THE STUDY OF ABANDONED CHANNELS AND THEIR SOCIO-ECONOMIC IMPORTANCE OF THE SANKOSH RIVER BASIN IN INDIA

A Thesis Submitted to the University of North Bengal

For the Award of
Doctor of Philosophy
In Geography and Applied Geography.

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March, 2021

DECLARATION

I declare that the thesis entitled **"THE STUDY OF ABANDONED CHANNELS AND THEIR SOCIO-ECONOMIC IMPORTANCE OF THE SANKOSH RIVER BASIN IN INDIA"** has been prepared by me under the guidance of Dr. Sudip Kumar Bhattacharya, Assistant Professor of Department of Geography and Applied Geography, University of North Bengal. No part of this thesis has formed the basis of any degree or fellowship awarded previously.

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CERTIFICATE

I certify that **Darshan Chandra Barman** has prepared the thesis entitled **"THE STUDY OF ABANDONED CHANNELS AND THEIR SOCIO-ECONOMIC IMPORTANCE OF THE SANKOSH RIVER BASIN IN INDIA"** for the award of Ph.D degree of the University of North Bengal under my guidance and supervision. He has carried out the research work at the Department of Geography and Applied Geography, University of North Bengal and the thesis has been prepared based on the primary and secondary source of information by the researcher.

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Dedicated

to

My Father and Mother

PREFACE

An abandoned channel is an inactive channel, defined as a former stream channel through which water no longer flows**.** They are recognized as depression in the landscape and located at the position of a formerly active channel, though typically of considerably reduced width and depth. In this regard, morphometric analysis has been done for the basin area of Sankosh River and various morphometric data have been calculated by using of topographical maps published by the Survey of India and Remote Sensing and GIS platforms. It is also mentioned that numerous abandoned channels are also identified with the study of the mechanism of meander cut-off, channel avulsion and braid formation and explained in the chapter-III in detail. All these abandoned channels are naturally formed and provides different morphological characteristics along the Sankosh River of the study area. These abandoned channels are represented as various geomorphological features such as ox-bow Lake, meander scar, meander cut-off etc. over the flood plain of the concern river. It is mentioned that abandoned channels constitute an important source of natural resources which yields high economic and livelihood values to local people inhabited surroundings of the abandoned channels of the study area. But, abandoned channels are facing different kind of problems due to huge population pressure, land use change, climatic change and environmental change day by day. Therefore, the attempts has been made in the chapter VII to bring out some unexplored facts about the Restoration, conservation and management of abandoned channels which are supposed to be more useful to socio-economic development as well as risk reduction for human habitation and sustainable use of lands of the surrounding channels areas.

Present researcher seeks to undertake detailed study of the fluvial processes of the abandoned channel formation with their associated problems and to make a value added appraisals of the socio-economic importance of the channels' surrounding areas with some recommendations for sustainable management.

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I am in short of words towards expressing my heartiest gratitude to my beloved parents, Bholanath Barman (Father) and Khukumani Barman (Mother) and other all members of my family for their moral support and encouragement throughout my studies and, therefore, I *dedicate this work to them. From the bottom of my heart, I am grateful to my wife Mrs. Banani Sarkar who has inspired me and actively cooperated in this regard.*

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Date: 02/03/2021

Place: Siliguri

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THE STUDY OF ABANDONED CHANNELS AND THEIR SOCIO-ECONOMIC IMPORTANCE OF THE SANKOSH RIVER BASIN IN INDIA

Abstract

An abandoned channel is an inactive channel, defined as a former stream channel through which water no longer flows**.** They are recognized as depression in the landscape and located at the position of a formerly active channel, though typically of considerably reduced width and depth. All these abandoned channels are naturally formed and provides different morphological characteristics along the Sankosh River of the study area. The abandoned channels are identified with the study of the mechanism of meander cut-off, channel avulsion and braid formation. In this regard, morphometric analysis has been done for the basin area of Sankosh River and various morphometric data have been calculated by using of topographical maps published by the Survey of India and Remote Sensing and GIS platforms. These abandoned channels are not only represented as various geomorphological features such as ox-bow Lake, meander scar, meander cut-off etc. over the flood plain of the concern river but also constitute an important source of natural resources which yields high economic and livelihood values to local people inhabited surroundings of the abandoned channels of the study area. But, abandoned channels are facing different kind of problems due to huge population pressure, land use change, climatic change and environmental change day by day. Therefore, the attempts has been made to bring out some unexplored facts about the restoration, conservation and management of abandoned channels which are supposed to be more useful to socio-economic development as well as risk reduction for human habitation and sustainable use of lands of the surrounding channels areas.

Sankosh River is one of the major rivers of North Bengal and Assam in India. This river system has covered up its mountainous parts of Bhutan, flowing through undulating plains of North Bengal and Assam and finally entered into Bangladesh to find its confluence in Brahmaputra River. In Bhutan, it is called as the Puna Tsang Chhu, Sankosh in India and Gangadhar in Bangladesh. The northern limit of the study area started at $26^0$44’24” North latitude where it creates boundary between India and Bhutan, and the Southern limit ends with the boundary shared between Bangladesh and India at $25^0$58’48” North latitude. The longitudinal extension ranges from $89^0$43’48” East to $89^0$55’12” East. The study area covers an area of 1012

sq.km (Map 1.1). The portion of this river basin falling within West Bengal and Assam is constituted of lower alluvial courses having significant dynamic fluvial characteristics for which frequent changes and abandonment of courses are manifested in the channel system which counts for adequate academic importance. Such changes of the river system have also sufficient social importance from the socio-economic point of view.

The present study has been conducted to identify the different types of abandoned channels resulted from various fluvial processes associated with them and to study the occurrences of sedimentary features associated with the abandoned channel fills. The researcher also investigated to identify the problems of human practices surrounding the abandoned channel areas and suggested some important recommendation to manage the problems and bring out the socio-economic importance of abandoned channel areas.

To fulfil the objectives of the research work, the methodology adopted, has been divided into three parts. In the pre-field study, secondary data has been collected from library, books, journals, various district and state offices, toposheet maps of Survey of India (SOI) etc. The field survey i.e. second part of the methodology, has been conducted to collect primary data from the field to analyse various morphometric parameters related to the research work and at the same time household survey has also been conducted to investigate various socio-economic data of the local people inhabited surroundings of the abandoned channels. In the post-field study, geo-referencing of the topographical maps to integrate or incorporated a whole or partial with the satellite images have been made and at the same time enhancement and the digital processing of satellite images for various applications have also been done with the help of different licensed and open source of GIS packages. Global positioning system (GPS) has been used for locational studies as a technique of data input and enhancement method of data interpretation wherever applicable and needful. In addition to this, some important statistical techniques have also been applied for the interpretation of primary as well as secondary data collected from the field and other sources.

The entire research work is divided into Seven chapters to fulfil all objectives of the present work. The chapter I includes a brief introduction of the research work with hypothesis, objectives and methodology along with the review of literatures. Physical and cultural set up of the study area has been discussed in the chapter II whereas the chapter III contains a brief morphometric analysis of the Sankosh river in the study area and also discussed about the identification of the abandoned channels. A thorough discussion about the mechanism of the formation of the abandoned channels has been analysed with the help of Remote sensing and GIS platform in chapter IV. In chapter V, various resulted landforms of the abandoned channels have been identified and explained with maps. Socio-economic importance of the abandoned channel has been investigated through field survey with the help of questionnaire in chapter VI and finally in chapter VII, various methods has been suggested for sustainable management of abandoned channels in the study area and enlisted major findings of the research work.

The adopted systematic approach has helped in achieving the basic objectives and research questions to complete this research work. The courses of Sankosh River have been analyzed with the remote sensing and GIS platforms and formation of abandoned channels were quantified from the point of view of fluvial processes. Identification, types and the mechanism of abandoned channel formations have been realized and documented by field investigations. Laboratory analysis and sampling tests of different variables helped to find out the mechanism of abandoned channels formation and their resultant landforms formation in different reaches of the study area. Different morphometric parameters have been calculated and analyzed to know the nature of the River Sankosh. Meander cut-offs, ie both the neck cut-offs and chute cut-offs have been analyzed in relation to the sinuosity index which is considered the fundamental mechanism of abandoned channel formation. The mechanism of channel avulsion has been investigated on the basis of overbank flow during the high flood which is also explained as another important mechanics of the formation of abandoned channels in the study reach. Meander cut-offs, channel avulsion, influences of braid formation have been observed and identified as the main mechanisms of the formation of abandoned channels in the study area.

Different erosional and depositional landforms development with the channel abandonment has been counted and analyzed to fulfill the concern objective of the research work. Abandoned channels are important elements of alluvial river system and these channels provide huge resources for the people inhabited surrounds the abandoned channel. In this regard, the socio-economic importance of these abandoned channels has been analysed for the benefit of the local people. On the other hand, human habitation on the abandoned channel area has been made different kinds of problem are also investigated in the study reach. For this reason, restoration processes, suggested guideline and a conceptual framework, has been prepared for the proper management of abandoned channels.

Abandoned channels are generally highly productive ecosystems, providing various key benefits to the environment. Records relating to the existing ecological values of the identified abandoned channels along the River Sankosh (main stream) is inadequate in the present era. This necessitates an urgent need to make a record on the types of abandoned channels, its formation and mechanisms, morphometric, hydrological and ecological records, surrounding land use and land cover, hydrogeology of the main stream basin, surface water quality, and socio-economic dependence, and highlight the pressure these systems are subjected to in the present context. Monitoring of water quality can be done by involving local NGOs and the regulating department of surface water, groundwater and ecology. Such programs and practices help in providing technical support and addressing hydrologic concerns, and consequently, this helps in boosting better consideration of these systems and formulating comprehensive measures regarding their management by restoration and conservation.

In the long run, it is expected that the outcome of this Ph.D. research work has fulfilled all the basic objectives of this research as well as contributed to the field of geomorphology in general and to fluvial geomorphology in particular. The research work has also demonstrated the application of geospatial technology in fluvial geomorphologic investigation.

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CHAPTER I

INTRODUCTION

1.1 Scope of study

Abandoned channels are a geomorphologic testimony of channel movement in the river valleys, (Willem H.J. Toonen, et al., 2012). They are recognized as depression in the landscape and located at the position of a formerly active channel, though typically of considerably reduced width and depth. An abandoned channel is an inactive channel, defined as a former stream channel through which water no longer flows**.**

Rivers have tendency to meander with their floodplains to balance the transport of water and sediments. As a result, both the neck and chute cut offs that occur are considered the main processes of abandoned channel formation. The neck cut off occurs when the river sediment is deposited continuously on the convex bank and sediment are eroded from the concave bend. This causes the sinuosity of the meander to increase and form a narrow neck of the land. Eventually, the neck disappears and a straight channel is formed, thus creating a cut off. When the cut off is sealed from the main channel by sediment deposition, an ox-bow lack is formed and left as abandoned channel. On the other hand, chute cut-off usually occurs when successive high-water flows develop a chute across the inside of a point bar and decreases the sinuosity of the main river channel. As a result, channel forms a bar in the river valleys and the river starts to flow as straight channel and the former channel becomes as an abandoned channel (Pierre Y. Julien et al., 2011). In this regard, it is mentioned that such channels reduce sinuosity and increase velocity gradient in flow and discharge through chute and neck leaving cut-offs which lead to the development of abandoned channels.

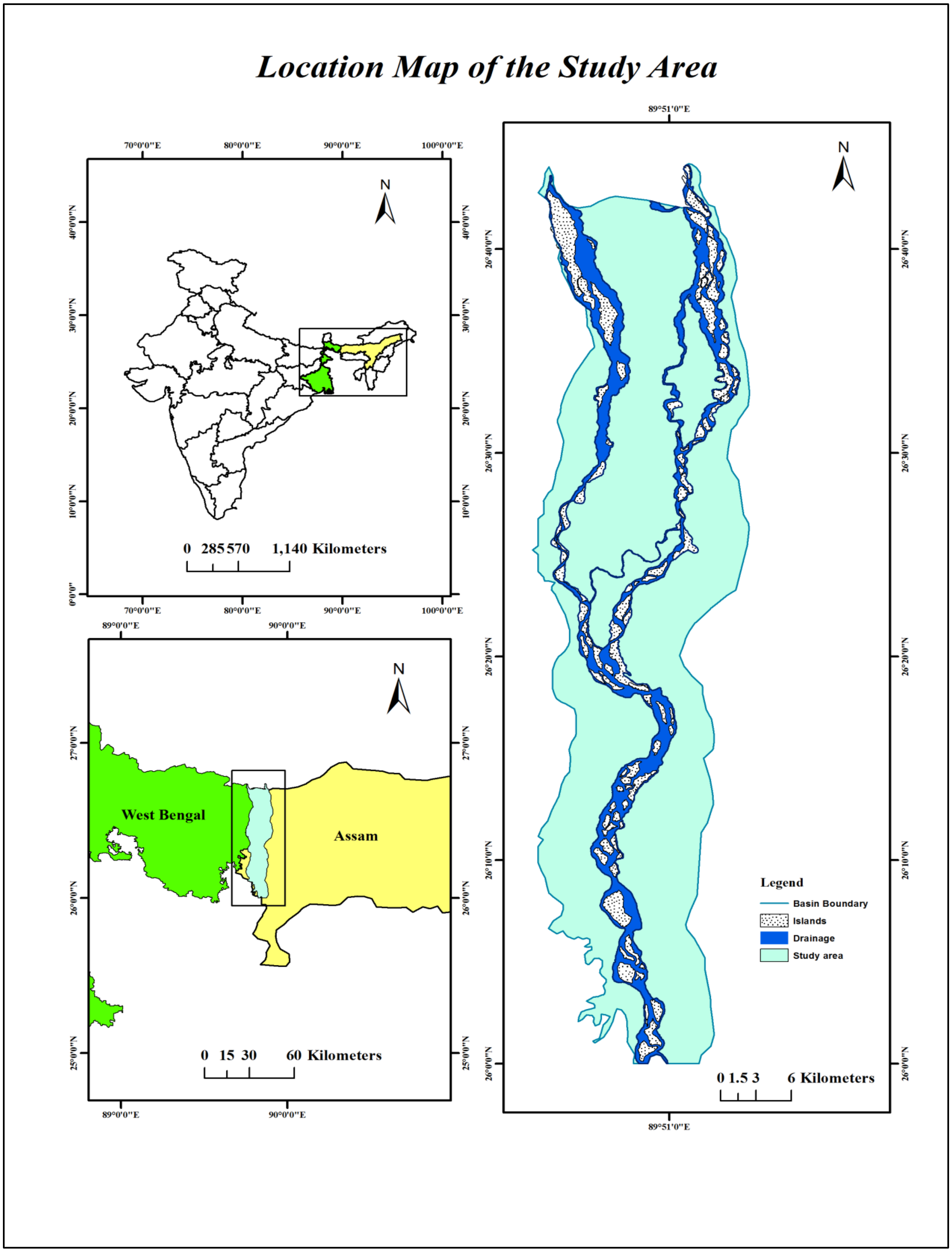
Abandoned channels are also the results from the channel shifting processes at various scale and channel bed avulsion (Willem H. J. Toonen, et al.,2012). On the one hand, channel abandonment occurs through stream capture when overland flow from the main channel accelerates and directs headword erosion of smaller channels heading on the fan surface (John Field, 2001). On the other hand, abandonment of channels occur where stream bed aggradations cause the stream to overflow due to climatic (Schumm, 1985) and human interferences. So, the occurrences of abandoned channel involve intricate mechanics of fluvial geomorphic processes which leave wide scope for investigation.

Abandoned channels are also important elements of alluvial river systems because these abandoned channels provide huge resources for habitation of some organisms having much economic value, e.g., the cultivation of fishes can be taken one of the examples. Moreover, abandoned channels areas and the substrate can be used for agricultural production of necessary crops. If managed in a scientific way, abandoned channels can be used as the source of irrigation. On the other hand, human habitation on the abandoned channels area can invite hazards to the cultural environment if they are not used in a scientific manner. Therefore, the study of abandoned channels and their socio-economic importance in the Sankosh river basin in India has been the focus of investigation.

Present researcher seeks to undertake detailed study of the fluvial processes of the abandoned channel formation with their associated problems and to make a value-added appraisal of the socio-economic importance of the channels' surrounding areas with some recommendations for sustainable management.

1.2 Study Area:

Sankosh River is one of the major rivers of North Bengal and Assam in India. This river system has covered up its mountainous parts of Bhutan, flowing through undulating plains of North Bengal and Assam and finally entered into Bangladesh to find its confluence in Brahmaputra River. In Bhutan, it is called as the Puna Tsang Chhu, Sankosh in India and Gangadhar in Bangladesh. The northern limit of the study area started at $26^0$44'24" North latitude where it creates boundary between India and Bhutan, and the Southern limit ends with the boundary shared between Bangladesh and India at $25^0$58'48" North latitude. The longitudinal extension ranges from $89^0$43'48" East to $89^0$55'12" East. The study area covers an area of 1012 sq.km (Map 1.1). The portion of this river basin falling within West Bengal and Assam is constituted of lower alluvial courses having significant dynamic fluvial characteristics for which frequent changes and abandonment of courses are manifested in the channel system which



Source: Compiled by researcher based on topographical map 78F/15, 78F/15 and US Army Map NG 45-8

Map 1.1: Location Map of the Study Area

counts for adequate academic importance. Such changes of the river system have also sufficient social importance from the socio-economic point of view.

On the basis of the Index map of Sankosh river catchment area delineated by Irrigation and Waterways Department, Government of West Bengal (www.wbiwd.gov.in, 2016) and the extent of the distribution of the tributaries and distributaries of the river Sankosh on the topographical maps (78F/14, 78F/15) of Survey of India (SOI) and US Army Map (NG 45-8) as well as field observations on selected sites over the adjacent areas, the study area has been finally delineated for the present study.

1.3 Review of the Related Literature

Abandoned channels are the important geomorphologic features in the alluvial river systems. They have existed in a complex geometry. Their processes of formation with related causes is an important part of the research work and at the same time, utilization of different resources surrounding the abandoned channels area and as well as their socio-economic importance and problem- related measures are also the keen interest in this research work.

Till today, some studies on the core area of abandoned channels along with few peripheral research works are found. But no Ph.D. work and research paper or book publication has been done so far on the study of abandoned channels and their socio-economic importance on the Sankosh river basin in West Bengal and Assam, India. Therefore, an attempt has been taken to fill up this gap. Following literature have been found which shows a few major and peripheral instances of the work taken under study:

1. C.W. Carlstone (1965), has studied "the relation of free meander geometry to stream discharge and its geomorphic implications", published in American journal of science volume -263 in 1965. This article attempts to highlight that "in the study of the ancient fluvial systems one of the basic approach is to locate and investigate abandoned channels still detectable on the surface." These provide information primarily on the late Pleistocene and Holocene changes in the environment. In this regard, it is said that based on the various morphometry and sedimentary structure of these channels various

conclusion can be made on the discharge of the forming river and the quality and quantity of its sediments.

2. Zheng Ren Xie Shunan (Qinghua university) *et al*. (1985), have studied the process of longitudinal profile adjustment of abandoned channel of the lower Yellow river in the period from 1149to 1855 which published in the Journal of Sediment Research Vol.(3) in Sept. 1985 as "The depositional profile of the abandoned channel and the main cause of continuous aggradation of the Lower Yellow River". They have mentioned two processes of longitudinal profile adjustment of abandoned channels. In the first one, the river channel adjusted its slope to meet the need of transporting the large amount of sediment coming from the Middle Yellow River and in the second stage, the whole channel profile rose continuously in order to balance the effect of the extension of the river course. Moreover, they have also explained the close relationship between the profile rising and the river courses extension which the retrogressive effect upon the river. As result, the profile of the lower yellow Rivers is quite similar to that of abandoned channel and relatively stable in the past forty years.
3. Holubova et al., (1999), in their research paper " Restoration of Slovak Morava River meanders" Phrase Project Report, Water Research Institute, Bratislava Slovakia has mentioned numerous restoration projects to connect the upstream and downstream ends of abandoned channels to the main flow to re-established connectivity". In this regard, the morpho-dynamical behaviour of the entrance and exit of the abandoned channel plays an important role in the success of such reconnection measures.
4. John Field., (2001), has studied the "channel avulsion on alluvial fans in southern Arizona"; published in American journal of 'Geomorphology' volume no-37, September 4, 2000. He stated that "An uninterrupted sequence of sediment-charged small flows, however, will eventually begin to back-fill the wide channels as vegetation growth stabilizes the bank. The stabilized and back-filled channels are now prone to abandonment during large floods because the decrease in the channel's capacity leads to the generation of overland flow beyond the margins of the shallower channels.

In this regard, it is found that the action of the small aggrading floods is critical in the avulsion process since the greatest amount of overland flow is generated where bank heights are low. As a result, both small and large floods are effective agents of landscape charge on the fans.

5. J.Steiger , A.M Gurnell and G.E. Petts (2001) have studied " Sediment deposition along the channel margins of a reach of the middle river Severn" published in the journal "Regulated Rivers: Research and Management", volume-17. Authors stated that "In channel deposition not only causes shallowing, but importantly also narrowing of the abandoning channel. This is caused by sedimentation at higher rates at the boundaries of the abandoned channel, which with help of establishing vegetation converts from a lacustrine environment into a terrestrial environment at accelerated pace".

6. C. Amoros and G. Bornette (2002), has explained the "Connectivity and bio complexity in water bodies of riverine floodplains" in their book "Freshwater Biology" and explained the hydrological connectivity of the abandoned channels to the main channel flow. In this regard, it is mentioned that the hydrological connectivity of the abandoned channel usually decreases in due course of time due to fast complex sedimentation process occurring in the upstream entrance and downstream exit of the abandoned channels.

7. J.C Rowland *et al*. (2005), have explained in title "Tie channel sedimentation rates, ox-bow formation age and channel migration rate from optically stimulated Luminescence (OSL) analysis of floodplain deposits ", published in the journal "Earth surface process and Landforms" volume-30. This article attempts to highlight "Downstream plug bar growth into the abandoned channel depression can be compared with delta propagation, as some of the discharge remain directed into the abandoned channel and produces distinct fore sets in the plug bar body". As mentioned above, it is found that the maturity of the plug bar greatly influences the sedimentary process in the distal part of the abandoned channel, as well as sedimentary processes and accumulation rates of channel fill during the next stages of disconnection.

8. WANG Yuan-ying (2007), have studied the Identification and application of abandoned channel in Meander River which published in the Journal of Daqing Petroleum Institute.

They have developed the logging model micro-facies and the method for identification and area grouping of abandoned channel.

9. ZHOW Xin-mao et al.(2010) have published their research work on the Journal 'Natural Science', Journal of Xi'an Shiyou University as the title "Analysis on the types and the sedimentation mechanism of the abandoned channel in meandering river and they explained the sedimentation mechanism of the abandoned channel based on the analysis of sedimentary evaluation characteristics Yakeshi segment of Hailaer river".

10. Willem H.J Toonen *et al*. (2012), published an article as the title "Sedimentary architecture of abandoned channel fills" in the journal "Earth surface processes and Landforms" volume-37, on 27 January in 2012. The author stated that "an abandoning channel may regain discharge over the courses of next flooding events and develop a new semi-stable channel bifurcation, this occurs often in low-angle split with a limited difference in gradient advantages and relative long period of abandoning, usually found in avulsion and chute cut-off low sinuous river". In this regard, it is mentioned that cut-off did lead to full abandonment of a meander channel.

11. John D. Horn, Robert M. Joeckel And Christopher R.Fielding (2012), have published their research paper as the title "Progressive abandonment and plan form changes of the central Platte River in Nebraska, Central U.S.A over historical timeframes" in the Journal entitled Geomorphology, Vol.139-140 and they explained that the Central Platte River was stabilized and abandoned during the period 1858-2006 due to the process of channel filling. They also mentioned that on the decadal scale, the channel morphology of the river system has been significantly affected by creation of dams, irrigation system by land use changes since 1900.

1.4 Hypothesis

1. Abandoned channels occur where stream bed aggradations cause the stream to overflow with rain storms.
2. Channel abandonment has positive relation with instability threshold of bank erosion.

3. Management of abandoned channels are supposed to be more useful to socio-economic development as well as risk reduction for human habitation and utilization of lands of the surrounding channel areas.

1.5 Objectives:

The present study has been conducted with the following objectives:

1. To identify the different types of abandoned channels resulted from various fluvial processes associated with them.
2. To study the occurrences of sedimentary features associated with the abandoned channel fills.
3. To identify the problems of human practices surrounding the abandoned channel areas.
4. To manage the problems and bring out the socio-economic importance of abandoned channel areas.

1.6 Materials and Method:

The present work is divided into three successive parts:

A. **Pre-field work**
B. **Field work**
C. **Post field work**

A. **Pre- field work:**
    1. Reviewed available literature from different libraries and offices regarding the abandoned channel formation and re-constructional planning of the study area.
    2. Topographical maps from Survey of India (SOI) on 1:50000 scale – 78 F/14, 78F/15, 78F/16 of the year 1980-81 and on 1:25440 scale – G 45-L of the year 1927-30 and US Army Map No-NG 45-8 of the scale 1:250000 of the year 1930-33 have been used for identifying abandoned channel, preparing base map of the entire study area.
    3. Historical data of rainfall from different farmhouse namely Kumargram farmhouse of Alipuduar district and Barokodali farmhouse of Coochbehar District, 2016 and sediment discharge and water discharge data had been collected from CWC offices

from Barobisha and Jalpaiguri to analyse rainfall variability and annual discharge of water and sediment.

4. The satellite images had been collected from NRSC to find out various abandoned channels in the study area and their processes of abandoning and formation along the Sankosh river over the time and space.
5. Geological data of the study area had been collected from the Geological Survey of India (GSI) to interpret the geological formation of the study area.
6. Geomorphological information's were collected from Bhuvan Geomorphological Map of West Bengal, (2005-2006).
7. Collection of others secondary data from the Department of Irrigation and Waterways, Agricultural offices and B.L.R.O offices of Coochbehar and Jalpaiguri districts of West Bengal has been included to interpret various socio-cultural aspects of the study area.

B. Field Work:

Primary data were generated by-

1. The field survey with various instruments has been conducted to generate primary data on river bank erosion, cross profile measurement, bank and bed materials, flow velocity, measurement of the area of abandoned channels etc. at various reaches of the study area.
2. Identification and mechanism of abandoned channels formation of the river Sankosh in the study area has been identified and mapped by using remote sensing data and topographical maps and then verified through field checks by collecting fluvial evidences. In this regard various satellite images of the RESOURSE SAT-1, LISS III (2016); LAND SAT-7, ETM(2017-18); LAND SAT-8, OLI-TIRS(2017-18); NBSS and LUP(2016); USGS Aster DEM (2017) have been used for preparation of maps and interpretation of data. On the other hand, land use and land cover maps of various abandoned channels had been prepared by using LISS II, BHUVAN (2018).

Table No. 1.1: List of Satellite Data used in the Present Study

Sl.No.	Satellite	Sensor	Year
1.	ASTER	Aster DEM	2017
2.	LAND SAT-7	ETM	2017
3.	LAND SAT-8	OLI-TIRS	2018
4.	RESOURCE SAT-1	LISS III	2016, 2018

3. Household survey by using questionnaire had been successfully conducted to collect various primary data relating to socio- economic conditions of the people inhabited surroundings the abandoned channels.
4. Mapping of the resulted landforms associated with the abandoned channels has been carried out by using Satellite images and Google Earth maps and verified through field checks and with the help of ground control points by using Global Positioning System (GPS).
5. Terrestrial photographs were taken during field survey to support and analyze the findings.

C. Post field work:

Geo-referencing of the topographical maps to integrate or incorporated a whole or partial with the satellite images have been made and at the same time enhancement and the digital processing of satellite images for various applications have also been done with the help of different licensed and open source of GIS packages, global positioning system(GPS) has been used for locational studies as a technique of data input and enhancement method of data interpretation wherever applicable and needful. However, some important statistical techniques have also been applied for the interpretation of primary as well as secondary data collected from the field and other sources.

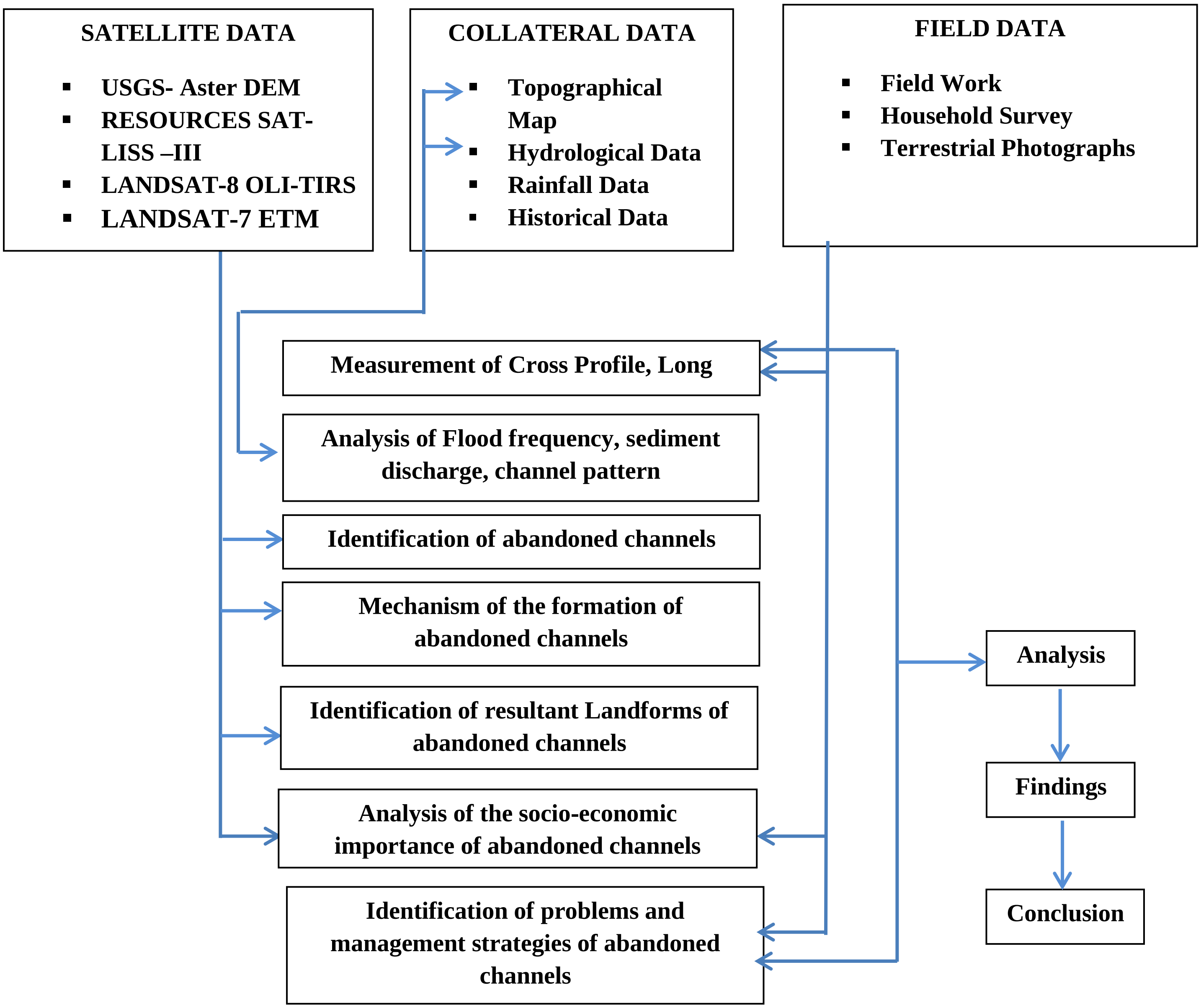


Figure 1.1 Flow Chart of the Methodology Adopted for the Present Study

To explain the methodology adopted for the present study, a flow chart has been prepared and shown in the (Figure 1.1) which provides an overview of the steps followed to complete this research work. These steps are-

1. Measurement of cross profile during field survey.

2. Analysis of water discharge, sediment discharge, channel patterns of the river Sankosh at various gauge station.
3. Identification of various abandoned channels after delineating of the study area.
4. Mechanism of the formation of abandoned channels in the study area.
5. Identification of resulted landforms associated with the abandoned channels.
6. Socio-economic importance selected abandoned channels.
7. Identification of problems and management strategies of the abandoned channels.
8. Major findings and conclusions.

1.7 Overview of Chapterisation:

The entire research work is divided into Seven chapters to fulfil all objectives of the present work. The **chapter I** includes a brief introduction of the research work with hypothesis, objectives and methodology along with the review of literatures. Physical and cultural set up of the study area has been discussed in the **chapter II** whereas the **chapter III** contains a brief morphometric analysis of the Sankosh River in the study area and also discussed about the identification of the abandoned channels. A thorough discussion about the mechanism of the formation of the abandoned channels has been analysed with the help of Remote sensing and GIS platform in **chapter IV**. In **chapter V**, various resulted landforms of the abandoned channels have been identified and explained with maps. Socio-economic importance of the abandoned channel has been investigated through field survey with the help of questionnaire in **chapter VI** and finally in **chapter VII**, various methods has been suggested for sustainable management of abandoned channels in the study area and enlisted major findings of the research work.

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CHAPTER II

PHYSICAL AND CULTURAL SETUP OF THE STUDY AREA

2.1. The Physical setup of the study area

2.1.1 Introduction:

The physical set up of any River basin plays a major role in research investigation. All the elements of physical set up like geology, geomorphology, climate, hydrology, sedimentology etc. determine the magnitude of gradational (degradation and aggradation) processes of fluvial environment. Although the Sankosh River basin is located in the region where tectonics activities are very high but the study area is situated in North Bengal plain. A detailed study of all the elements of physical set up give a better understanding of the geo-environment of the study area which has been analyzed in following headings. In this context it is included as Physical setup of our study area is concerned with natural properties of the earth's surface such as geology, geomorphology, relief, slope, drainage network, climate, drainage system, soil and natural vegetation.

2.1.2 Physical Background:

The Sankosh river basin is originated from the part of the Himalaya Mountain which is thought to be significantly unstable due to the collision of Angaraland in the north and Gondwanaland in the south (Gansser, 1983). The Himalayan and surrounding regions are a result of tectonic events and its topography, geologic structure, soil structure and texture influenced by it. In this context, it may be mentioned that along the strike, the Himalayan Orogeny may be classified into three major divisions. These are:

I. Western Himalaya (66° 00'E to 81° 00'E)
II. Central Himalaya (81° 00'E to 89° 00'E)
III. Eastern Himalaya (89° 00'E to 98° 00'E)

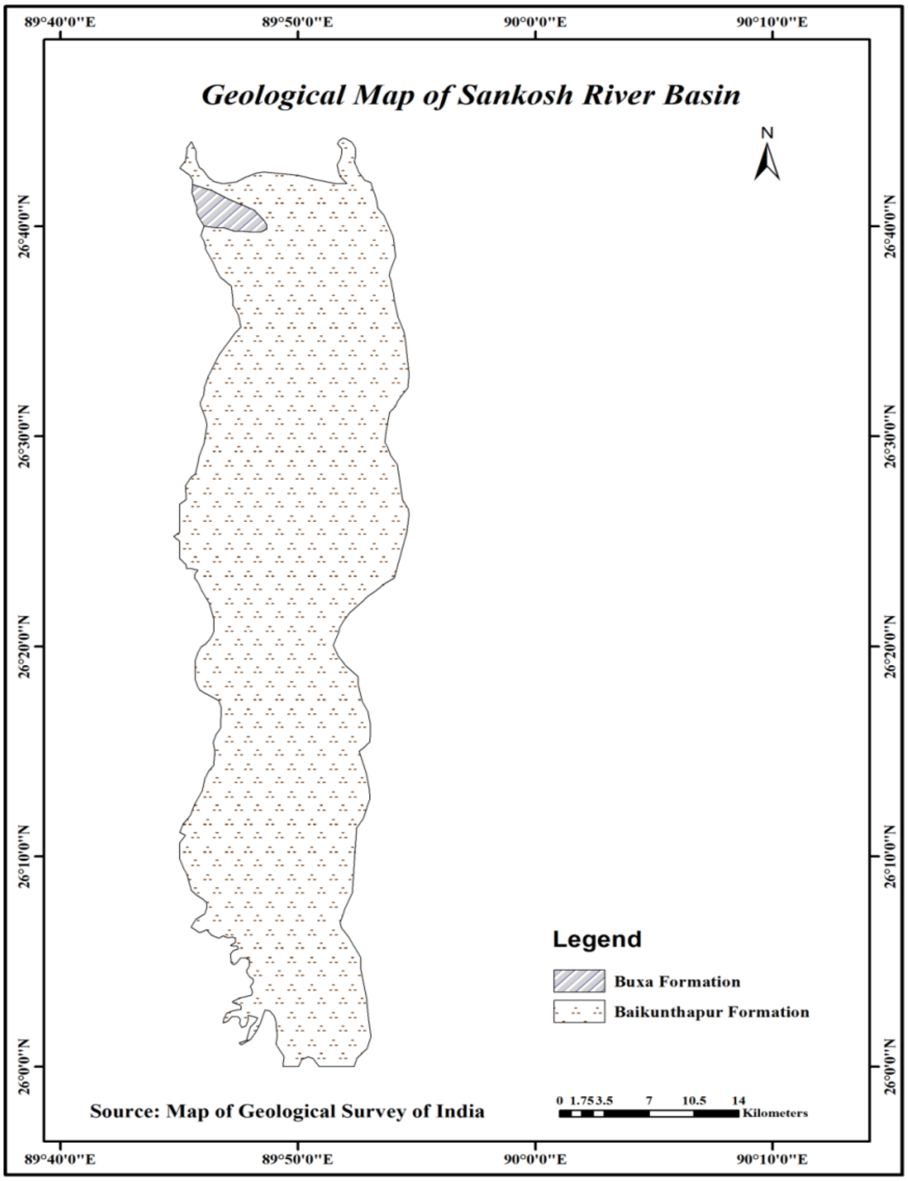
Gansser (1983) has identified five zones for the Himalaya Mountain from South to North. These main zones from south to North are (i) Sub-Himalaya with a belt of molasses like elastic deposit, the Siwaliks, which border the Foreland basins. (ii) The Lower Himalaya with huge sedimentary sections of mostly late Pre-Cambrian age covered by Gondwana type rocks and by crystalline thrust sheets exposing a reversed metamorphism. (iii) The High Himalaya consisting of thick crystalline thrust sheets which form the base of the Tethyan sediments to the north, (iv) The Tibetan Himalaya or Tethys Himalaya with an independent tectonic on top of the crystalline sheets and involving a conformable stratigraphical column from late Pre-cambrian to Eocene; and lastly, (v) The Indus-Tsangpo zone, a major suture zone displaying orogeny sediments, ophiolites and ophioliticmelange formations with exotic block sand large ultramafic thrust sheets. Out of these five zones, only the sub-Himalayan belt is found in the Northern part of the study area whereas other zones are found in the upper course of Sankosh River which is located in Bhutan.

2.1.3 Geology:

Geological structure of an area is generally studied by the morpho and litho-stratigraphy. Thornbury (2004), in his Second fundamental concept has mentioned that “geologic structure is a dominant control factor in the evolution of landforms and is reflected in them.” Accepting Davisian concept of landform development he emphasised on structure, process and time as controlling factor. According to the accounts of most of the geologists, the piedmont region of Northern part of West Bengal and western part of Assam, experienced subsidence and uplift due to thrust and faulting. Tectonic activities are frequent in this area along the faults to affects the pediment and flood plain deposits. On the basis of Geological map of Cooch Behar and Alipurduar District of West Bengal and Kokrajhar and Dhubri District of Assam, the study area is covered with different geological formations. (Map 2.1) In the upper part, only a small portion of the study area is covered by Buxa formation and whereas maximum part of the study area has been covered by Baikanthapur formation.

2.1.4 Geomorphology:

Geomorphologic history of study area has been featured by successive catastrophic events of accelerated deposition during the post-Pleistocene period. Uplift of the Himalayas during the Quaternary time led to the creation of faults parallel and transverse to the Himalayas and Sub-Himalayan tract. Geomorphologically, (Map 2.2) the study area has been classified into two geomorphic units. (Bhuvan Geomorphological Map of West Bengal, 2005-2006). These are - i) Piedmont Zone and ii) Alluvial Zone.



Map 2.1: Geological Map of Sankosh River Basin

a) Piedmont zone:

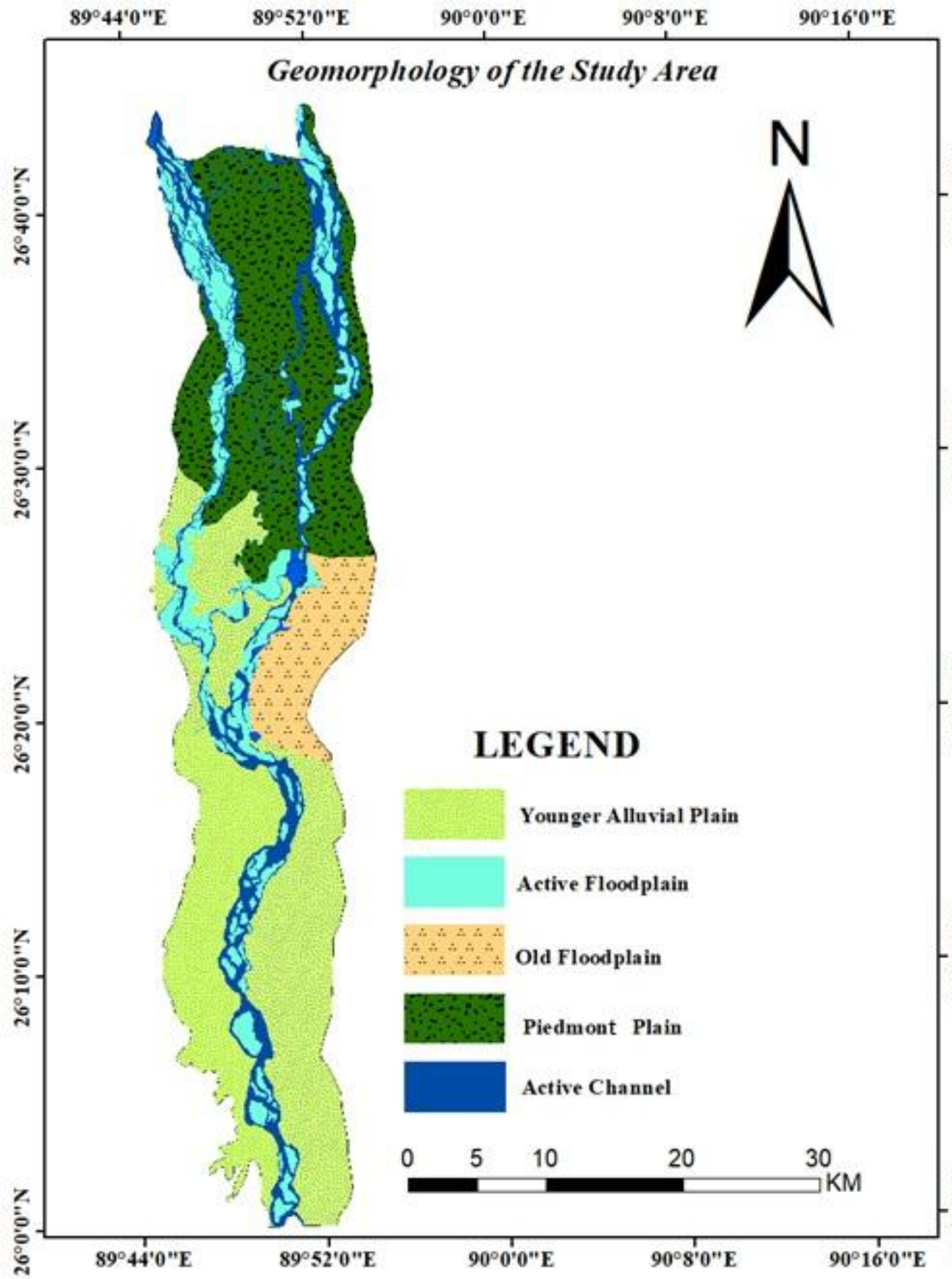
The piedmont zone is only found in the northern most part of the study area under the Sub-Himalayan foot hill zones. The average elevation of this zone is 250m from the mean sea level. This zone receives high rainfall throughout the year and covered by forests and tea plantation. This piedmont zone has arranged as a low-lying relief which is generally controlled by fluvial impact.

b) Alluvial zone:

The alluvial zone covers most of the study area. This zone is fluvial originated and characterised by low lying homogeneous flat surface. On the basis of Bhuvan Geomorphological map of West Bengal (2005-2006), this alluvial zone is divided into following geomorphic units:

a) Younger alluvial plain
b) Older flood plain
c) Active flood plain

From the above-mentioned geomorphic units, fluvial origin younger alluvial plain is found in the lower part of the study area. Active flood plain has been developed along the active channel of River Sankosh but old flood plain stretches over the left bank of the River Sankosh at mid-stream whereas river shifting scenario is very common. It is mentioned that River Sankosh and River Raidak-II is confluences very near to the old flood plain. Northern part of study area is almost covered by piedmont plain of fluvial origin but spatio-temporal changes of geomorphic landform are very common phenomena in the alluvial channel. Moreover, among all of these identified geomorphic features of lower basin of River Sankosh, younger alluvial plain is mostly found which suitable to agronomic and allied activity.



