	41.19	56.75	66.26	86.4
33.71	43.015	41.22	56.84	66.25	86.35
33.76	43.175	41.19	56.81	66.2	86.3
33.75	43.22	41.41	56.84	66.1	86.25
33.84	43.235	41.73	57.01	66.01	86.24
33.55	43.195	41.6	57.94	66.01	86.2
33.33	43.095	41.64	58.44	66	86.24
33.34	43.205	42	58.35	65.9	86.25
33.21	43.105	41.63	58.37	66	86.3
33.28	43.005	41.75	58.39	66.01	86.35
32.91	43.093	41.755	58.53	66.02	86.4
33.44	42.957	41.84	58.62	66.09	86.5
33.76	42.821	41.29	58.7	66.1	86.6

34.48	42.856	41.26	58.75	66.01	86.55
34.98	42.816	40.67	58.76	66.01	86.5
34.88	42.856	41.46	58.85	66.01	86.45
34.98	42.836	41.39	58.91	65.99	86.43
34.68	43.596	41.02	59.002	65.97	86.4
35.18	44.126	41.22	59.069	65.98	86.39
35.37	44.216	41.38	59.112	65.9	86.37
35.08	44.202	41.08	59.152	65.9	86.35
35.43	44.512	41.18	59.212	65.85	86.33
35.13	44.285	40.88	59.262	65.84	86.32
35.09	44.392	41.288	59.392	65.83	86.3
35.03	44.417	40.47	59.44	65.82	86.29
34.73	44.462	41.02	59.39	65.81	86.26
34.53	44.467	40.97	59.922	65.8	86.25
33.93	44.492	40.67	59.44	65.85	86.23
33.63	44.477	40.45	59.48	65.87	86.22
33.53	43.612	40.39	59.56	65.89	86.2
33.74	43.032	40.41	59.69	65.9	86.1
33.84	42.952	40.49	59.46	65.95	86
33.24	42.932	40.71	59.35	65.99	85.95
33.19	42.752	40.67	59.18	66.01	85.9
33.14	42.842	40.57	58.802	66.08	85.88
33.09	42.882	40.65	58.94	66.1	85.87
32.28	42.982	40.59	58.87	66.2	85.86
31.13	43.012	40.47	58.77	66.3	85.85
30.96	42.992	40.61	58.76	65.9	85.86
30.46	43.032	40.58	58.71	65.8	85.81
30.26	43.052	40.6	58.67	65.7	85.85
32.14	43.092	40.47	58.63	65.6	85.84
32.11	43.092	40.31	58.6	65.4	85.82
31.41	43.027	40.29	58.59	65.45	85.8
32.11	42.952	40.06	58.6	65.47	85.78
32.21	42.881	39.17	58.48	65.48	85.76
32.36	42.792	39.13	58.45	65.49	85.75
32.46	42.612	39.23	58.435	65.5	85.7
32.56	41.682	39.08	58.37	65.55	85.65
32.38	41.667	38.97	58.27	65.59	85.6
32.31	41.692	38.87	58.21	65.6	85.55
32.47	41.787	39.17	58.08	65.64	85.5
32.86	41.682	38.98	58.14	65.65	85.3
33.36	41.582	38.88	58.17	65.7	85.31

35.6	41.482	38.78	58.22	65.75	85.32
35.55	41.422	40.96	58.19	65.8	85.39
35.49	41.542	42.61	58.16	65.84	85.4
34.79	41.272	42.04	58.09	65.85	85.5
34.58	40.952	41.75	57.97	65.94	85.6
34.55	40.732	41.75	57.59	65.95	85.7
34.46	40.512	41.9	57.35	65.96	85.8
34.37	40.552	42.35	57.46	65.97	86.1
34.57	41.302	42.46	57.9	65.99	86.5
34.16	41.412	42.76	58.73	66	86.6
34.19	41.382	43.06	58.72	66.02	86.7
34.45	41.592	45.41	58.75	65.109	86.9
34.46	41.282		58.57	66.2	87.5
34.26	41.122		58.31	66.4	88
34.44	40.592		58.34	66.45	
34.54	40.392		58.34	66.49	
34.44	39.542		58.22	66.5	
34.34	39.912		58.14	66.54	
34.13	39.79		58.16	66.56	
32.03	39.53		58.21	66.59	
35.63	40.372		57.67	66.6	
35.8	42.47		57.06	66.65	
35.89	44.922		57.24	66.68	
35.74			57.42	66.69	
35.59			57.44	66.8	
35.65			57.55	66.9	
35.73			57.75	67	
34.75			58.55	67.1	
34.69			58.51	67.2	
34.59			58.5	67.3	
34.49			58.41	67.4	
34.69			58.43	67.5	
34.59			58.39	67.7	
34.69			58.25	67.65	
34.54			58.03	67.6	
34.32			58.01	67.55	
34.19			58.38	67.5	
34.04			58.69	67.45	
34.09			57.94	67.4	
34.19			58.25	67.35	
34.14			58.31	67.3	