Source: Resourcesat-1 LISS III

Map 2.2: Geomorphology of the Study Area

2.1.4.1 Relief of the study area: The relief (Map 2.3) is the difference in elevation between given two points. The maximum basin relief is the difference in elevation between the confluence at the river Brahmaputra and upper part of the study area. The study area is basically under the plain region. The northern part of the study area is a part of piedmont plain is located at the foothill of the Himalaya and the southern part of the study area is under the monotonous plain region. Relief ratio strongly influences the sediment loss since the force exerted on the surface of the study area and it is directly related to relative humidity in one hand and rainfall and vegetation cover of the study area also affect in sediment loss on the other hand. On the basis of elevation, the study area has been classified into various relief zones. These are:

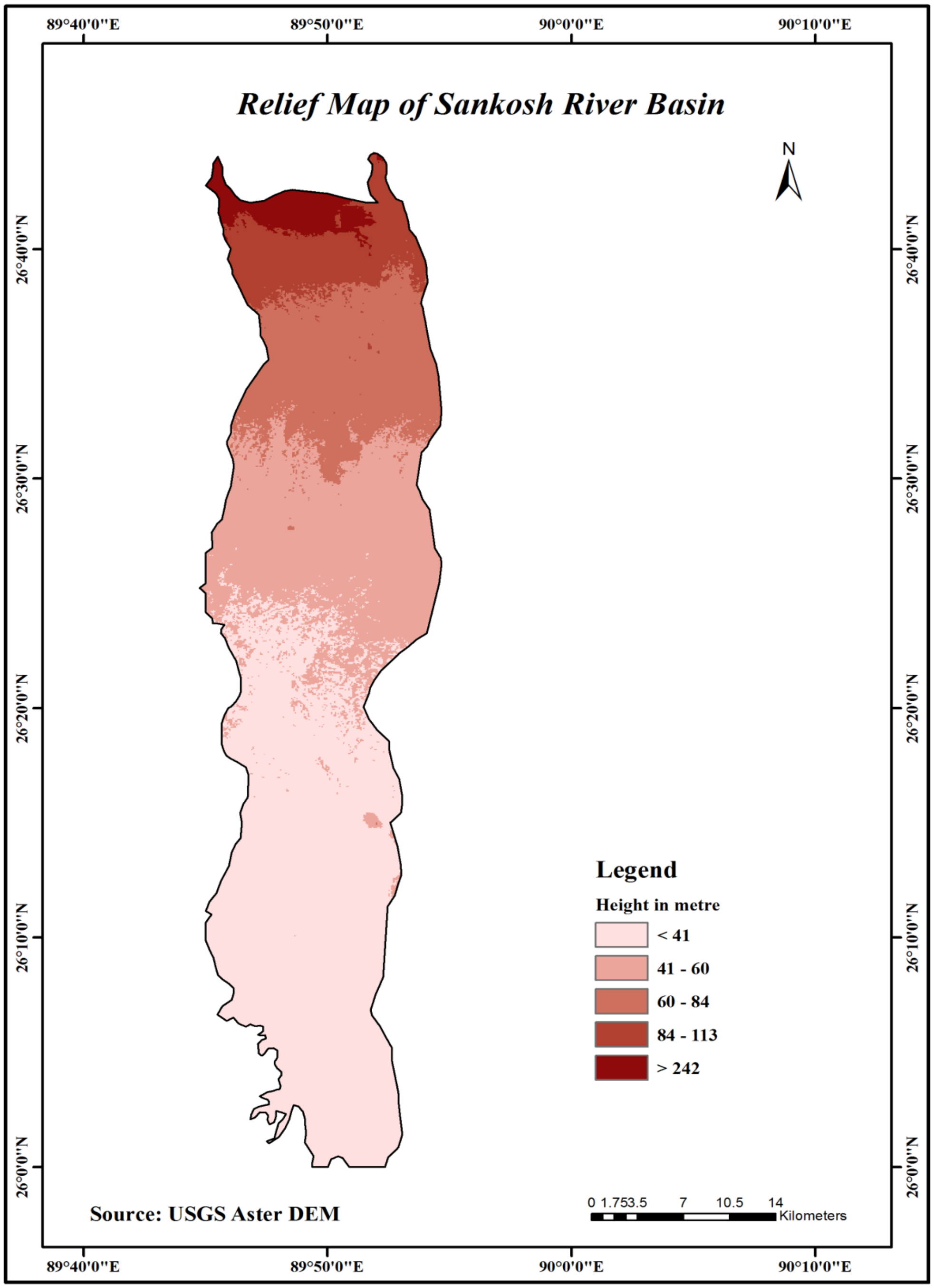
a) Low relief zone (below 50m): Lower part of the study area; along the Downstream.
b) Medium relief zone (50m to 100m): Middle part of the study area; along the Midstream.
c) High relief zone (above 100m): Upper part of the area; along the upstream.

2.1.4.2 Physiography: Physiographically, the study area can be divided into two sections. These are:

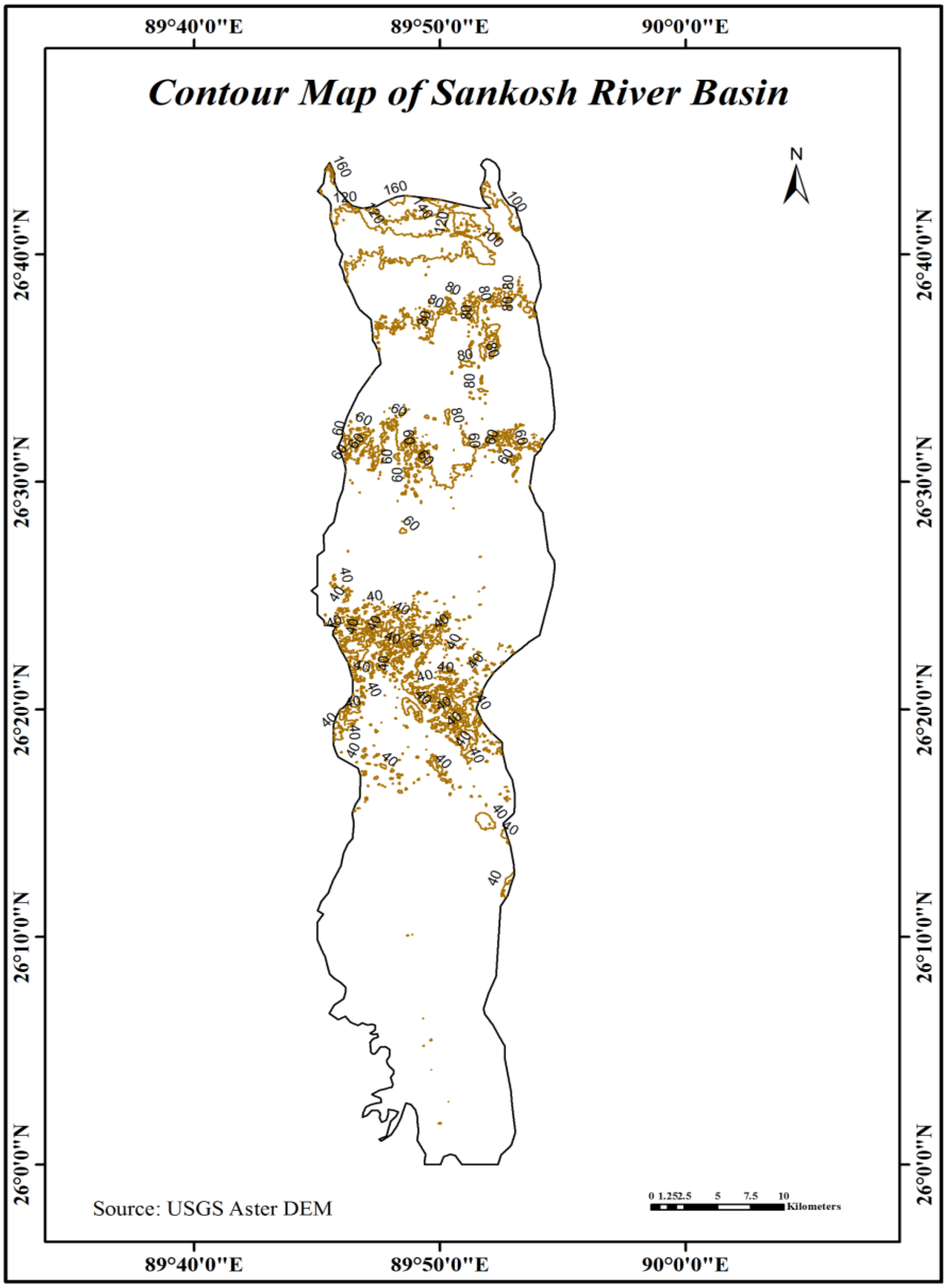
a) Piedmont region: The northern most part of the study area is under the piedmont region comprising Kumargram C.D. blocks of Alipurduar district of West Bengal and Gosaigaon C.D. block of Kokrajhar district of Assam.

b) Plain region: Most of the part of the study area is under the plain region. This plain region may be varied from place to place on the basis of their formation. Younger flood plain is found in the lower part of the study area comprising most of the land along the River Sankosh.

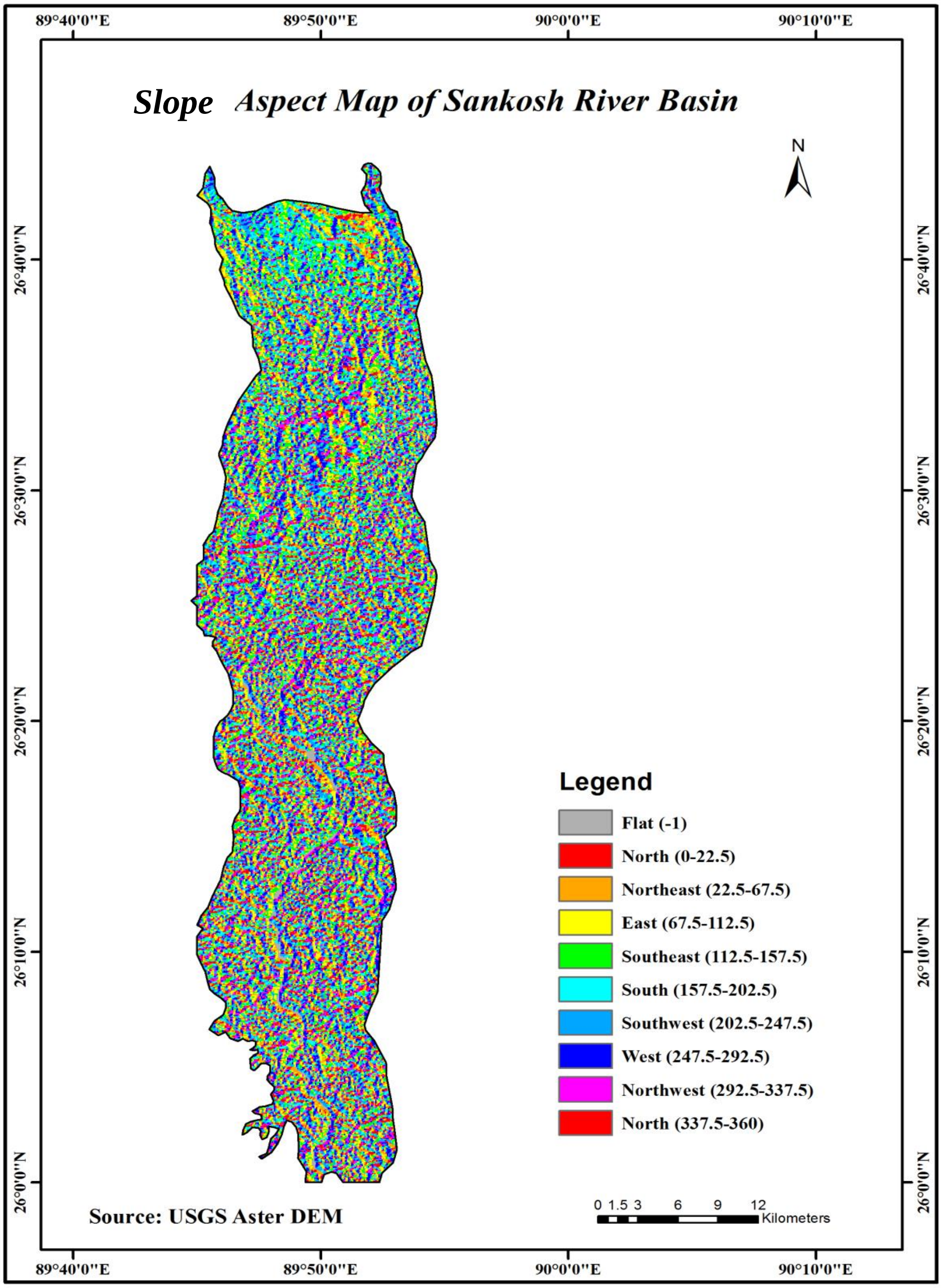
2.1.4.3 Slope and Slope aspects: Slope (Map 2.6) is one of the most important physical aspects of basin geomorphology and it is the **result** of both endogenic and exogenic forces. Slope may vary from place to place due to the influence of different factors like structure, process, geology, climate, relief etc. and form different degrees of slope. In the study area, high slope range, from 5% to 15% is found in foothill zones in the north of the study area and beyond this most of the study area is under the very low slope region. The average slope of the study area is about 9° and the general slope direction is from north to south. It may be mentioned that some small upland areas occur in parts of Kokrajhar district where slope is high with the value of 18.01° while at the confluence (near River Brahmaputra) the slope is very low e.g. 0.56°.



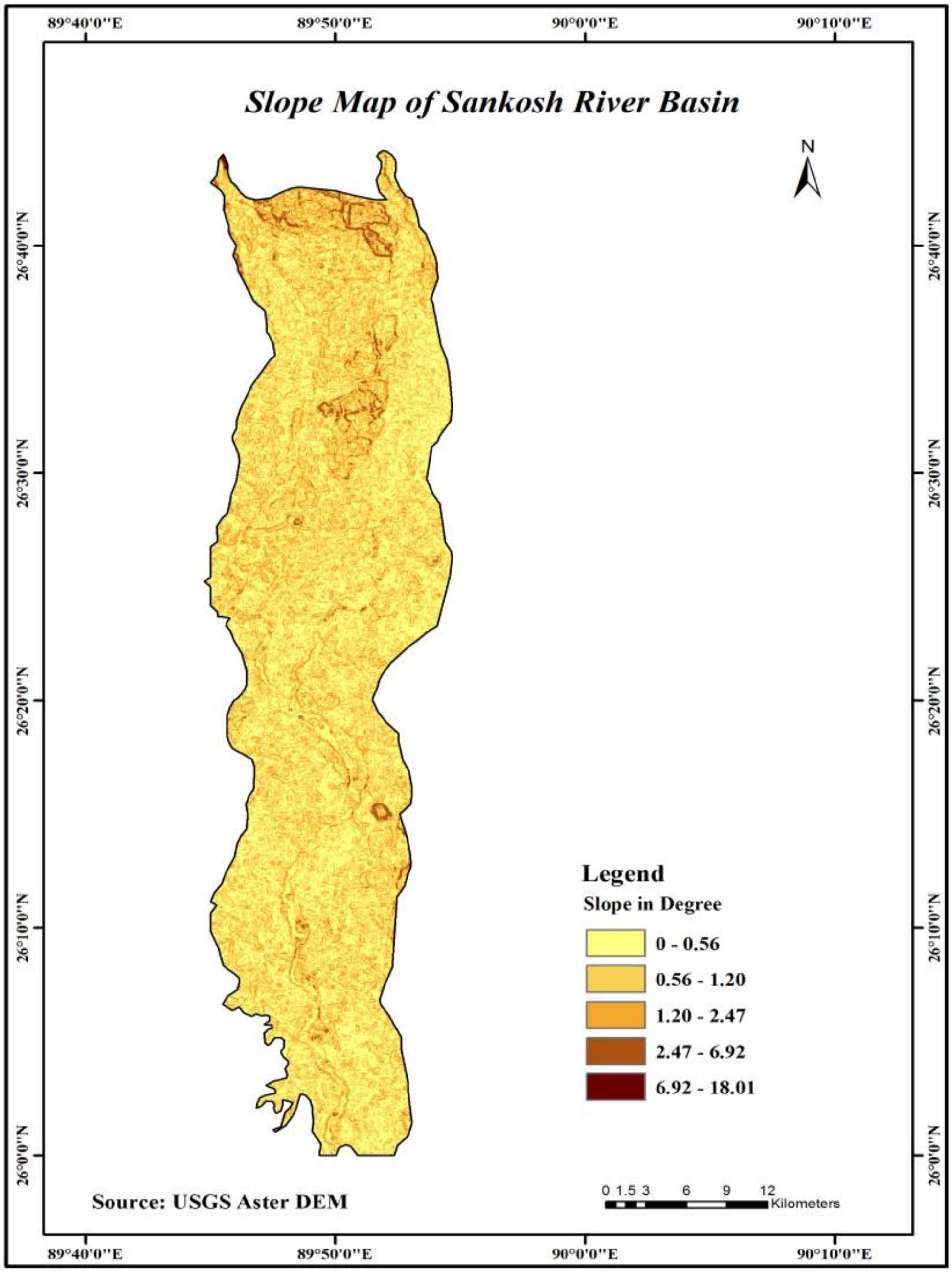
Map 2.3: Relief Map of Sankosh River Basin



Map 2.4: Contour Map of Sankosh River Basin



Map 2.5: Slope aspect Map of Sankosh River Basin



Map 2.6: Slope Map of Sankosh River Basin

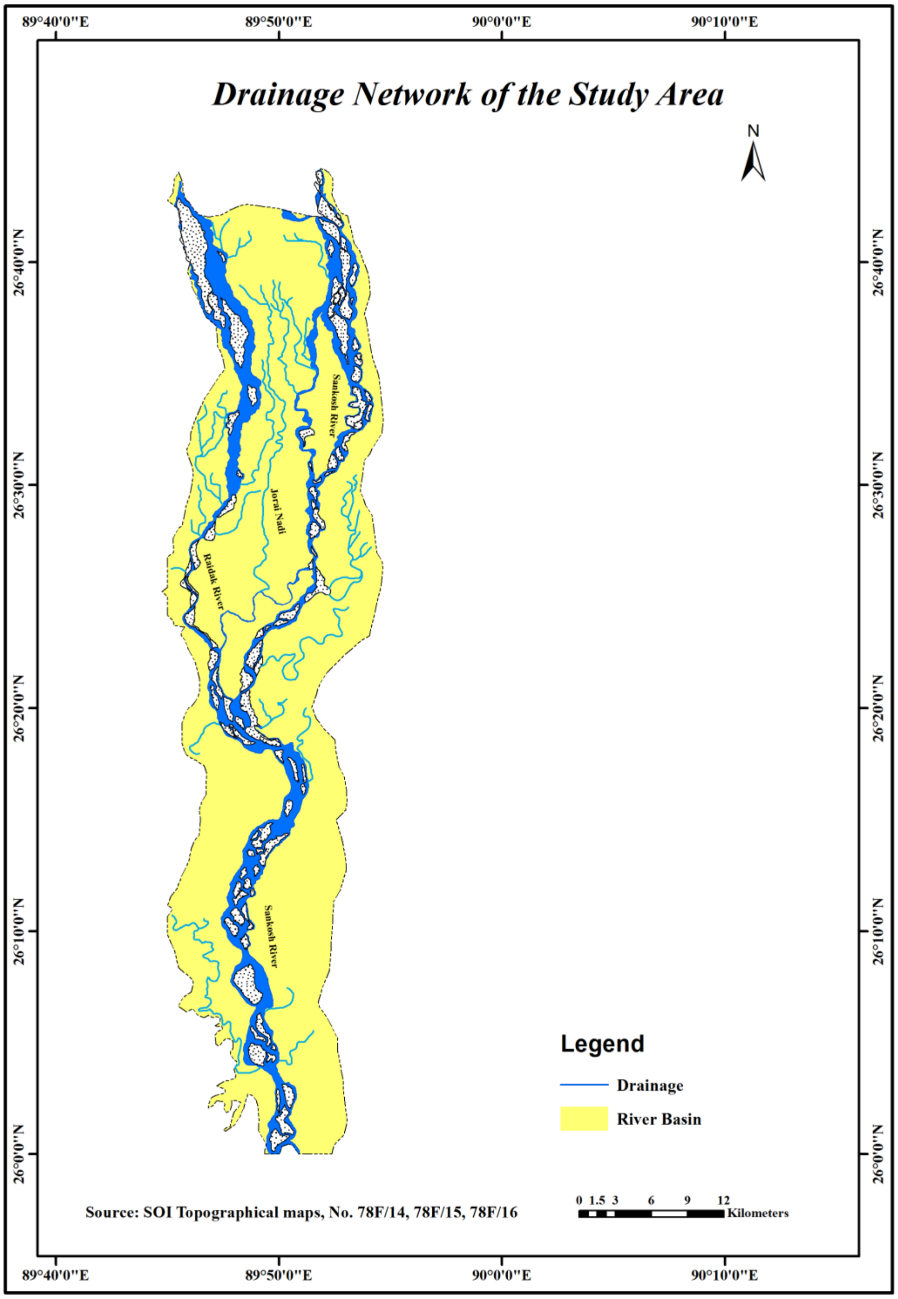
2.1.4.4 Drainage Network:

The River Sankosh (Mo-Chu) originates from the Bhutan Himalaya and marks the border between West Bengal and Assam. The catchment area covers an area of 10746 sq. km. out of which only 1012 sq. km lies in sub-Himalayan part of West Bengal and Assam (fig:). The River Sankosh is characterized by its highly notorious and unpredictable nature, heavy inundation and sedimentation during flood and problem of lateral bank erosion, bank line shifting, and channel avulsion, cut-off (chute cut-off and neck cut-off), multiple development of abandoned channels and paleochannels etc.

The River Sankosh which in its upper course is called as the Puna Tsang Chhu and its lower course named as the Gangadhar, comes from the territories of independent Bhutan and after a course of 7 miles through the Duars, the first five of which form the boundary between the western and eastern duars and the lower two lie through the Guma duars, enters the district from the east in the south-east of taluka Garbhanga, just where a small stream of the name *Takulla* falls into it from the north. From the mouth of the Takulla the river flows south-east, and then south, along the north-west of taluk Falimari, when it receives on its right bank the river *Jorai* in the south of Garbhanga and the *Raidak* –II in the south of Jaldhoya (Census of India, 1961).

Drainage network (Map 2.7) of the studied basin includes some tributaries and distributaries coming from the northern Sub- Himalayan zone. Of the tributaries of the Gadadhar, the *Raidak*-II is by far the most important. It is the easternmost of the two rivers of the same name and is formed within the Weastern duars by the union of two rivers, the Ghoramara and the *Kulkuli*, both of which came from southern slope of Bhutan hills. The next tributary is the *Jorai* and it is a small channel rising in the Bhaluka forest (Duar), the upper portion of which is called the *Gholani*. Only a short time ago the river instead of flowing east through Jaldhoya, poured south by the east of Mahishkhuchi, and passing the Bunder and Police out-post in that taluk, fell into the Gadadhar in the south-west of Pherusabari (Census of India, 1961).

The study area bounds in marshes, beels and small pools of stagnant water. These are remnants of the old beds of river which have not wholly dried up, which in many places faithfully retain the names of chhara, dara, beel, doba or kura (Census of India, 1961). Of the numerous beels and chhara the following are the abandoned channel of Sankosh River: *Nayachhara, Purbachhara, Khalisamari beel, Kamandanga beel, Tamanadi* etc.



Map 2.7: Drainage Network of the Study Area

2.1.5 Climate:

The study area is fully lying in the tropical region and influenced by tropical monsoon climate. The principal characteristics of this climate are a cold and foggy winter, a moderately cool spring and a fairly temperate but very humid summer. January is the coldest month and mean temperature is about 16° C and on the other hand maximum temperature is found in the month of June. There is a marked difference in temperature and rainfall (Figure 2.1) between northern and southern part of the study area due to seasonal variation and as well as the altitudinal variation. An analysis of the temperature and rainfall data of the study area helps to bring out the variation of climate and its impact upon the basin area.

2.1.5.1 Seasonal Variation:

The study area has been enjoying four dominant seasons in the whole year. These are as follows:

2.1.9.1.1 Summer season (May to September)
2.1.9.1.2 Autumn Season (October to November)
2.1.9.1.3 Winter Season (December to February)
2.1.9.1.4 Spring Season (March to April)

2.1.5.1.1 Summer season:

This is the largest season in the study area. In this season, Temperature goes up daily with humidity. The average temperature in this season is about 28^{0} C. The maximum temperature is recorded in the month of June and humidity varies from 87% to 58%. Northern part of the study area experiences high humidity due to excessive cloudiness. In this season, maximum rainfall occurs by South-West monsoon wind. The study area received highest rainfall in the months of June to July. Rainfall variation is also found from northern part to southern part of the study area (figure 2.1), water discharge becomes high in the basin area and different erosional activities go up.

2.1.5.1.2 Autumn Season:

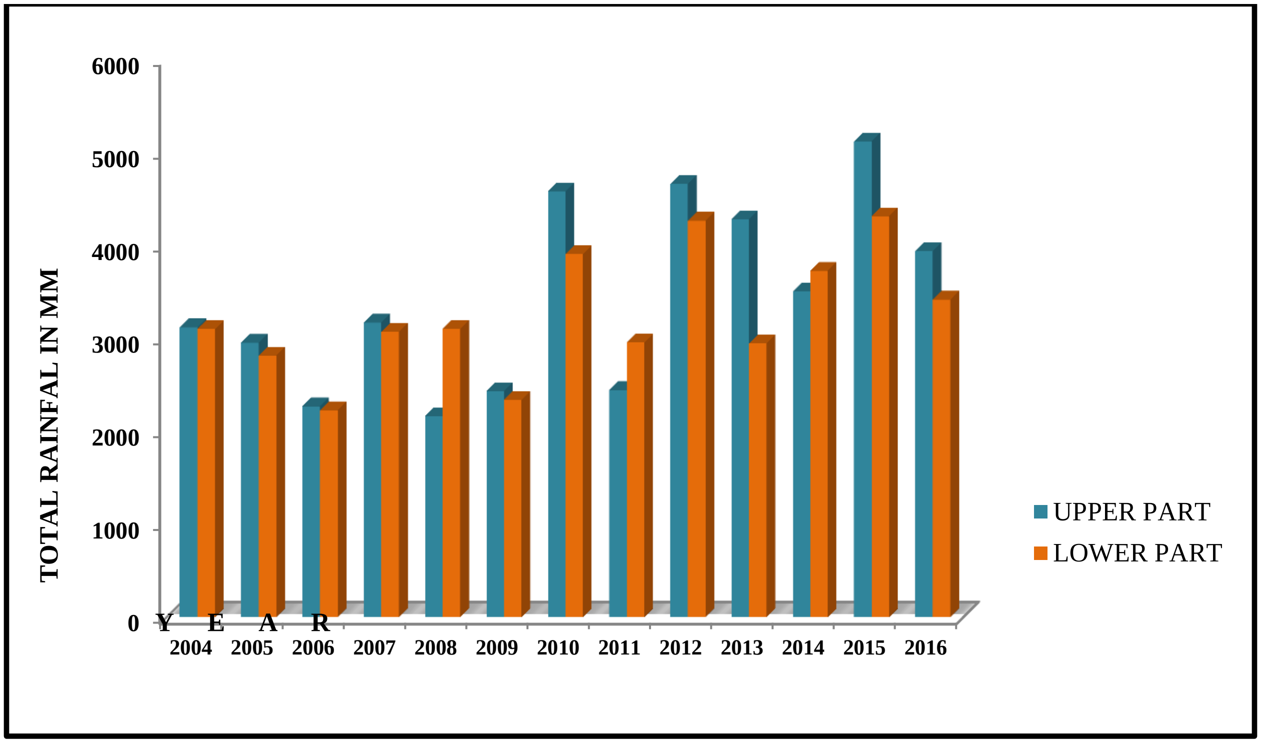
Temperature and rainfall both decrease in this season. Sometime, cyclonic rainfall occurs in this season. In the beginning of this season high temperature is found and it gradually falls down.

2.1.5.1.3 Winter Season:

The study area enjoys cold weather and the minimum temperature is recorded in this season. Most of the time of this season becomes foggy and dry. The lowest temperature is about 10^0 C found in the month of January. Rainfall rarely occurs in this season.

2.1.5.1.4 Spring Season:

Spring is the most pleasant season among the all seasons. Temperature gradually rises, but the weather remains dry. Very little rainfall occurs in this season.



Source: Kumargram and Barokodali Farmhouse of Alipurduar and Tufanganj respectively, 2016

Figure 2.1: Comparison of Annual Rainfall Distribution in the Study Area

2.1.6 Soils of the Study area:

Soils of the study area are alluvial in nature. Most parts of the study area are covered with fertile alluvial soil. But many tracts of the study area especially where the bank erosion is dominant, sandy soil is found. The soil of the study area is alluvial of recent formation and has an admixture of sand which is known as sandy loam. The soil properties like sand silt and clay varies from place to place of the study area. The river causes flood in every year and its effects on soil formation in the study area and the soil properties are frequently changed due to the deposition of sediment. Anthropogenic activities like mining in Bhutan, dam construction, deforestation etc. also affect the rate of soil formation in the lower course of the river basin. Soils of the study area are characterized by sandy, highly acidic, heavily leached and poor in base and plant nutrients. On the basis of NBSS and LUP soil map, the study area is divided into four different soil zones, (Map 2.8). These are as follows:

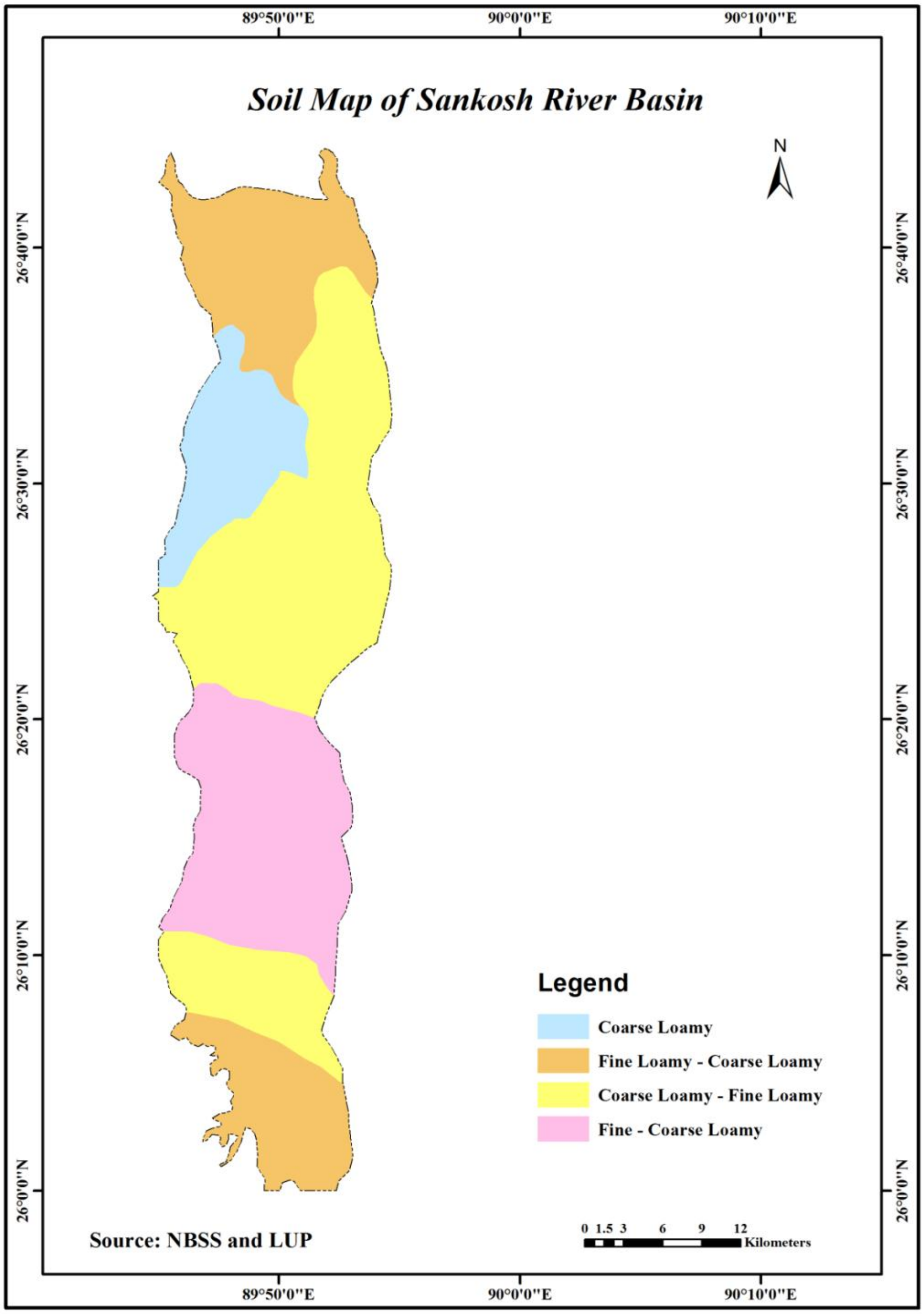
i) Fine loamy to coarse loamy
ii) Course loamy
iii) Coarse loamy to Fine loamy
iv) Fine Coarse loamy

This soil is superlative for the cultivation of paddy, jute, vegetables, maize etc. The turbulent water of different rivers carry huge amount of detritus material, which have an adverse effect on crop production as well as the hydrology of the study area. Recurrent floods have also been affecting the quality of the soil and cultivation. The colour of the soil varies from ash to black (Census, 1971).

2.1.7 Natural Vegetation:

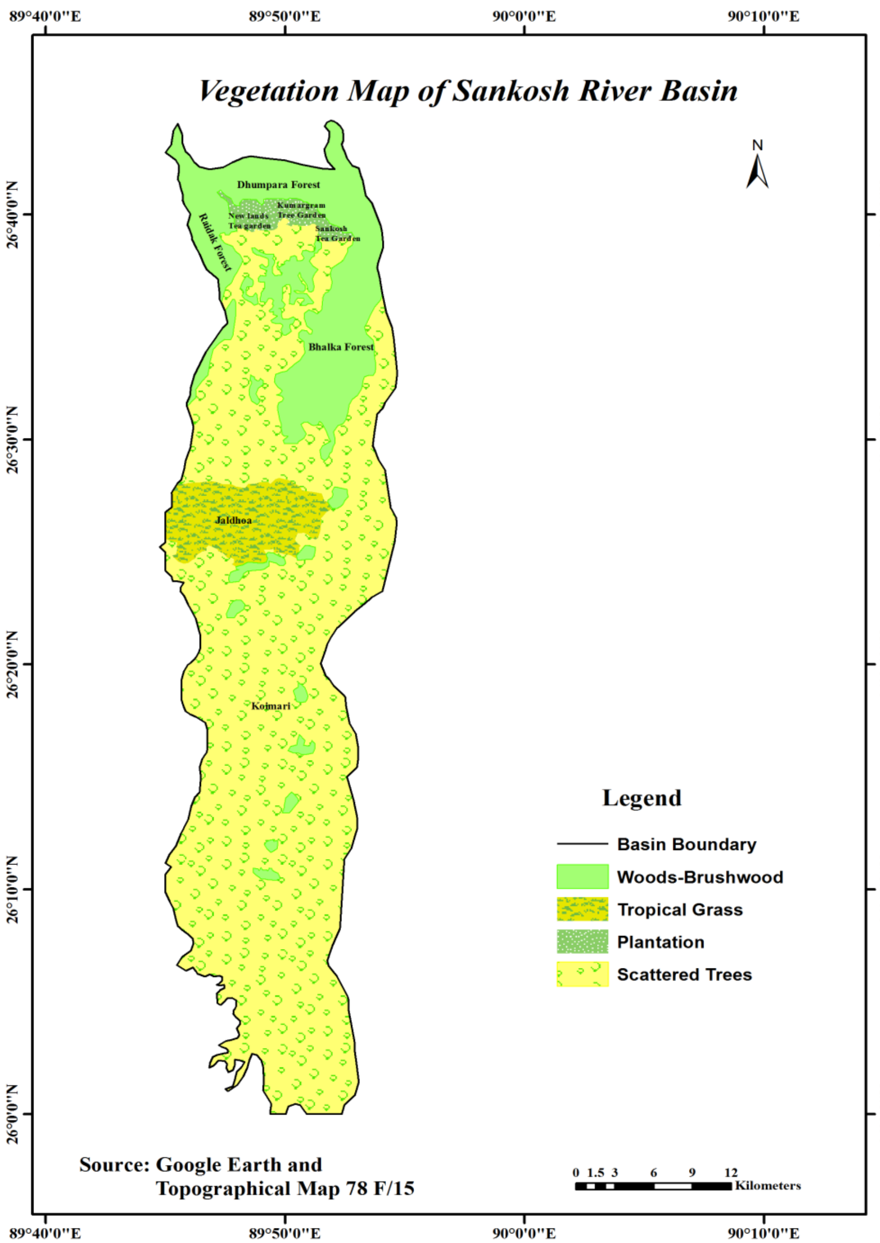
Northern part of the study area is predominantly covered by forest. It is one of the most prominent wildlife areas of the state of West Bengal and Assam. The forests of the study area can be broadly classified into four categories, namely riverine forest, plain forests, hill forests and Savannah forests. Near the streams and moist area, occur a type of evergreen forest is known as North Bengal tropical Evergreen forest. (Forest Survey of India,1999)

The study area is predominantly covered by the moist tropical forest. From the field survey it is observed that the northern part is covered by reserved forest and tea garden whereas the southern part of the study area is covered by mixed vegetation. Most notable reserved forests are woods-brushwood and tropical grass and the major predominant tea gardens are Raidak tea garden, Turturi tea garden, Kohirer tea garden, Sankosh tea garden etc. On the other hand lower and middle part of the study area is covered by open mixed jungle, scattered plants, riverine forest



etc.

Map 2.8 Soil Map of Sankosh River Basin



Map 2.9: Vegetation Map of Sankosh River Basin

2.2 Socio-Cultural set-up of the study area

2.2.1. Introduction:

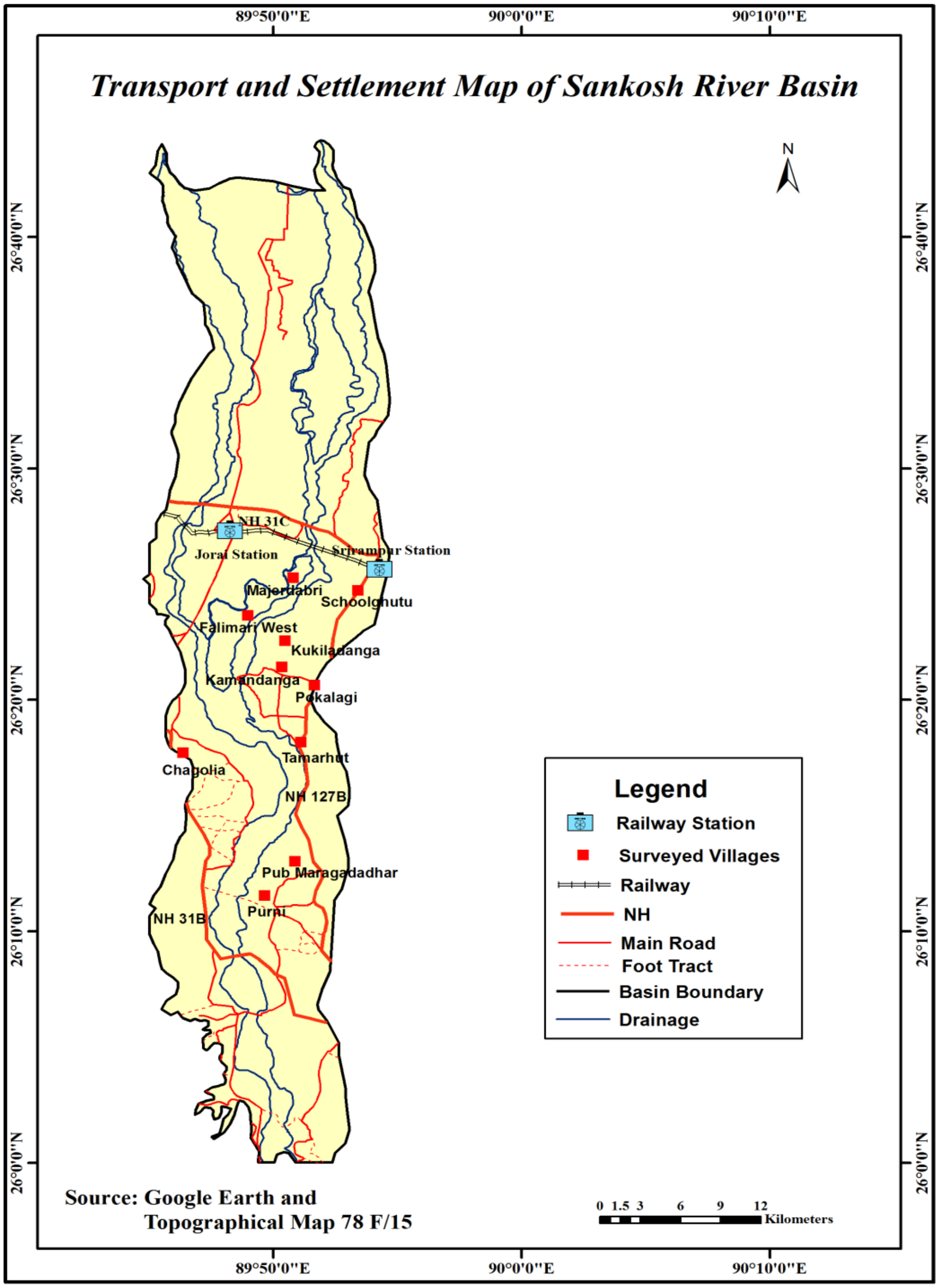
Socio-cultural set up of the study area include different components i.e. population, settlement, occupational characteristics and transport and communication etc. All these components are here after discussed in below under the following headings.

2.2.2. Population:

Population forms an important component in the whole process of socio-economic and as well as cultural development of any area. The people inhabited in the study area and along the abandoned channels of Sankosh River belongs to agrarian family and some people also in habitat in the char, called as char dwellers, face very poor economic condition in their daily life. The maximum concentration of population on the both bank of the Sankosh River belongs to Rajbanshi and Muslim community. Some other concentration of population belongs to tribal community. On the basis of caste category, Scheduled Caste population is highly distributed in the study area and then Other Backward Classes both A and B, General caste, Scheduled Tribes are distributed respectively. People of the study area carried different culture on the basis of their customs and heritage and also their livelihood.

2.2.3. Settlement:

People are settled on the both bank of the River and along the abandoned channels for the advantages of available fertile land, use of water for irrigation and other purposes, fishing facility etc. Most of the People built their houses by using the materials like tin, bamboo, dry jute stripes and some other peoples settled in pucca houses also. The settlement pattern along the abandoned channel is mostly formed linear type whereas other places of the study area compact and semi compact settlement patterns are found.



Map 2.10: Transport and Settlement Map of Sankosh River Basin

2.2.4. Transport and Communication:

Transport and communication (Map 2.10) is a pre requisite for any kind of socio-economic development. In the study area, Transport and communication is poorly developed in comparison to other places of both states. In the upper part of the study area, a National Highway (NH-31A) is passing from west to east and on the other hand, NH-31B is passing over the study area in lower reach. Some state High way and other pucca and kutcha road are also poorly distributed over the study area.

Communication system is poorly developed in the study area. Only few post offices viz. Falimari post office of Tufanganj-II block of Coochbehar District of West Bengal and Koimari post office and Tamarhat post office of Kokrajhar District of Assam etc. are dominantly distributed in the study area where as other means of communication system like telegraph and telephone line and others are poorly developed.

2.2.5. Occupational structure in the study area:

Agriculture is considered as dominant occupation of the people in the study area. Out of total population, more than 65%of population engaged in the occupations of cultivator and agricultural labourer. On the other hand, more than 29.2% of population engaged in other activities and 3% in household occupation respectively in the study area. Beyond these some other allied economic activities has also observed by the people are selling of vegetable, vendors etc.

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CHAPTER III

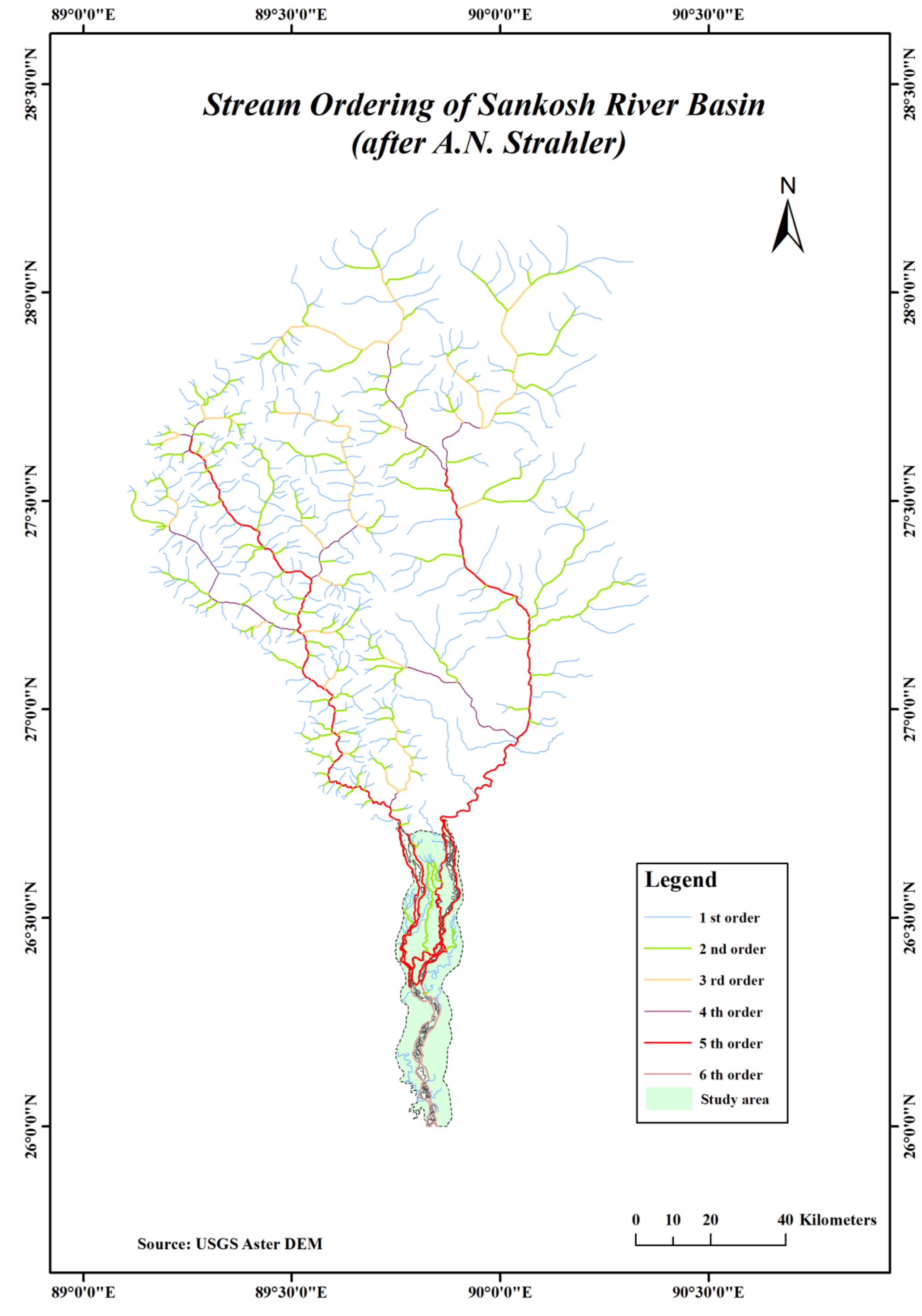
IDENTIFICATION OF ABANDONED CHANNELS

3.1 Introduction:

The Mo-Chu or Sankosh River also known as Puna Tsang Chhu in its upper reaches which located in the northern part of Bhutan. The River Sankosh rises in the great Himalayan region of Bhutan and it starts to flow towards the south, following the regional slope of Bhutan Himalaya and find its confluence at the river Brahmaputra in Bangladesh. It is mentioned that total Basin area of Sankosh River is about 9734 sq.km in Bhutan and on the other hand, the Sankosh River drains a basin about 1012 sq.km in West Bengal and Assam states of India. At Punakha, the Sankosh River is joined by a tributary named the Pho Chu and 20 km further downstream at Wangdi Phodrang by the Tang Chu. Many mountain streams join the Sankosh River on both sides. At its exit into the Duar plain, it is a deep river flowing mainly over a bed of boulders. Moreover, the portion of this river basin falling within West Bengal and Assam is constituted of lower alluvial courses having significant dynamic fluvial characteristics for which frequent changes and abandonment of courses are manifested in the channel system which counts for adequate academic significant.

3.2 Brief morphometric analysis of Sankosh River:

According to Clark (1966), morphometry is the measurement and mathematical analysis of the configuration of the Earth surface, shape and dimensions of its landforms. The morphometric analysis does, therefore include different aspects like erosional development of drainage network, the intensity of landform contrast, the phase of the development of lands through various fluvial processes etc. It is mentioned that morphometric analysis of the studied basin includes the measurement of linear, areal and relief aspects of the basin and slope configuration (Nag & Chakraborty, 2003). In the study area, the measurement of various morphometric parameters such as stream order, stream length (Lu), mean stream length (Lsm), stream length ratio (Rl), bifurcation ratio (Rb), mean bifurcation ratio (Rbm), Elongation ratio (Re), etc. has been carried out.



Map 3.1: Stream Ordering of Sankosh River Basin (after A.N. Strahler)

3.2.1 Stream ordering:

The drainage basin is considered as an important geomorphic unit on the surface of the Earth. The drainage basin area is considered as an area which contributes water for a particular channel or a set of channels within the drainage basin. A drainage basin provides a limited unit of the surface of the Earth within which basic climate quantize can be measured and characteristics landforms described and a system within which a balance can be struck in terms of inflow and outflow of energy (Luna B. Leopold, Wolman, Miller, 1964). River Sankosh contributes a drainage basin in Bhutan and India with a number of tributaries and reveals various morphometric characteristics and associated erosional and depositional landforms in the Sankosh River basin.

In a drainage basin, Stream ordering is considered the process of identification of links in a drainage network. The Strahler's method (1952, 1964) of stream ordering system has been adopted in determining stream order in the Sankosh river basin. The Stream order analysis reveals that the Sankosh river basin belongs to 6^{th} order basin. It is mentioned that the whole basin area of Sankosh River has formed in different run-off zone on the basis of stream order. In the Sankosh River basin it is observed that the total number of 1^{st} order River is 510 and 148, 26, 10, 2, 1 are 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} order respectively.

3.2.2 Drainage Network Composition:

Bifurcation ratio is a unit less number indicating the ratio between the number of streams of one order and those of the next-higher order in a drainage network. The relationship between streams of different orders has calculated by Bifurcation ratio. (Table 3.1) The Bifurcation Ratio has deep significance to analysis a drainage basin as it is the leading parameter for linking the hydrological regime within a watershed under any topological and climatic conditions. The shape of the basin and run off behaviour of a drainage basin has also be calculated by bifurcation ratio. Bifurcation ratio may be a useful measure of flood frequency and discharge where the higher the ratio value, the shorter will be the time taken for discharge to reach the passage, and higher will be indicate the peak discharge which leading to a greater possibility to flooding. Bifurcation ratio (Table 3.1) correlates positively with drainage density i.e. a high bifurcation ratio indicates a high drainage density. Higher bifurcation ratio also suggests that the area is tectonically active and prone to extreme events. The value of bifurcation ratio can also explain which parts of a drainage basin are more likely to extreme event i.e. flood, comparatively, by looking at the separate ratios.

Bifurcation ratio (Rb):

$$Rb = \frac{Nu}{Nu + 1}$$

Where, ***Rb*** = Bifurcation ratio,

Nu= Number of segments of a given number,

Nu+1 = Number of segments of the next higher order.

Stream length ratio (Rl):

$$Rl = \frac{Mean\ Lu}{Mean\ Lu{-}1}$$

Where, ***Rl*** = Stream length ratio,

Lu = the total stream length of order,

Lu − 1 = the stream length of next lower order.

Table 3.1: Linear properties of Sankosh River basin

Stream order ***(u)***	Stream numbers ***(Nu)***	Total length of stream of order u ***(Lu km)***	Mean Stream length in km ***(Mean Lu = Lu/Nu)***	Bifurcation Ratio ***Rb*** $= \frac{Nu}{Nu+1}$	AV Rb= Reg. Coefficient b^{-1}	Stream length ratio ***Rl = Mean Lu/Mean Lu-1***
1st	**510**	**2321.64**	**4.55**			
2nd	**148**	**821.03**	**5.55**	**10.63**		**1.21**
3rd	**26**	**299.72**	**11.52**	**5.70**		**2.07**
4th	**10**	**183.06**	**18.31**	**2.6**	**4.23**	**1.58**
5th	**2**	**325.16**	**162.58**	**5.0**		**8.87**
6th	**1**	**51.29**	**51.29**	**1**		**0.09**
Total	**697**	**4001.9**	**253.8**			**13.82**
Mean	**116.17**	**666.99**	**42.3**			**2.764**

Source: Data compiled by researcher.

It is observed that Sankosh River basin shows an average bifurcation ratio 4.23 which is within the normal value ranges 3 to 5 and this indicates that higher concentration of water from lower stream order to higher stream order. As a result, the lower basin of Sankosh River influenced by fluvial geomorphology and lithology. It is also mention that evolution of drainage network in the lower reaches of the study area decreased and at the same time the length of 6th order stream increased due to high bifurcation ratio. Naturally, the basin width decreases in the lower reaches which promote elongation of basin shape of Sankosh River.

Table No.3.2 History of Flood Occurrences over Sankosh River Basin

Year	Magnitude	Causes	Affected areas
1787	V	Earthquake, landslide followed by heavy rainfall	Almost whole basin area affected and river course shifting had taken place.
1840	IV	Heavy rainfall	The river Sankosh shifted its course.
1906	III	Heavy rainfall	Lower part of study area.
1950	IV	High intensity rainfall	Almost whole basin area affected and heavy damage of land had occurred.
1968	V	Cloud-burst over the basin and large part of sub-Himalayan West Bengal.	Almost whole basin area affected and massive deposition took place.
1993	IV	Cloud-burst over Lower Bhutan Himalaya.	Whole basin area affected and massive fluvial transformation had taken place.
1998	IV	Cloud-burst over the lower Bhutan Hills.	Whole basin area affected and huge sediment deposited.
2003	III	Heavy rainfall in catchment area.	Large scale destruction of crops
2005	II	Heavy rainfall in catchment area.	Many people affected at lower part of the study area.

History of flood occurrences (Table 3.2) of the Sub-Himalayan Rivers including the River Sankosh has been documented by Bolt, 1772; Fergusson, 1710-79; Rennel, 1779; Hunter, 1787; Buchanan-Hamilton, 1810; Gunning, J.F, 1911; Dash, A.J, 1947; Mitra, 1964; Sunder, D.H.E,

1985. From this point of view, it is mentioned that the basin area under the study had been influenced by a number of great devastating flood caused channel shifting, channel avulsion, sediments deposition etc. in the study area. Here a numbers of great flood occurrences have been listed in the (table no. 3.2)

3.2.3 Discharge Characteristics:

The discharge of a river is one of the most important measurements to determine various hydrological characteristics. The discharge (m^3s^{-1}) is basically determined from the velocity multiplied by the cross-sectional area of the Sankosh River at different gauge stations.

Moreover, discharge can often be measured automatically giving a continuous record (i.e. hydrograph) of the changing level or direct discharge of the river. In the study area it is observed that the cross-sectional area (Figure 3.6) fluctuates with the change in water level or river stage. Further it is also mentioned that with known cross-sectional area, the discharge can be derived by measurement of the water level at different selected gauge station in the study area.

The discharge and its annual, as well as long fluctuations are primarily influenced by different characteristics of the studied drainage basin such as the size, shape and the geological formation. On the other hand, physiography, climate, hydrology and other factors also play an important role in the generation of discharge of the Sankosh River in the study area. In the study area climate is considered as the principal factor causing large fluctuation in discharge and which determines the distributions of rainfall over the year. Moreover, the composition and structure of the sub-soil found in the study area are also considered as important factors of river discharge. Furthermore, geological condition of the studied basin plays a significant role in variation in the discharge rates. Lastly, the presence of vegetation also exerts an influence on the generation of discharge variation of Sankosh River in the study area because it largely determines the quality of surface run-off.

Discharge characteristics of the Sankosh River are greatly modified by the nature of watershed changes in relation to the infiltration rate of the ground water system. It is found that when infiltration increases within the watershed during the peak flow or flood stage has a much lower discharge. The increase in discharge is not only a function of the storm intensity but is also related to the duration of rainfall, soil water saturation etc. in the study area.

The measurement of discharge in the study area provides a direct measure of water quantity and hence the availability of water for different purpose or uses for the people inhabiting both banks of the Sankosh River. It also helps to calculate loads of specific water quality variables. Moreover, the study of discharge provides the basis for understanding of different fluvial processes that act in the Sankosh river basin and help to study different erosional and depositional landforms over the floodplain in the study area.

Table No.3.3: Calculation of Recurrence Interval (T) of Sankosh River During the Period of 1999 to 2008 at Golakganj.

Year	Q_{max} (Cumec)	Recurrence Interval (T)	Flood occurrence Probability (P)	Rank (m)
1999	2818	2.22	0.45	5
2000	3652	5.56	0.18	2
2001	2654	1.82	0.55	6
2002	3871	11.11	0.09	1
2003	2524	1.37	0.73	8
2004	2892	2.78	0.36	4
2005	2566	1.56	0.64	7
2006	1866	1.22	0.82	9
2007	3022	3.7	0.27	3
2008	1752	1.1	0.91	10

Probability (P) = m / (n+1)

Recurrence Interval (T) = 1/p

Where, P= Probability,

m= Rank,

n= Number of Year

T= Recurrence Interval

Here, based on the discharge data (Table 3.3) for the period of 1999 to 2008 from CWC office, Jalpaiguri flood probability and recurrence interval has been calculated to know the overall conditions of the occurrences of floods and flood discharge in the study area.

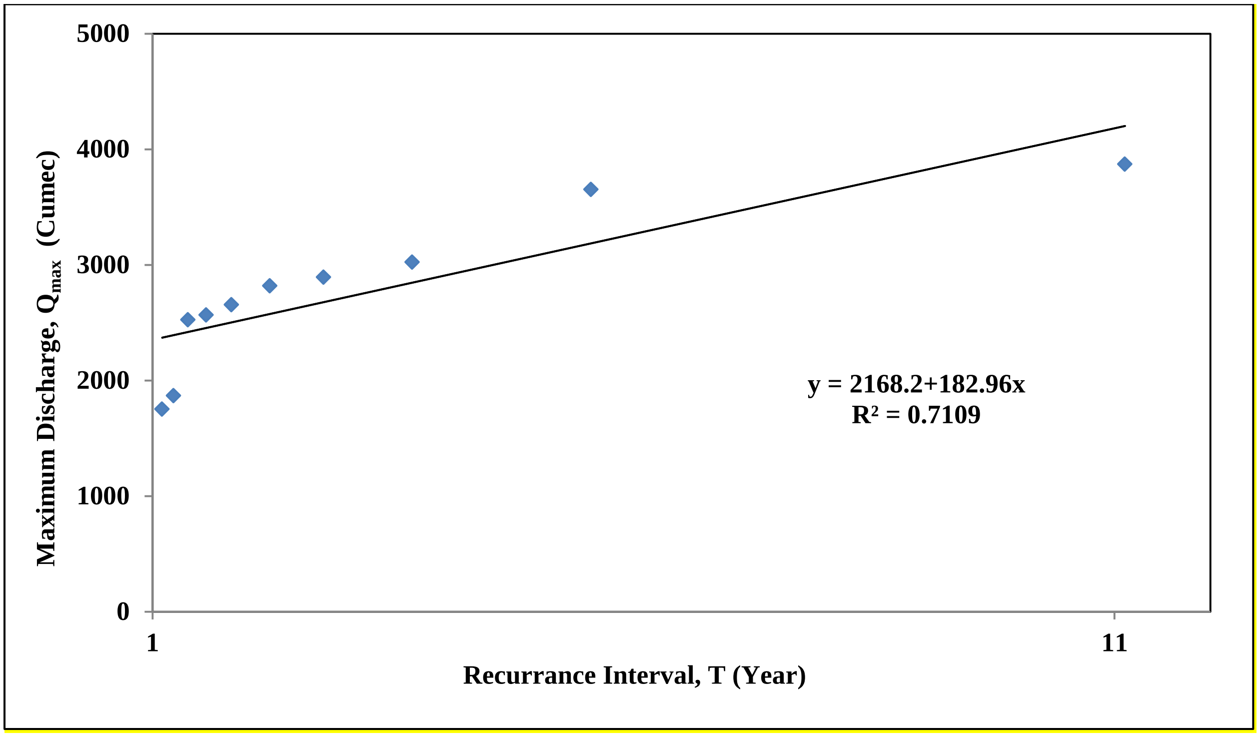


Figure 3.1 Flood Frequency Curve of Sankosh River for the Period of 1999-2008 at Gauge Station of Golokganj

From the above figure 3.1 and table 3.3, it is found that the peak discharge is highest in the year 2002 and the flood event of the same magnitude recurring within 11 years but the probability of flood of the same magnitude is found lowest. On the other hand, the peak discharge is found lowest in the year 2008 but the probability of flood occurrence is very high with the recurrence interval of one year.

3.2.3.1 Analysis of Hydrographs:

Hydrograph (Figure 3.2, 3.3 &3.4) is the plot of discharge against time during a rainstorm event. It is the slope of the flood wave at the location of any particular gauging station. Hydrograph at any gauging station is generally used to define the changing slope of the flood wave as it runs towards the downstream. In the study area, it is observed that the hydrograph is mostly depending on the intensity of rainfall and the characteristics of the basin area. Detailed analysis of flood hydrograph is very important to know about the information of peak discharge and water level, duration of flooding, flood control and forecasting etc.

In a hydrograph, main components are:

I. The rising limb,
II. The crest segment and
III. The recession limb.

The rising line is the connection of curve which represents the increase in discharge due to rain storm over the basin area. Crest segment contains the peak discharge within it. On the other hand, recession limb is also known as the falling limb which extends from the point of inflection at the end of the crest segment represents the withdrawal of water.

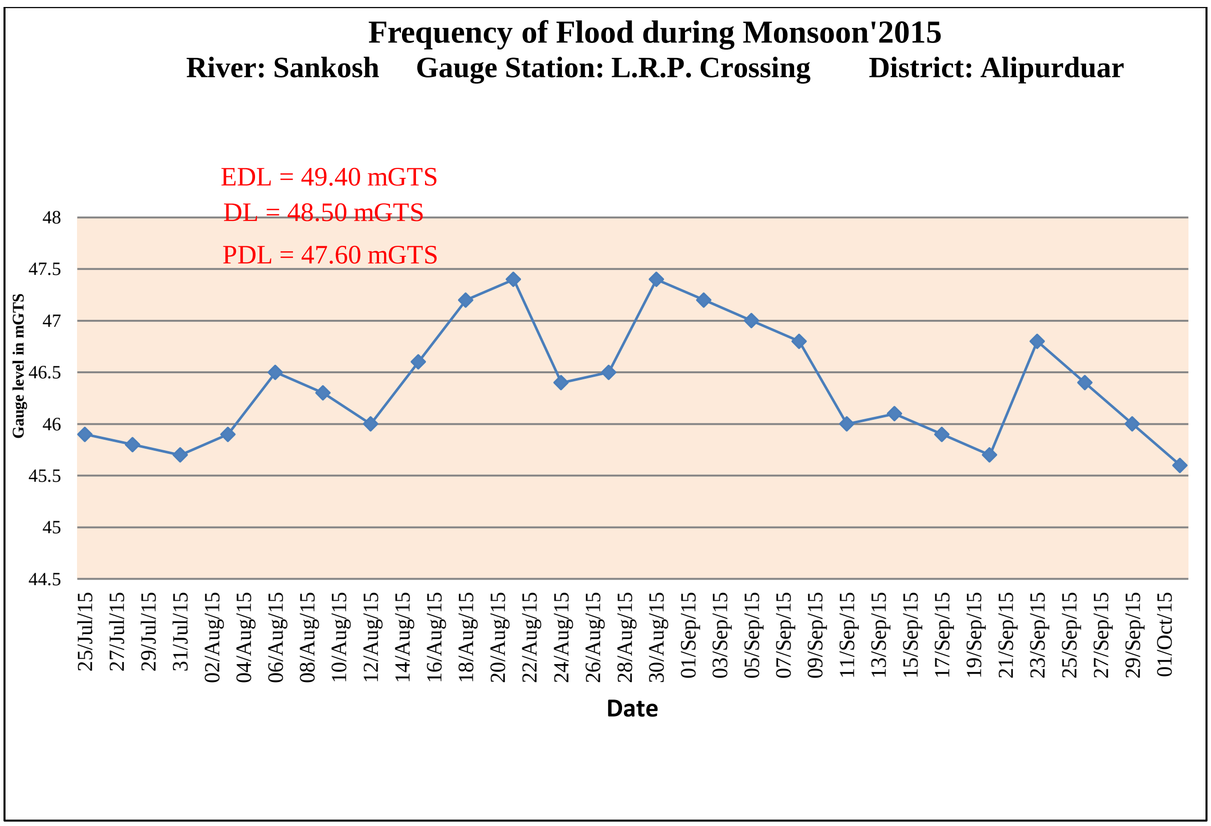


Figure 3.2: Frequency of Flood during Monsoon’2015

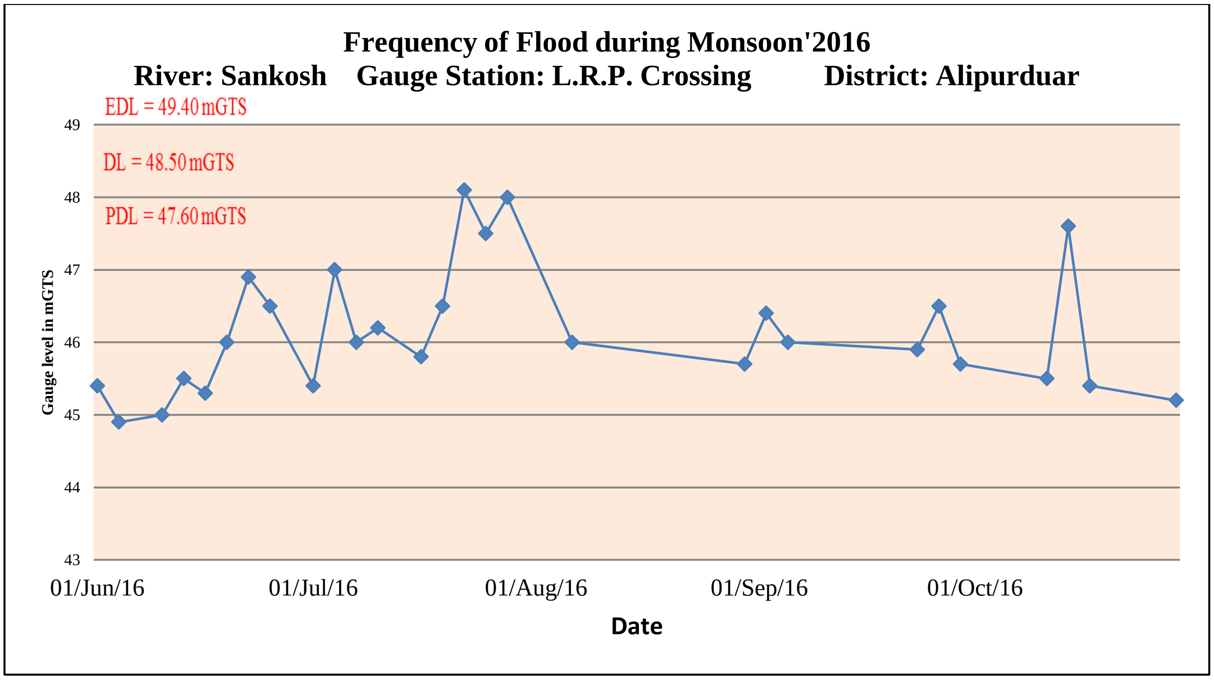


Figure 3.3: Frequency of Flood during Monsoon'2016

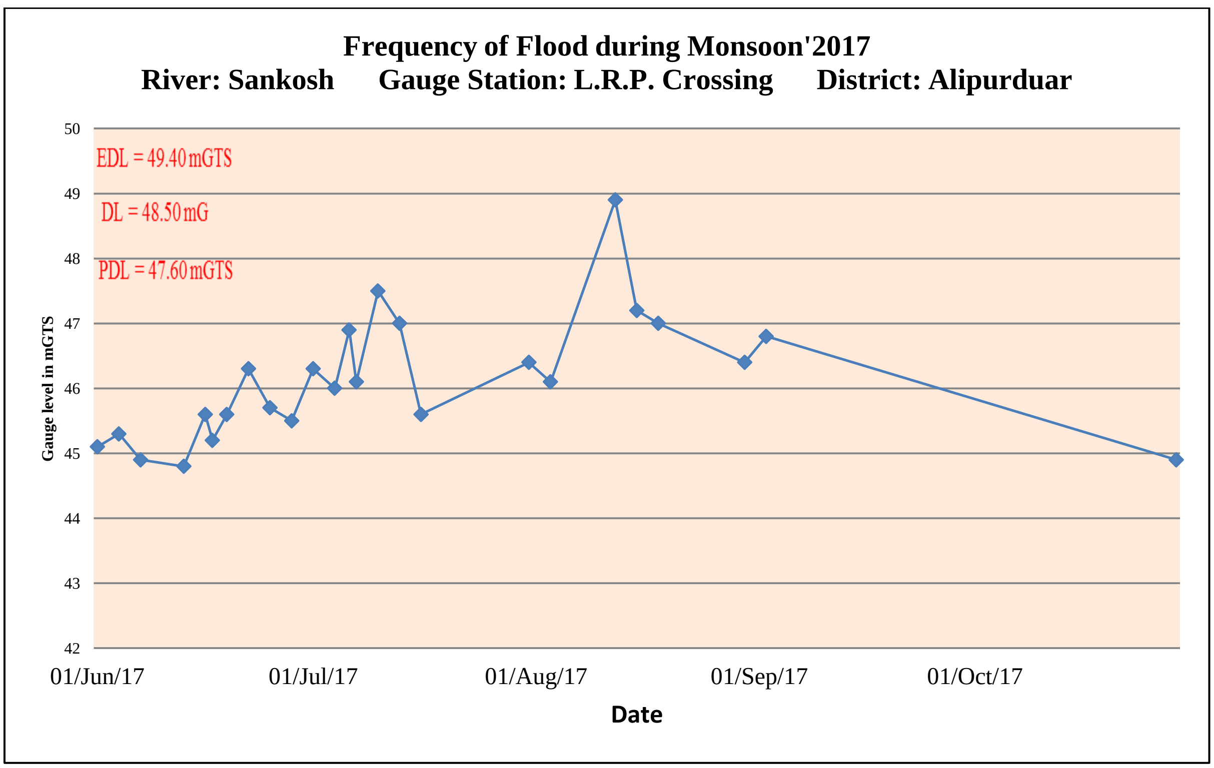


Figure 3.4: Frequency of Flood during Monsoon 2017

In the study area hydrograph of Sankosh river has been constructed for consecutive three years (i.e. from 2015 to 2017) from the collected data. From the constructed hydrographs it is observed that hydrographs are multi peaked in nature in the study area. So, it can be inferred that rain storm occurs before the run-off of the previous storm ceases. From the above figure it is found that the hydrographs for the year 2016 is skewed to the left which indicates that the peak occurs relatively quickly. On the other hand, in the year 2015, the hydrographs are skewed to the right and which reveals the longer lag occurring peak and remain one hydrograph of the year 2017 indicates the intermediate peak occurrence in the study area. In this regard, it is concluded that flood magnitude and frequency are responsible for the local changes in the flood plain slope relative to the channel belt slope and which initiate the processes of channel avulsion with respective time and location (Mackey and Bridge, 1995) in the study area.

3.2.4 Long profile of Sankosh River:

The alluvial section of the lower Sankosh river channel at fatal stage reveals a concave-upward slope along its downstream gradient (figure 3.5) with an elevation 110m above the mean sea level at 23m located a distance of about 92.9 km downstream the studied segment of Sankosh river while the elevation at 110m above mean sea level which is about 92.9km downstream of River Sankosh, Thus the river drops 92.9km along the studied reach. As a result, longitudinal zone of channel forms may be identified from the headwaters downstream to the river mouth.

It is observed that the profile is punctuated at different points where the river cuts through valley floors as indicated at about 4 km distance which is clearly influenced by human interference of the location of a barrage and sand mining activity respectively.

The gradual lowering of the channel gradient provides explanation of erosional and depositional work of the river along the meanders and braided section and the possible reason for the increase in fluvial landform within the study area. Features like ripples and pools sequence are evidenced at the concave and convex section of these meanders which are characterized by braids between 70 km to 80 km downstream distance. These types of features are formed by pattern scour and deposition at bankful discharge where the ripples tend to occur at inflection points and pools at bends.

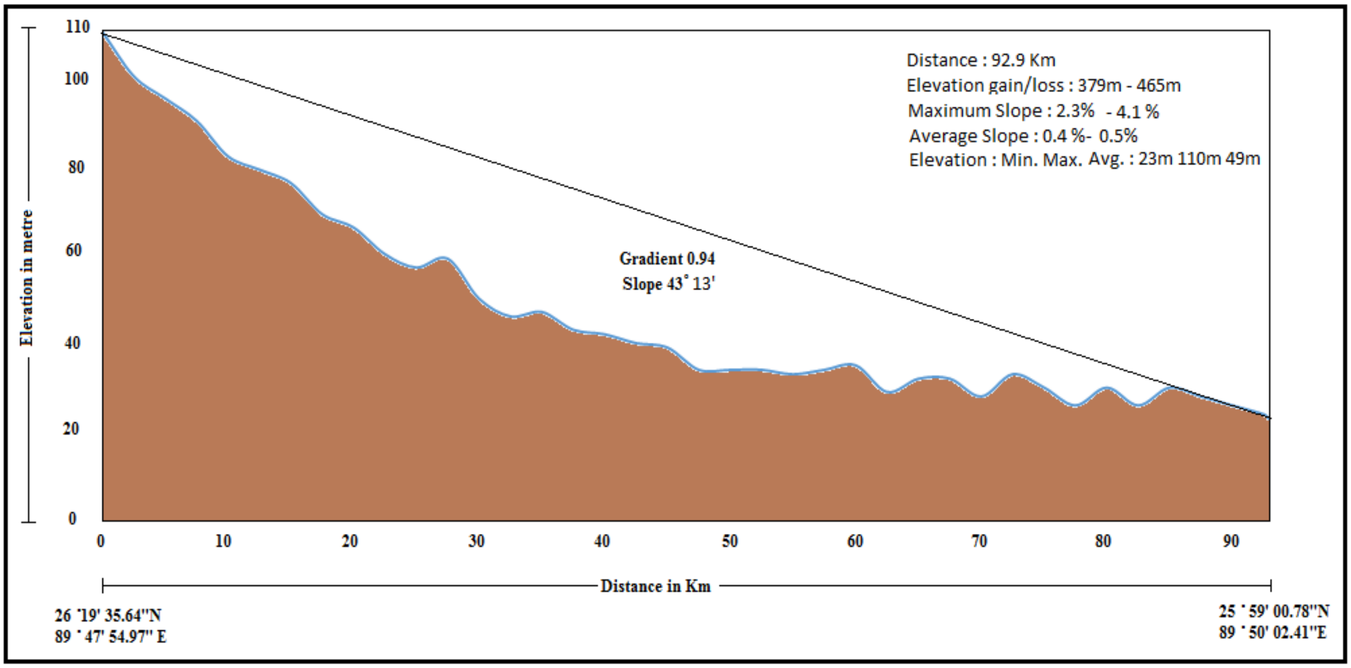


Figure 3.5: Long profile of Sankosh River from Indo-Bhutan border to Indo-Bangladesh Border

It is also observed that ox bow lake, a lake with curved plan occupying cut-off channel reach that has been abandoned were encountered along the stretch while point bars deposit occurred on the inside of the meander bend largely by accretion are more pronounced.

3.2.5 Cross profile of Sankosh River:

The shape of the cross profile of a river channel is a function of its flow, the nature and amount of sediment in movement and the character and composition of the materials making up the bed and banks of the channel (Leopold, Woolman & Miller, 1964). In this context to study the varying attitude of the channel wetted perimeter and specially the impact of massive flood on the channel surroundings, a detailed survey of the cross-sections at the following three different sites in the study area of the river Sankosh was undertaken:

I. **The upstream Gauge:** At Barobisha.
II. **The midstream Gauge:** At Falimari.

III. The downstream Gauge: At Koimari.

3.2.5.1 Characteristics changes of the cross profiles:

The cross-profiles (Figure 3.6, 3.7 & 3.8) of the River Sankosh at the three reaches is distinctive due to braiding and bed load meandering is featured by a number of wetted perimeter separated by sand bars, mud-flats or mid islands, which repel the water flow against the side walls of the channels causing erosion and avulsion.

3.2.5.1.1 Progressive changes in the cross-sectional area:

At any particular reach, the changes in the cross-sectional area depend on seasonal regime. In the study area, the changes in the cross-sectional area occurs at three different gauge stations due to occurrences of flood in different periods and reveals different morphometric characteristics along the cross sections.

3.2.5.1.2 Progressive changes in the wetted perimeter:

In this context, while making a comparative study between the upstream wetted perimeter and downstream wetted perimeter it is observed that there is a rising tendency for the wetted-perimeters from the up to downstream profile. No specific trend in variation of the wetted-perimeters is noted from year to year. The wetted perimeter is the perimeter of the cross-sectional area of a river which is indicated as ‘wet’ generally the term wetted perimeter is common in the field of hydrology and geomorphology. It is associated with the hydraulic diameter or hydraulic radius along the cross-section of a river.

In the study area, the wetted perimeter is characterized as the surface of the channel bottom and sides in direct contact with the aqueous body. It is mentioned that the wetted perimeter is increased when friction losses typically increased at the downstream reach of Sankosh River, resulting in a decrease in head. Moreover it is also found that when the channel of Sankosh River is much wider than it is deep, the wetted perimeter approximates the channel width or equal to the channel width.

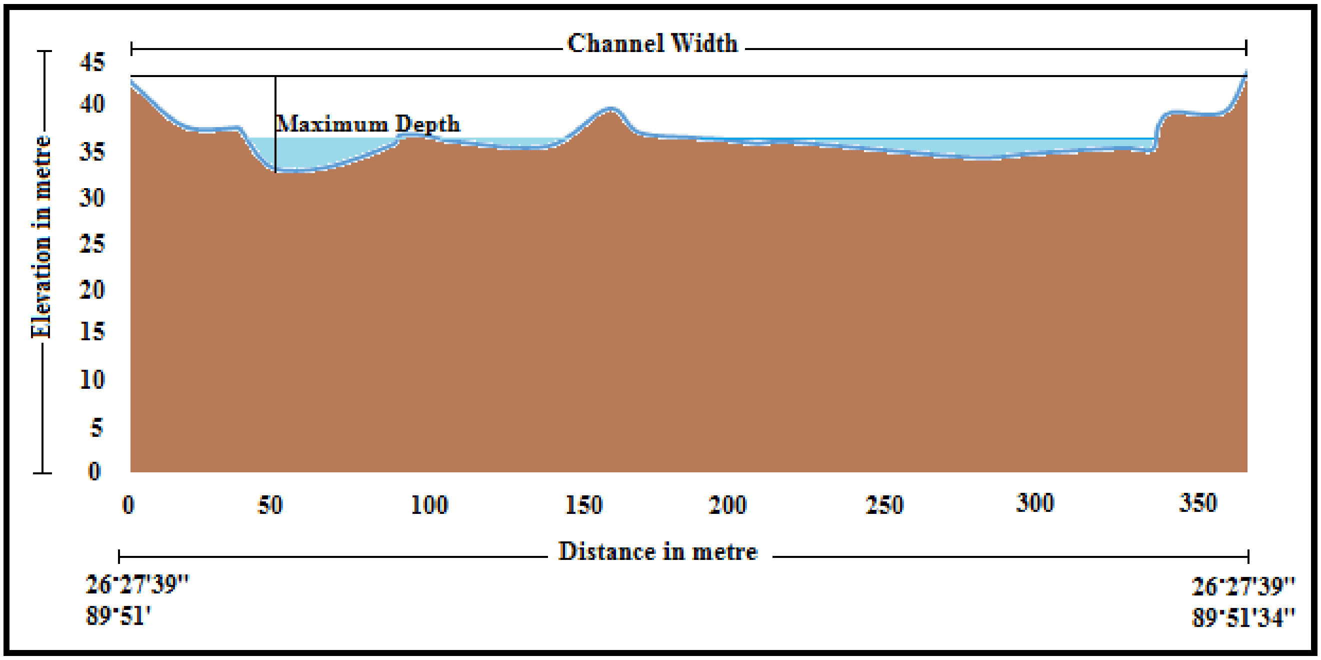


Figure 3.6: Cross Profile at Upstream Gauge Station at Barobisha

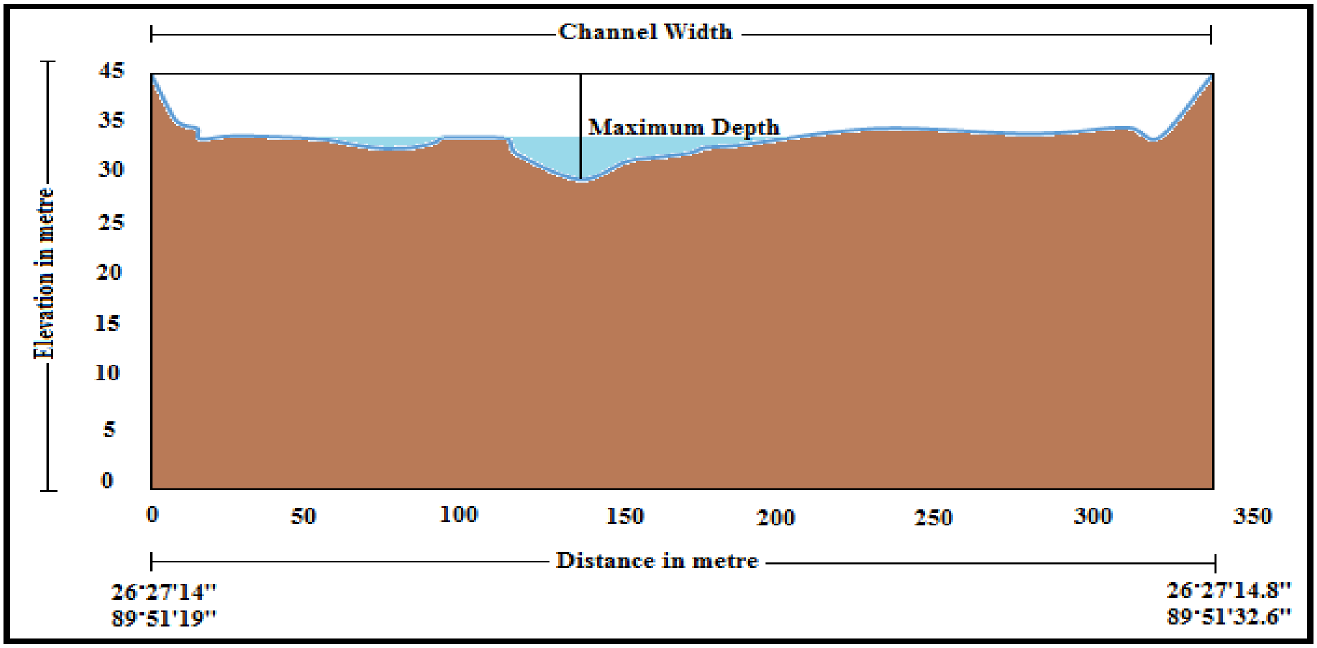


Figure 3.7: Cross Profile at Midstream Gauge Station at Falimari

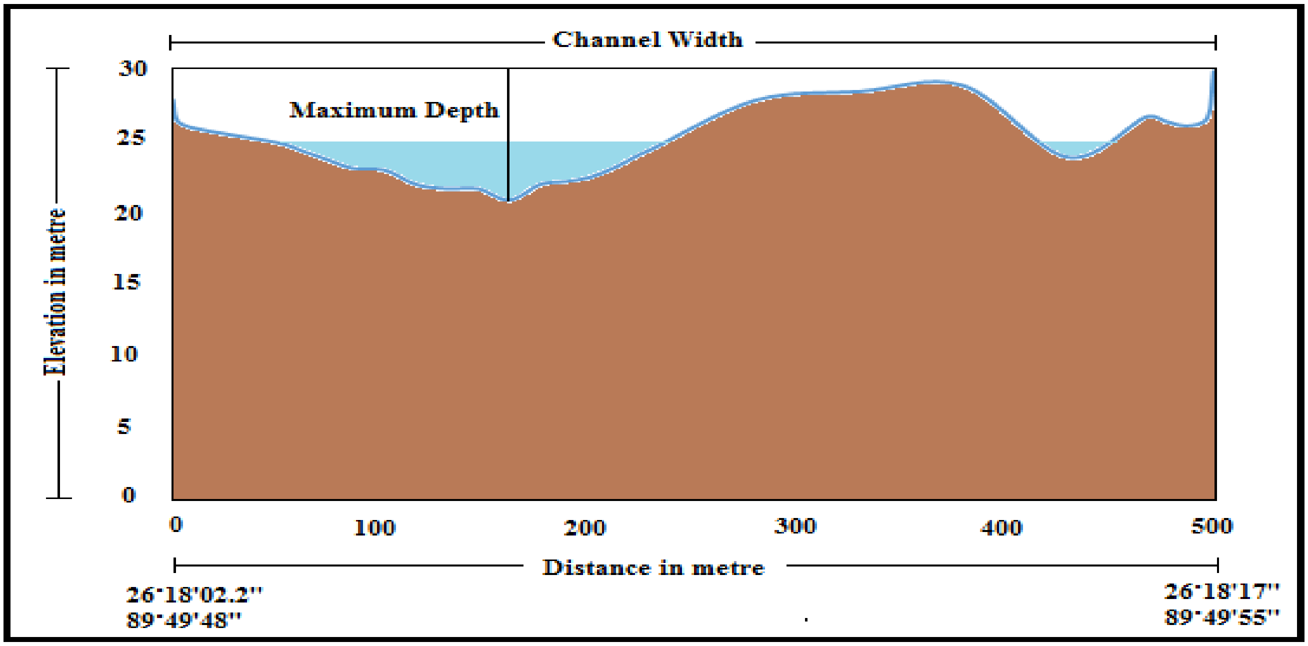


Figure 3.8: Cross Profile at Downstream Gauge Station at Koimari.

3.2.5.1.3 Progressive changes in Hydraulic radii:

All the sections do not change in the same way or to the same extent from year to year. From the three cross-sections it is seen that the impact of change of the hydraulic-radius of one cross-section on the other is insignificant. The data of hydraulic-radius of a particular section tends to increase from year to year but after that this tendency has completely been reversed as evident from the values.

3.2.5.1.4 Progressive changes in discharge:

The variation of discharge of the river over the years is more or less due to the fluctuations in the rainfall in the catchment area. From the changes in discharges, it would be evident that the process of scouring and silting usually takes place alternately and it takes a three-year gap before the process is completely reversed. The variation in discharges can never be categorically proved as the deteriorating condition of one year is readily compensated in the very next year.

Plate 3.1: Measurement of Cross Section at Barobisha

Plate 3.2: Measurement of Cross Section at Falimari

The river channel presents a three-dimensional form, defined by its slope, cross section and pattern (G. Petts and I. Foster, 1985). Infact, geometry of a channel represents length, depth and width of the cross section and long profile of a particular channel which consists of wetted perimeter, meander wavelength, radius of channel curvature, bends of that channel, channel thalwegs and their relation to each other.

3.2.6 Pattern variation along the channel segments

By channel pattern is meant the configuration of a river as it would appear from satellite image. The channel patterns that have been recognized are meandering, braided and straight. Rivers are seldom straight through a distance greater than about ten channel widths, and so the designation straight may imply irregular, sinuous or non-meandering. There is no sharp distinction between any of these patterns. Rather river pattern is a continuum from one extreme to another (Wolman, Leopold, Miller 1963). Channel pattern in general associated with alluvial channels. The channel pattern or map view of a river is usually considered as straight, meandering or braided (M. Morisawa, 1985) , S.A. Schumm (1963, 1972), A.D. Miall (1978) several geomorphologists have classified alluvial channel on the basis of different criteria i.e. Sinuosity index value, sediment load, slope-discharge relationships etc. In the study area, four types of channel patterns in the lower basin of River Sankosh have been identified according to the classifications done by M. Morisawa, 1985; A. Schumm 1963; A.D. Miall 1978 based on several criteria i.e. sinuosity index, sediment load types, erosive behaviour and depositional behaviour.

In the study area, based on M.Morisawa (1985), S.A Schumm (1963b), and A.D Maill (1978) Sankosh River basin has been classified into four channel pattern viz. Mixed-Load Straight Channel, (Map 3.2) Suspended- Load Channel with High Sinuosity,(Map 3.3) Meandering-Braided Transitional Channel (Map 3.4) and Bed-Load Channel (Braided) (Map 3.5). The sinuosity index of these channel patterns reveals that each pattern consists some important morphological characteristics within the channel. In this regard it is mentioned that upstream of the study area is formed straight channel with the deposition of loads carried by the river. As a result, river bed rises during flood season and which creates favourable conditions for channel avulsion and after a long period of time the entrance of the avulsed channel is closed due to continuous sediment deposition and the channel remains as abandoned. On the other hand, in the midstream channel a meandering channel pattern is formed, due to lateral bank erosion and at the same time channel bar is also formed within the channel. As a result, neck and chute cut-off are formed in both banks of the River Sankosh in the study area. Here, it is also mentioned that after a long time these cut-offs remain as abandoned channels in the study area. Moreover, in case of braided pattern, bar formation continuously progresses due to sediment deposition within the channel which divides the main river into a number of secondary channels. As a result, after a period of time these secondary channels are detached from main channel due to head ward extension of bar and remains as abandoned channels in the study area.

In the study area, pattern variation along the River Sankosh has been analysed under the following heads:

3.2.6.1 Mixed Load Straight channel:

The channel is straight and it is usual for the thalweg, or line of maximum depth, to wander back and forth from near one bank to other (Wolman, Leopold, Miller 1963) which in our study is found at the northern part of the study area and Sinuosity index is less than 1.05 because of high degree of slope (Map 2.6) which is responsible for higher velocity in the channel flow.

3.2.6.2 Suspended- Load Channel with High Sinuosity

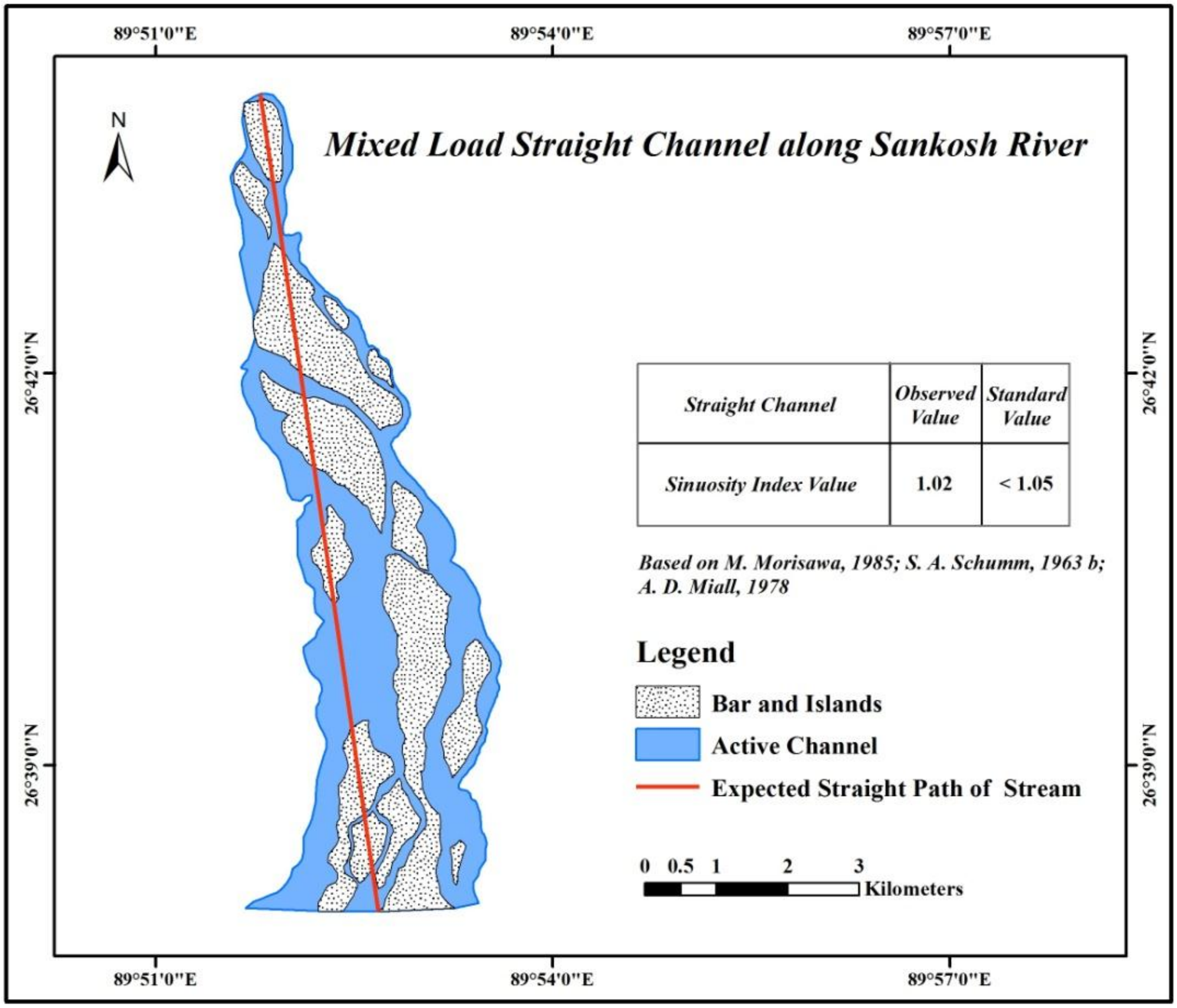
An alluvial channel when Sinuosity index is between 1.05 and 1.5 is called sinuous channel, is found in the lower portion of straight pattern of River Sankosh.

3.2.6.3 Meander- Braided Transition Channel:

An alluvial channel pattern having sinuosity index more than 1.5 is called meandering channel and it is characterized by pools at the bends and rifles at the crossovers of the main stream and is found at midsection of the study area with high curvature.