34.58			59	67.25	
34.23			59.05	67.2	
34.39			58.88	67.1	
34.54			58.91	66.9	
34.64			58.81	66.8	
34.69			58.805	66.7	
34.93			58.85	66.65	
34.79			58.8	66.6	
34.84			58.91	66.55	
34.89			59.19	66.51	
34.87			59.01	66.5	
34.94			59.19	66.55	
34.89			58.97	66.59	
34.79			59.07	66.6	
34.64			59.15	66.65	
34.74			59.12	66.69	
34.76			59.029	66.7	
32.97			59.025	66.72	
33.77			58.98	66.75	
32.27			58.84	66.76	
32.46			58.69	66.75	
32.47			58.27	66.79	
32.92			58.28	66.8	
35.52			58.3	66.75	
			58.26	66.7	
			58.15	66.65	
			58.1	66.6	
			58.15	66.55	
			58.14	66.5	
			58.12	66.45	
			58.1	66.4	
			58	66.35	
			57.91	66.3	
			57.56	66.35	
			57.48	66.4	
			57.56	66.45	
			57.66	66.5	
			57.56	66.55	
			57.57	66.6	
			57.56	66.7	
			57.47	66.8	

			57.37	66.9	
			57.22	67	
			57.12	66.9	
			57.11	66.85	
			56.92	66.8	
			56.74	66.75	
			56.57	66.64	
			56.36	66.6	
			56.35	66.55	
			56.38	66.52	
			56.37	66.51	
			56.18	66.5	
			56.1	66.4	
			56.04	66.2	
			56.11	66.3	
			56.15	66.4	
			56.12	66.3	
			56.1	66.2	
			56.14	66.3	
			56.16	66.4	
			56.02	66.45	
			56.19	66.4	
			55.94	66.5	
			55.73	66.45	
			55.35	66.44	
			55.87	66.4	
			56.95	66.35	
			56.99	66.33	
			56.98	66.3	
			56.97	66.25	
			56.96	66.23	
			57.05	66.2	
			56.63	66.09	
			56.62	66.07	
			56.63	66.06	
			56.61	66.01	
			56.59	65.9	
			56.48	65.85	
			56.82	65.8	
			56.77	65.75	
			56.83	65.7	

			56.8	65.6	
			56.78	65.5	
			56.86	65.55	
			56.76	65.6	
			56.07	65.65	
			55.75	65.7	
			55.65	65.75	
			55.55	65.8	
			55.45	65.9	
			56.35	66	
			56.45	65.9	
			56.65	65.85	
			56.67	65.8	
			56.64	65.75	
			56.55	65.7	
			56.61	65.65	
			56.66	65.63	
			56.69	65.6	
			56.77	65.65	
			56.75	65.67	
			56.69	65.7	
			56.67	65.65	
			56.57	65.6	
			56.55	65.65	
			56.39	65.67	
			56.25	65.7	
			56.29	65.75	
			56.3	65.8	
			56.27	65.85	
			56.24	65.87	
			56.22	65.9	
			56.41	65.95	
			56.37	65.97	
			56.3	65.99	
			56.21	65.99	
			56.1	65.95	
			55.91	65.9	
			55.8	65.99	
			55.94	66.01	
			56.22	66.05	
			54.75	66.09	

			53.65	66.1	
			53.71	66.3	
			54.1	66.2	
			54.88	66.05	
			54.95	66.04	
			55.05	66.02	
			55.15	65.9	
			55.27	65.89	
			55.5	65.85	
			55.71	65.82	
			55.45	65.8	
			55.75	65.77	
			55.82	65.75	
			55.95	65.74	
			56.1	65.73	
			56.18	65.72	
			55.82	65.7	
			55.68	65.75	
			56.02	65.79	
			56.07	65.8	
			56.26	65.85	
			56.3	65.9	
			56.36	66	
			56.4	66.1	
			56.46	66.2	
			56.48	66.25	
			56.46	66.28	
			56.5	66.4	
			56.56	66.6	
			56.84	66.8	
			57.16	66.9	
				67	
				67.1	
				67.2	
				67.3	

Source- Field Survey - May, 2016