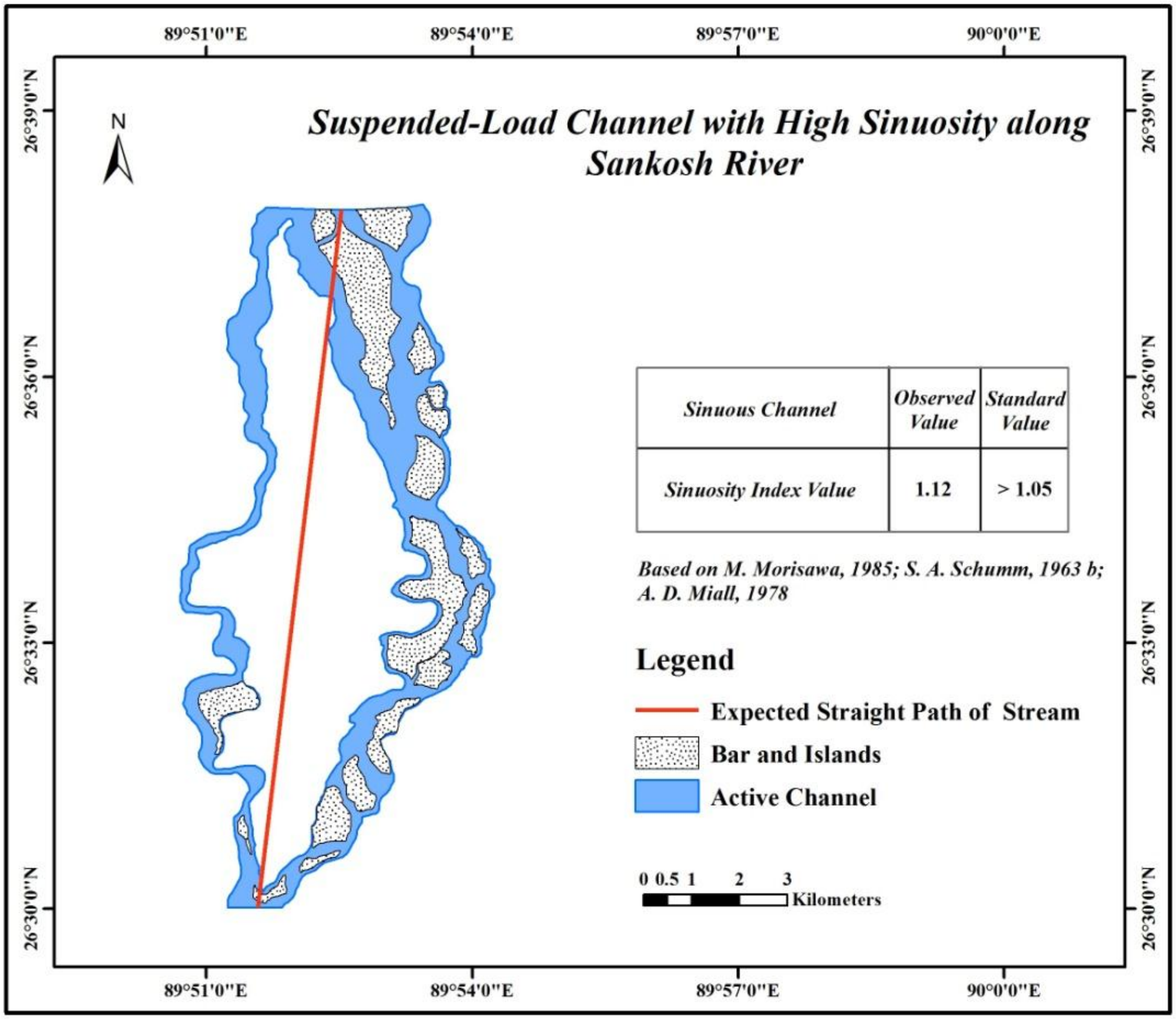
3.2.6.4 Bed- Load Channel (Braided)

The separate channels of a braided stream are divided by islands or bars. Bars which divide the stream into separate channels at flow are often submerged at high flow (Wolman, Leopold, Miller 1963). In this study braided channel is a very common feature and is found in the entire Sankosh river basin.



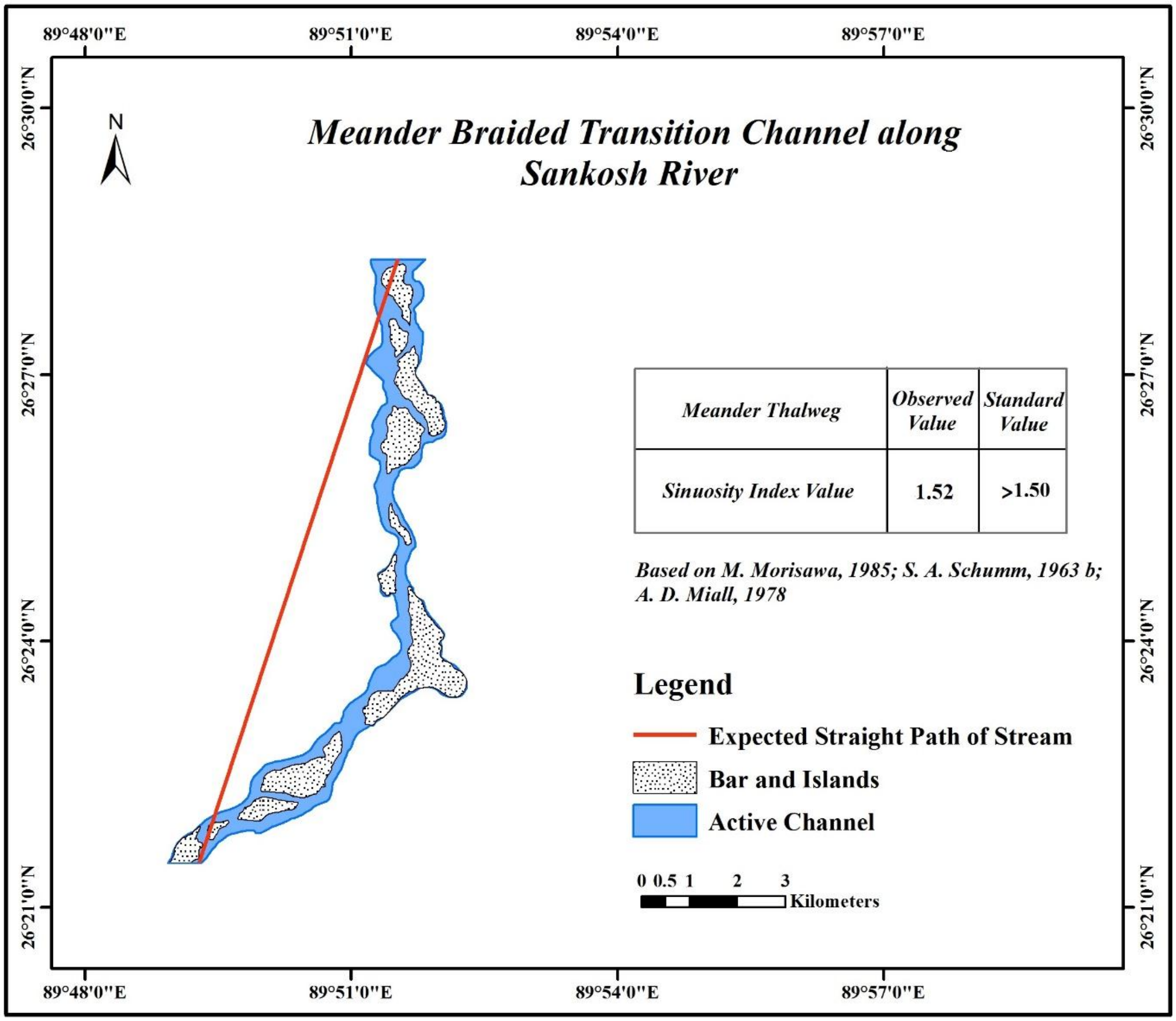
Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.2 Mixed Load Straight Channel along Sankosh River



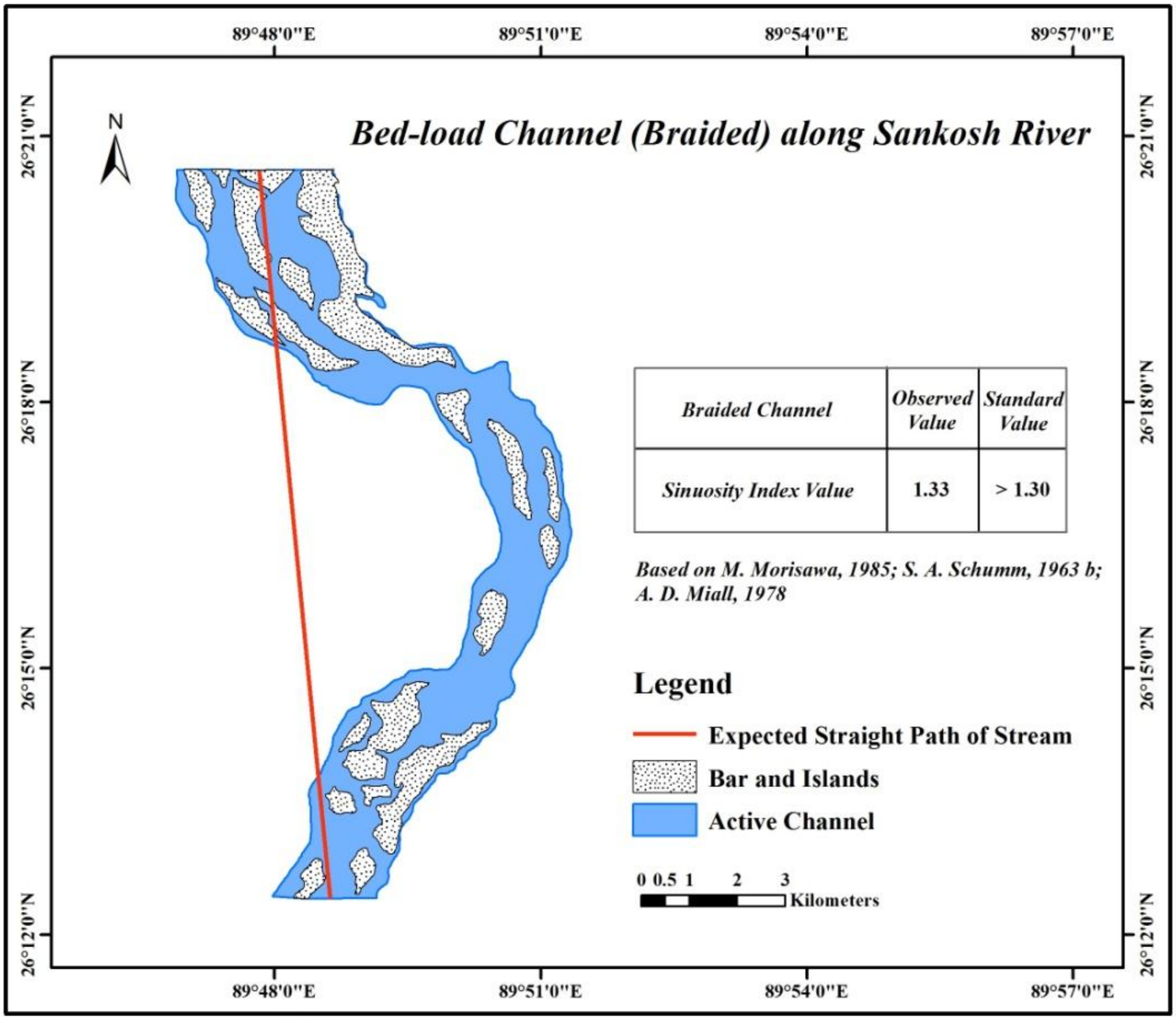
Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.3: Suspended-Load channel with High Sinuosity along Sankosh River.



Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.4: Meander-Braided Transition Channel along Sankosh River



Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.5: Bed-Load channel (Braided) along Sankosh River

The Sinuosity index has been defined in the formula given below:

$$Sinuosity\ Index = \frac{channel\ thalweg\ length}{valley\ length}$$

Table 3.4: Pattern variation along the channel segments

Type	Sinuosity	Sediment load type	Erosive behaviour	Depositional behaviour
Mixed-Load Straight channel	1.02	Mixed sediment load	Minor channel widening and incision	Skew shoals
Suspended- Load Channel with High Sinuosity	1.12	Suspended load	Increased widening and incision	Skew shoals
Meander- Braided Transition Channel	1.52	Suspension or mixed load	Channel incision and meander widening	Point bar formation
Bed- Load Channel (Braided)	1.33	Bed load	Channel widening dominent	Channel aggradation and mid channel bar formation

Based on: M. Morisawa, 1985; A. Schumm 1963; A.D. Miall 1978

3.3. Identification of various types of abandoned channels of Sankosh River

Abandoned channels are more commonly formed along the alluvial river. These abandoned channels are the result of channel shifting processes at various scales, including meander cut-off and channel belt avulsion (Willem H.J. Toonen et al. 2011). In this regard, channel shifting of the Mississippi river (Schumm, 1977) and changing courses of Kosi River (Sinha, 2014) can be stated. An abandoned meander of the Narmada River is seen near Hosengabad (Kale& Gupta, 2001). Large number of abandoned channels is formed along many rivers of Ganga-Brahmaputra plain in North and North eastern India.

The method for the identification of abandoned channels has been based on the topographical maps of Survey of India and satellite images of different time periods starting from 1965 t0 2010. As it is known that abandonment is a process of detachment and separation of the part of the main channel, therefore, the channels which have been truly separated for a prolonged period of time have been carefully checked in topographical maps and satellite images of different periods and justified by field investigation in different selected sites. All the abandoned channels have been identified and their causes of occurrences have been mentioned in the table 3.5

Table 3.5: List of Abandoned Channels in the Study Area.

Sl.no.	Name of the abandoned channels	Causes of Occurrences
1.	Khalisamari beel	Due to meander cut-off
2.	Kamandanga beel	Due to meander cut-off
3.	Purbachhara beel	Due to meander cut-off
4.	Nayachhara	Due to channel avulsion
5.	Tama Nadi	Due to channel avulsion
6.	Abandoned channel at Falimari	Due to channel avulsion
7.	Abandoned channel at Tamarhat	Due to braid formation

In the study area, numerous abandoned channels are also identified and it is also found that different types of processes associated with their formation.

Common types of abandoned channels in lower fluvial reaches are categorized as follows:

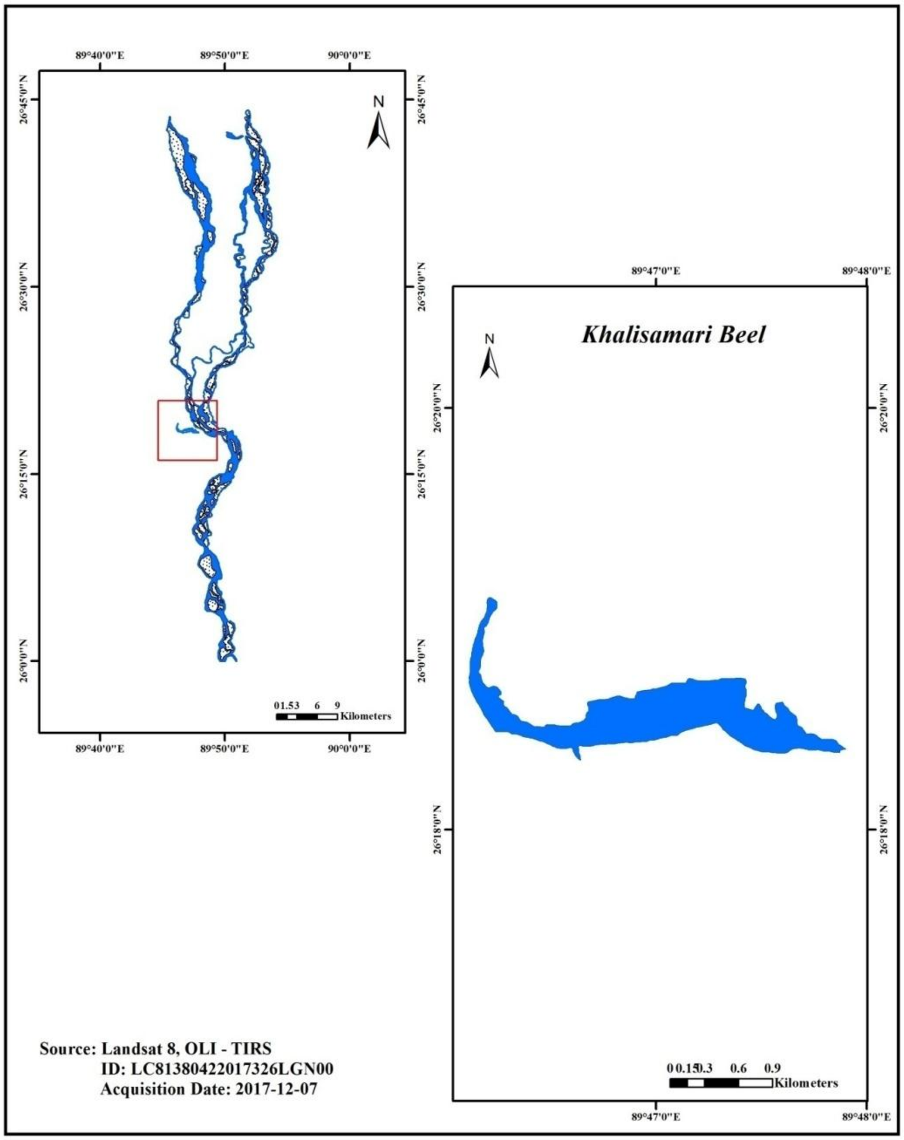
I. Oxbow lakes, formed by single meander bend neck or chute cutoff (Fisk,1947; Lewis and Lewin, 1983, Hooke, 1995)
II. Channels abandoned over multiple meander lengths, left inactive due to an upstream avulsion (Smith et al., 1989; Stouthamer and Berendsen, 2000)

A detail study of the identification of abandoned channels is explained below under the following heads.

3.3.1 Abandoned due to meander cut off:

3.3.1.1 Khalisamari Beel:

Khalisamari Beel (Map 3.6) is located at Chagalia village of Dhubri district of Assam. At present Khalishamari Beel is an abandoned channel of Sankosh River. This abandoned channel was a main channel of Sankosh river in the past which disconnected by the process of chute cut-off for long time. This abandoned channel occupies about 70 acres of land and exhibits a ground elevation of about 32 m from mean sea level. The length of this abandoned channel is around 8 km from Chotto Guma to Kaimari village. The depth of water of this abandoned channel is about 5m to 6m in rainy season and 3m to 4m in dry season andis affected by floods in the rainy season. In the earlier times, this Khalishamari beel was owned by the king of Gouripur.



Map 3.6: Location Map of Khalisamari Beel

At present it is owned by a local resident, named Ganesh Chandra Sarkar and his seven sons which equally divided to them without any boundary. Nowadays some marginal area of this abandoned channel is occupied by local people of the village and they use some portion for their cultivation and as well as for their settlement. This abandoned channel is rich for fishery and is considered as a source of economy for the local people.

3.3.1.2 Kamandanga Beel:

Kamandanga Beel (Map 3.7) is located at Pokalagi village and Kamandanga village of Dhubri district of Assam. Geographically it is situated in the left bank of Sankosh River at 26̊ 12' latitude and 89̊ 50' longitude. It is an important abandoned channel and its geographical area is about 188 bigha. Its length is 1.5km to 2.0km with 200m to 300m width. The water depth of this abandoned channel is 4m to 6m in rainy season and 3m to 4m in dry season. This Kamandanga Beel is socio-economically very sound. Water of this beel is used for irrigation and agricultural purpose, fishery and other household purpose of the people of the village. It is also mentioned that this beel is controlled by Govt. Of Assam and a legal tender is opened every year for fishery.

3.3.1.3 Purbachara Beel:

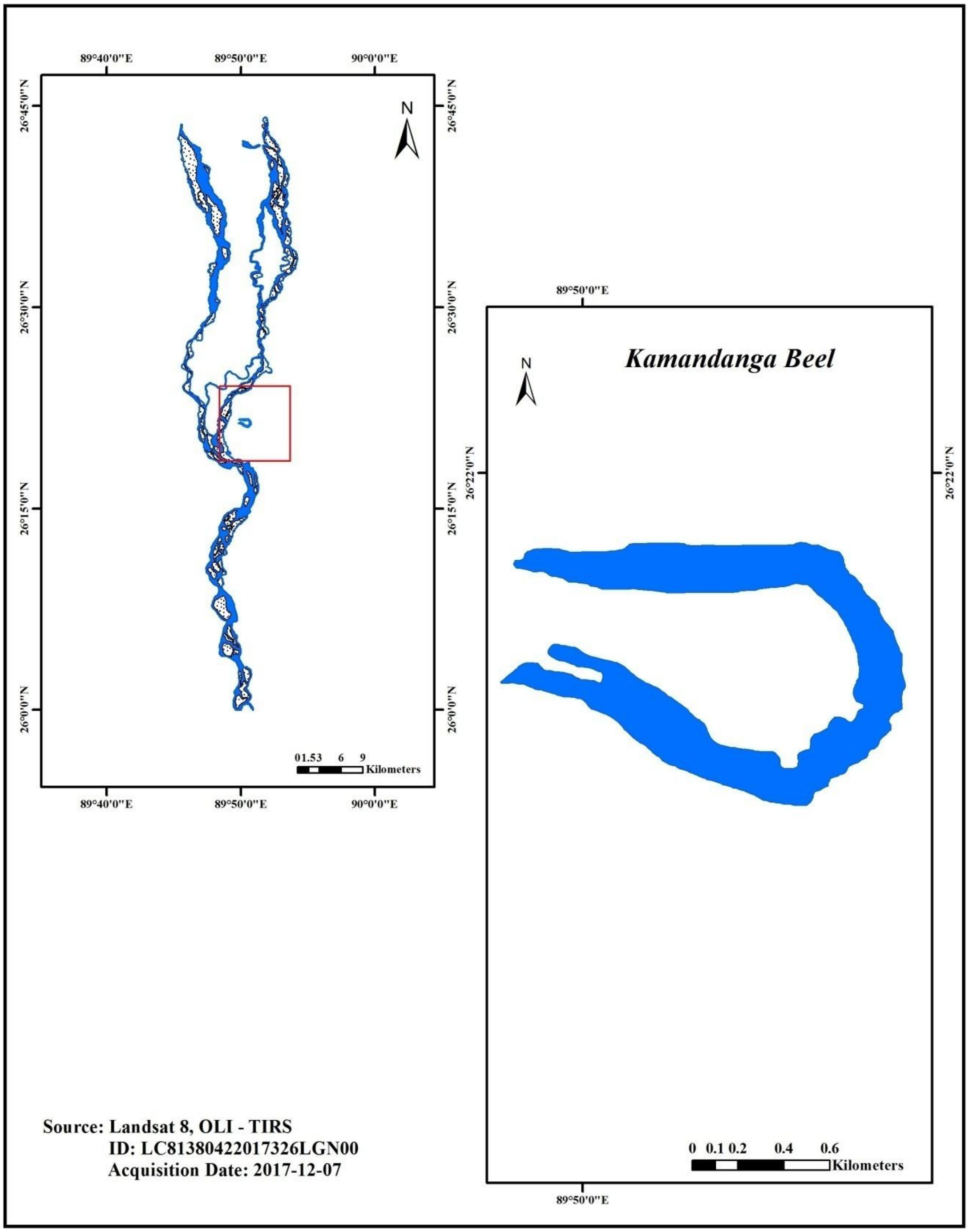
A semi-circular, curved shaped perennial abandoned channel formed by meander cut-off named Purbachara (Map 3.8) is located at Schoolghutu village of Kokrajhar district of Assam. Geographically it is located in the left bank of Sankosh river at 26̊ 21'latitude and 89̊ 53' longitude. The length of this channel is about 1km to 1.5km and water level is about 2m to 3m in dry season and 3m to 4m in rainy season, Socio-economically this abandoned channel is more important and used for agricultural and other purposes by the local people.

3.3.1.4 Other meander cut offs:

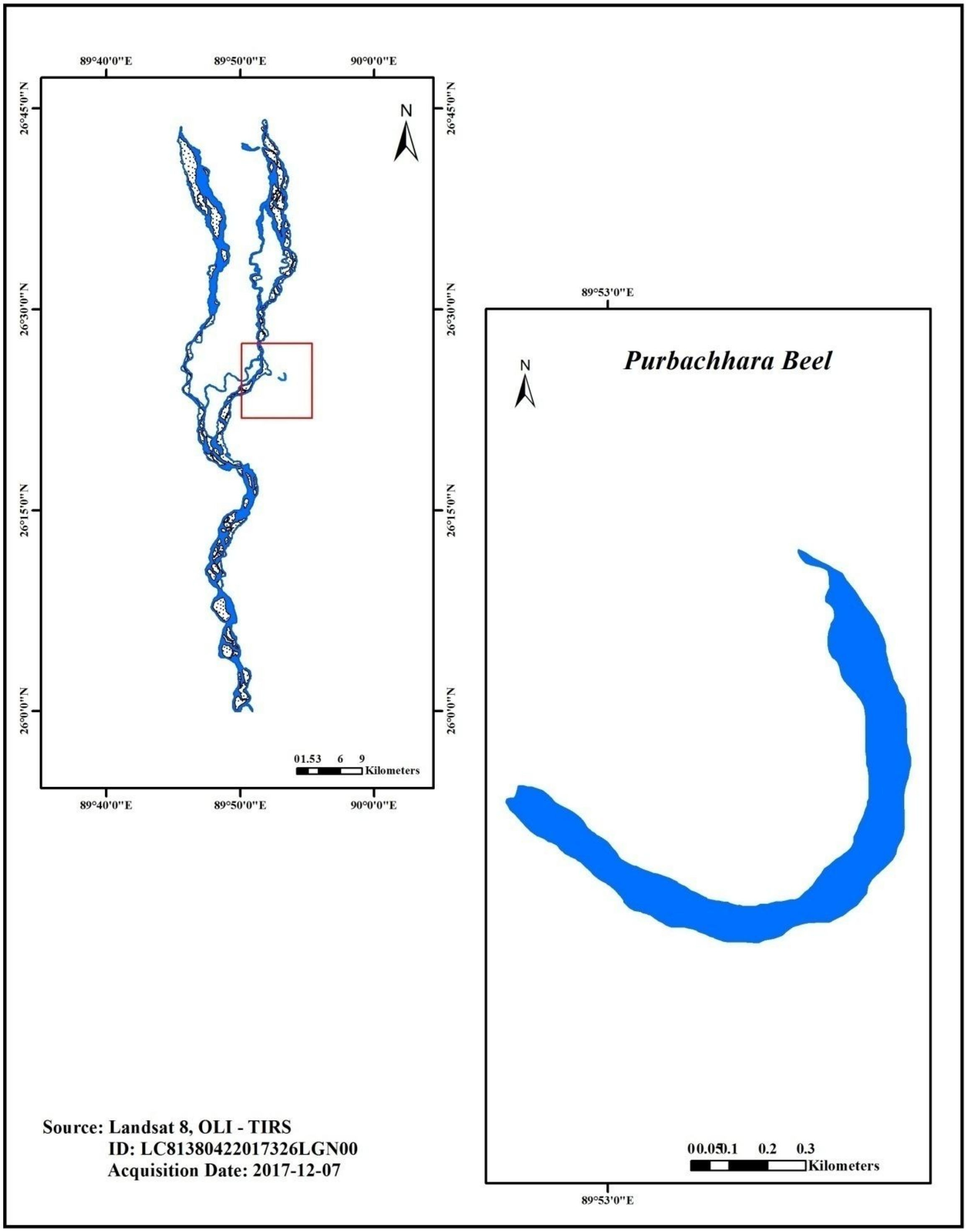
Numerous meander cut-offs i.e. neck and chute cut-offs are also found in both the banks of Sankosh River in the study area. Ghirtinga beel, a meander cut off is situated in the left bank of the Sankosh River near the village Ramnathpur of the state of Assam. It was formed due to the neck being cut off of the main river and formed geomorphological features on the flood plain of Sankosh River. It approximately covers an area around one sq.km and the length of this abandoned channel is about 2.97km. Socio-economically this abandoned channel has a great importance over the surrounding area.

Multichhara Beel is another important abandoned channel formed by the mechanism of neck cut off which is located in the left bank of Sankosh River near the village Failaguri of Kokrajhar district of Assam. The length of this abandoned channel is about 2.68km and the depth of water

3.2 m in summer season and 1.8 m in winter season. This abandoned channel is important for agricultural and fishing purposes for the local villagers.



Map 3.7: Location Map of Kamandanga Beel



Map 3.8: Location Map of Purba chhara

3.3.2 Abandoned due to channel avulsion:

Avulsion is the natural process by which flow diverts out of an established river channel in to a new permanent course on the adjacent flood plain (R.L. Slingerland and Norman D. Smith). Avulsions are primarily fluvial features of aggrading floodplains. They are not restricted to any particular pattern, shape, size etc. of a river channel and may recur in any fluvial system for as long as some aggradation continues. Avulsion frequency varies widely among the few modern rivers for which such data exist, and may be as low as 28 years for the Kosi River (Stouthamer & Berendsen 2001).

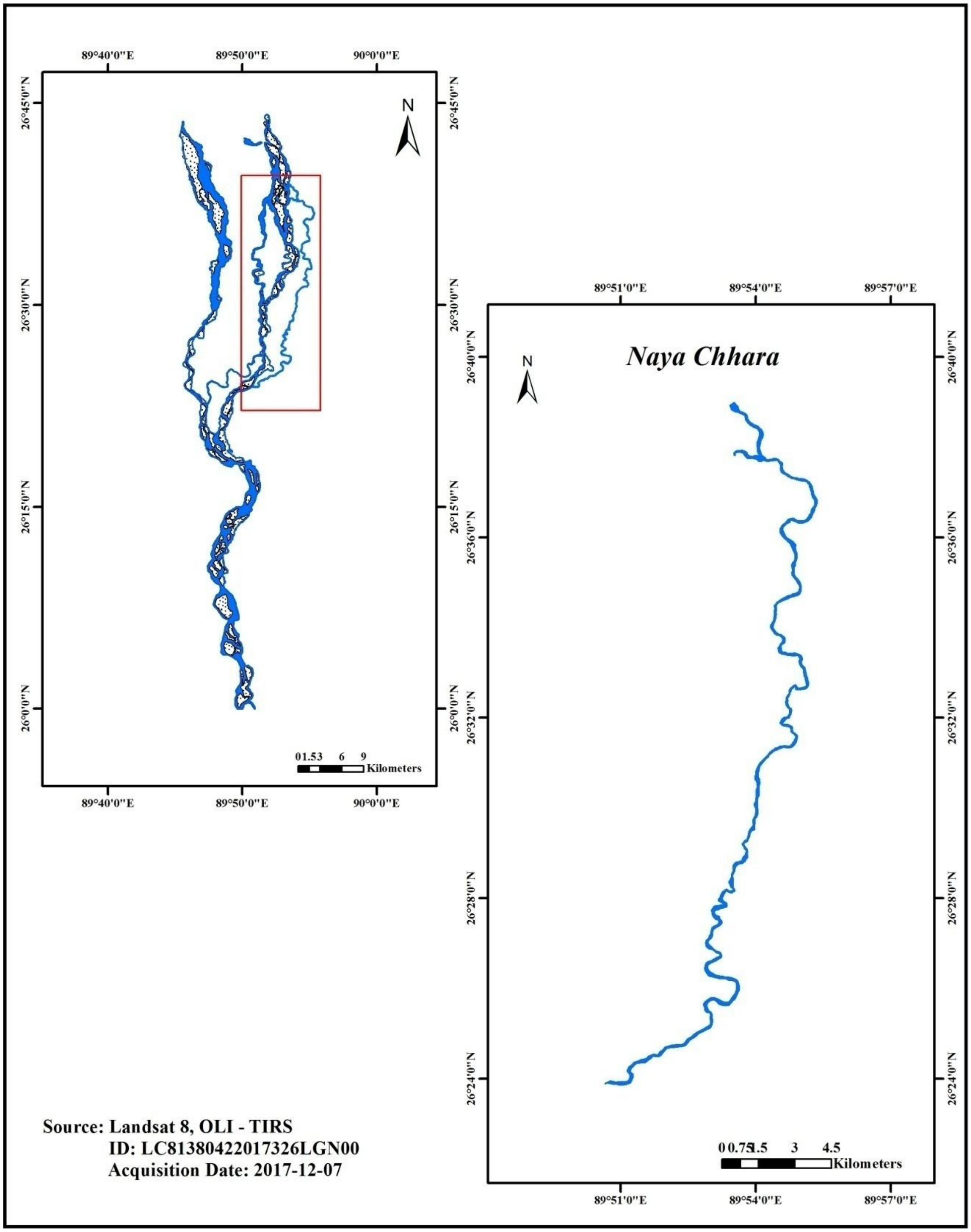
In the study area, it is evident that two types of channel avulsions have been identified. Out of these two types, one is recognized as local channel avulsion at the upstream reach and another is recognized as partial channel avulsion at the middle stream reach. Both types of channel avulsions have occurred due to incision, where new channels are scoured into the floodplain surface as a direct result of the avulsion during peak flood discharge in the study area.

3.3.2.1 Nayachhara:

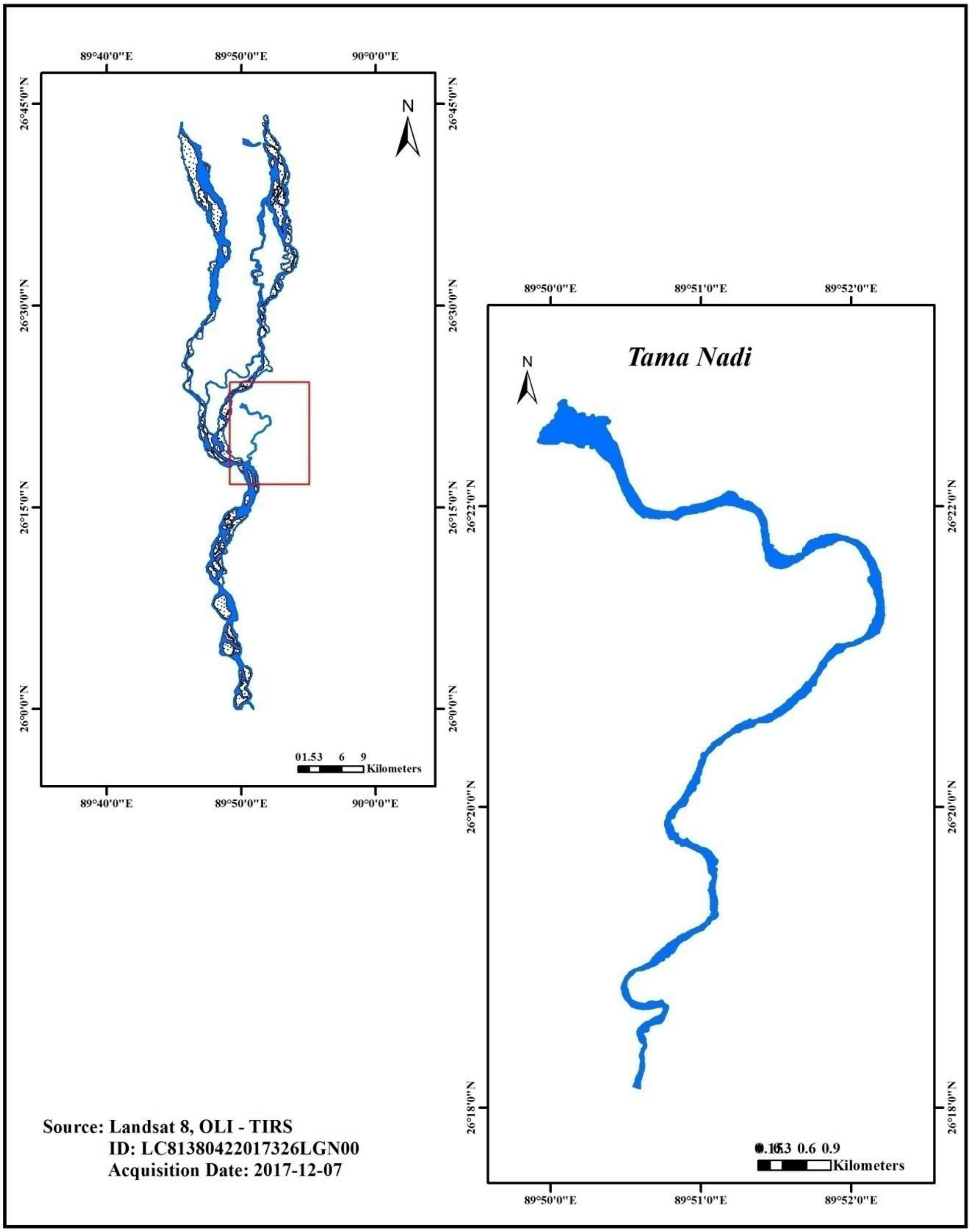
An avulsed channel Nayachhara (Map 3.9) of Sankosh river is found at the Fulkumari village of okrajhar district of Assam in the left bank of the main channel. Due to siltation and dense forest cover, this avulsed channel disconnected with the main river and now flows a few km to the south direction and again meets the main channel of the river Sankosh at Majherdabri village of Cooch Behar district of West Bengal. Numerous meander formations are found in this avulsed channel and it has great importance to local people residing in the surrounding areas of the abandoned channel.

3.3.2.2 Tamanadi:

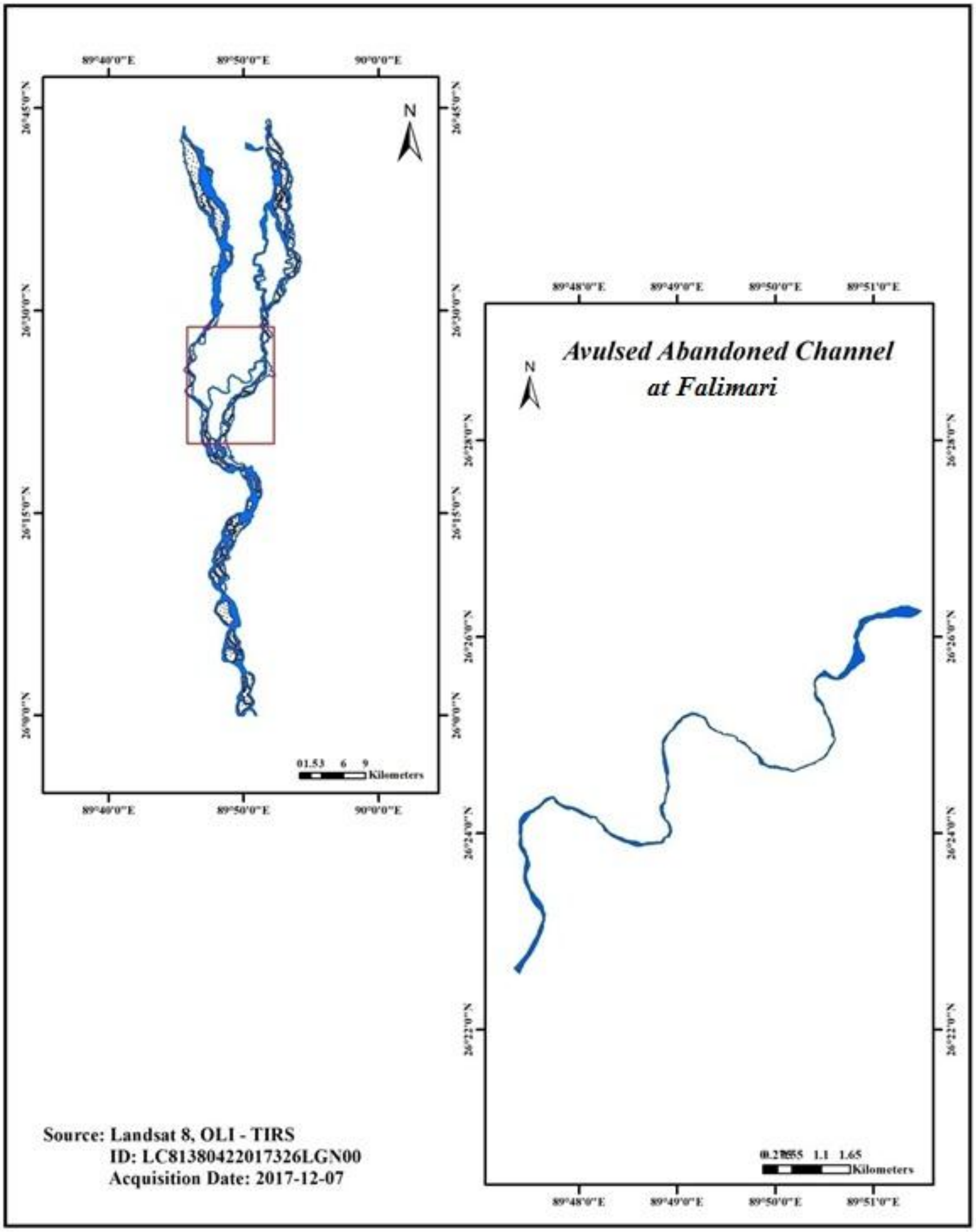
A locally avulsed abandoned channel is found in the middle stream reach of Sankosh River of the study area. It has been observed that Tamanadi (Map 3.10) has formed due to channel infilling at the entrance. The total length of this avulsed abandoned channel is about 13 km. It is noticed that the entrance portion of this avulsed channel forms an extensive flood plain and some portion is occupied by local dwellers for settlement and use of surrounding land for agriculture, livestock grazing and other economic activities.



Map 3.9: Location Map of Naya Chhara



Map 3.10: Location Map of Tama Nadi



Map 3.11: Location Map of Avulsed Abandoned Channel at Falimari

3.3.2.3 Other avulsed abandoned channels:

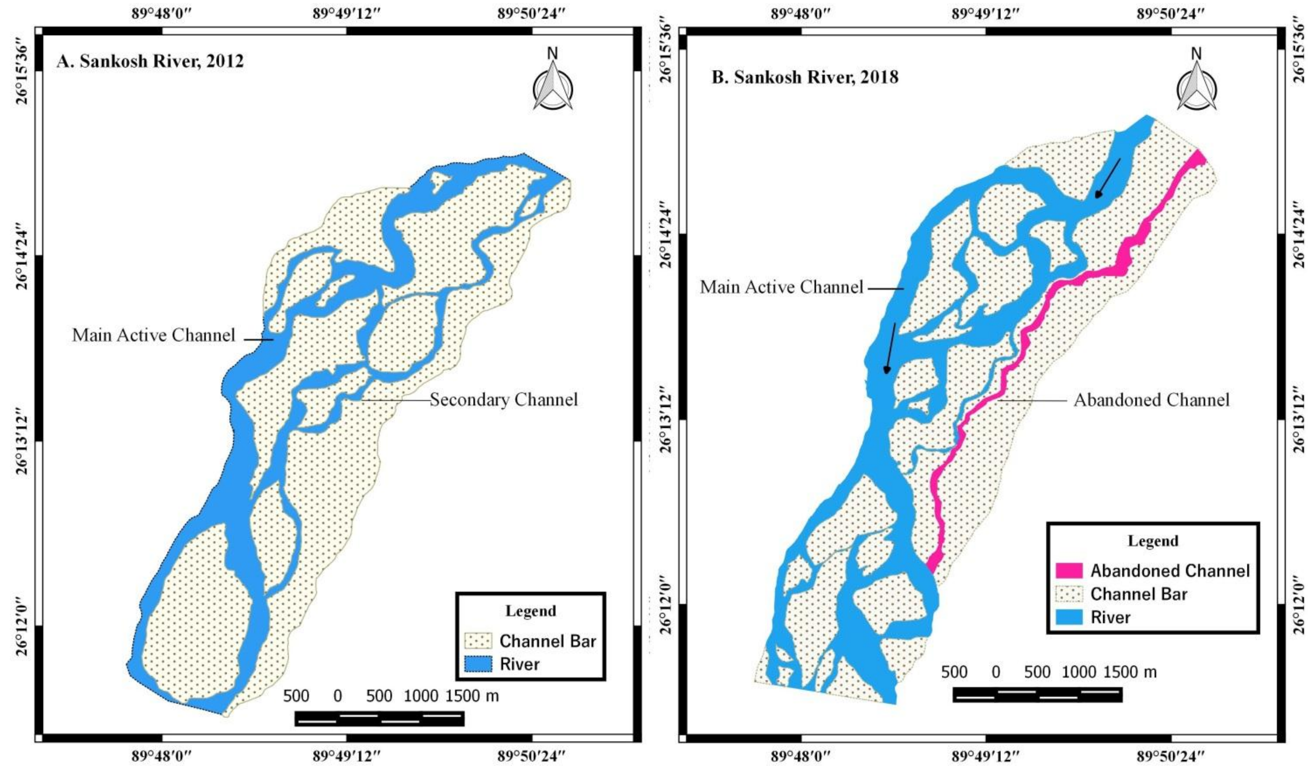
A partial avulsed abandoned channel (Map 3.11) is found in the middle course of the Sankosh River at Majerdabri, Falimari village of Cooch Behar district of West Bengal. The left flow of Sankosh River was called Gadadhar at that time and on the other hand right flow of Sankosh was the main flow of Sankosh River. This abandoned channel avulsed from the main channel of the Sankosh River due to overbank flow, channel in filling factors and joined to the river Raidak-II at Jaldhoya village of Cooch Behar district. The length of this abandoned channel is about 12.8km and width is about 200 m. Jorai Nadi also meets this channel and jointly flows about 16.2km and to meet Raidak-II river. Some areas of this upper portion of avulsed abandoned channel is filled by sediments and at the same time human settlement has taken over some sections. No water flow is found in dry season, only in rainy or flood season water flow is found. Nowadays it has become a source of fertile land for agriculture.

3.3.3 Channel braiding and abandonment

Braiding is one of the most important river patterns of a large river (Chalov, 2001). To respond the pulsation of discharge and sediment load during the flood, the morphological features like various types of bars and channels of braided rivers experience major changes in terms of area, shape and spatial distribution and making the river network complex (Welber et. al.2012). Large braided rivers characterised by wide channels, rapid shifting of bed materials and continuous shifting of the position of the river course (Leopold et. al., 1964). Braided channels have some important characteristics. These are: a) Relatively straight channel banks, b) Division of flow into several channels separated by bars and islands, c) Heavy bed load and shifting of thalweg, d) Wide flat- bottomed shallow transverse section and , e) Relatively steep longitudinal profile etc. In this study area all these above mentioned characteristics are found and form braided reach with multiple sandbars and islands. In this region, the main channel of Sankosh River bifurcates into a number of channels and these channels flowing in between the bars and islands meet and gets divided again and secondary channels remain as abandoned channels (Fig: 3.13) in the study area.

3.3.3.1 One identified abandoned channel at Tamarhat

From the map 3.12, it is observed that Sankosh River at the lower reach in the study area has formed a braided pattern in the year 2012. In this pattern the main active channel is divided into a number of secondary channels and as a result, a mid-channel bar has formed on the channel bed. Continuous deposition of sediment has increased the shape and size of the bar and at the same time the shifting of thalweg has also been observed here. In 2018, this braided pattern has changed due to rapid shifting of bed materials and continuous shifting of the position of the main active channel (Leopold et. al., 1964) of the River Sankosh. In this way, the secondary channels of this braided pattern are becoming abandoned day by day.



Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.12: Channel braiding and abandonment at Tamarhat in the year 2012 to 2018.

3.4 Discussion and Conclusion:

The drainage basin is considered as an important geomorphic unit and which provides water for a particular channel or a set of channels within a basin area. In relation to this, the importance and significance of morphometric analysis of drainage basin are recognized as standard geomorphic units which have been felt over since the publication of the classic paper by Horton (1945). In the present work, morphometric analysis has been done for the basin area of Sankosh

River and various morphometric data have been calculated by using of topographical maps published by the Survey of India and Remote Sensing (RS) and GIS platforms. The ratio of stream channel length to down valley distance was measured along the long profile of Sankosh River which was indicated the alluvial stream. On the other hand, the river discharge which is closely related to the flow velocity and the channel cross sectional area summarizes the process occurring within the alluvial section of the Sankosh river channel and different resultant fluvial landforms such as braid, incised meanders, point bars, riffles and pools have been identified. It is also mentioned that numerous abandoned channels are identified with the study of meander cut-off, channel avulsion and braid formation and explained in this chapter in detail. All these abandoned channels are naturally formed and provide different morphological characteristics along the Sankosh River of the study area.

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CHAPTER IV

MECHANISM OF THE FORMATION OF ABANDONED CHANNELS

4.1 Introduction:

The dynamics of abandoned channels is a main theme in the field of fluvial geomorphology. So the present researcher has focused on the mechanisms which are responsible for their development and formation along the main channel of the river. Abandoned channels are the result from channel shifting processes at various scales, including meander cut-off and channel belt avulsion (Willem H.J. Toonen et.al, 2012). So, it is found that abandoned channels are product of meander bend cut-off (both chute and neck cut-off) on the one hand and channel avulsion is also considered an important mechanism of channel abandonment on the other hand. An avulsion is a process that results in relatively sudden abandonment of a river channel for a new course in the flood plain (Allen, 1965; Kingstone, 1998). It is also mentioned that avulsions differ in their frequency and as well as their size. Moreover, braid formation in alluvial river may also accelerate the process of channel abandonment (Ashmore., 1991). Braided rivers are quite dynamic with strong fluvial activities and rapidly change their flow and subdivided into many branches. During the high flow stages, major changes take places due to rapid rates of stream migration caused by high velocity/ high flow and unstable banks. There can also be extensive changes in stream position as sub-branches flows are abandoned or earlier abandoned channels are reactivated. Lastly, the anthropogenic activities and cumulative human pressure on channel geometry, sediment flux and discharge regime play an important role to channel abandonment. In the study area, all these mechanisms are associated with the channel abandonment.

4.2 Channel avulsion and abandonment:

Avulsion has been defined as a rapid and spatially discontinuous shift of a river or distributaries channel to a new course on a lower part of a floodplain (Allen,1965) and is considered a major fluvial hazard in large population centres (Jain and Sinha, 2009). Avulsion commonly occurred when a reach of the alluvial river is at or near an avulsion threshold (Jones and Schumm, 1999). It is mentioned that the avulsion process can be studied or may be explained through identification and quantitative characterization of threshold conditions and the controlling factors that can help in prediction of channel avulsion (Jain et al, 2012). In the study area, channel avulsion has been occurred in different portions of the main channel and these avulsions differ in their size and frequency.

4.2.1 Factors of channel avulsion:

Channel avulsion largely depends upon the regional slope conditions and lowest elevation in the study area. Therefore, it is said that topographic analysis is the most important factor controlling channel avulsion. In this regard, the relationship between the channel slopes in the cross sectional and longitudinal direction determines the key point of channel avulsion (Map 4.1) Moreover channel movement and temporal changes in plan-form characteristics also influence the avulsion process along the river Sankosh. In this regard an increase in sinuosity results in the decrease in the down valley gradient of the channel with respect to cross valley gradient, which in turn may trigger channel avulsion (Jones and Schumm, 1999). This is actually caused by aggradation of the materials on the down valley sections in respect of upper reach of the channel. This furthermore results in changes of bar area or braid channel ratio (Friend and Sinha, 1993) which may reflect changes in river behaviour in terms of aggradations and degradation processes, which play an important role on channel avulsion process (Map 4.1).

4.2.2 Types of Channel avulsion:

An avulsed channel is formed as a result of the avulsion from the parent channel. Slingerland and Smith (2004) have mentioned that avulsion may be full or partial. According to them, full avulsion results in abandonment of the parent channel downstream of the diversion site, whereas partial avulsion leads to new channel that co-exists with the parent channel. They also mentioned additional classifications of avulsion which include nodal versus random and local versus regional avulsion. Nodal avulsions are recurring events that originate from a nodal area of a flood plain whereas random avulsions may occur from anywhere along the parent channel (Leeder, 1978). Moreover, a local avulsion is one that forms a new channel and alter passing few distance again re-joins its parent channel in the downstream reach where as a regional avulsion indicates a larger scale event, affects the location of the channel everywhere in the downstream reach from the site of origin (Heller and Paola, 1996).

On the basis of Slingerland and Smith’s (2004) classification, partial and local avulsion has been identified in the study area through field observation and analysis of the abandoned channels initially recognised in the topographical maps and satellite images (Map no. 78F/14, 78F/15 and ID: LC81380422017326LGN00, ID: LE71380421991319SGS00)

4.2.3 Channel abandonment by avulsion in the study area:

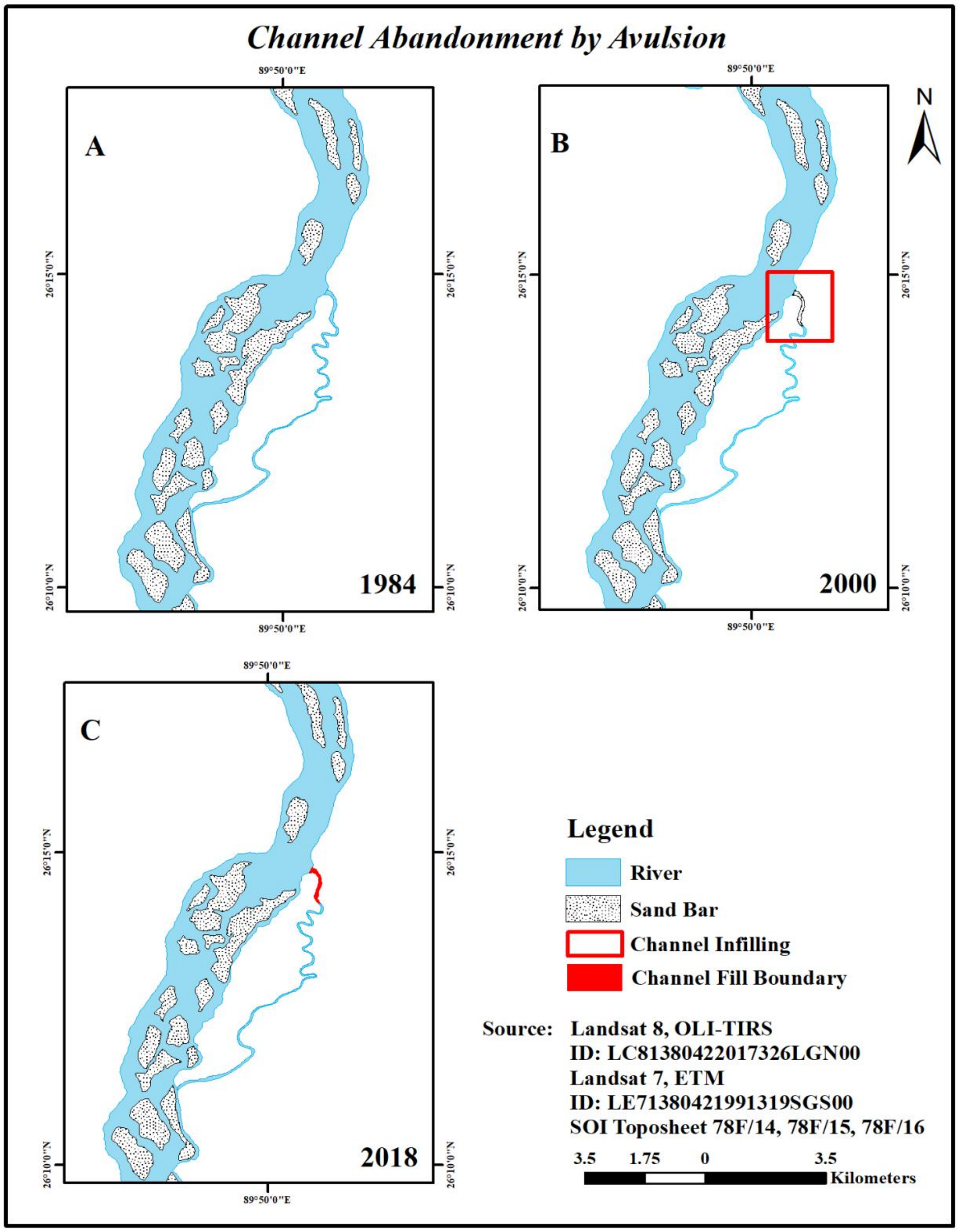
In the alluvial course of the river Sankosh, the river tries to maintain the state of equilibrium with well-balanced conditions of some important hydrological parameters such as the discharge, sediment load, sediment size and the slope. In this regard, it is mentioned that the changes of these parameters cause the change in its course, resulting in aggradation and degradation (Morisawa, M 1968, Starkel.L and Sarkar,S 2002). It is evident from the field data that the length of the cross-section varies from one location to another and from one year to another indicating deposition or erosion at each of the cross-section in the study area. During the field survey it was also observed that there are areas, where very high scouring has been identified. In this regard, it is mentioned that the rate of scouring is 165 cm over a period of 14 years from 1986 to 2000 (WAPCOS, 2003). Moreover, it is observed that high intensity and prolonged rainfall causes devastating landslides and mass movements during the monsoon period in the upper catchment of the Sankosh river. As a result, huge amounts of load are transported from the upper catchment to the river. In this condition, loads are incapable of being transported under the existing hydrological conditions. Thus, the Sankosh river beds are subjected to rise at many places resulting in the lessening of cross-sectional areas which are also incapable of arresting the unusual monsoonal discharge. Ultimately, devastating floods have occurred. Furthermore, it is evident that the sub Himalayan Rivers like Sankosh River is producing a huge amount of sediments (per unit of area) every year and transporting them through the channel. It is found that the concentration of mean annual suspended loads of Sankosh River is 3.62 million metric tons, (Sarkar, S 2008). From the above discussion and evidences, it is observed that the river Sankosh have a tendency to avulsion and the entrance of the avulsed channel has been subjected to aggradation during the flood season with the supply of huge sediments and suspended loads.

In the study area, as revealed from the field observation and from the relevant toposheet maps, it is found that a partial avulsion (Map 4.2) has occurred along the channel of Sankosh river in the study area near upstream and it has extended for a distance of around 12 km and after that this avulsed channel meets the main channel of Raidak River-II at 26^0 19'N. Takula and Jorai Rivers also join with this avulsed channel at midstream. In a partial avulsion, only a portion of the main flow is transferred and leads to a new channel due to the occurrences of high floods that co-exist with the parent channel. In case of partial avulsion, both channels (avulsed channel and main channel) slope remains the same. In this condition, after a period of progradation and basin filling, avulsed channel become abandoned as the gradient advantage between the channel and flood basin is promoted by continuous deposition.

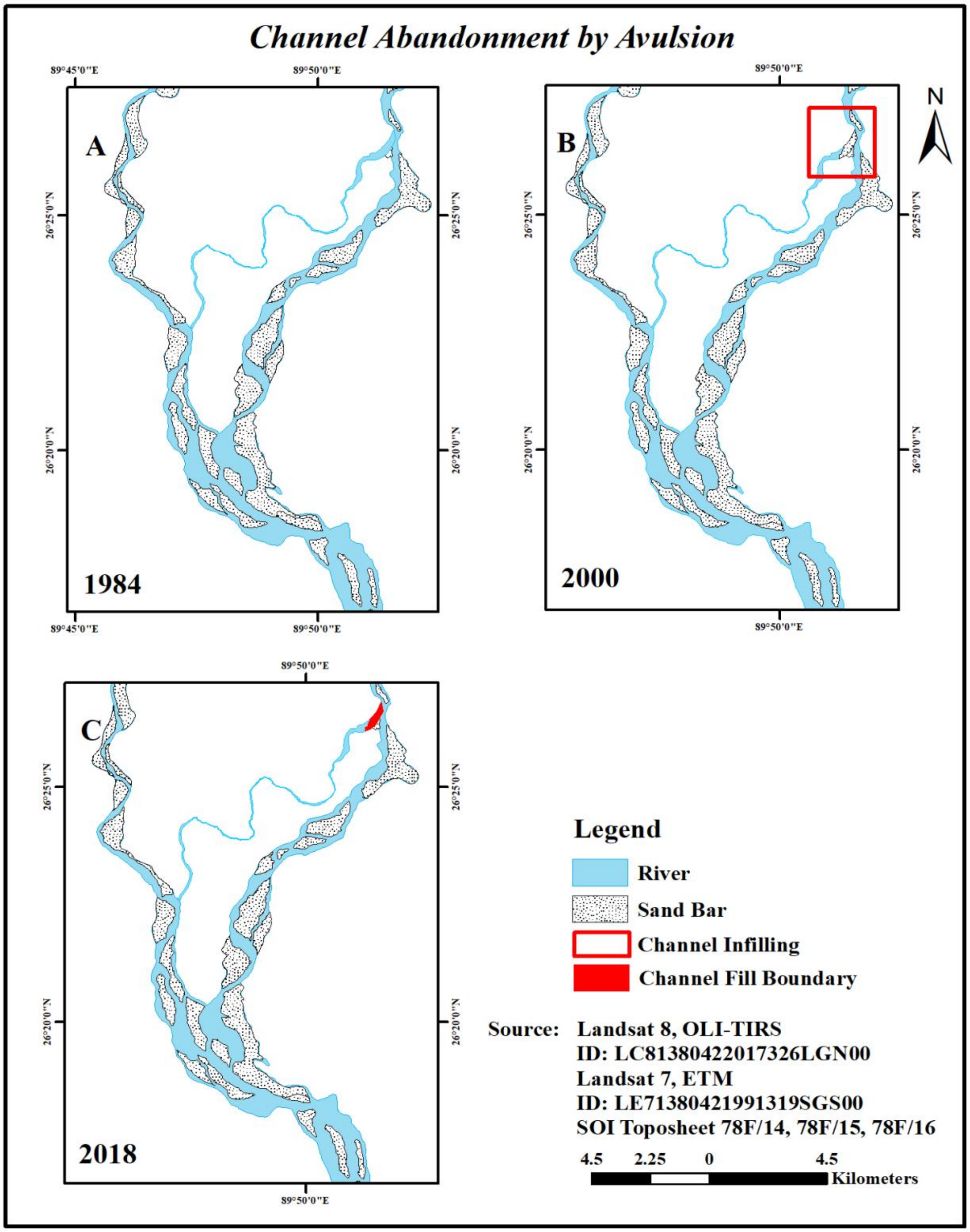
On the other hand, local avulsion has also occurred along the channel of Sankosh River in the study area near upstream and after flowing a few kms of distance, it again re-joins its parent channel at River Sankosh. (Fig: 4.1) Local avulsion has occurred by the process of incision during the peak flood which involves the erosion of new channels directly to the flood plain surface. As the flow proceeds down the flood plain slope, the channel eventually intersects another channel more commonly at a point downstream to the parent channel. The newly occurred incised channel facilitates the huge volume of water during peak flood to obtain a new path to release the water in the form of concentrated run off and thereby the main channel is torn off to a new channel, thus local avulsion takes place. Moreover, as the flood frequency curve of the Sankosh river during monsoon period in the year 2016 (Fig. 3.3) has been reached thrice at danger level (DL) and in the year 2017 (Fig. 3.4) it has been reached once at extreme danger level (EDL). So it is evident that the occurrences of rainstorms are present in the study area is the important cause of channel avulsion.

From the above discussion, it can be said that all the avulsed channels have nowadays become abandoned channels due to the silt deposition at the entrance of avulsion caused by high flood and high sediment load carried by the parent channel during last few years. On the other hand, vegetation cover and different human activities and their settlement and other related activities are also accelerating the process of channel abandonment along the Sankosh River in the study area.

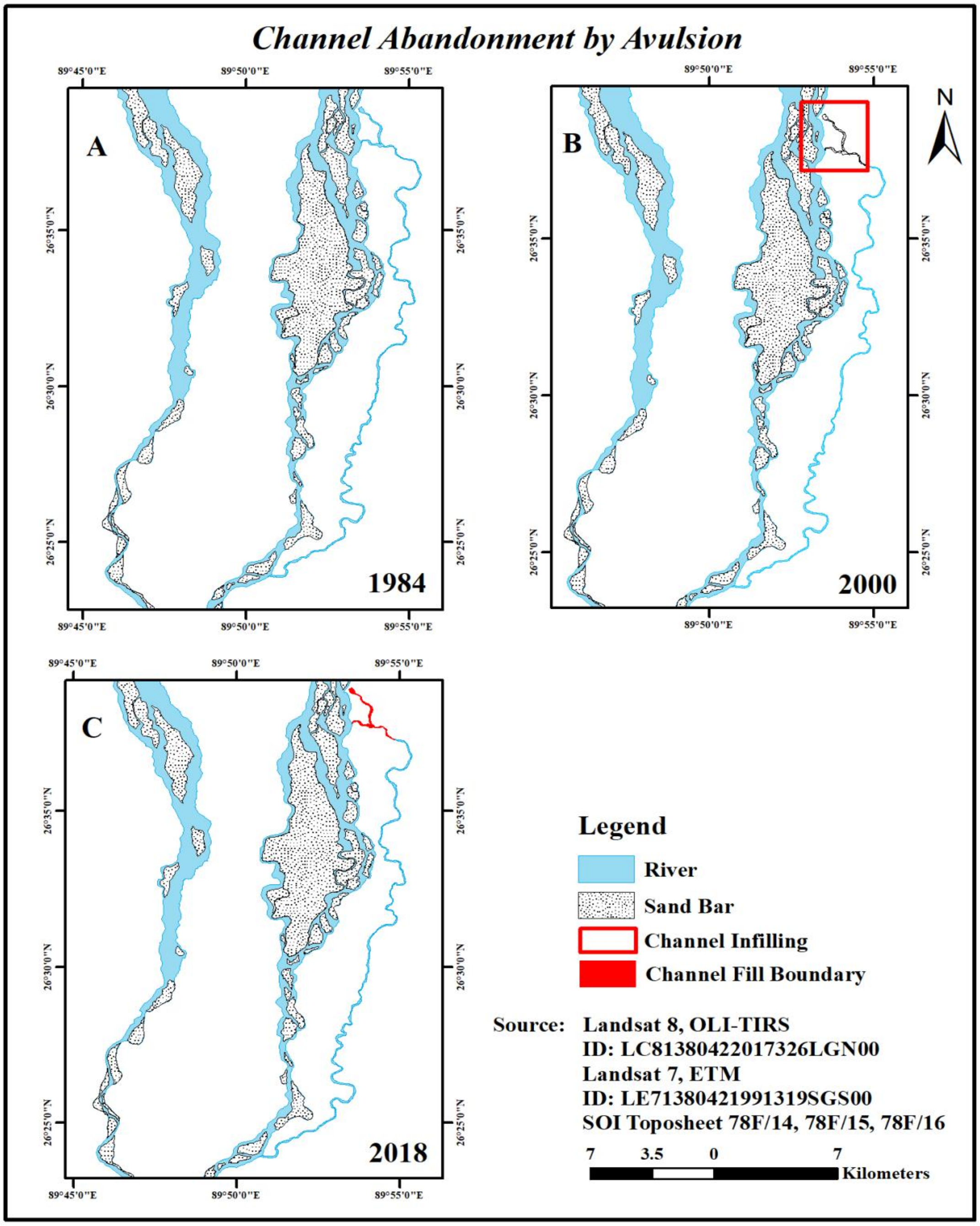
From the above mentioned mechanisms of channel avulsion in the Sankosh river, resulted by the process of aggradation on the channel regime after rain induced high flow, it can be said that the 1^{st} hypothesis '**Abandoned channels occur where stream bed aggradations cause the stream to overflow with rain storms**' is justified and accepted.



Map 4.1: Map shows the Channel Abandoning by Avulsion in the Years 1984, 2000 and 2018.



Map 4.2: Map Shows the Channel Abandoning by Avulsion in the Years 1984, 2000 and 2018.



Map 4.3: Map Shows the Channel Abandoning by Avulsion in the Years 1984, 2000 and 2018.

4.3 Formation of Meander cut-off and channel abandonment:

Meander cut-off is a general process for the development of an alluvial channel or meandering stream. In general, a meandering channel has featured by some deeps (pool) at the concave slope of bends and shallow fills (riffle) at the convex slope of bends along its river course. In consideration "a pool is characterized by a water surface profile less than the mean stream gradient and by finer bed material. Whereas a riffle has water surface slope steeper than the mean stream gradient and is composed of coarser bed material (Morisawa, 1985). Consequently, the most meandering channels having sinuosity index value >1.5 is defined as bends are facing down valley and traverse downstream from a geometric viewpoint.

In the downstream of meandering river, expansion of transverse direction accelerates to bank erosion which leads to shift of meander loops at various rate depends on its planform geology or lithological characters. Eventually the banks at the neck breach by a chute channel, called cut-off that connects the neck of the loop (Gagliano and Howard, 1984; Hooke 1995). Besides bank-breaching, cut-off may also occur when floods incise a floodplain channel or chute that evolves in to the dominant conveyor of river flow (Hooke 1995; Gay et al. 1998). The cut-off initiates channel abandonment and then initial flow continuing with straight down slope. Meandering channel bend may graduals developed again in another part after the formation of ox-bow lake as an abandoned channel.

4.3.1. Controlling Factors of Meander cut-off:

The incision of chutes has occurred due to over bank flow (Howard & Knutson, 1984) and a significant stage difference between the upstream and downstream ends accelerated the process of chute formation when a gradient advantage is attained with respect to the original bend of main river (Grenfell et al., 2012). The above explanation, keeping in mind various controlling factors, has been identified for meander cut-off in the study area. These are:

4.3.1.1. In channel flow features:

During the flood season, water levels is normally raised and stage difference along the meander undergoing cut-off further is increased by the formation of plug bars. In the Map no. 4.4, it is observed that continuous sediment deposition has occurred during the past historical floods

(Table no.3.2) which formed plug bar within the main channel. As a result, the bend apex promotes a tendency of the stream to bifurcate into an outer and then inner part and is subjected to a potential precursor of chute cut-off.

4.3.1.2. Discharge variability:

According to Schuurman et. al., (2016) Discharge variability is an important factor for the formation of chute cut-off. Here it is mentioned that the frequency and occurrences of chute cut-off is closely related to the changes of the frequency of flood events in the study area because discharge variability depend on the changes of the frequency of the flood events.

4.3.1.3. River morphology:

According to Howard & Knutson, 1984 wide channel is favourable for chute cut-off where bend curvature is strong. In the study area, it is observed that the middle reach of the Sankosh River is very wide and forms a number of meander bends and at the same time a number of strong bend curvatures are also formed. As a result, chute cut-off is formed due to strong bend curvature along the River Sankosh at the middle reach in the study area.

In our study basin of river Sankosh (lower course) we have found several meandering cut-offs which are at present, existing as abandoned channels also called oxbow lakes. These abandoned channel formation process through meandering chute cut-off and neck cut-off is illustrated in below figure (fig.4.4) in a schematic manner. There are mainly four stages of abandonment which are generally distinguished under the below discussion.

4.3.2 Cut-off initiation:

According to Lewis and Lewin, (1993); Hooke (1995); the triggering of the cut-off initiates when the majority of the river discharge becomes diverted from the meander and starts to flow along the newly activate channel. In catchment of Sankosh downstream, due to heavy rain storms every year there is an increase in the channel discharge and velocity which accelerate the meander incisions in its expected thalweg course. As a result of discharge diversion downstream, extension and in-channel flow velocity get triggered. An accumulation of these causes, meander cut-offs may be the utmost result of this basin, wherein the consequent localized erosion of bank material in some cases lead to the formation of a pre-chute erosional embayment (Constantine et al. 2010).

4.3.3 Plug bar and Point bar formation:

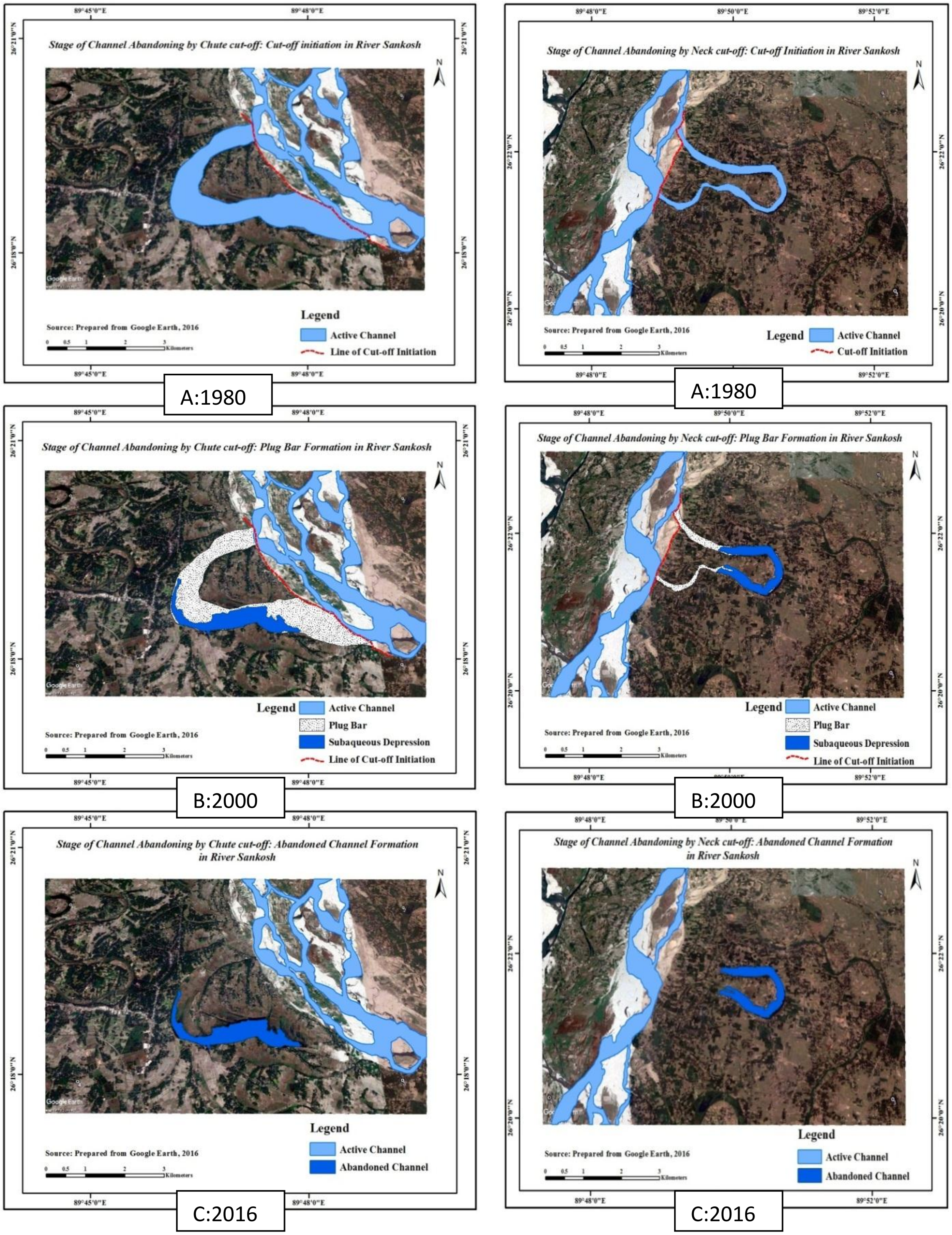
The plug bar is defined as a bed sediment bar that forms at the entrance of a bifurcated channel, hindering flow into a channel (Fisk, 1947; Gagliano and Howard, 1984; Hooke, 1995). Angle of the entrance of a channel from main flow and depositional figures (bars, cones etc) of landscape are the influencing factor to determine the permanence and thickness of a plug at pre cut-off situation. Here in my research I have found that meander channel entrances have connected to inner bends which are responsible for more and more bed load supply. In the Sankosh downstream areas, near inner bends of Khalisamari Beel, the plug bar (Map 4.4) has been perpetuated by bed load supply and with more bed load appears to stop the inner channel flow and resulted cut-off from the crest of bends.

4.3.4 Swallowing and narrowing:

Plug bar formation and in channel deposition result in channel swallowing. In the present investigation, it was observed that recent active channel shallowing due to bar formation and sedimentation have resulted in high river bank flow during successive floods. So it is clear that the swallowing of channel gets associated with reduction of water level. In this regard, in-channel deposition not only causes shallowing of channels but it is also significant for narrowing of channels. Both the rate of swallowing and narrowing are the controlling factors which put the channel regime in instability threshold. Eventually the abandonment of that part of the channel in the form of cut off takes place, following the disconnection mechanism (discussed below) after threshold exceedance. Thus, infrequent rainstorms during peak monsoon, flooding, shallowing and narrowing by aggradation all combine to cause abandonment of channels of Sankosh River.

By Chute cut-off

By Neck cut-off



Map 4.4: Meander Cut-off by Chute and Neck Cut-off

From the above figure, it has been found that a highly meandering course of Sankosh river was formed on the right bank at the villages of Falimari of Cooch Behar District of West Bengal and Koimari and Khalishamari villages of the Dhubri District of Assam. It is evident that a meander chute cut-off was initiated with the deposition of sediments at the inner part of the bend and it was gradually increased with the occurrences of successive extreme bankful discharge. As a result, meander channel entrances that have connected to inner bends are responsible for more and more bedload supply. In that position plug bar formation was started at Sankosh downstream near inner bends of Khalisamari Beel and finally the plug bar (Map 4.4) formation has been completed by bed load supply and more bed load appeared to stop the inner channel flow and resulted cut-off from the crest of bends.

4.3.5 Disconnection:

It can be noted, the flooding regime within the active channel is not stationary (Citterio and Piegay.2000; Piegay et al., 2000, 2002, 2008). So, it has been mentioned that Sankosh River basin was not influenced by flood in every year. As a result, by filling of coarse and fine sediments up to the proximity to the active channel and maturity of plug bar formation, consequently, after that there is a decreasing rate of upstream discharge and lowering of the water level resulting in channel disconnection and abandonment at Sankosh downstream near inner bends of Khalisamari Beel and at the same time some important *subaqueous topographic depressions* are also formed as geomorphic features in the study area of Sankosh River basin.

In the study area, it is found that the disconnection of the meander bend with the main channel had occurred after the completion of plug bar formation. This disconnected portion of meander bend is recognized as chute cut-off and then becomes an abandoned channel in the study area. The length of the abandoned channel decreases day by day due to gradual siltation and at the same time with the extension of agricultural land and settlement in and around the abandoned channel (Map 4.4).

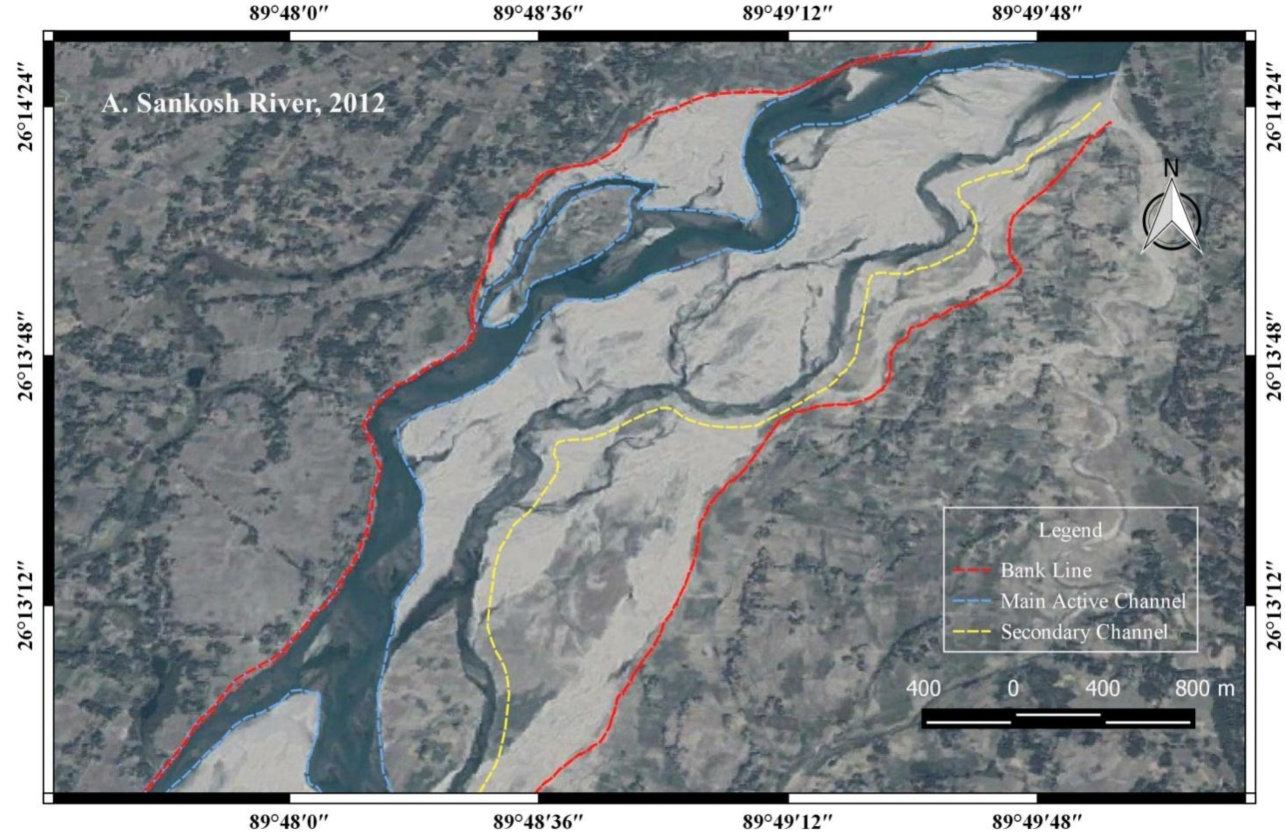
River by aggradation on one bank and rapid erosion on the other, which makes torturous meander bends unstable and cut off takes place with significant reduction of sinuosity when meander threshold is crossed. Therefore, the hypothesis 2 '**Channel abandonment has positive relation with instability threshold of bank erosion**' is justified and proved.

4.4 Other mechanisms found in Sankosh River:

During the field survey it was found that the abandonment of channels also occurs by the mechanism of braid formation at the lower reaches of the Sankosh River in the study area. The whole process of channel abandoning by the mechanism of channel braiding has been discussed under the following heads.

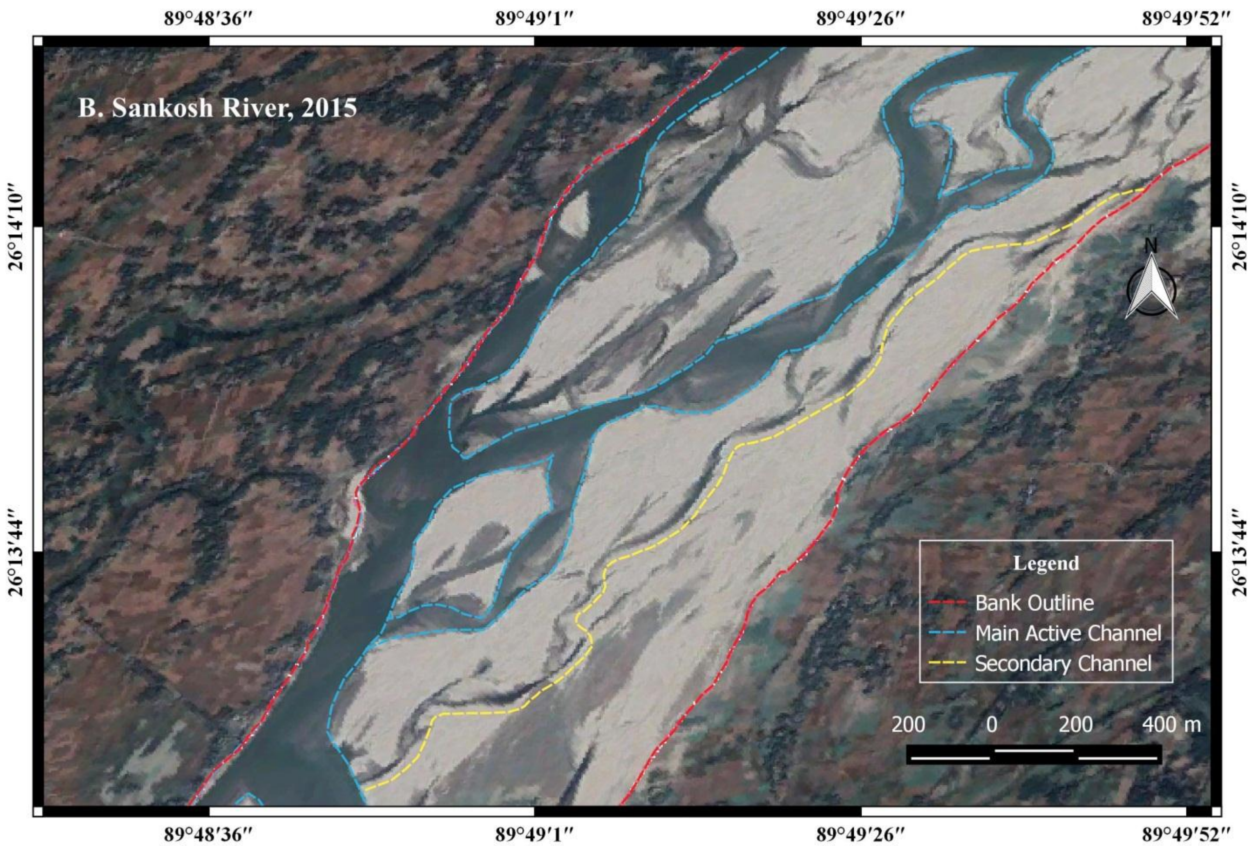
4.4.1 Braiding and abandonment:

Braided rivers are wide and shallow and it divided into a number of semi stable or unstable middle bars, transverse bars or islands. Braided rivers are defined as one that flow in two or more channels around alluvial bars or islands. Brice (1964), in his work Loup River in Nebraska, has attempted to define the braiding pattern by an index called *Braiding Index*. According to him this is ratio of twice the sum of the lengths of bars and islands in the reach to the length of the reach measured midway parallel to the banks. Fahnestock (1963), Leopold et al (1964), Schumm (1977) have defined braided channels as single channel bed load rivers, which at low water has islands composed of sediments or relatively permanent vegetated islands, in contrast to multichannel rivers in which each branch may have its individual pattern. It is mentioned that braiding of river is mainly governed by its high sediment load and its weak bank materials. According to Goswami et.al, 1991, 1992; the intensity of braided channel is marked by drastic channel changes, dramatic bank line recession, rapid aggradations of river bed and active process of braiding and bar formation. In this regard, it is observed that the main channel of Sankosh River bifurcates into a number of channels and these channels flowing in between the bars and islands meet and gets divided again and secondary channels remain as abandoned channels (Fig:4.5) in the study area.



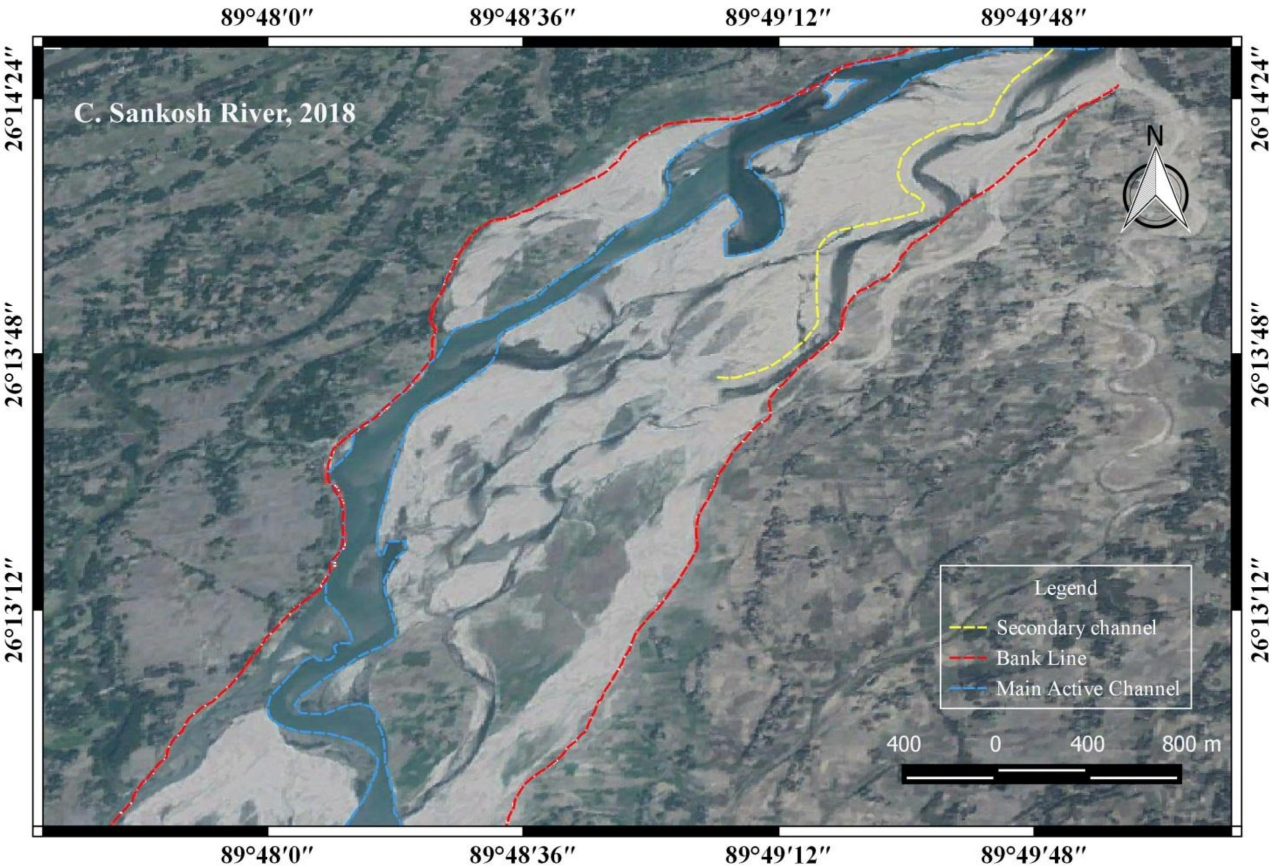
Source: Google Earth, 2016

Map 4.5: Map shows the Braided Pattern of Sankosh River in 2012.



Source: Google Earth, 2016

Map 4.6: Map shows the Braided Pattern of Sankosh River in 2015.



Source: Google Earth, 2016

Map 4.7: Map Shows the Braided Pattern with Abandoned Channel (Secondary Channel) in 2018

A braiding index includes both the total braiding intensity (BI_T) and Active braiding intensity (BI_A) which determines the flow level of the channel and the transformation of bed materials at a given time. In this context, it is mentioned that the gradual development of the braided network (BI_T) demonstrates that new channels continue to be added and abandoned over a significant period of time. However, for a given discharge, a stable average value of BI_T is established in equilibrium with prevailing discharge. The fact that BI_A remains essentially constant during this process indicates that BI_T develops by sequential, rather than simultaneous, formation of new channels or abandonment of former channels.

A fully developed braided river able to convey all the flow within the channel network and at this position BI_A and BI_T remains approximately constant on average. But the braided pattern configuration continues to change by partial avulsion which temporarily adds active secondary channel segments branching from the main channel of the Sankosh River. Moreover, the network continually changes configuration by local switching of the main channel and formation or abandoned of secondary channels related to migration of the main active channel. In this way the formation of a second, large active channel drew water from the smaller chute channels and which was able to reduce BI_T (BI_T= Total Braiding Intensity) but increased BI_A (BI_A= Annual Braiding Intensity) for some periods of time. It can also be mentioned that this second active channel was later divided due to the formation of mid channel bar and which also diverted a portion of the flow into a new channel and previously abandoned chute cut-off channels. In this way, total braiding intensity is increased and there is shortening of the length of the active portion of the second active channel. Naturally, these new channels increased the flow to the main active channel, which then fall into a process of migration, bar formation and create partial avulsion in the downstream area of the flume.

4.4.2 Factors influencing river braiding:

Bristow and Best (1993) have mentioned that the discharge fluctuations are a prerequisite for braiding especially in sand bed rivers. It is also mentioned that rivers may act as a single course during bankful conditions and it reveals braided pattern at lower stages. Braiding of river is influenced by different factors. According to Lane (1957), the braiding can be caused by two main factors, namely *Overloading* and *Steep slopes*.

Braiding index values calculated for the Sankosh river reach of the study area using Brice method (1964) shown below table.

$$\textbf{\textit{Braiding index (BI)}} = \frac{\mathbf{2(Li)}}{\mathbf{L}}$$

Where, Li= Sum of the length of the braid bars and islands

L= Length of the river course

Table 4.1: Braiding Index at Different Reach of Sankosh River

Channel Section of the Sankosh River Reach	Computed Braiding Index
Upstream reach/ section	1.97
Middle stream reach/ section	2.05
Downstream reach/ section	4.03
Sankosh River reach/ section (Average)	2.23

Based on Topographical map

From the above table 4.1, it is evident that the upstream reach of Sankosh River exhibits very low degree of braiding with computed braiding value of 1.97 and the middle stream reach with low braiding index value of 2.05. On the other hand, the downstream exhibits high degree of braiding with braiding index value of 4.03. So, it is observed that the braiding index values of Sankosh River at different reaches shows increasing trend of braiding from upstream to downstream. There are several factors associated with channel braiding of Sankosh River. These are:

a. Decrease of channel gradient gradually toward the downstream of Sankosh River,
b. Bed aggradations occur due to continuous sediment deposition in the Sankosh River bed,
c. Fluctuations of water discharge in pre-monsoon, monsoon and post monsoon and in flood season in Sankosh River, and
d. Frequent changes of channels in the lower reach of Sankosh River.

From the above discussions, it is found that the braiding index value gradually increases from upstream to downstream of the Sankosh River and initiates the process of channel abandoning in the lower course of the study area.

4.4.3 Mechanism of river braiding:

Braiding is one of the most important river patterns of large river (Chalov, 2001). To respond the pulsation of discharge and sediment load during the flood, the morphological features like various types of bars and channels of braided rivers experience major changes in terms of area, shape and spatial distribution and making the river network complex (Welber et. al.2012).

Alluvial rivers are characterized by channel braiding and this has a complex mechanism. Ashmore (1991) has been identified four types of mechanisms of channel braiding. These are:

a. *Middle bar accretion*
b. *Transverse conversion*
c. *Chute cut-off and*
d. *Multiple bar disconnection*

Leopold and Wolman (1957) were the first to study the mechanism of inception and development of braided plan forms through laboratory experiments. According to them, the development of braided planform by middle bar accretion which takes place through a sequence of events that comprises of deposition in mid-river and erosion of banks.

All these processes or bar formation has also been observed in the study area, i.e. along the channel of Sankosh River. Due to the low channel gradient, the lower reach of Sankosh River naturally favours the growth of central bars, which cause deflection of flow towards the bank initiating erosion and on the other hand, the channel bars continue to grow upwards to the water surface. Subsequently, local scour in the channel lower the water level causing the bars to come out of water as an island. As a result, the bars cause a decrease in total cross-sectional area leading thereby to instability of the channel and then lateral erosion starts on the one or both the banks. In this way, by repetition of these processes, a well-developed braided channel pattern with multiple sand bars and island is produced in the divided reach of the Sankosh River.

Moreover, the mechanism involves the deposition of coarse grains carried as a bed load by the river flow, where a small change of local flow depth can be adequate to reduce the local bed shear stress below the threshold bed shear stress, being incompetent to transport the coarser particles inside middle bar in the Sankosh River. In the lower part of the study area, this type of middle bar formation is found. In this regard, it is investigated that, the main channel of the Sankosh river bifurcates into a number of channels i.e. secondary channels and these channels that are flowing in between bars and islands meet and get divided again and finally after a period of time these secondary channels get disconnected from the main channel due to headward extension of the bar and remain as an abandoned channel in the study area.

Plate 4.1: Measurement of meander cut-off

Plate 4.2: Measurement of Avulsed Channel

4.5 Discussion and Conclusion:

Abandoned channels result from channel shifting processes at various scales, including meander bend cut-off (both chute cut-off and neck cut-off) and channel belt avulsion (W.H.J. Toonen et al, 2012). In this regard it is explained that the process of diversion of the main flow, causing meander cut-off or the avulsion bifurcation, triggers the initial stage of channel abandonment which leads to plug bar formation at the entrance and then shallowing and narrowing in the channel downstream along the Sankosh river in the study area on one hand, continuous sedimentation, channel infilling during peak flood events accelerates the disconnection stage of the channel abandonment along the Sankosh river on the other hand. It is also observed that plug bar formation due to bed load aggradations at the entrance of the meander bend is recognized as the important process of the formation of oxbow lake which is later on considered as abandoned channels in the study area. Moreover, the mechanism of channel abandoning of Sankosh River in the study area is also explained by the processes of channel avulsion. During the field study channel abandonment by braid formation has also been observed and analyzed in this chapter with suitable cartographic techniques.

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CHAPTER V

RESULTANT LANDFORMS OF ABANDONED CHANNELS

5.1 Introduction:

Abandoned channels are the result of meander neck and chute cut-off and channel avulsion. In this regard, it is said that channel infilling is considered a more useful record of channel abandonment processes (Willem H.J.Toonen et al. 2012). The investigator here focuses mainly on the study of various channels abandonment style and associated sedimentary landforms with them in the study area.

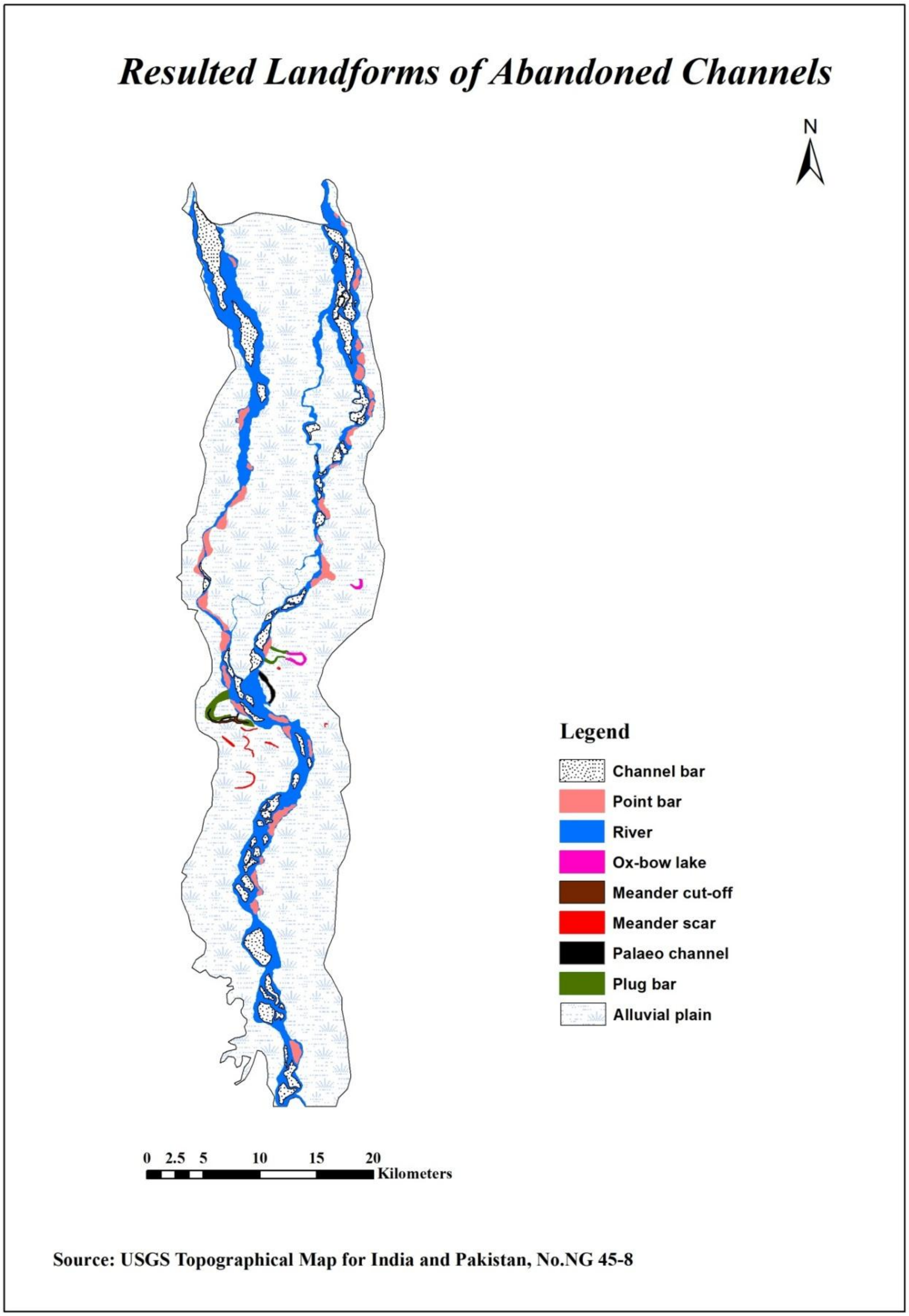
The common type of abandoned channels are: i) oxbow lake: which are formed by single meander bend neck and chute cutoff (Fisk,1947; Lewis and Lewin,1983; Hooke,1995, Larsem, 2011) and ii) channels abandoned over multiple meander lengths, left inactive due to an upstream avulsion (Smith et al., 1989; Southamer and Barendsen, 2000). In the study area, both types of channel abandonment are found and which left a wide scope of the study of associated sedimentary landforms within them.

5.2 Resultant sedimentary landforms associated with abandoned channels:

In the study area, following resultant landforms are identified at the time of field study in different reaches of River Sankosh. These are:

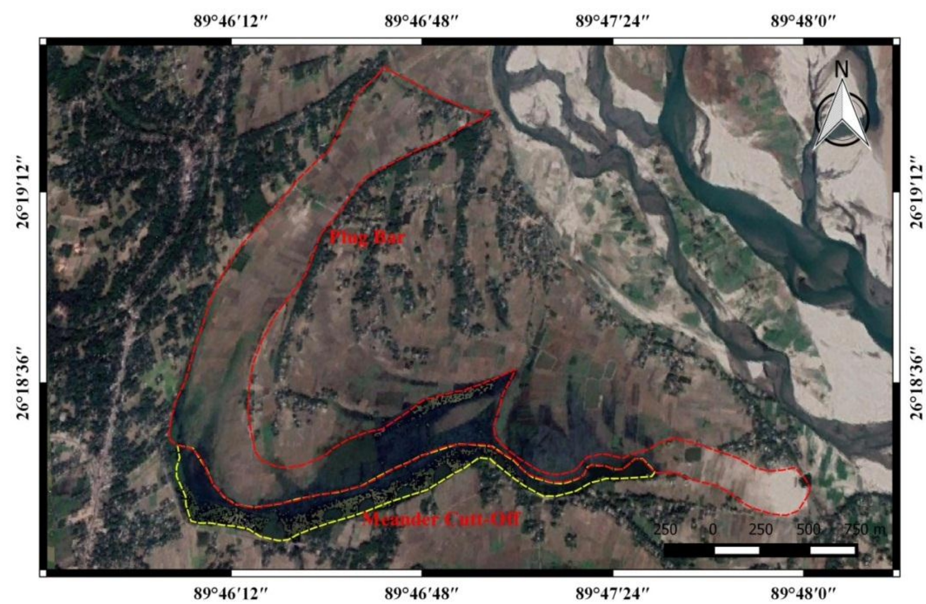
5.2.1 Meander cut- off:

Meander cut-off is the most important mechanics of channel abandonment. When meander bends cut-off initiates, this effectively reduces the length of the flow path and at the same time it increases the channel gradient in the new channel. As a result, transport capacity is remarkably reduced within the abandoned bend and triggers mixed load accumulation and starts the preservation of underlying channel bed forms. It can also be mentioned that when a cut-off meander actually forms, some portions of the former main channel become sited in isolating the meander bend from the rest of the river.



Map 5.1: Resulted Landform of Abandoned Channels, 2018

In the study area, it is observed that Khalishamari beel is located on the right bank of Sankosh River and Kamandanga beel is situated on the left bank of Sankosh River. Both are considered as meander cut offs that have become abandoned channels at present. These are formed due to the accumulation of mixed load for a long period of time and where preservation of underlying channel bed forms has occurred. Some portion of both meander cut-off is occupied by the local people inhabiting the surroundings of these abandoned channels and the area of these channels shrink day by day (Map 5.2).

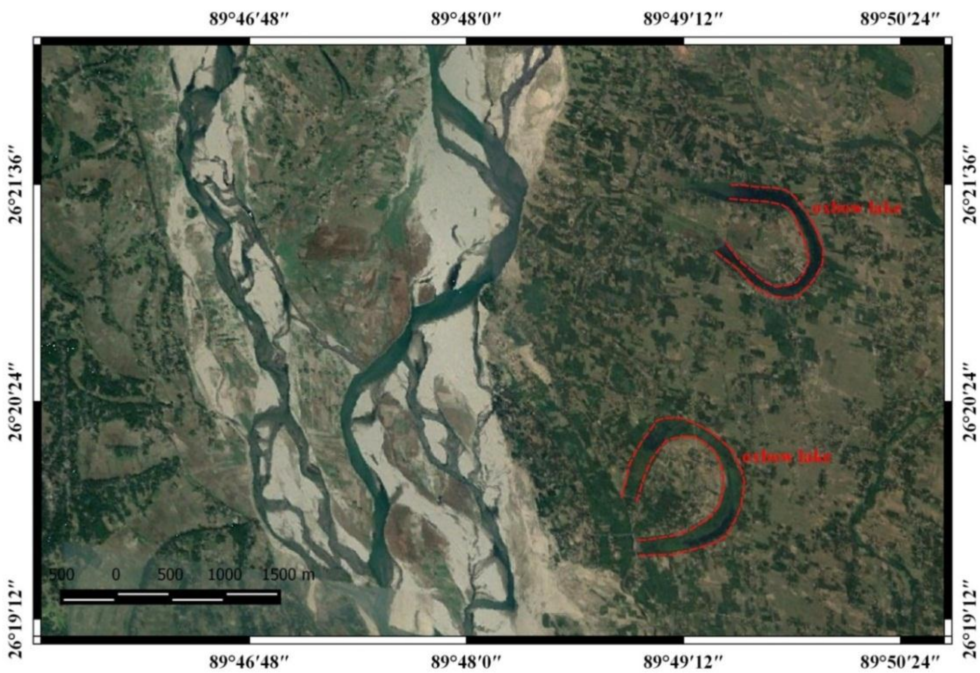


Map 5.2, Meander Cut-off (Khalishamari beel)

5.2.2 Ox-Bow Lake:

Abandoned channels remain as ox bow lakes in the flood plain. It is observed that after the initial cut off event during a flood, sedimentary processes begin to seal off the channel, especially during the initial and subsequent floods. Ultimately, the bend of meander can become a disconnected ox bow lake in the flood plain (Willem H.J.Toonen et al. 2012). After that these abandoned meanders (Ox-Bow Lake) carry a very small percentage of the discharge during rare high magnitude floods only. It is also mentioned that ox bow lakes are considered as the resultant depositional landforms of abandoned channels in the study area.

During the field study it is observed that a number of ox bow lakes are formed in the both bank of Sankosh River in the lower reach of the study area. In this regard, Kamandanga beel and Ghirtinga beel (Map 5.3) have been shown in the map. Both the ox bow lakes have formed due to the neck cut-off mechanism. These are the sources of huge aquatic resources which have much economic value and at the same time, people use water of these ox bow lake for irrigation and other domestic purposes.

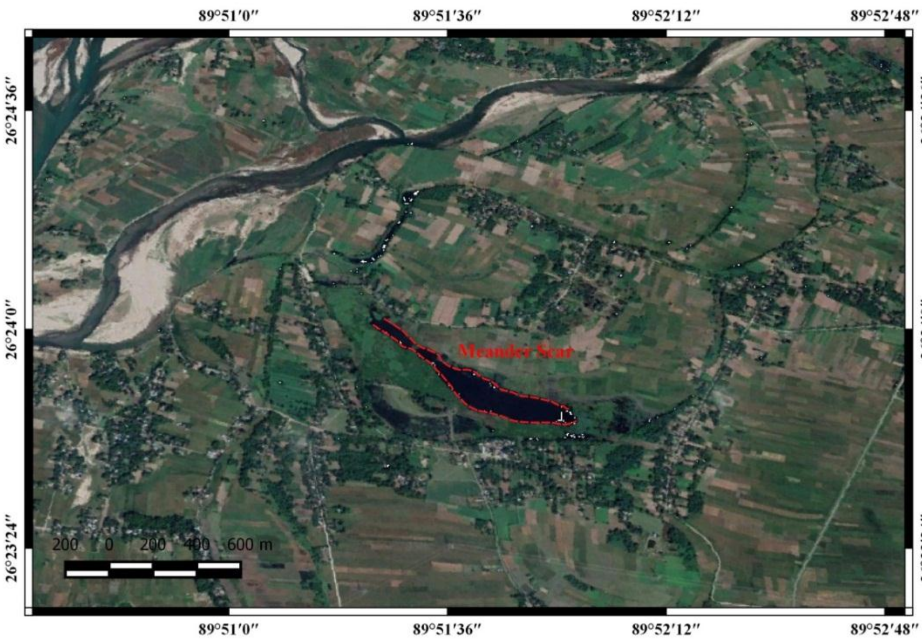


Map 5.3: Ox Bow Lake (Kamandanga beel and Ghirtinga beel)

5.2.3Meander Scar:

Flood plains of large rivers are littered with numerous ox bow lakes. In addition to the ox bow lakes, it is mentioned that the adjacent point bar deposits occur on the inside of a migrating meander and it tends to build numerous crescent sandy ridges that are parallel. These types of features are known as meander scars. It is also called the remnants of a meandering water channel, currently found within the river channel.

In the study area, numbers of meander scars are found in the left and right bank of Sankosh River. A meander scar has been identified on the left bank of Sankosh River (Map 5.4) at the village Garumarachar –II in the study area. This meander scar previously was a meander bend of the main channel and then due to continuous channel fills it is disconnected from the main channel and has remained as a meander bend cut-off for long time. At present it is situated as a remnant of meander channel. Lowering of water depth, shrinkage of its area, increase of human settlement etc are observed during the field survey as the main problems of this meander scar.



Map 5.4: Meander Scar

5.2.4 Palaeo channels:

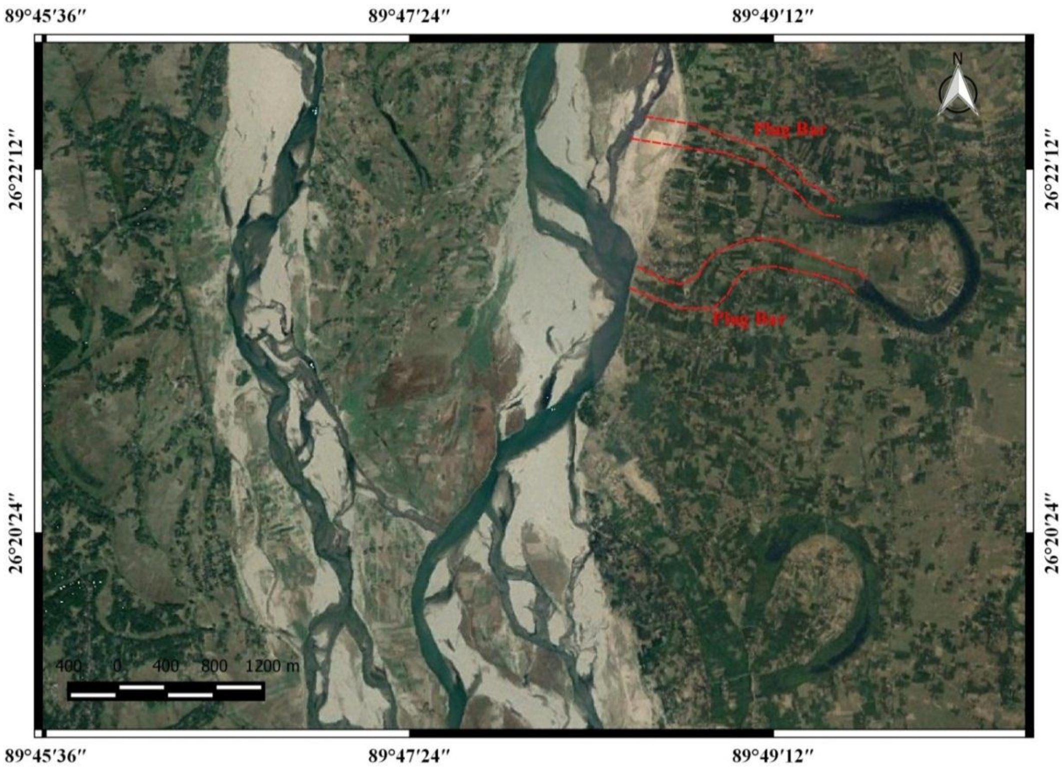
A palaeochannel is a remnant of an inactive river or stream channel. It has been filled up or buried up by younger sediment for a long time. A palaeochannel is distinct from the over bank deposit of currently active river channels. It is mentioned that palaeochannels can be easily identified as broad erosional channels into a basement that underlines a system of depositional sequences that may contain a number of episodes of deposition and represent meandering peneplain streams. Palaeochannels form when river channels continuously aggrade and so, sediment deposition occurs on their bed in a sequence. Palaeochannels may also be preserved on non-depositional floodplains in which the main river migrates or avulses away from its previous river course on a short term basis.

It is evident that in the study area the existence of numerous palaeochannels is found. Older erosional surfaces and levels, sedimentary records, climate change, history of rainfall, history floods are notably mentioned as evidences in this regard in the study area. It was the main channel in the past but due the meander cut-off and westward shifting of the main channel it remained as abandoned channel for a long period of time and at present it became a palaeochannel in the study area due to sequential deposition for a long time. Moreover, it is also observed that, a number of palaeochannels occur on the right bank of the river Sankosh which were also the evidence of the former main channel shifting in the study area.

5.2.5 Plug bar:

The plug bar is defined as a bed sediment bar form at the entrance of a bifurcation channel, hindering flow into a channel (Fisk,1947; Gaghiano & Howard 1984; Hooke,1995). Bulle (1926) It is observed that the entrances of the channels are connected to inner bends which is considered more susceptible to plug bar formation because of huge bed load supply. It is also evident that plug bar formation is characterized by high sedimentation rates during the onset of abandonment.

In the study area, plug bar is recognized as an important depositional feature which formed at the entrance of meander bend cut off of Sankosh River and accelerates the process of channel abandoning. During the field survey it is observed that plug bar formation has occurred along and around the Khalisamari & Kamandanga beel. (Map 5.5). Khalishamari beel is an example of chute cut-off and its entrance received huge amount of sediment for the formation of plug bar. Continuous deposition of sediment at the entrance is finally formed as a plug bar at the entrance of Khalishamari beel in the study area.



Map 5.5: Plug bar

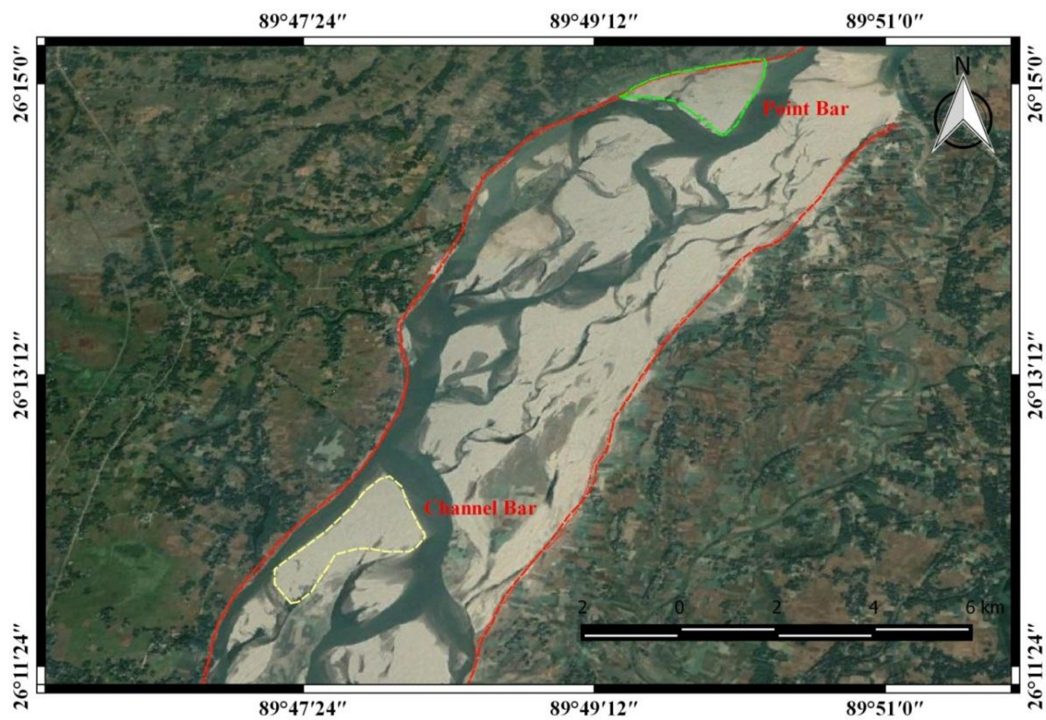
5.2.6 Point bar:

This alluvial river has formed numerous meander bends and the water flows within these bends in a helical pattern. It is mentioned that the water in the meander bends erodes concave banks due to the centrifugal force. It is also mentioned that greater the radius of curvature of the meander bends, lesser is the centrifugal force that acts on it. In this condition, the thalweg gradually shifts towards the concave bank due to continuous bank erosion. Naturally eroded materials from the concave bank are transported towards the downstream and deposited on the convex bank of the main river. According to Sakalowsky (1974) and others, the materials of the concave bank are transported across the channel and are deposited on the opposite convex bank. On the other hand, Leopold and Wolman (1960), Friedkin (1945), Martvall and Nilsson (1972) and others have mentioned that the eroded materials of the concave bank are also deposited on the convex bank of the same side of river. However, point bars are formed on the convex bank due to the deposition of transported material from the concave bank.

Point bars are depositional features in the alluvial regime of the basin associated with meandering channel. These features are found in the course of the River Sankosh where the river has formed numerous meander bends. It is mentioned that these types of point bars are formed along left and right banks of the River Sankosh. These point bars are characterized by deposition of silt and clay in the study area (Map 5.6).

5.2.7 Channel bars:

The process of bar development is closely related to the occurrences of flood and morpho-dynamics of the river and channels. The process of growth of a bar is highly influenced by the rate of bank erosion of the river than the development of new channels. The bars are generally matured within the duration of eight and ten years in relation to the both relative height and vegetarian cover.



Map 5.6: Point Bar and Channel Bars

The channel bars are also considered as important depositional landforms. These are associated with the braided channels which are observed at the lower reaches of River Sankosh in the study area. Most important characteristics of these channel bars are: i) Coarser deposits occur near the point of the rivers entering the plain and ii) deposition of clay and silt are found in the channel bars at the downstream reaches of the study area.(Map 5.6.)

5.3 Discussion and Conclusion:

Abandoned channels are considered as the former active channel. They are also recognized as depression in the landscape and located at the position of a formerly active channel, though typically and considerably with reduced width and depth (Willem H.J. Toonen. et al. 2012). These abandoned channels are represented as various geomorphological features over the flood plain of the concerned river. From the above discussion it is mentioned that various types of erosional and depositional landforms have developed along, around and on the bed of abandoned channel. In study area, erosional landforms i.e. meander cut-off and depositional landforms i.e. ox bow lakes, meander scars, point bars, plug bars and channel bars are found, which have been developed in different parts of Sankosh river. All these erosional and depositional landforms have developed along and around the abandoned channels by the process of channel fills for a long period of time and created much morphological diversities in the study area.

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CHAPTER VI

SOCIO-ECONOMIC IMPORTANCE OF ABANDONED CHANNELS

6.1 Introduction:

Abandoned channels are recognised as depressions in the landscape and are located at the position of a formerly active channel (Willem H.J. Toonen et. al., 2012) These abandoned channels receive surface run-off water by rivers and consequently become very extensive water bodies during monsoon with heavy rainfall on one hand and partially dries up in the post-monsoon periods on the other hand. It is evident that abandoned channels have been recognized as one of the important life-support systems on Earth, in addition to the agricultural lands and forest lands. These abandoned channels support a wide variety of agricultural crops for the local people. These are also considered as habitat and breeding ground for fish and other aquatic species. Moreover, abandoned channels can provide habitat for wildlife and maintain biodiversity of aquatic habitat which have much economic value. At present, the common use of abandoned channels comprises fishing, cultivation, irrigation, jute retting, fodder collection, bathing, washing cloths and utensil, duck rearing and other household activities. The survival of these abandoned channels and their resources are not only important for economic development of the local people but also important for the preservation of biodiversity.

6.2 General socio-economic discussion:

People staying in and around the abandoned channel of the Sankosh River are directly or indirectly dependant on this abandoned channel. From field data it is observed that their socio-economic condition, especially economic development is influenced by these abandoned channels. People use water of abandoned channels for their irrigation and agricultural purposes. In this regard, Boro cultivation in dry season can be mentioned as a notable example. Fishing is considered another important practice of the people of fringe villages. Moreover, food and fodder collection is also abundantly noticed at the time of field investigation. So, it is mentioned that people inhabiting surroundings of the abandoned channels use these for their different purposes, as a result, land use and land cover of the study area is changing day by day.

6.2.1 Demographic characteristics:

In general, demography is the study of the human population i.e. distribution, sex ratio, structure, ethnicity in a particular place in a particular period of time. Demographically, the study area is well populated.

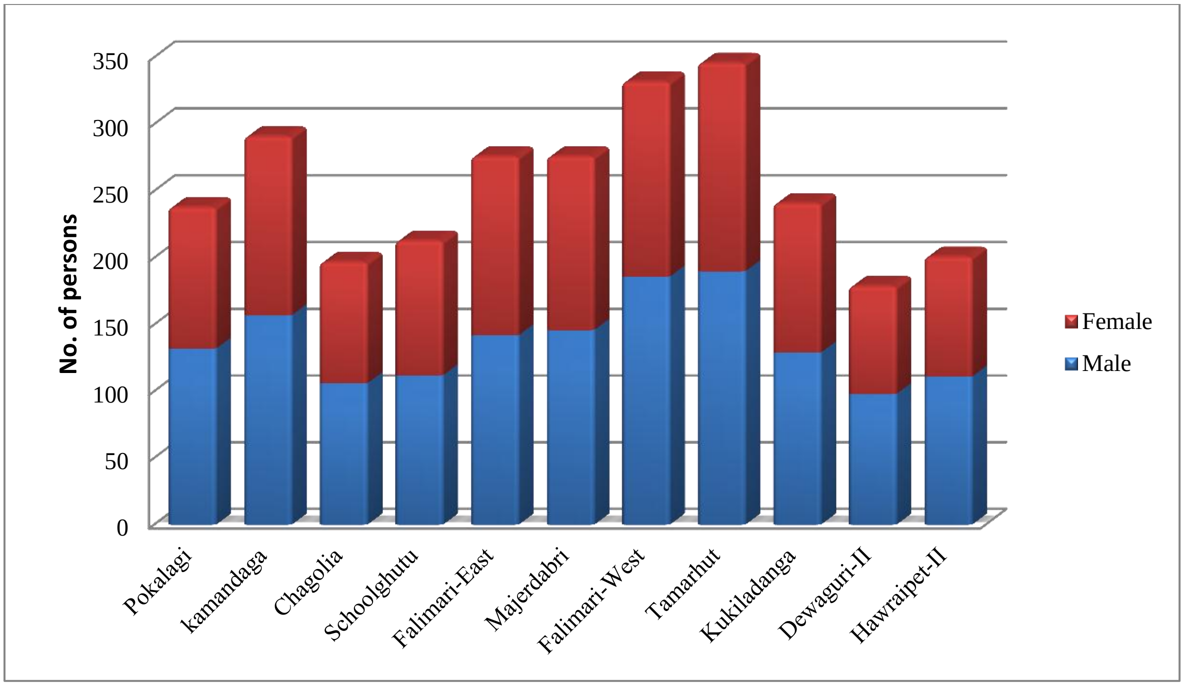
The distribution of population in different villages of study area of the Sankosh river basin is influenced by the Sankosh river and as well as by the presence of abandoned channels. Density of population is higher in the surroundings areas of the abandoned channels than other villages of the study area. It has occurred due to the scope for various occupational opportunities and at the same time the availability of fertile agricultural land in and around of abandoned channels especially in dry season when water level goes down. From the field data it is found that different societies or groups of people are engaged in different types of economic activities and field data reveals that more than 60% are people engaged in agricultural activities, where most of population belongs to the social group of Rajbanshi, Muslim, Namasudra etc.

On the other hand, Santhal and other tribal communities are mostly engaged in food and fooder collection in the study area and they are also engaged in fishing for their own consumption. So it is mentioned that population i.e. their distribution spatial or temporal change, ethnicity, occupational structure, societal bondage etc. all are attached with the presence of abandoned channels in the study area.

Table No. 6.1: Population Characteristics in the Fringe Villages of Abundant Channels in the Study Area

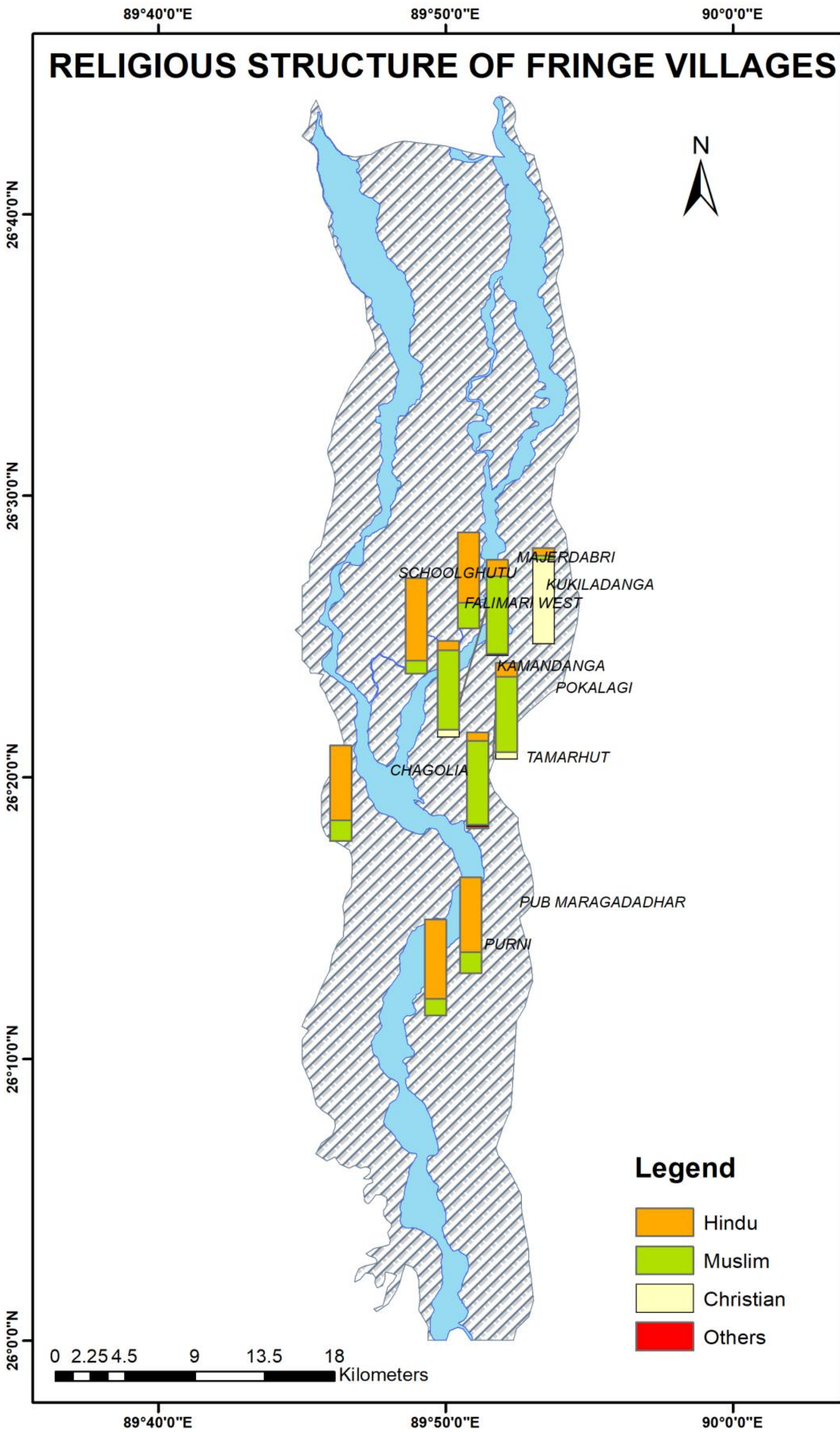
Sl No	Name of Village	Total Population	On the Basis of Sex		On the Basis of Religion				On the Basis of Caste			
			Male	Female	Hindu	Muslim	Christian	Others	Gen	SC	ST	OBC
1	Pokalagi	238	132	106	35	187	16	-	22	11	25	180
2	Kamandaga	291	157	134	28	241	22		18	17	29	227
3	Chagolia	197	106	91	154	43	-	-	117	37	12	31
4	Schoolghutu	213	112	101	17	9	187	-	6	6	192	9
5	Falimari-East	276	142	134	253	23			142	93	21	20
6	Majerdabri	276	146	130	202	74	-	-	124	72	15	65
7	Falimari-West	332	186	146	286	46	-	-	172	102	12	46
8	Tamarhut	346	190	156	30	303	6	7	22	12	15	297
9	Kukiladanga	241	129	112	42	195	4	-	25	21	13	182
10	Dewaguri-II	179	98	81	148	31	-	-	115	15	18	31
11	Hawraipet-II	201	111	90	157	44			95	28	34	44

Source: Primary Survey

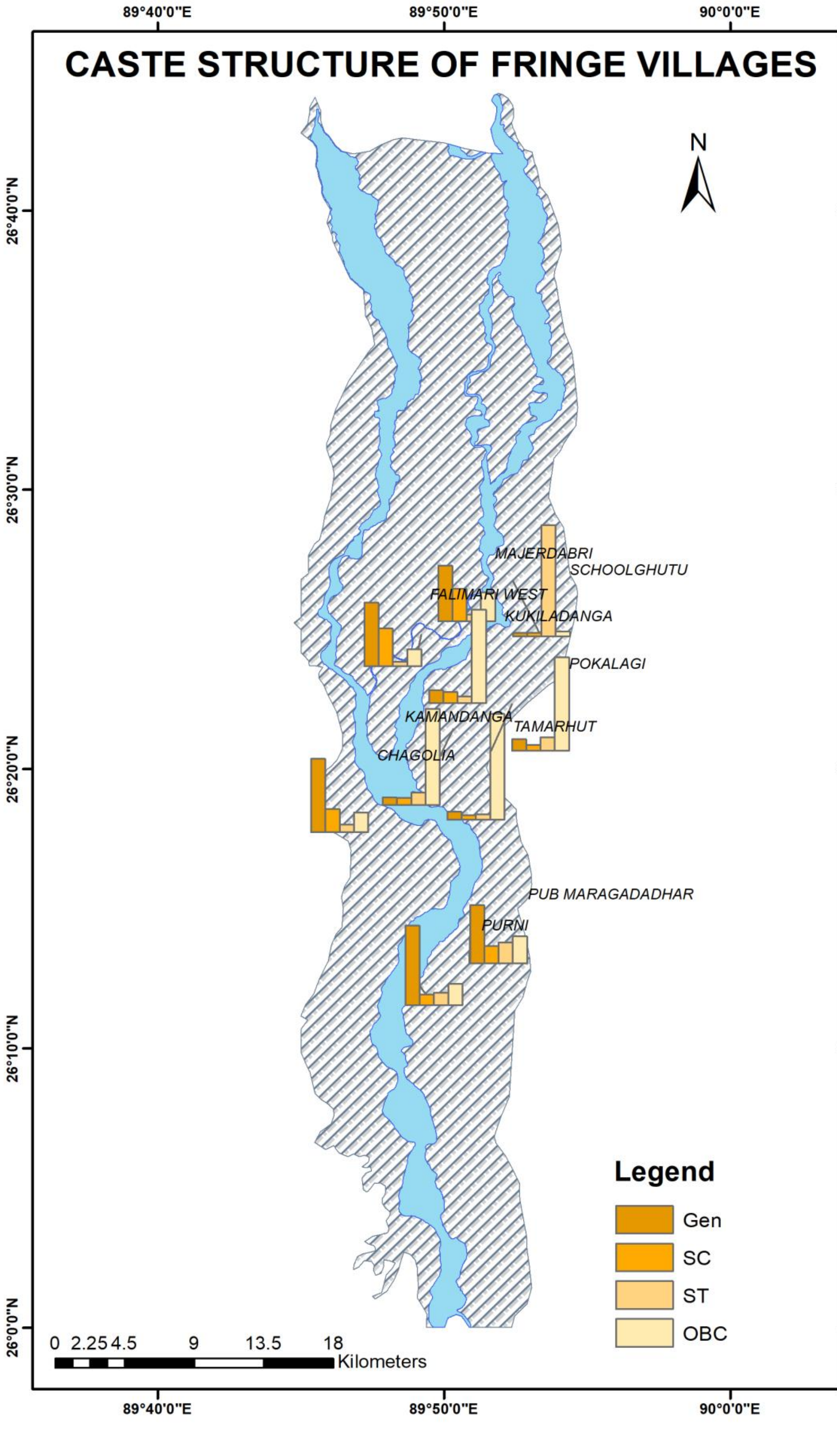


Source: Primary Survey

Fig. 6.1: Sex Structure of Fringe Villages



Map 6.1: Religious Structure of Fringe Villages



Map 6.2: Caste Structure of Fringe Villages

6.2.2 Levels of Education:

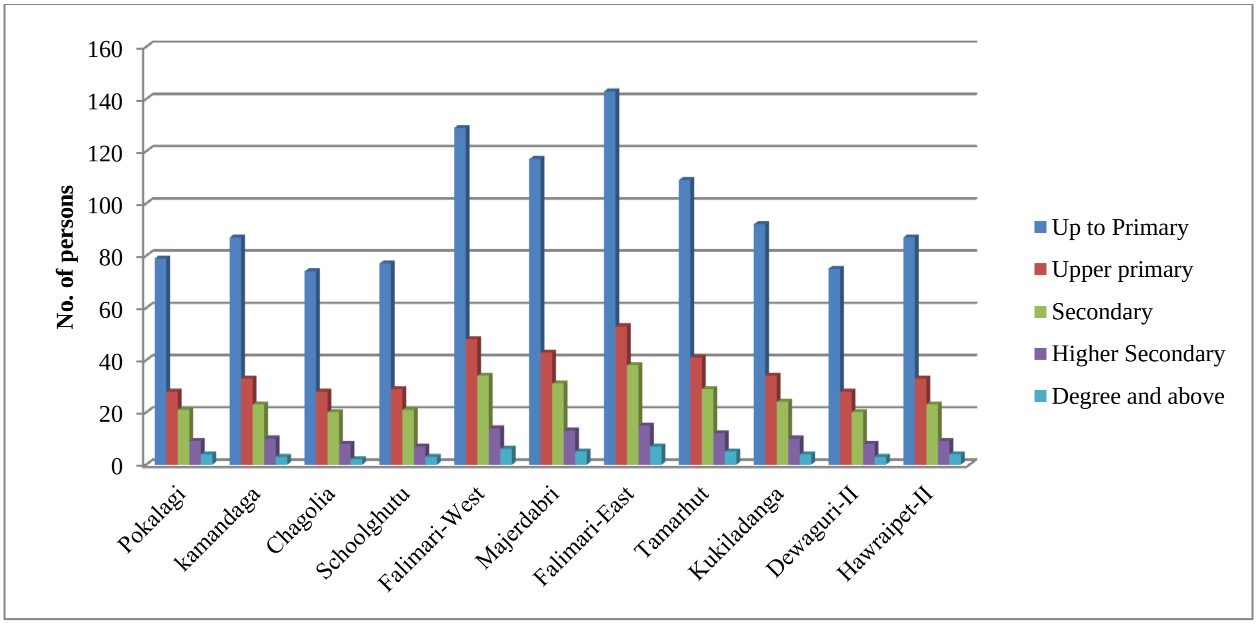
Education improves the quality of people lives and leads to broad social benefits to the society and for their own. It plays a very crucial role in their economic development and at the same time their social progress. It is also mentioned that education is improving income distribution of the people inhabiting the surroundings of the abandoned channels of the study area. From the field data, it is found that education level is poor in the surveyed villages. Most of the people of the surveyed villages belong to Primary level and the percentage is 56.18 followed by Upper Primary (20.94%), Secondary (14.82%), Higher Secondary (6%) and Degree and above (8.06%) etc.

The above-mentioned data of education proves that poor educational status made the areas economically backward on one hand and it increases the dependency on abandoned channels on the other hand.

Table No. 6.2: Levels of Education in the Fringe Villages

Sl No.	Name of Village	Numbers in Persons				
		Up to Primary	Upper Primary	Secondary	Higher Secondary	Degree and above
1	Pokalagi	79	28	21	09	04
2	kamandaga	87	33	23	10	03
3	Chagolia	74	28	20	08	02
4	Schoolghutu	77	29	21	07	03
5	Falimari-West	129	48	34	14	06
6	Majerdabri	117	43	31	13	05
7	Falimari-East	143	53	38	15	07
8	Tamarhut	109	41	29	12	05
9	Kukiladanga	92	34	24	10	04
10	Dewaguri- II	75	28	20	08	03
11	Hawraipet-II	87	33	23	09	04

Source: Primary Survey



Source: Primary Survey

Figure 6.2: Levels of Education in the Fringe Villages

6.2.3 Occupational structure:

The study of occupational structure of population occupies a significant role in the field of population studies, as well as the socio-economic conditions of the study area. It also determines the economic strength of the people inhabiting the surroundings of the studied abandoned channels. Moreover, the study of occupational structures is very important for researcher or planners who initiate plans and policies for social and economic development of any part of a region. In this regard, the study of the occupational structure of the surveyed villages helps to understand the overall socio-economic condition of the villagers and at the same time helps to formulate plans and policies for socio-economic development for future generation.

According to the Census of India (2011), workers have been classified into two broad categories i.e. main workers and marginal workers and these two also been classified into four sub-categories:

1. Cultivators
2. Agricultural labourers
3. Workers in household industries (HHI)

4. Other workers.

Based on the above industrial classifications of workers, mentioned in the census of India (2011), the research survey has been conducted in a number of villages during the field study in the study area. From the field data of the surveyed villages, it is found that the maximum population are mainly engaged in agriculture and allied activities. Cultivators (33.2%) and agricultural labourers (35.4%) both constitute 68.6% of the total work force in the study area and followed by household industries (3%) and other workers (29.4%) respectively. Here, it is mentioned that the work force in the study area is varied from the percentage of the work force of the national level. It is observed that the percentage of work force in cultivators and agricultural labourers is 33.2% and 35.4% respectively in the study area which is higher than the national level of 24.6% and 30% respectively. On the other hand, the percentage of workforce in household industry (3%) and other workers (29.2%) in the study area is lower than the workforce of national level of 3.8% and 41.6% respectively. Moreover, the occupational structure varies from place to place and from male to female population also. Here it is found that out of total male population, 66.2% of are engaged as cultivators and the corresponding figures for the female population is about 33.8%. On the other hand, out of total female population, 58.4% of are engaged as agricultural labourers and the corresponding figure for male population of about 41.6% is found in the study area. So, it is apparent that the occupational structure not only helps to formulate plans and policies for socio-economic development of the people but also emphasise on particular categories of population belonging to a particular caste and community.

Table 6.3: Occupational Structure at Fringe Villages

Sl. No	Name of the Village	Category of Workers			
		Cultivators	Agricultural labourers	HHI	Other workers
1	Pokalagi	78	84	07	69
2	Kamandaga	96	101	08	84
3	Chagolia	65	68	06	57
4	Schoolghutu	70	74	06	61
5	Falimari-West	96	91	09	77
6	Majerdabri	97	92	08	76
7	Falimari-East	116	109	10	96
8	Tamarhut	114	121	11	97
9	Kukiladanga	79	85	07	69
10	Dewaguri-II	59	62	05	52
11	Hawraipet-II	66	70	06	58
	Study area (%)	**32.8**	**35.2**	**2.9**	**29.1**
	India (%)	**24.6**	**30**	**3.8**	**41.6**

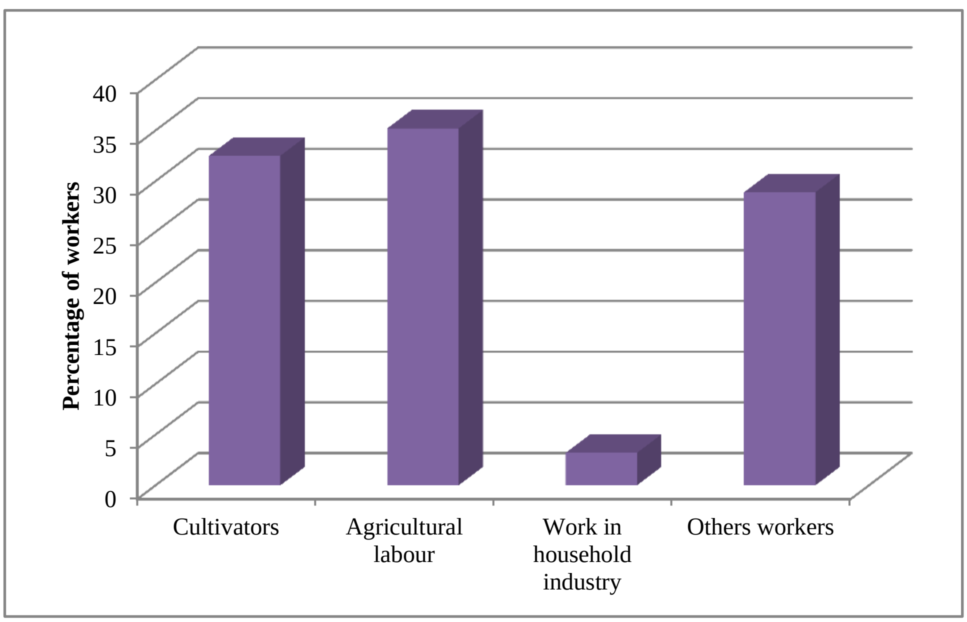


Figure 6.3: Occupational Structure of Kamandanga Village

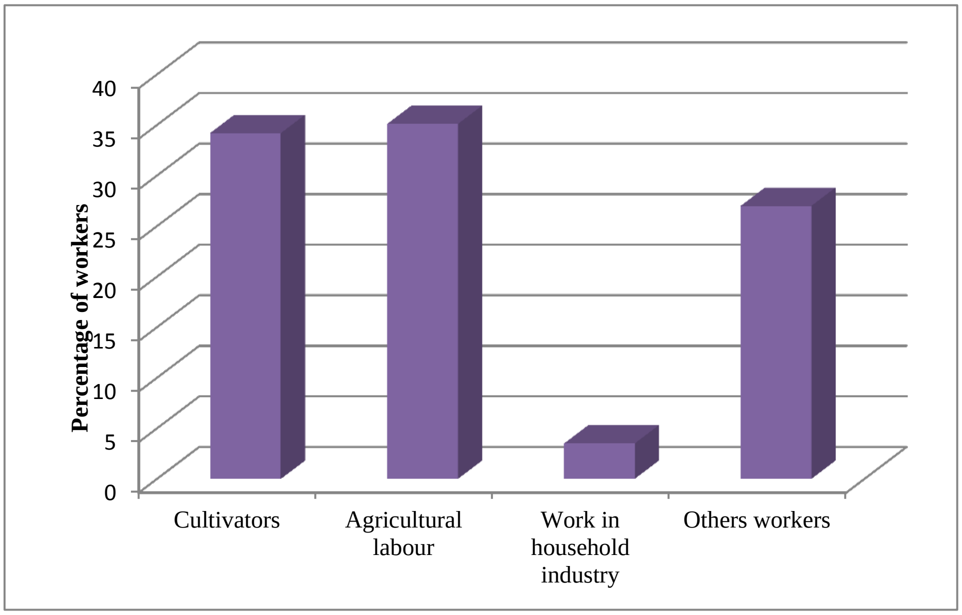


Figure 6.4: Occupational Structure at Chagolia Village

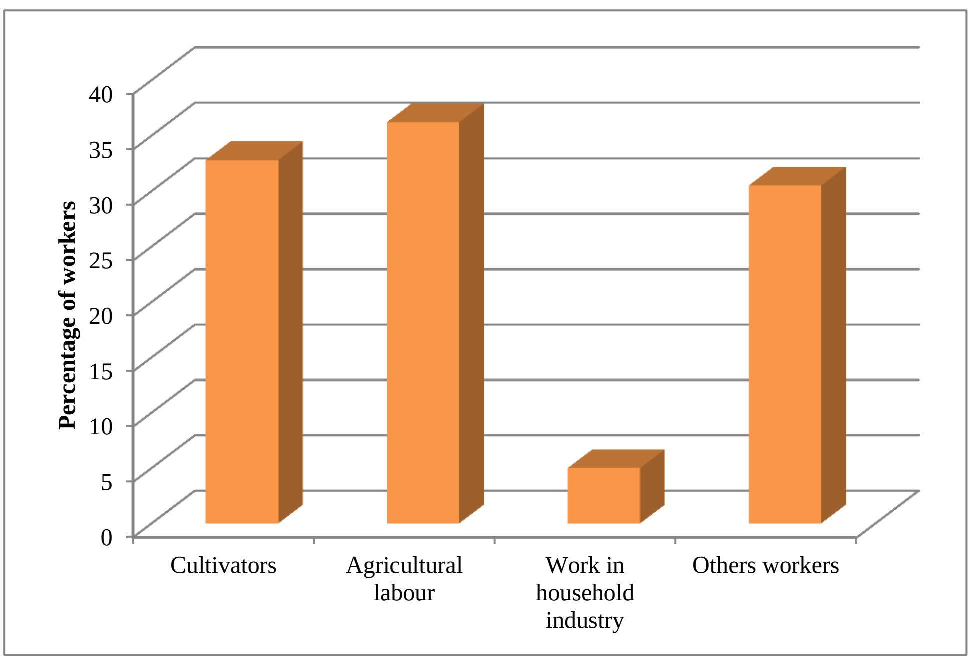


Figure 6.5: Occupational Structure at Schoolghutu Village

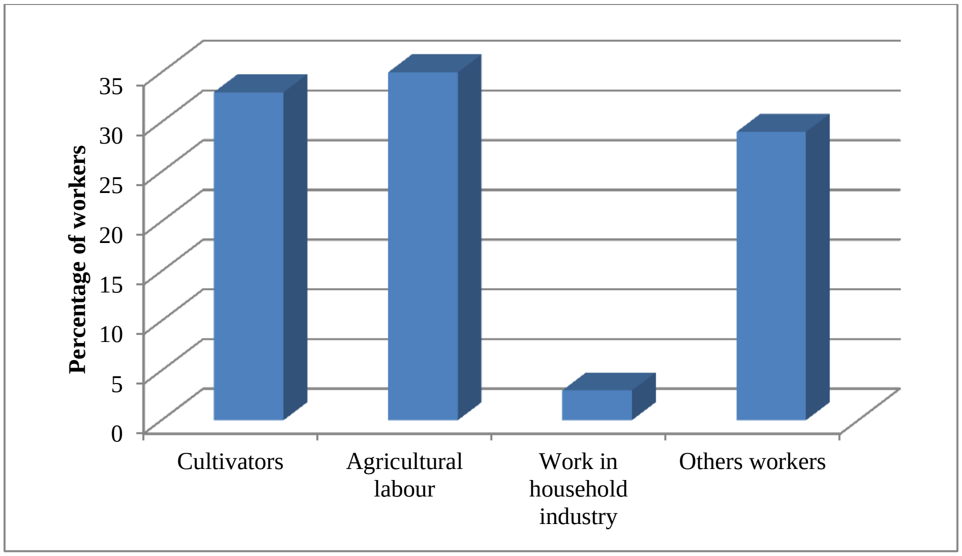


Figure 6.6: Occupational Structure at Pokalagi Village

6.2.4 Dependent Livelihood Options:

Agriculture and allied occupations are the most common livelihood options for the rural people. Major livelihood activities for rural population include cultivation of food crops like paddy, wheat, maize etc. and cash crops like jute, tobacco and fish farming, cattle rearing, dairy farming, food processing, wood industries etc. But in the study area, only few livelihood options have been identified during the field survey through focus group discussions. These identified livelihood options are agriculture, agricultural labourers, fishing, food and fodder collection, livestock and others. Here it is found that there is a limitation of livelihood options for the development of local people in the study area. So, the identification and analysis of all livelihood options in the study area is very essential to generate and promote more livelihood options for the local people. On the basis of occupational habit of the local people and availability of natural resources in and around of abandoned channels in the study area, the livelihood options have been categorized into the following options:

a) Agriculture
b) Agricultural labourers
c) Fishing
d) Food and fodder collections

e) Livestock and
f) Others.

6.3. *Socio-Economic importance of abandoned channels*

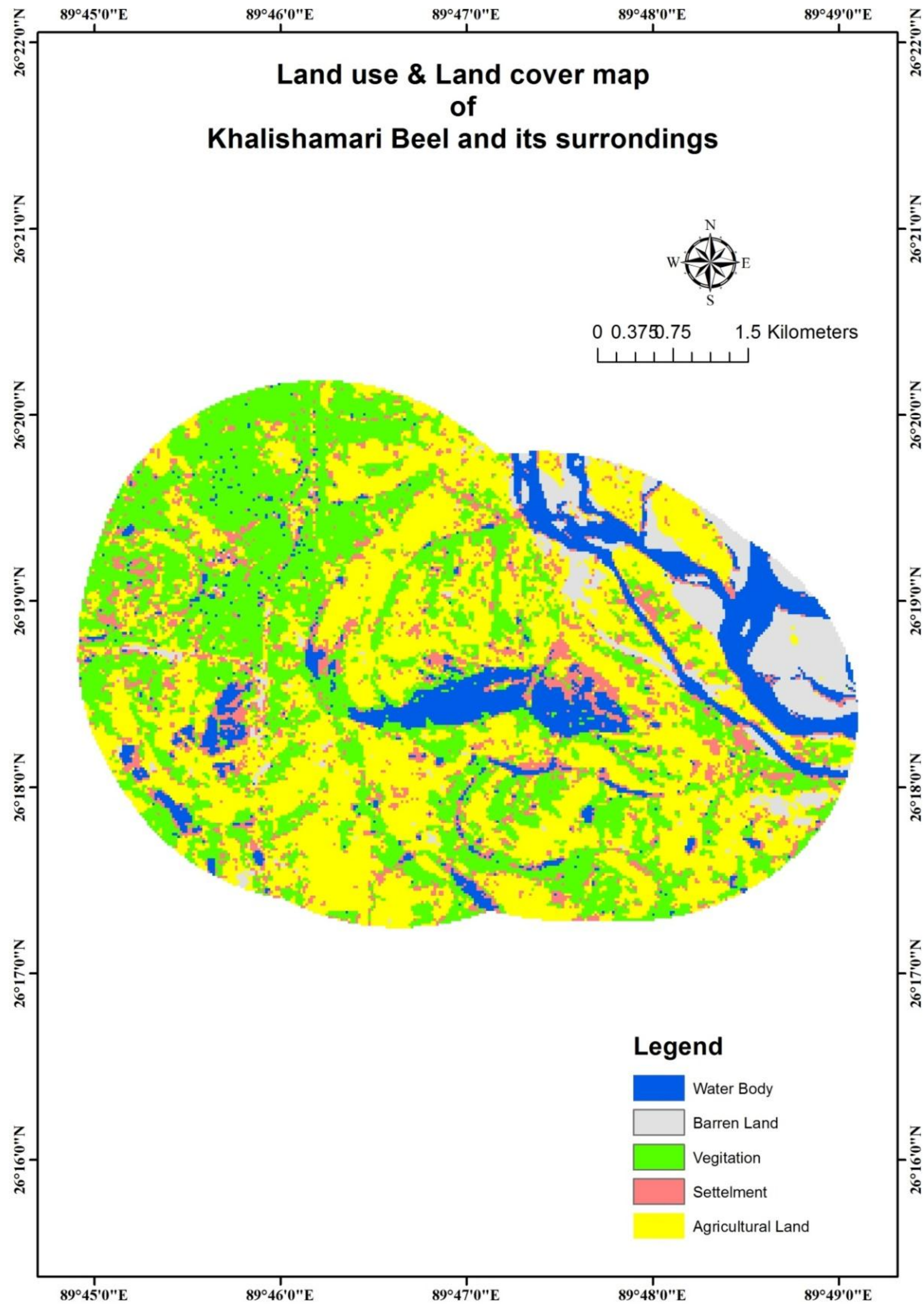
Over all socio-economic conditions of the selected abandoned channels has been analyzed by using primary data through questionnaire during the village survey. All the parameters regarding socio-economic conditions of the local people of the surveyed villages have also been carefully investigated by using various cartographic techniques and on GIS platform.

6.3.1. Abandoned channel 1: Khalisamari beel

Khalishamari beel is an important abandoned channel formed due to chute cut-off along the right Bank of River Sankosh which are associated with various importance upon which rural socio-economic conditions have depended. It has more and more been valued for natural resources and facility, and the essential biological significance provided to local populations. It is important for people living outside of the abandoned channels for various purposes. Various socio-economic importance as well as biological significance of this abandoned channel has been discussed below.

6.3.1.1 Land use and Land cover:

Based on 1km peripheral buffer area, land use and land cover map has been prepared. From this map, complex land use setup has been identified in the surroundings area of the Khalisamari beel. From the collected data from the land use and land cover map it is found that the agricultural land covers the 40% area, and Vegetation covers (31%) area. It is mentioned that both agriculture and forest have occupied more than 70% area of the total area and which have a great significant regarding socio-economic development. On the other hand, water body covers (11%) area, and followed by settlement (11%) and barren land (7%).



Source: LISS-III, BHUVAN (2019)

Map 6.3: Land Use and Land Cover Map of Khalishamari Beel and its Surroundings, 2019

From the above data, it is also mentioned that abandoned channels have a number of utility and uses for socio economic development but due to high rate of population growth day by day, the abandoned channel services have faced different kinds of problems and sometimes have steadily diminished. In this regard, it is also mentioned that fishing is considered an important service of this abandoned channel but nowadays fishing intensity, breeding ground and scope of fishery gradually has been going down.

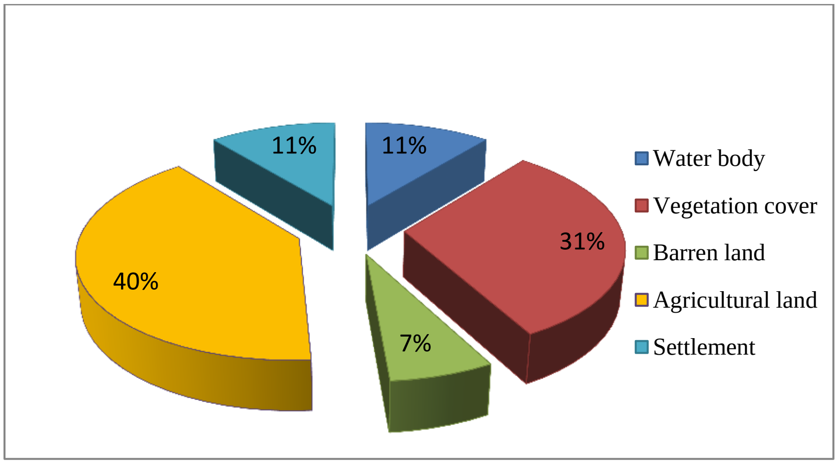


Figure 6.7: Distribution of Land Use and Land Cover at Surroundings of Khalishamari Beel, 2019

6.3.1.2 Dependent livelihood:

The livelihood pattern of the residents inhabiting the surroundings of the abandoned channel at Khalishamari beel is primarily based on the availability of occupations supported by the huge reserve of natural resources provided by the abandoned channel itself. This has resulted in bringing which economic gains to the local people. Moreover the immense population pressure and advances in modern technology is also having a marked detrimental effect on the natural environs of Khalishamari beel and is also diminishing the biodiversity of the natural wetland.

Table 6.4: Pair wise Ranking for Livelihood Option at Khalisamari beel

Livelihood Option	**Agriculture**	**Agricultural labour**	**Fishing**	**Food and fodder collection**	**Livestock**	**others**
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Fishing	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Fishing	*	Fishing	Fishing	Fishing
Food and Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Food and Fodder Collection	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Table 6.4a Ranking for Livelihood Option at Khalisamari beel

Rank	**Livelihood Option**	**Ranking Points**
1	Agriculture	1
2	Agricultural labour	3
3	Fishing	2
4	Food and fodder collection	4
5	Livestock	5
6	Others	6

Source: Compiled by Researcher

6.3.1.2.1 Agrarian Status:

The main occupation of Khalishamari residents is agriculture that is dominated by cropping of boro paddy in the shallow water areas as well as in the drier sections of the abandoned channel.

The high nutrient value of the alluvial soils and the availability of sufficient water content ensure that the boro paddy cultivation is now a common practice in this area of the study area, especially during the dry season when the cultivators can expect higher productions of paddy as their main source of livelihood.

The common practice by these farmers is to start boro paddy cultivation in the months of January to February every year, when the marginal areas of the abandoned channel is raised up since the flood waters reduce and the level of the water goes down. Taking advantage of this seasonal process, farmers having ownership of the land of the abandoned channels at Khalishamari beel convert the rivarine areas into agricultural land for boro paddy cultivation. It has been observed that these converted abandoned channels are very rarely allowed to regain the original status and continue to be used for agricultural purposes.

6.3.1.2.2 Fishing:

Abandoned channels are popularly known as beel or chhara by local people in the study area. These beel and chhara are recognised as habitat and breeding ground for fish. These are also the source of fish for the consumption of poor people in surrounding villages. At the same time, lease holders who have also occupied these beel and chhara for their business purpose. From the field data, it is also mentioned that a major group of people have been involved in an organized way for hunting of fish in the Khalisamari abandoned channel. There are various purposes of fish hunting in the study area. These are:

a. Fishing for daily consumption of the local people.
b. Fishing for the livelihood of the fishing community of the study area.
c. Lease holders who occupy abandoned channels for fishing and for their business.

In the field, we surveyed 35 households at the villages surrounding of Khalishamari abandoned channel. Out of 35 households, 20% of the people directly involved in fish hunting for their livelihood, 12% for own consumption and 4% for their business. So, it is investigated that fish hunting plays an important role on economic development of the villagers inhabited in surrounding areas of the Khalishamari abandoned channel.

6.3.1.2.3 Livestock:

The field survey revealed that the rural economy of the residents of the surrounding areas of the abandoned channel at Khalishamari beel is greatly dependent on livestock rising. It not only acts as a primary source of food/nonfood items but is also crucial in contributing to rural livelihoods by way of providing employment, generating a source of income as well as alleviating poverty for the local inhabitants of the study area.

During the field survey it was observed that the most important livestock are cattle, goats, pigs and duck with a predominance and preference for goat and pig cultivation by the locals. Therefore it can be asserted that livestock ranching plays a significant role in the livelihood pattern of the residents within this study area.

6.3.1.2.4 Others:

Fodder collection is an important activity in Khalisamari abandoned channel of the study area. People collect various waterborne vegetation and supplement fodder etc. from this abandoned channel for their livestock in the monsoon and non- monsoonal periods. Generally, in the dry season when grasses dry up, this abandoned channel becomes the only source of fodder. Moreover, people inhabiting the surroundings of the abandoned channel collect various edible plants like Kalmi, Hincha, Shusni etc. from this abandoned channel for their own consumption. Some other people collect various edible plants also for selling in the local market. Furthermore, Khalisamari abandoned channels also provides wide grazing land for cattle population in the winter and summer season when water level of abandoned channel remains low and which become an important occupation of the people inhabiting the surrounding of Khalisamari abandoned channels. Thereafter, fish farming or pisciculture is also considered as an important economic practice in the Khalisamari abandoned channel. It is also mentioned that due to high demand of fish in the market it makes a profitable business for the local people.

6.3.1.3 Biological importance:

Khalishamari abandoned channel has great significance in terms of ecological importance and biological diversity in the syudy area. The beel serves as an important reserve of natural resources as it is a natural habitat for both terrestrial and aquatic flora and fauna, greatly increases the biodiversity stock and contribution to its preservation. The Khalishamari beel plays a significant environmental function in maintaining the food chain and food web of this ecotone region.

During field investigation, the Khalishamari beel was also found to serve as a sanctuary for the migratory birds during the winter months. A significant number of medicinal plants are also found there. The region is also host to a large variety of mammals and reptiles including snakes, frogs, turtles, toads, tortoises, squirrels etc. Thus it has been seen that this abandoned channel has much biological significance for the preservation of biodiversity, ecology, ecosystem and the sustainable development of this area.

Plate 6.1: Focus Group Discussion at Khalishamari Beel

6.3.2. Abandoned channel 2: Kamandanga beel

Kamandanga beel which plays a very important role economically as well as ecologically in the surroundings of the abandoned channel. It has formed along the East Bank of River Sankosh upon which rural socio-economic conditions have depended. A variety of socio-economic importance as well as ecological significance of this abandoned channel has been discussed below.

6.3.2.1 Land use and Land cover:

Land use and land cover within the 1km peripheral area of the (abandoned channel) Kamandanga beel reveals a complex land use setup. From the collected data during village survey it is found that the agricultural land covers the 44% of area followed by settlement (28%), vegetation cover (12%), water body (11%), and barren land (5%) out of the total area of this abandoned channel.

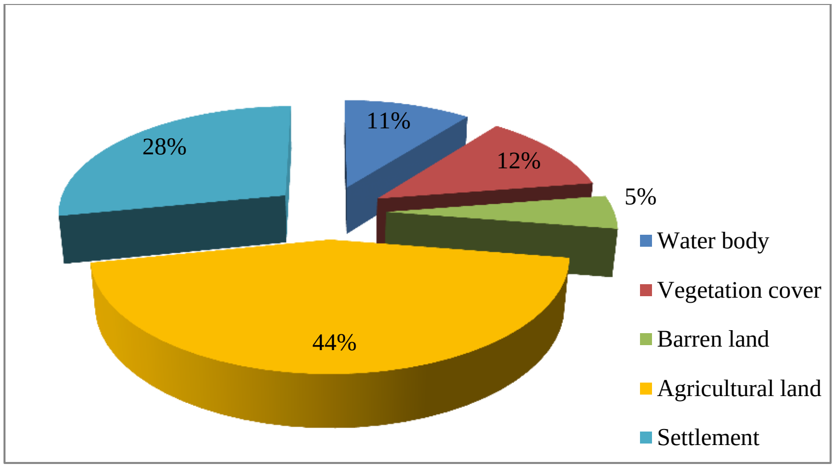
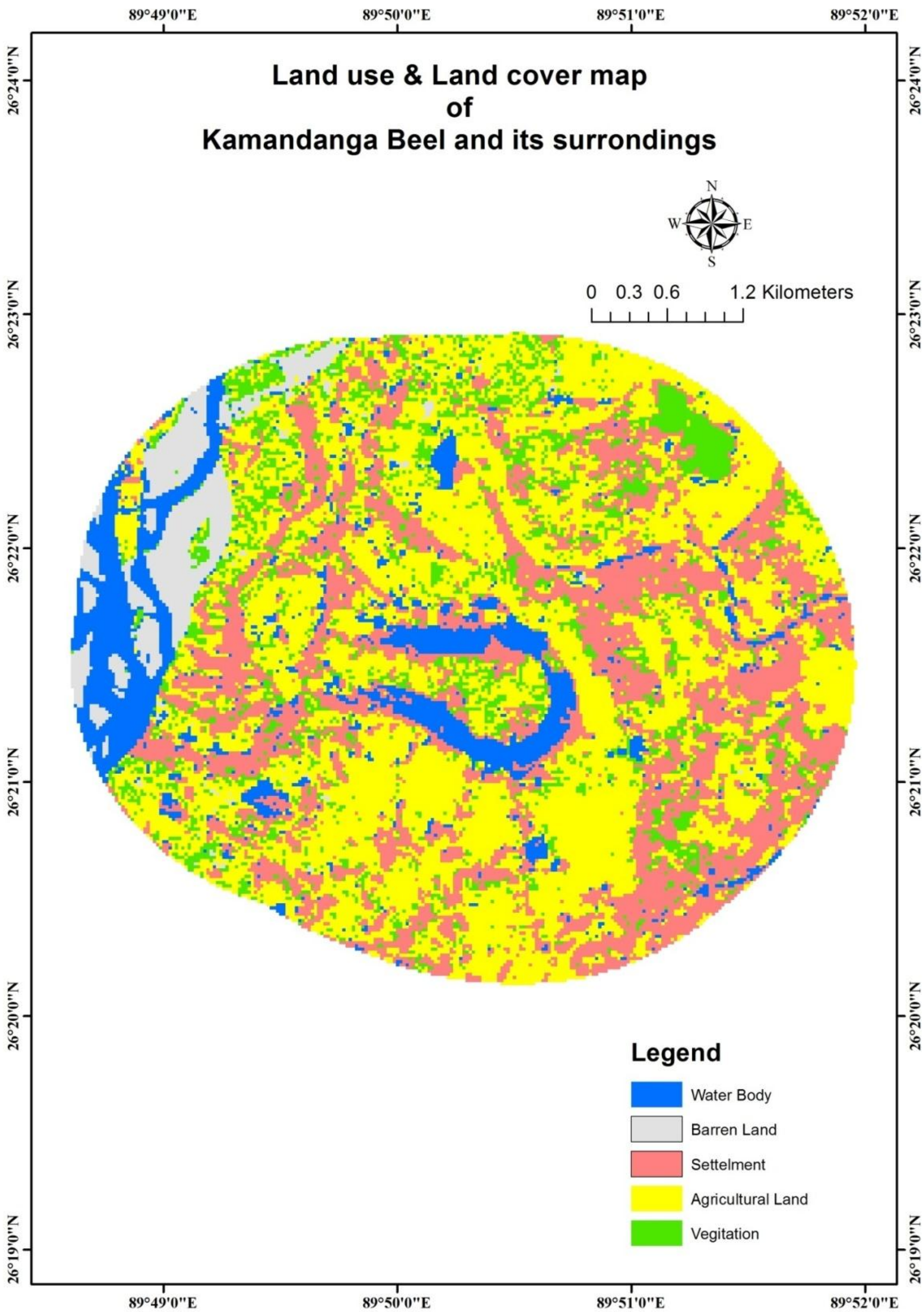


Figure 6.8: Distribution of Land use and Land cover at Surroundings of Kamandanga Beel, 2019

From the collected data, it has been clearly mentioned that abandoned channel has a number of utility and uses for socio economic development but with increase of population day by day most of the abandoned channel services have faced different kinds of problems and sometime have steadily diminished. In this regard, it is also mentioned that fishing is considered an important service of abandoned channel but nowadays fishing intensity, breeding ground and scope of fishery is gradually going down. Other uses of Kamandanga abandoned channels are rarely found there due to unavailability of different biotic and abiotic components, which provide the specific services.

6.3.2.2 Dependent livelihood:

On the basis of available occupational habit and allied economic activities of the local people of the study area, various livelihood options have been selected through focus group discussion during village survey. The main livelihood options of the local people are agriculture, agricultural labour, fishing, food and fodder collection, livestock and others. Here, it is also mentioned that this abandoned channel provides huge number of natural resources which have much economic value for the local people. But due to immense population pressure over the abandoned channel and the development of modern technology, some important natural resources are decreasing and disappearing day by day and environment of the surroundings areas of Kamandanga beel has been affected very badly.



Source: LISS-III, BHUVAN (2019)

Map 6.4: Land use and Land cover Map of Kamandanga Beel and its Surroundings, 2019

Table 6.5: Pair wise Ranking for Livelihood Option at Kamandanga beel

Livelihood Option	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	Others
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Fishing	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Fishing	*	Fishing	Fishing	Fishing
Food and Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Food and Fodder Collection	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Source: Compiled by Researcher

Table 6.5a: Ranking for Livelihood Option at Kamandanga beel

Rank	Livelihood Option	Ranking Points
1	Agriculture	1
2	Agricultural Labour	3
3	Fishing	2
4	Food and Fodder Collection	4
5	Livestock	5
6	Others	6

Source: Compiled by Researcher

6.3.2.2.1 Agrarian Status:

Agriculture is the mainstay for the local people inhabited surroundings of the Kamandanga beel. In the study area, presently agricultural practices are changed due to technological innovations, demographic changes and inclusion of new high yielding varieties of different crops. In this regard, Boro paddy cultivation can be mentioned. It is now under the agricultural practice in the shallow water areas mainly in the dry areas of Kamandanga abandoned channels in the study area. High nutrient value of soil and water content have made favorable conditions for Boro paddy cultivation in the study area. As a result, the Boro paddy cultivation in the surroundings areas of Kamandanga abandoned channel becomes a common agricultural practice especially in dry season and where cultivators accept a higher production of paddy for their livelihood. Generally, Boro paddy cultivation starts in the month of January –February every year when the water level goes down and marginal areas of abandoned channels are raised up as fertile land. In this situation, farmers having ownership of the land of Kamandanga abandoned channel convert it into agricultural land for Boro paddy cultivation in the study area. It is also observed that once the lands of abandoned channel are converted into agricultural land, it never regains the original status.

It was observed during field survey that nearly 40% of area of total area of Kamandanga abandoned channel is under the Boro paddy cultivation and about 59.29% people engaged directly with this agricultural practice and 5.71% people are also engaged as agricultural labourers and this practice increases day by day.

6.3.2.2.2 Fishing:

Abandoned channels are also known as beel or chhara by local people in the study area. These are recognised as habitats and breeding grounds for fish and are also the source of fish for the poor people in the surrounding villages. From the field data, it is found that there have been large groups of people involved in organised fishing in the Kamandanga abandoned channel. These are:

d. Fishing for daily consumption of the local people.
e. Fishing for the livelihood of the fishing community of the study area.
f. Lease holders who occupy abandoned channels for fishing and for their business.

In the field survey, out of 53 households, 15.64% of the people are directly involved in fishing for their consumption. So, it is mentioned that fishing plays an important in the role economic development of the villagers inhabiting the surroundings of the Kamandanga abandoned channels.

6.3.2.2.3 Livestock:

Livestock plays an important role in rural economy of the local people and it also contribute to rural livelihoods, employment and poverty relief for the local people of the study area. Livestock provides food and non-food items for the rural people and also helps to earn money from the rural as well as neighboring urban market. In the study area most important livestock are cattle, goats, pigs, and duck, chicken. Some of these provide milk and meat as food and some other provide non-food materials like fibre, skin etc. which have much economic value. Cattle rearing are highest in the grazing lands of Kamandanga abandoned channel followed by poultry and goats.

On the other hand, goats and pigs cultivation are also abundantly practiced by the local people in the surroundings areas of the Kamandanga abandoned channel. So, finally it is investigated that the livestock provides food and non-food items to the people on one hand and it is also plays an important role in the development of economy for local the people in the study area on the other hand.

6.3.2.2.4 Others:

Fodder collection is another important activity in the Kamandanga abandoned channel of the study area. People collect various water-borne vegetation and supplement fodder etc for their livestock in the monsoon and non-monsoonal periods. Generally, in the dry season when grasses dry up, this abandoned channel becomes the only source of fodder. Apart from the fodder collection, the surrounding households collect various edible plants like Kalmi, Hincha, Shusni etc. from this abandoned channel for their own consumption. Some people collect various edible plants also for selling in the local market. Moreover, Kamandanga abandoned channel also provides wide grazing land for cattle population in the winter and summer seasons, when water level of the abandoned channel remains low and this becomes an important occupation of the people inhabiting the surrounding areas of Kamandanga abandoned channel. Thereafter, fish farming or pisciculture is also considered as an important practice in the Kamandanga abandoned channel.

6.3.2.3 Biological importance:

Kamandanga abandoned channel has a great ecological importance to the environment. It provides habitat for wildlife and maintains biodiversity of aquatic habitat. It is also recognized as an important natural resource and significant biodiversity stock in the study area. Moreover, it is also significant for environmental functions and maintains the food chain and food web formations.

During the field observation it is found that Kamandanga beel is also considered as the home for migratory birds that pass the winter there. A significant number of medicinal plants are also found there. Moreover, in the study area, a number of varieties of mammals and reptiles including snakes, frogs, turtles, toads, tortoise, squirrel etc. inhabit in and around the surrounding areas of Kamandanga beel. So, it is investigated that this abandoned channel is biologically more significant for the preservation of biodiversity, ecology, ecosystem and sustainable development.

Plate 6.2: Paddy cultivation at the Peripheral Areas of Kamandanga Beel

6.3.3. Abandoned channel: Purba Charra

One objective of this study was to determine whether gender, education and abandoned channels functions have multiple influences on the annual income of the local population. Purbachhara is an abandoned channel formed beside the east bank of River Sankosh and is associated with various occupations upon which the surrounding rural, social and economic status of the local residents have depended. An assessment of the socio-economic consequence as well as the biological importance of this abandoned channel has been discussed below.

6.3.3.1 Land use and Land cover:

Land use and land cover within the 1km peripheral area of the (abandoned channel) Purba Chhara reveal a complex land use setup. From the collected data, it is found that the water body covers the 35% of the area, followed by settlement (14%), agricultural land (12%), vegetation cover (11%), and barren land (11%).

From the above data, it can be clearly seen that the abandoned channel has a number of utility and uses for socio-economic development but with increasing population day by day, most of the abandoned channel services have faced different kinds of problems and have steadily diminished over time. In this regard, it is also mentioned that fishing is considered an important service of abandoned channel but nowadays, fishing intensity, breeding grounds and scope of fishery is gradually decreasing.

6.3.3.2 Dependent livelihood:

The structure of the livelihood pattern based on abandoned channel varies from place to place in the study area. It is also mentioned that this abandoned channel provides a huge number of resources which have much economic value for the local people. But due to immense population pressure and the development of modern technology, environment of the surroundings areas of Purbachhara beel is affected very badly and has today degraded the natural wetland also.

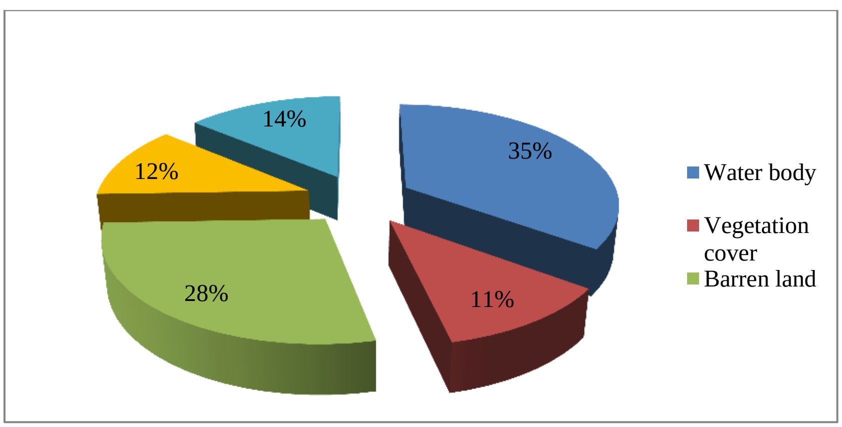
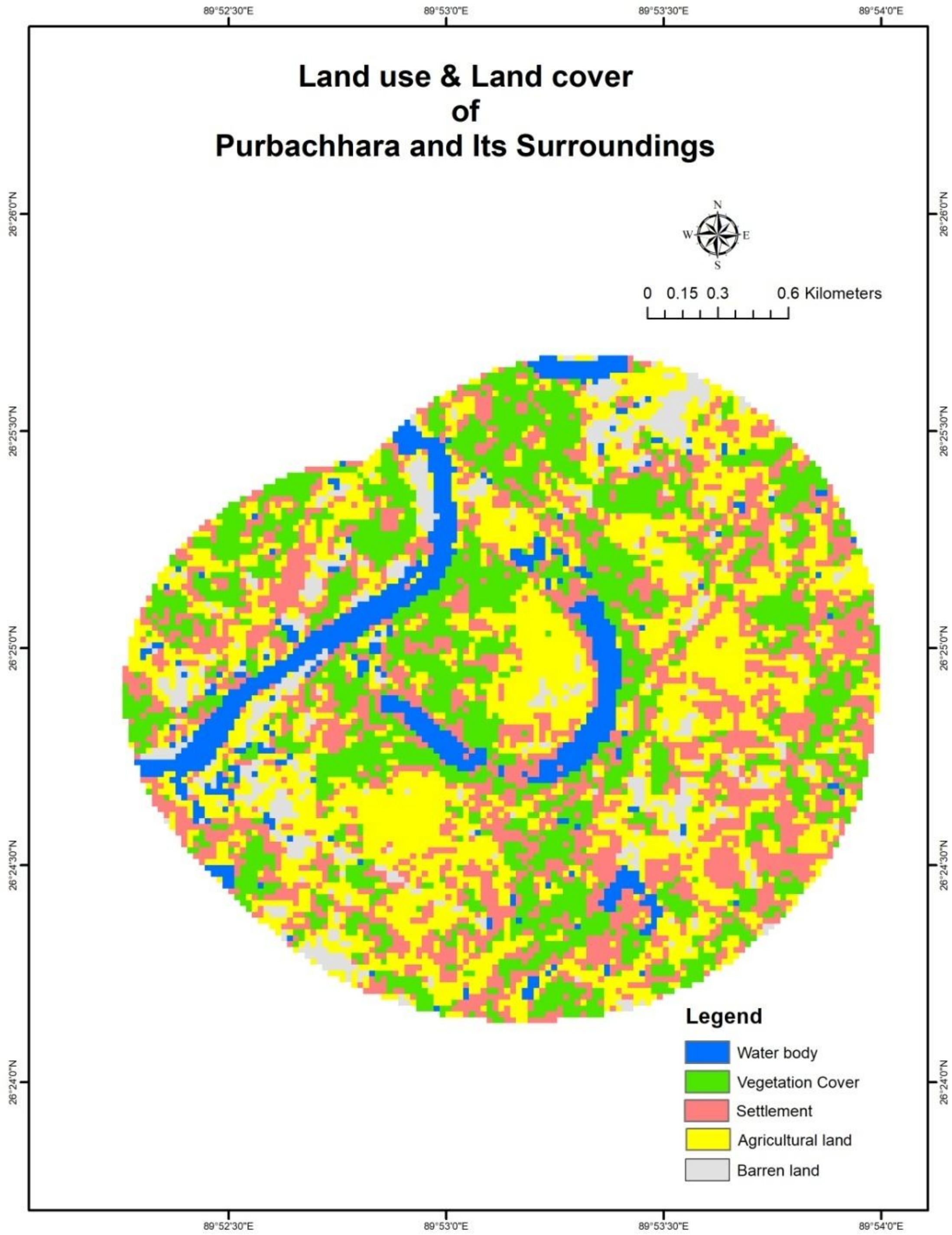


Figure 6.9: Distribution of Land use and Land cover at Surroundings of Purba Chhara, 2019



Source: LISS-III, BHUVAN (2019)

Map 6.5: Land use and Land cover map of Purbachhara and its Surroundings, 2019

6.3.3.2.1 Agrarian Status:

At present, agriculture remains the primary occupation of the people living in the surrounding areas of the Purbachhara beel. These practices have been markedly overhauled by technological innovations, demographic changes and new high yielding varieties of different crops. In this case. As with earlier case study areas, the cultivation of Boro paddy predominates within the dry areas of Purbachhara abandoned channel in the study area.

Table 6.6: Pair wise Ranking for Livelihood Option at Purba Charra

Livelihood Option	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	Others
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Fishing	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Fishing	*	Fishing	Fishing	Fishing
Food and Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Livestock	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Livestock	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Table 6.6a: Ranking for Livelihood Option at Purba Charra

Rank	Livelihood Option	Ranking Points
1	Agriculture	1
2	Agricultural Labour	3
3	Fishing	2
4	Food and Fodder Collection	5
5	Livestock	4
6	Others	6

Source: Compiled by Researcher

6.3.3.2.2 Fishing:

The Purbachhara beel is recognized as an important habitat and breeding ground for fish and also as a source of fish for the poor people in the surrounding villages. From the field data, it is found that this beel falls within the Kokrajhar district of Assam. A large number of local people are involved in organized fishing in the Purbachhara abandoned channel.

6.3.3.2.3 Livestock:

Livestock plays an important role in rural economy and it also contributes to rural livelihoods, employment and poverty relief for the local people of the study area. In the study area, the common livestock are cattle, goats and chicken, which are sources for provision of milk, meat as well as food, while some other provide non-food materials like fibre, hide etc. It also plays a key role in the economy of the people of the study area.

6.3.3.2.4 Others:

Fodder collection is another important activity in Purbachhara abandoned channel of the study area.. Generally in the dry season when grasses dry up, this abandoned channel becomes the only source of fodder. Apart from the fodder collection, the surrounding households collect various edible plants like Kalmi, Hincha, Shusni etc. from this abandoned channel for their own consumption. Moreover Purba Chhara abandoned channel also provides grazing land for the cattle population. Fish farming or pisciculture is also considered as an important practice in the

Purba Chhara abandoned channel. It can also be mentioned that due to high demand of fish it serves a profitable means of livelihood for the local people.

6.3.3.3 Biological importance:

Purbachhara abandoned channel has a significant ecological importance relating to the environment and to the locality, chiefly as a habitat for wildlife and by maintaining biodiversity of the area. Moreover, it is also significant in environmental functions and in all food chain and food web formations.

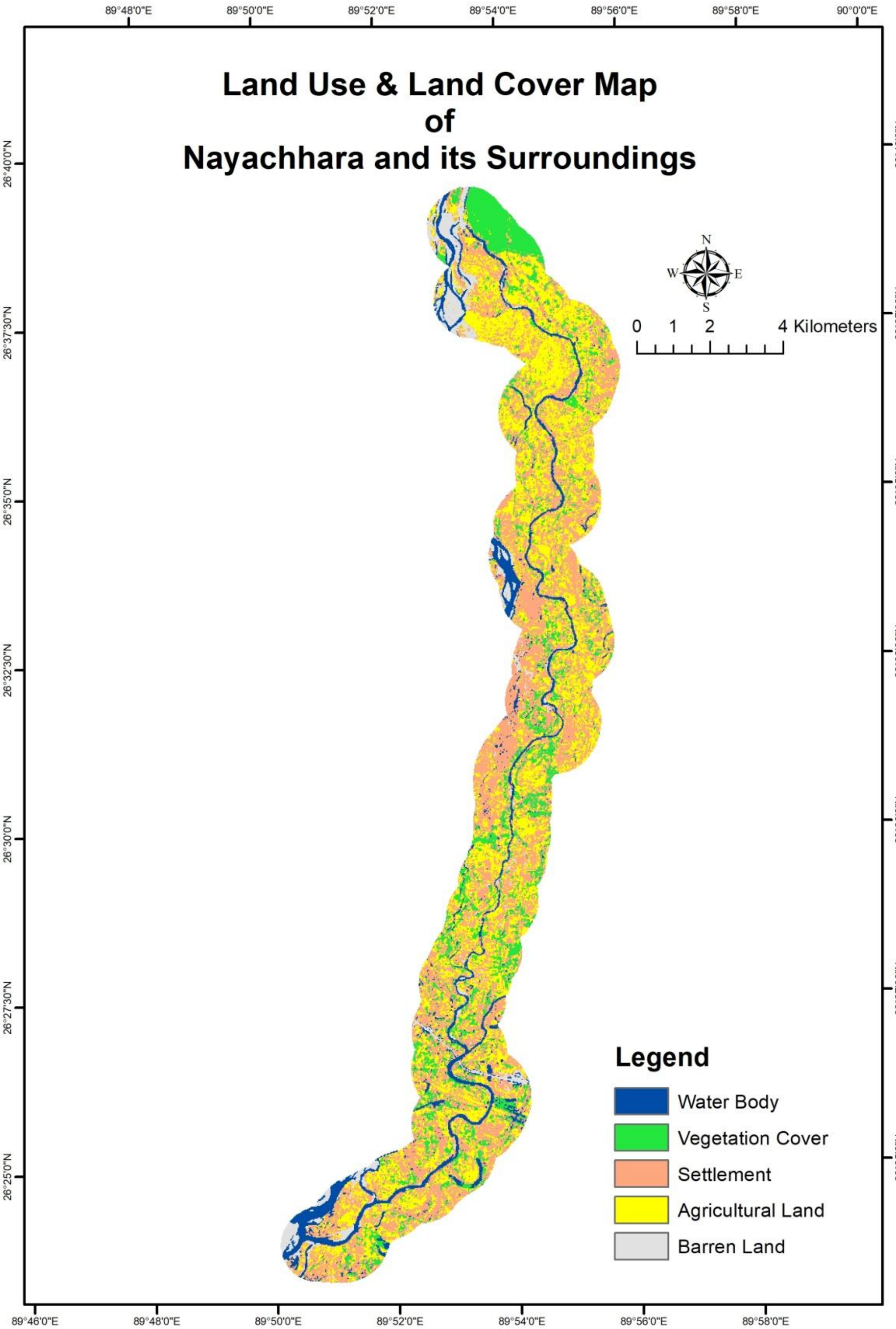
In the field investigation, it was observed that Purbachhara beel also serves as a home for migratory birds during the winter months. This abandoned channel hosts a significant variety of local flora and fauna, including some important medicinal plant species. Thus, it is evident that this abandoned channel is biologically more significant for the preservation of biodiversity and ecology of the region.

6.3.4. Abandoned channel 4: Naya Charra

Abandoned channels benefit the surrounding environment, essentially by way of flood control, groundwater recharge, and pollution reduction (Bhattacharya et al. 2008). Naya chhara is an abandoned channel, along the east bank of River Sankosh in Assam and has a considerable impact on the local people's socio-economic environment.

6.3.4.1 Land use and Land cover:

Land use and land cover within the 1 km peripheral area of the (abandoned channel) Nayachhara beel reveal a complex land use setup. From the collected data, it is found that the agricultural land covers the 42% area followed by settlement (32%), vegetation cover (13%), water body (8%), and barren land (5%). From the above data, it can be clearly mentioned that abandoned channel has a number of utility for socio economic development but with an increase of population day by day most of the abandoned channel services have faced different kinds of problems and sometimes, have steadily diminished. In this regard, it can also be mentioned that fishing is considered an important service of abandoned channels, but has gradually diminished.



Source: LISS-III, BHUVAN (2019)

Map 6.6: Land use and Land cover map of Nayachhara and its Surroundings, 2019

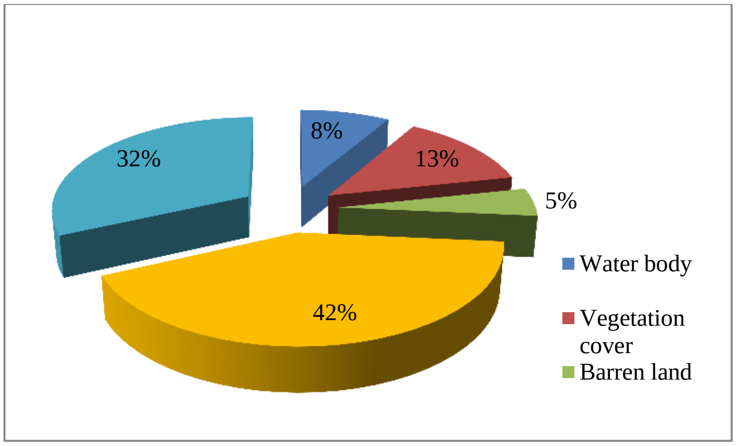


Figure 6.10: Distribution of Land use and Land cover at surroundings of Naya Chhara, 2019

6.3.4.2 Dependent livelihood:

The structure of the livelihood pattern based on abandoned channel varies from place to place in the study area. This abandoned channel provides a huge number of resources which have much economic value for the local people. But due to immense population pressure and the development of modern technology, the environment of the surroundings areas of Nayachhara beel has been affected very badly and has also diminished the natural wetland.

6.3.4.2.1 Agrarian Status:

Due to the high nutrient value of the soils and water content, the boro paddy cultivation in the Purba Chhara abandoned channel areas is now a common practice, especially in the dry season and where cultivators except a higher production of paddy for their livelihood.

In the field survey, it was found that out of total area of Nayachhara abandoned channel, nearly 42% area was under cultivated land and near about 49.29% people engaged directly with this agricultural practice.

Table 6.7: Pair wise Ranking for Livelihood Option at Naya Charra

Livelihood Option	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	Others
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Agricultural Labour	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Agricultural Labour	*	Fishing	Fishing	Fishing
Food and Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Food and Fodder Collection	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Table 6.7a: Ranking for Livelihood Option at Naya Charra

Rank	Livelihood Option	Ranking Points
1	Agriculture	1
2	Agricultural Labour	2
3	Fishing	3
4	Food and Fodder Collection	4
5	Livestock	5
6	Others	6

Source: Compiled by Researcher

6.3.4.2.2 Fishing:

These abandoned channels are recognized as habitats and breeding grounds for fish. From the field data, it was found that these areas fall within the Kokrajhar district of Assam and is characterized by a group of people who are involved in organized fishing in the Nayachhara abandoned channel.

In the field survey, there were 130 households at the villages surrounding Nayachhara abandoned channel. Out of these 15.81% of the local people were directly involved in fishing for their livelihood, which supports the economic development of the villagers inhabiting the surrounding areas of the Nayachhara abandoned channel.

6.3.4.2.3 Livestock:

Livestock plays an important role in rural economy and it also contribute to rural livelihoods, employment and poverty relief for the local people of the study area. In this study area also, most important livestock were cattle, goats, pigs, and duck, chicken. Goat rearing took up the highest rank in grazing lands of Nayachara i.e., 3.71%. Thus, the livestock provides food and non-food items to the people on one hand and it are also plays an important role in the economy of the people of the study area on the other hand.

6.3.4.2.4 Others:

Fodder collection is another important activity in Nayachhara abandoned channels of the study area. Generally, in the dry season when grasses dry up these abandoned channels become the only source of fodder. Some people collect various edible plants also for selling in the local market.

6.3.4.3 Biological importance:

Nayachhara abandoned channel has a great ecological importance to the environment and to the locality. It can provide habitat for wildlife and maintains biodiversity of aquatic habitat also. It is recognized as an important natural reserve and significant for the biodiversity stock and its preservation.

In the field investigation it was found that Nayachhara beel is also considered as the home for migratory birds that pass the winter there. A significant number of medicinal plants are also found there. So, it is said that this abandoned channel is biologically more significant for the preservation of biodiversity, ecology, ecosystem and sustainable development.

6.3.5. Abandoned channel 5: Tama Nadi

Tama Nadi is an abandoned channel formed along the west bank of River Sankosh. A multiple socio-economic importance as well as biological significance of this abandoned channel is examined below.

6.3.5.1 Land use and Land cover:

Land use and land cover within the 1km peripheral area of the abandoned channel Tama Nadi reveals a complex land use setup. From the collected data it is found that the agricultural land covers 42% of the area, followed by vegetation cover (27%), water body (11%), settlement (12%) and barren land (7%). From the above data, it can be clearly mentioned that abandoned channel has a number of utility and uses for socio economic development.

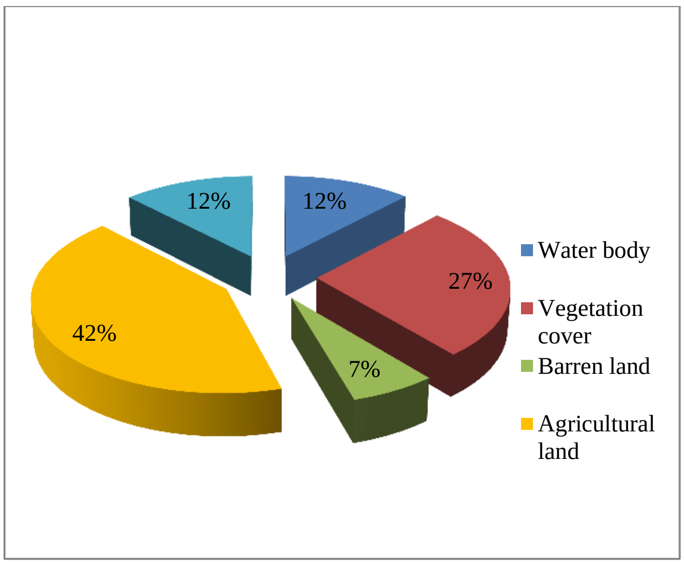
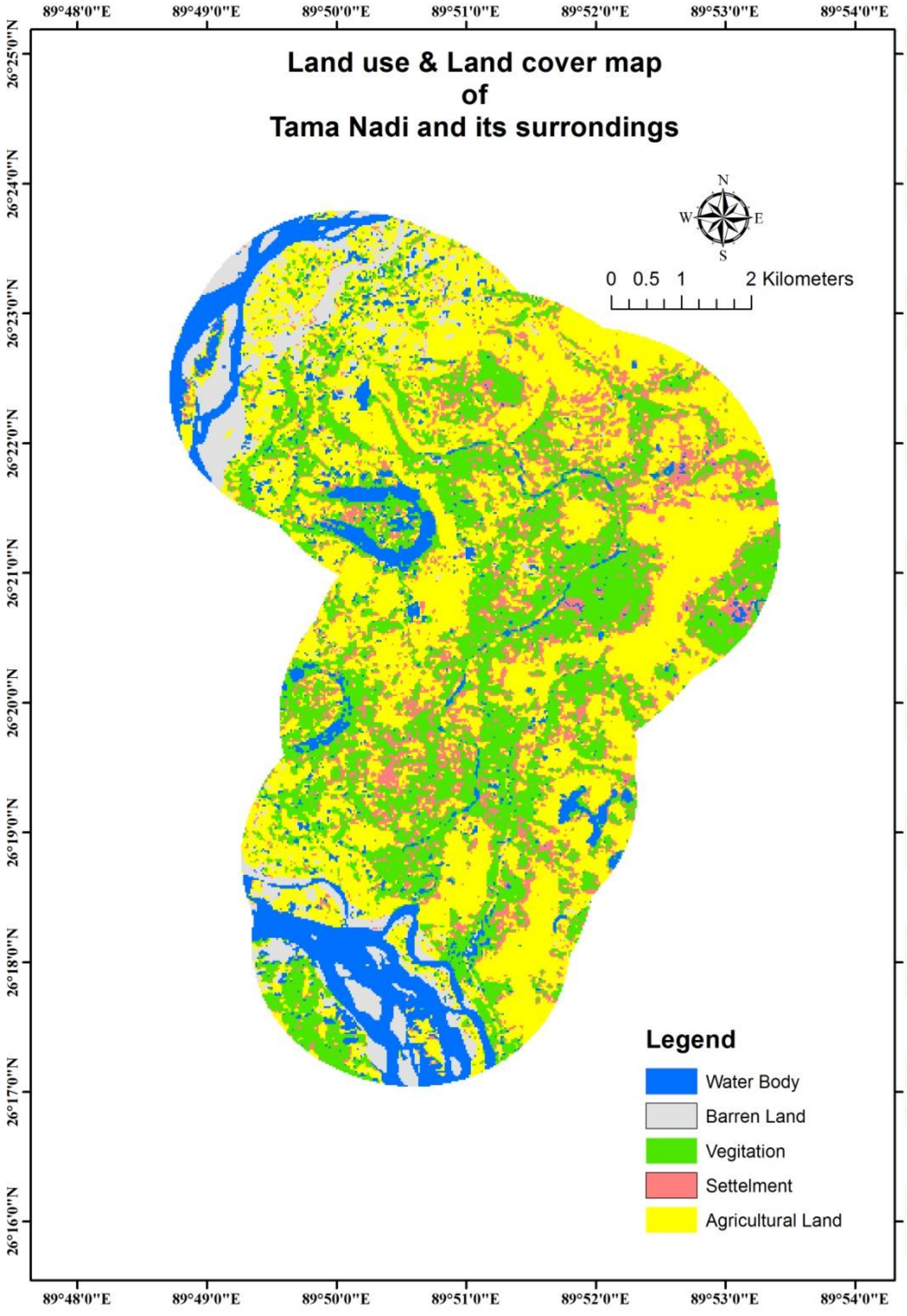


Figure 6.11: Distribution of Land use and Land cover at Surroundings of Tama Nadi, 2019

6.3.5.2 Dependent livelihood:

The structure of the livelihood pattern based on abandoned channel varies from place to place in the study area. This abandoned channel provides a huge number of resources which have much economic value for the local people. But due to immense population pressure and the development of modern technology, the environment of the surroundings areas of Tama Nadi is getting degraded day by day.



Source: LISS-III, BHUVAN (2019)

Map 6.7: Land use and Land cover Map of Tama Nadi and its Surroundings, 2019

Table 6.8: Pair wise Ranking for Livelihood Option at Tama Nadi

Livelihood Option	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	Others
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Fishing	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Fishing	*	Fishing	Fishing	Fishing
Food And Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Livestock	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Livestock	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Table 6.8a: Ranking for Livelihood Option at Tama Nadi

Rank	Livelihood Option	Ranking Points
1	Agriculture	1
2	Agricultural Labour	3
3	Fishing	2
4	Food and Fodder Collection	5
5	Livestock	4
6	Others	6

Source: Compiled by Researcher

6.3.5.2.1 Agrarian Status:

At present, agricultural practices are dominated by the cultivation of boro paddy, owing to the high nutrient value of the soils and water content in the Tama Nadi abandoned channel area, especially in dry season. agricultural land for boro paddy cultivation. It is observed that once the lands of abandoned channel are converted into agricultural land, they never regain their original status.

In the field survey, it was found that out of the total area of Tama Nadi abandoned channel, nearly 42% area was under paddy cultivation, whereas 50.52% areas cultivated seasonal vegetables. Sometimes mono cropping with paddy cultivation was prevalent.

6.3.5.2.2 Fishing:

From the field data, it was found that nearly 21.68% people were directly involved in fishing. So, it can be mentioned that fishing plays an important role in the economic development of the villagers inhabiting the surroundings of the Tama Nadi abandoned channel.

6.3.5.2.3 Livestock:

Livestock provides food and non-food items for the rural people and also helps them to earn money from the market. In study area, the most important livestock are cattle, goats, pigs, duck, chicken. Among all the livestock dependent people, 7.22% engaged in cattle rearing as means of sustainable livelihood.

6.3.5.2.4 Others:

Fodder collection is another important activity in and around the areas of the Tama Nadi abandoned channel of the study area with 5.67% of the people engaged in this occupation. People collect and supplement fodder etc for their livestock in the monsoon and non-monsoonal periods. Generally, in the dry season when grasses dry up this abandoned channel become the only source of fodder. Moreover, the Tama Nadi abandoned channel also provides a wide grazing land for cattle population in the winter and summer seasons, when water level of abandoned channel remains low and this becomes an important occupation of the people inhabiting the surroundings of the Tama Nadi abandoned channel.

6.3.5.3 Biological importance:

Tama Nadi abandoned channel hae a great ecological importance. It provided habitat for wildlife and maintains biodiversity of the aquatic habitat. Moreover, it is also significant in environmental functions and in all food chain and food web functions.

Table 6.9: Biological Importance of Different Local Plants

Scientific Name	Local Name	Uses
Enydra fluctuans Lour	Helencha	Used as vegetable
Ipomoea aquatic Forssk	Kalmi sak	Used as vegetable
Alocasia indica(Lour.)Spach	Kachu	Used as vegetable
Centella asiatica	Thankuni	Used as vegetable
Alternanthera philoxeroides (Mart.)Griseb	Jaldhora	Used as vegetable

In the field investigation it is found that Tama Nadii abandoned channel also serves as the home for migratory birds that pass the winter there. A significant number of medicinal plants are also found there. Moreover, there are a number of varieties of mammals and reptiles in and around the surroundings area of Tama Nadii abandoned channel. So, it is said that this abandoned channel is biologically more significant for the preservation of biodiversity and sustainable development.

Plate 6.3: Jute Wetting at Tama Nadi

6.3.6. Abandoned channel 6: Avulsed Channel at Falimari

A fully avulsed abandoned channel is found in the middle course of the Sankosh River at Majerdabri, Falimari village of Cooch Behar district of West Bengal. This abandoned channel avulsed from the main channel of the Sankosh River due to overbank flow and channel infilling. The length of this abandoned channel is about 12.8km and width is about 200 m. Jorai Nadi also joins at the middle part of this channel and jointly flows about 16.2 km and thereafter, it meets with the River Raidak-II. Some areas of this upper portion of avulsed abandoned channel are filled by sediments and at the same time there is encroachment in the form of human settlements. No water flow is found in the dry season, whereas water flow is available only in rainy or flood seasons. At present, it serves as a fertile land for agriculture.

6.3.6.1 Land use and Land cover:

Land use and land cover map has been prepared within the 1km peripheral area of the (abandoned channel). This avulsed channel reveals a complex land use setup. From the collected data it is found that the agricultural land covers the 40% of the area, followed by vegetation cover (28%), settlement (14%) water body (11%), and barren land (7%). From the above data, it can be clearly mentioned that the avulsed channel has a number of utility for socio economic development such as paddy cultivation but with accelerating increase of population day by day, most of the avulsed channel services have faced different kinds of problems and sometime have steadily diminished.

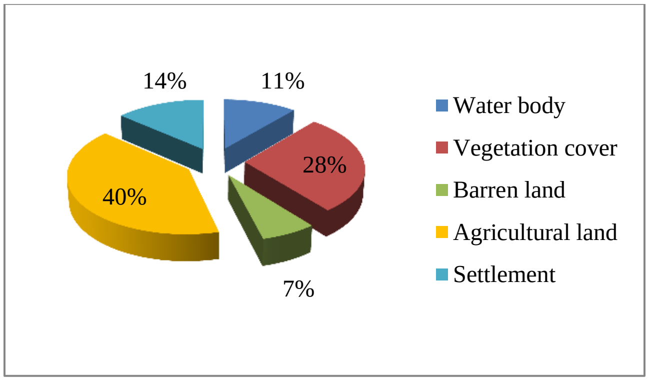
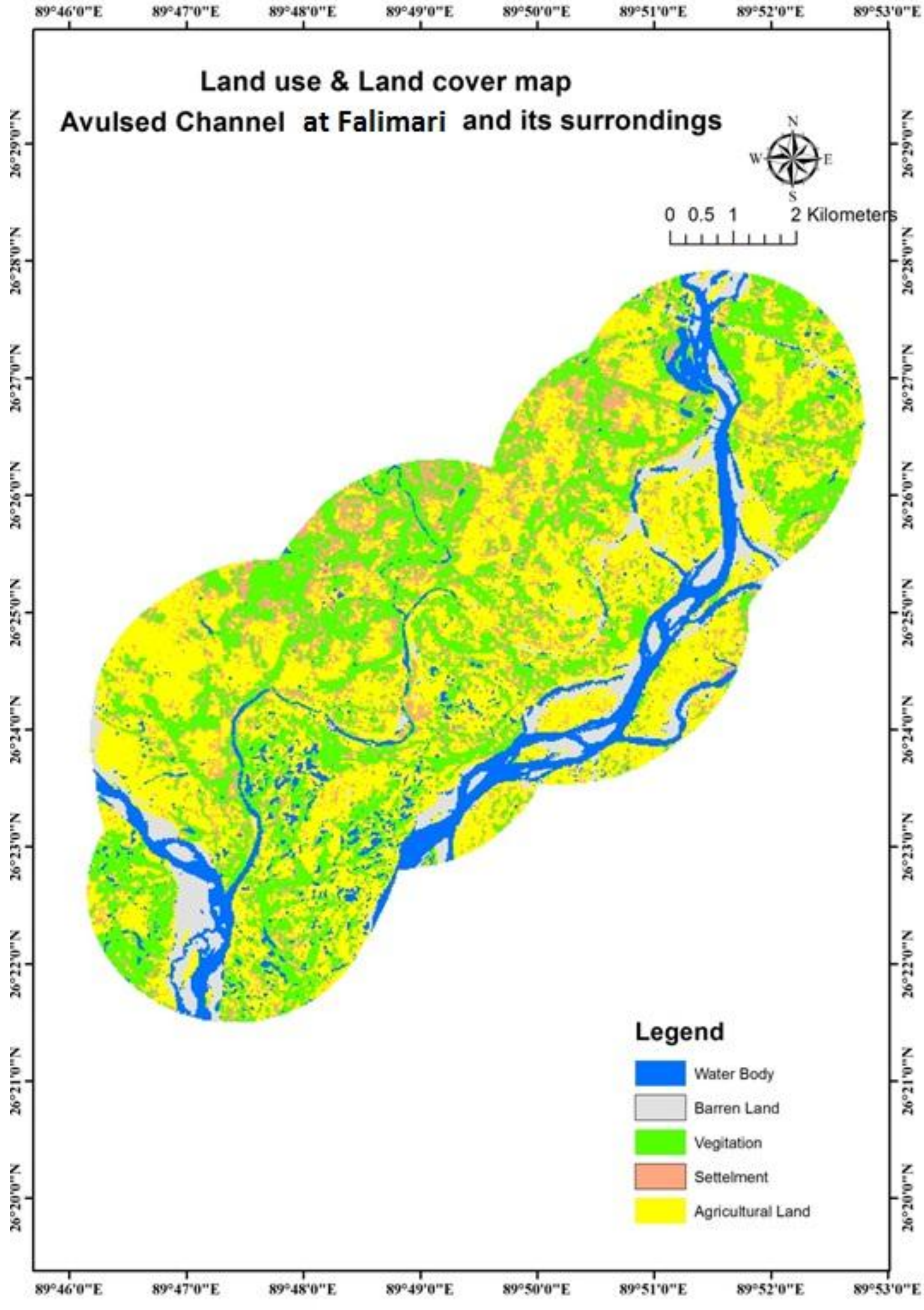


Figure 6.12: Distribution of Land use and Land cover at Surroundings of Avulsed Abandoned Channel at Falimari, 2019



Source: LISS-III, BHUVAN (2019)

Map 6.8: Land use and Land cover map of Avulsed Abandoned Channel at Falimari and its Surroundings, 2019

6.3.6.2 Dependent livelihood:

This avulsed channel provides a huge number of resources which have much economic value for the local people. However, due to immense population pressure and the development of modern technology, the environment of the surroundings areas of this avulsed abandoned channel has become very adversely affected and has also diminished the natural wetland.

Table 6.10: Pair wise Ranking for Livelihood Option of the Avulsed abandoned Channel at Falimari

Livelihood Option	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	Others
Agriculture	*	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
Agricultural Labour	Agriculture	*	Fishing	Agricultural Labour	Agricultural Labour	Agricultural Labour
Fishing	Agriculture	Fishing	*	Fishing	Fishing	Fishing
Food And Fodder Collection	Agriculture	Agricultural Labour	Fishing	*	Livestock	Food and Fodder Collection
Livestock	Agriculture	Agricultural Labour	Fishing	Livestock	*	Livestock
Others	Agriculture	Agricultural Labour	Fishing	Food and Fodder Collection	Livestock	*

Table 6.10a: Ranking for Livelihood Option of the Avulsed abandoned Channel at Falimari

Rank	Livelihood Option	Ranking Points
1	Agriculture	1
2	Agricultural Labourer	3
3	Fishing	2
4	Food and Fodder Collection	5
5	Livestock	4
6	Others	6

Source: Compiled by Researcher

6.3.6.2.1 Agrarian Status:

Owing to the high nutrient value of the soils and water content, the boro cultivation in the Avulsed abandoned channel areas is now a common practice especially in dry season and where cultivators except a higher production of paddy for their livelihood. Generally, cultivation starts in the month of January –February every year when the water level goes down and marginal areas of abandoned channels are raised up. In this situation, farmers having ownership of the land of avulsed abandoned channel convert it into agricultural land for boro paddy cultivation. In the field survey, it was found that out of the total area of the avulsed abandoned channel, nearly 40% area is under paddy and vegetables cultivation and near about 57.38% people are engaged directly with this agricultural practice which is increasing day by day.

6.3.6.2.2 Fishing:

The avulsed channel is recognized as a habitat and breeding ground for fish and it also is the chief source of fish for the poor people in the surrounding villages. From the field data, it was found that there are a large number of people involved in organized fishing in the avulsed abandoned channel. These are:

a. People who fish for their daily consumption.
b. The fishing community who fish for their livelihood.
c. Lease holders who occupy the abandoned channels for fishing as their main business.

In the field, the researcher surveyed more than 64 households at the villages surrounding the avulsed abandoned channel. Out of these, 15.63% of the people were directly involved in fishing for their livelihood.

6.3.6.2.3 Livestock:

Livestock also plays an important role in rural economy of the local people of the study area. Livestock provides food and non-food items for the rural people and also helps them to earn money from the market. In the study area, the most important livestock are cattle, goats, pigs, duck and chicken. Cattle rearing occupies 2.79% of the grazing lands of the avulsed abandoned channel. Goats and pig rearing are also common occupations of the residents of the avulsed abandoned channel. Thus, it is evident that the livestock provides food and non-food items to the people on one hand and it is also plays an important role in the economy of the people of the study area on the other hand.

6.3.6.2.4 Others:

Fodder collection is another important activity in the avulsed abandoned channel of the study area. Moreover, the avulsed abandoned channel also provide grazing lands for cattle population in the winter and summer season. Pisciculture is also considered an important practice in the avulsed abandoned channel and due to high demand of fish it makes a profitable business for the local people.

6.3.6.3 Biological importance:

This avulsed abandoned channel has a significant ecological role in maintaining and preserving the biological diversity of the study area. It provides a habitat for wildlife and biodiversity of aquatic species that are recognized as important natural resources and significant for the biodiversity stock and its preservation. In the field investigation it was observed that the avulsed abandoned channel also serves as the home for migratory birds that pass the winter there. A variety of medicinal plants are also found there. The avulsed abandoned channels has great biological and ecological significance for the preservation of biodiversity in the region.

From the collected primary data during the village survey and from the above diagram it is observed that people inhabiting the surroundings of all the abandoned channels are mostly engaged in agricultural activity. About 59.29% of the population is engaged in agriculture at Khalishamari beel which considered as the highest among all the abandoned channels and which is followed by 59.10% at the avulsed abandoned channel. Corresponding figures were 56.54% at Kamandanga beel and 56.38% at the surroundings of Tamanadi. Fishing is considered the second highest livelihood option in most of the abandoned channels except Purba chaara and avulsed abandoned channel in the study area. Fishing activity is highest (20%) at Khalishamari beel which followed by Nayachaara (19.84%), Tama Nadi (18.93%) and the lowest is about 13.00% found at the avulsed abandoned channel. Out of the total population of the surveyed villages, about an average 14.14% of population chose their livelihood option as agricultural labour in the study area. Food and fodder collection, livestock and some other economic activities were also found in the study area and their average percentage of engagement is about 4.18%, 3.53% and 5.27% respectively.

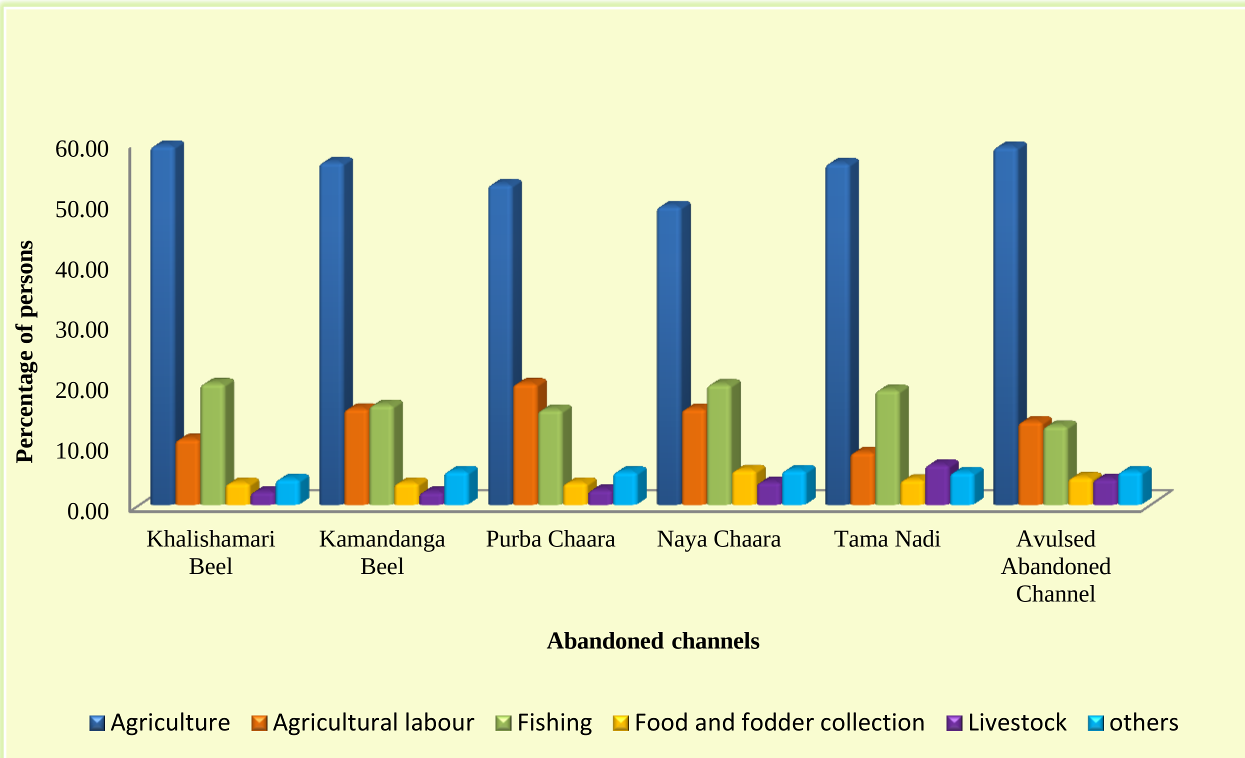


Figure 6.13: Comparisons of Various Livelihoods among the Abandoned Channels

6.4 Discussion and Conclusion:

Socio-economically abandoned channels are very important for the people inhabiting the surroundings areas. These abandoned channels are considered as the source of various natural resources which are essential for their daily life. Local people collect food and fodder from these abandoned channels and they also engage in various occupations based on these abandoned channels such as fishing etc. It is observed that people used fertile land of abandoned channels for cultivation in the dry season and they also use the water of these channels for their irrigational purposes. Apart from the economic purpose, abandoned channels also play an important role in maintaining the biological balance of the study area. Moreover, these abandoned channels can also be recognized as containing very rich components of bio-diversity which have a great significance at local, regional and national levels.

In conclusion, it is apparent that abandoned channels constitute an important source of natural resources which yield high economic and livelihood values to the local people inhabiting the surroundings of the abandoned channels of the study area. Population is increasing day by day and at higher rates, but the natural resources of the abandoned channels are not increasing at the same rates. Moreover, poverty also greatly affects the natural environment and it is at a critical stage in the study area, since it influences the local people who willfully and consistently persist in the destruction of the resources of these abandoned channels. In this situation, prevention of further destruction of the abandoned channels will require the adaption of multiple-use land managements, based on the principles of sustainable management.

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CHAPTER VII

MANAGEMENT OF ABANDONED CHANNELS

7.1 Introduction:

The fluvio-dynamic characteristics of the River Sankosh in the study area and its frequent changes and abandonment of courses counts for adequate academic importance from behavioral point of view of alluvial channels in the zone of sub-Himalayan margin. The areas associated with abandoned courses in the lower course of the basin have significant importance from the socio economic and environmental point of view also. Therefore, an attempt has been made in this chapter to investigate some important unexplored facts about the restoration, conservation and management of abandoned channels which are supposed to be more useful to socio-economic development as well as risk reduction for human habitation and sustainable use of lands of the surrounding channels areas in the studied basin.

7.2 Management strategies and recommendations of abandoned channels:

Abandoned channels are recognized as important elements of alluvial river system (Julian, P.et al. 2008). These abandoned channels provide huge natural resources for habitation of some organism having much economic value such as the cultivation of fishes and other aquatic resources. Moreover, surrounding areas of the abandoned channels and the substrate can be used for agricultural production of necessary crops and can also be used as the source of irrigation.

But, abandoned channels of the River Sankosh in the study area are facing different kinds of problems due to huge population pressure, land use change, climatic change and environmental change day by day. In this regard, some major problems of abandoned channels of Sankosh River basin have been broadly summarized as:

I. Shrinkage of channel area due to encroachments, settlements and others.
II. Hydrologic alterations, due to direct surface drainage, de-watering by consumptive use of surface water inflows, unregulated draw down of unconfined aquifer from either groundwater withdrawal or by stream channelization by various anthropogenic activities.

III. Increase of sedimentation, nutrient, organic matter, metals, pathogen and other water pollutant loadings from wastewater discharges from the adjacent areas.
IV. Continuous overexploitation of channels resources and products.
V. Occurrences of more insidious chemical and deposition of various pollutants into water bodies of the abandoned channels mainly by both from the agricultural pollution and bathing of domestic animals.
VI. Changes in characteristics of channel flora and fauna (exotic) due to the change of water quality etc. as a result of change in the adjacent land uses deliberately or naturally.

Based on the above-mentioned problems, appropriate management and restoration mechanism is required to be implemented to regain and maintain sustainability of the abandoned channels of the Sankosh River in the study area. In this regard, some important proposed recommendations and management strategies have been discussed under the following heads.

7.2.1 Conceptual Framework for management of abandoned channels:

This study has summarized a number of articles and literature reviews regarding management of abandoned channels with several examples from national and international levels. Abandoned channels need a collaborated investigation involving natural, social and inter-disciplinary study aimed at understanding and analysing various components, such as, monitoring of water quality, socio-economic dependency, biodiversity and other activities as an essential tool for formulating conservation strategies for long term (Kiran et al., 1999).

A developing country like India has an important need to analyze and ensure proper management of abandoned channel due to high population growth and economic development. On the other hand, there have emerged some pressures including resource exploration, expansion of built up area, agricultural development, shifting livelihood patterns by these drivers which make some changing scenario about physical, biological and socio-cultural attribute in the abandoned channels in the study area. There is an urgent need to take some necessary action or management to reduce ecological degradation of abandoned channels and reserve the sustainability of socio-economic development of the local people. In this context, we need long term actions and conservation policies for the sustainable use of abandoned channels and its restoration.

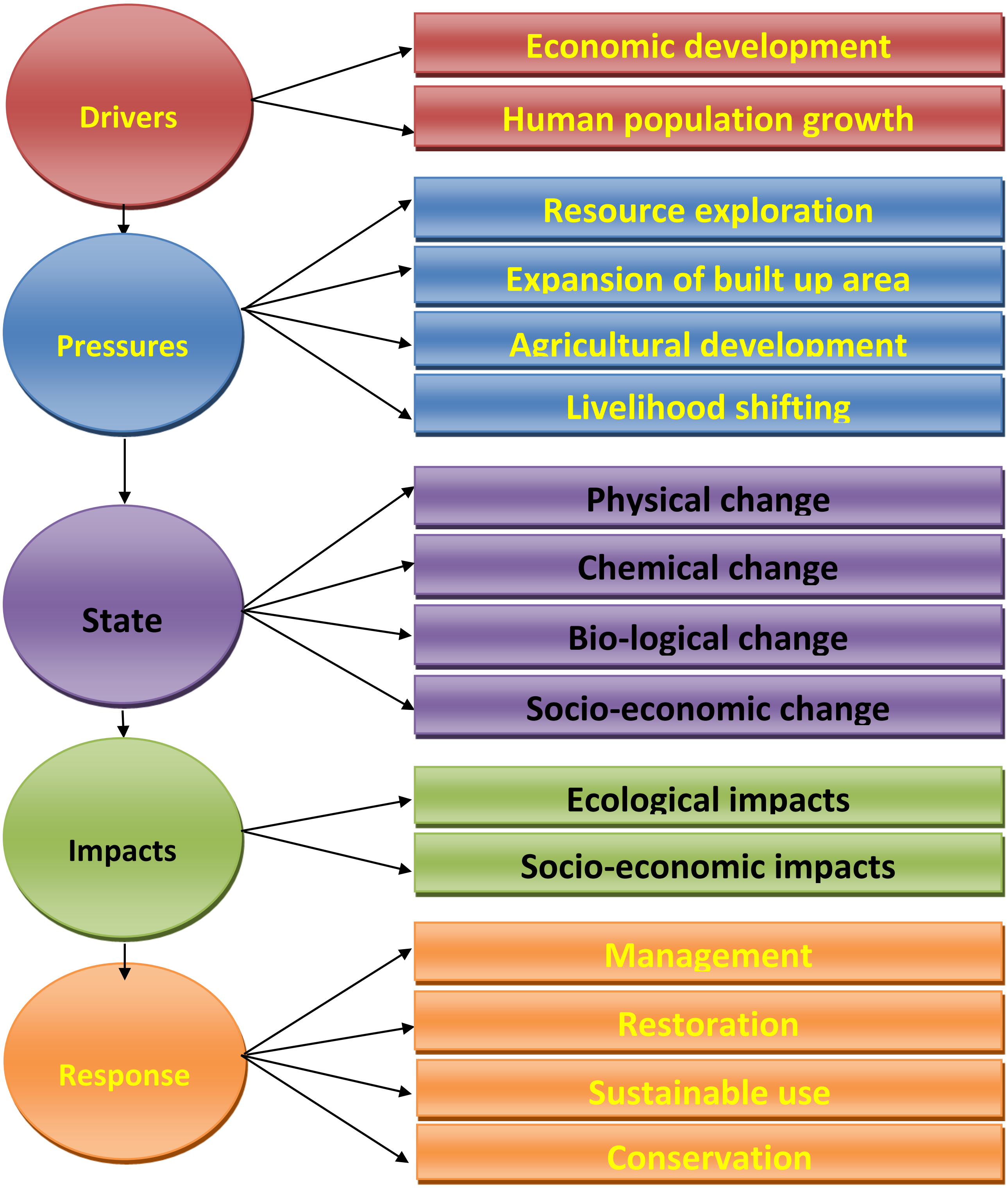

Figure 7.1 Conceptual Framework for Management of Abandoned Channels

A conceptual framework has been prepared with the objective that addresses levels of interventions required for prioritisation (Committee on Restoration of Aquatic Ecosystems et al, 1992).

7.2.2 Guidelines for Abandoned Channels Management:

The watershed management program generally involves activities to protect, restore, manipulate, and provide for the functions and values emphasizing both quality and acreage by advocating sustainable usage of them (Walters, C. 1986). An intense monitoring, interaction and co-operation among the various agencies (state departments concerned with environment, soil, natural resource management, public interest groups, citizen groups, agriculture, forestry, urban planning and development, research institutions, government, policy makers, etc.) has required for the management of abandoned channels in the study area. Some important guiding principles have been discussed below to manage, restore and conserve the abandoned channels.

I. Management goals should not only involve buffering channels from any direct human pressures that could affect the channels normal functions, but also in maintaining important natural processes that operate on them that may be altered by human activities.
II. Channel management has to be an integrated approach in terms of planning, execution and monitoring requiring effective knowledge on a range of subjects from ecology, economics, watershed management, and planners and decision makers, etc. All this would help in understanding channels better and evolving a more comprehensive solution for long-term conservation and management strategies.
III. In this context, it summarizes that there are multiple formations and problems that are associated with all abandoned channels but it needs some management effort which provides benefit to local people with long-term effectiveness.

7.2.3 Restoration:

Abandoned channels are important elements of an alluvial system. These channels can provide habitat for wildlife, biodiversity of aquatic habitat and huge natural resources for the livelihood of the local people. But there are some important problems such as shrinkage of abandoned channel area, reduction of water level, increase of non-point source pollution that can affect aquatic environment and resources of the abandoned channels. Moreover, these problems also adversely impact the socio-economic life of the local people inhabiting the surroundings of the studied abandoned channels. So, restoration of abandoned channels is essential to solve the above-mentioned problems and to preserve them in the study area.

Restoration is here defined as returning to a pre-disturbance physical state of an abandoned channel. It is also mention that river restoration as assisting the recovery of ecological integrity in a degraded watershed system by re-establishing hydrologic, geomorphic, and ecological processes, and at the same time replacing lost, damages or compromised biological elements. Different types of restoration efforts are to be applied for abandoned channel management. Restoration denotes re-establishment of pre-disturbed aquatic functions and the related physical, chemical and biological features (Cairns, 1988) which aim to emulate environmental and a self-regulating system that is integrated ecologically with the landscape and the functions that the abandoned channels execute.

In this study, it was typically found that most of the abandoned channels along the main stream i.e. River Sankosh has formed due to cut-off (chute cut-off and neck cut-off both) and avulsion also. In this regard there are some management practices to restore the abandoned channels. In this context, engineering solution consists of construction of weir, hydraulic dredging, connectivity with the main river are some most impactful restoration methods to conserve the abandoned channels. Some agronomic methods by BMP include agriculture-stream buffers and bank stabilization, preventing neck cut-off, and erosion control are very important. In all of these cases, all types of restoration have valuable benefits and effectiveness for the entire abandoned channels.

7.2.3.1 Hydraulic Dredging:

Hydraulic dredging is an important restoration process or operation of excavating materials from a water environment for the purpose of improving existing water features. It helps in reshaping land and water features to alter drainage, navigability and use of aquatic resources for socio-economic development of the local people inhabiting the surrounding of the abandoned channels. It also acts to suck up and filter the bottom to remove contaminants and increase the depth of water level of the abandoned channels. Moreover, as a concern of environmental sensitivity, hydraulic dredging seems to be the more effective method to restore abandoned channels in the study area. Furthermore, the abandoned channels are experiencing undue macro-phytes and algal bloom, thus restoration strategy has been constructed to remove the organic, nutrient rich sediment and deepen channels as experienced through Collins Lake, which is an oxbow lake along the Mohawk River in Scotia, New York restored through hydraulic dredging in 1977 and 1978 (Snow et al. 1979). It is best used for abandoned channel restoration technique. In this regard, it is mentioned that Kamandanga beel (Figure 6.8) and Khalishamari beel (Figure 6.7) need to operate hydraulic dredging to restore the depth of water level and aquatic environment in the study area.

7.2.3.2 Connectivity with Main River:

The hydrological connectivity of these studied abandoned channels usually decreases in time due to fast and complex sedimentation processes occurring in the upstream entrance and downstream sections of the abandoned channels in the study area. In this regard, numerous restoration projects can be applied to reconnect the upstream and downstream ends of abandoned channels to the main river to re-establish connectivity and enhance the quality of ecological habitat (Holubova et.al, 1999; Baptist and Mosselman, 2002). It is also mentioned that the morphodynamical behavior of the entrance and exit of the abandoned channels plays a significant role in the success of such reconnection method in the study area.

Moreover, it is observed that erosional and depositional processes are taking place at the entrance of an abandoned meander or any avulsed abandoned channel, where the exit is still connected to the main channel, but the upstream entrance is closed. In such a condition, this method suitability applied to re-connect abandoned channels with main river to restore them. Here, Nayachhara (Figure 6.10) and other avulsed abandoned channel (Figure 6.12) can be mentioned as being possible to be reconnected their upstream entrance with the main river.

7.2.3.3 Best Management practices (BMP):

The main objective of Best Management Practices (BMP) is to implement edge-of-field practices and agronomic methods including conservation of tillage and winter cover crops to reduce non-point source pollutants from agricultural run-off (Cullum et al., 2006; Knight et. al., 2002). In relation to this restoration program, BMPs help in correcting point and non-point sources of pollution wherever and whenever possible and to restore aquatic environment including natural resources in the study area. This program along with the implementation of rules, regulations and planning strategy for wildlife habitat and fishes helps in arresting the declining water quality and the rate in loss of abandoned channels. It is also mentioned that intensive planning, leadership financial support and active involvement from all levels of organization (governmental, NGOs, citizen groups, research organizations etc.) are required to achieve the goal of this restoration program in the study area.

In the study area, BMPs can be applied in Khalishamari abandoned channel (Figure 6.8) to reduced sedimentation, nitrogen, phosphorous with the implementation of agronomic methods including crop rotation.

7.2.3.4 Planning of buffer zones:

Creation of buffer zones limiting anthropogenic activities around the selected sites of the abandoned channels along the river Sankosh could revive their natural functions. In this regard, Castelle et al., 1994 has mentioned some important criteria for determining adequate buffer size to protect various abandoned channels and their aquatic resources. These are as follows:

- Identify the functional values by evaluating aquatic resources within the abandoned channels in relation to their economic cost.
- Find out the magnitude and source of disturbances, landuse and identify the possible consequences of identify the possible consequences of such stress in long term perspective.
- Buffer characteristics such as vegetation density, structural complexity, soil condition and other conditions are to be taken under consideration.

During the field study it is observed that some areas of Khalishamari beel especially north-western parts are occupied by local people for their agricultural land and settlement. In this regard buffer zone can play an important role to restore the surrounding or peripheral areas of these abandoned channels. On the other hand, western part of Kamandanga beel is also densely settled. So, creation of buffer zones can reduce agricultural land and settlement human impacts by limiting easy access and acting as a barrier.

Table 7.1: Summary of Problems and Prospects of Abandoned Channels

Abandoned Channel	Parent River	Type	Problems	Restoration	Benefits and Effectiveness
Khalishamari beel	River Sankosh	Natural chute cut-off	• Sedimentation • Excessive Agriculture	• Constructio n of weir • Hydraulic Dredging • Agriculture-stream buffers and bank stabilization	• Prevent flow as secondary channel and flood control • Agriculture and fishing
Kamandanga beel		Natural Neck cut-off	• Built-up encroachment • severe erosion due to neck cut-off	• Prevent neck cut-off • Erosion control	• Agriculture, Livestock grazing and fishing
Purbachhara beel		Natural Neck cut-off	• Excessive Agriculture	• Agronomic method by BMP	• Agriculture, Livestock grazing and fishing
Nayachhara beel		Natural Avulsed channel	• Seasonal dewatering	• Constructio n of weir • Connectivit y with main river	• Agriculture, Livestock grazing and fishing • flood control
Tama Nadi		Natural	• Reduced fishing • sedimentation	• Agriculture-stream buffers and bank stabilization	• Agriculture, Livestock grazing and fishing • flood control

Source: Data compiled by researcher.

7.2.4 Remedial measures for conservation of abandoned channels:

Conservation is the term associated with manipulation of an ecosystem to ensure maintenance of all functions and characteristics of the specific ecosystem. Thus, the balance of an ecosystem of any particular water body is usually accompanied by irreversible loss in both the valuable environmental functions and amenities important to the society.

In this context, a detailed study of channel management, conservation and its implications are required for socio economic development and as well as from the biological and hydrological perspective.

In this regard, it is summarized that some important measures must be taken for the conservation of studied abandoned channels. These are as follows:

Firstly, a short-term fix might be providing connection to the main stream by previous path i.e. nearby plug bar of the abandoned channels.

Secondly, to determine the sedimentation rates and evolutions along the main stream by collecting sediment core samples.

Thirdly, to analyse topographical maps, satellite images and aerial photographs over different time periods.

Fourthly, the study area surrounded by abandoned channels needs monitoring with regard to water quality, to improve biological diversity and identify the sources of pollution.

Fifthly, restoring the riparian agricultural land adjacent to abandoned channels to reduce inundation and sedimentation and provide bank stabilization.

Sixthly, there is an urgent need to assess the aquatic resources i.e. flora and fauna especially and maintain the biological importance.

Seventhly, to identify the functional and economic values by evaluating natural resources generated by abandoned channels in terms of the economic costs and its benefits.

Eighthly, the study needs some conservation strategies to protect and restore the abandoned channels to its original state.

The discussion done in the chapter 6 and 7 therefore reveals that if abandoned channels are properly managed as discussed above, the socio-economic development of the study area can be possible along with the risk reduction for human habitation and proper utilization of land resources of the study area. Therefore, the hypothesis 3 " ***Management of abandoned channels are supposed to be more useful to socio-economic development as well as risk reduction for human habitation and utilization of lands of the surrounding channels areas'*** is justified for management of the abandoned channels of Sankosh river basin.

7.3 Major Findings and Conclusion:

7.3.1 Major findings:

This Ph. D. research work has been completed with several remarkable and unknown findings of the study of abandoned channels and their socio-economic importance of the Sankosh river basin in India. There are different objectives to study and identify the several mechanisms of abandoned channel formation and its socio-economic significance. The study has the following findings based on the different objectives which are also dealt with the research issue:

I. Stream ordering and bifurcation ratio of the study area proves that the lower part of Sankosh river has a tendency to overflow or over bank flow in flood season (Map 3.1 and Table 3.1) and which influences the process of channel abandoning.

II. Flood frequency analysis (fig.3.2) and hydrograph shows that the river flow have been diverted or shifted or bifurcated by the process of channel avulsion.

III. Different types of channel avulsions are identified in different parts of Sankosh river of the study area (Map 4.1) and these are considered important processes of abandoned channel formation.

IV. In accordance to *John Field, 2001* sometimes a minor incision with a narrower channel creates channel abandonment by avulsions that are inset into the old channel bed.

V. In the study area, Sankosh River had formed a meander bend cut-off ie, both chute cut-off and neck cut-off. In this connection, sinuosity index is calculated in different parts of Sankosh river (fig. 3.4) within the study area. This mechanism is considered the main process of the formation of abandoned channels in the study area.

VI. An abandoning channel may regain discharge over the courses of next flooding events and develop a new semi-stable channel bifurcation, this occurs often in low-angle split with a limited difference in gradient advantages and relative long period of abandoning, usually found in avulsion and chute cut-off low sinuous river (Willem H.J Toonen *et al*. 2012)

VII. Braid formation is an important process of channel abandoning and is found in different parts of the study area (Map. 4.5). In relation to this, the braided index is also calculated (table 4.1).

VIII. According to *Friend and Sinha, 1993*, difference in bar area or braided channel ratio would be influenced to changes in channel behavior in terms of aggradation and degradation processes which will have a significant result on avulsion processes.

IX. Different morphological features are also formed by the processes of channel abandoning in the study area which is extensively discussed in the Chapter No. V with suitable maps (Map 5.1)

X. Some resultant landforms are also considered as abandoned channels like oxbow lakes, meander cut-offs and meander scars.

XI. Biological and as well as socio-economic importance of these abandoned channels are also explained in a systematic way.

XII. Sustainable management of these abandoned channels is required to minimize the problems associated with them.

XIII. Abandoned channels restoration methods are suggested for proper utilization or use of abandoned channels for the benefit of local people inhabiting the surroundings of the abandoned channels of the study area.

XIV. Numerous restoration projects are to be taken up to connect the upstream and downstream ends of abandoned channels to the main flow to re-established connectivity in the study area.

XV. The channel morphology of the river system has been significantly affected by creation of dams, irrigation systems and other anthropogenic activity.

XVI. Population pressure over the abandoned channels should be controlled by law and rules governed by the state and central govts.

7.3.2 Conclusion

The adopted systematic approach has helped in achieving the basic objectives and research questions to complete this research work. The courses of Sankosh River have been analyzed with the remote sensing and GIS platforms and formation of abandoned channels were quantified from the point of view of fluvial processes. Identification, types and the mechanism of abandoned channel formations have been realized and documented by field investigations. Laboratory analysis and sampling tests of different variables helped to find out the mechanism of abandoned channels formation and their resultant landforms formation in different reaches of the study area. Different morphometric parameters have been calculated and analyzed to know the nature of the River Sankosh. Meander cut-offs, ie both the neck cut-offs and chute cut-offs have been analyzed in relation to the sinuosity index which is considered the fundamental mechanism of abandoned channel formation. The mechanism of channel avulsion has been investigated on the basis of overbank flow during the high flood which is also explained as another important mechanics of the formation of abandoned channels in the study reach. Meander cut-offs, channel avulsion, influences of braid formation have been observed and identified as the main mechanisms of the formation of abandoned channels in the study area.

Different erosional and depositional landforms development with the channel abandonment has been counted and analyzed to fulfill the concern objective of the research work. Abandoned channels are important elements of alluvial river system and these channels provide huge resources for the people inhabited surrounds the abandoned channel. In this regard, the socio-economic importance of these abandoned channels has been analyzed for the benefit of the local people. On the other hand, human habitation on the abandoned channel area has been made different kinds of problem are also investigated in the study reach. For this reason, restoration processes, suggested guideline and a conceptual framework, has been prepared for the proper management of abandoned channels.

Abandoned channels are generally highly productive ecosystems, providing various key benefits to the environment. Records relating to the existing ecological values of the identified abandoned channels along the River Sankosh (main stream) is inadequate in the present era. This necessitates an urgent need to make a record on the types of abandoned channels, its formation and mechanisms, morphometric, hydrological and ecological records, surrounding land use and land cover, hydrogeology of the main stream basin, surface water quality, and socio-economic dependence, and highlight the pressure these systems are subjected to in the present context. Monitoring of water quality can be done by involving local NGOs and the regulating department of surface water, groundwater and ecology. Such programs and practices help in providing technical support and addressing hydrologic concerns, and consequently, this helps in boosting better consideration of these systems and formulating comprehensive measures regarding their management by restoration and conservation.

In the long run, it is expected that the outcome of this Ph.D. research work has fulfilled all the basic objectives of this research as well as contributed to the field of geomorphology in general and to fluvial geomorphology in particular. The research work has also demonstrated the application of geospatial technology in fluvial geomorphologic investigation.

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Appendix I: Photo Plates

Plate1: Women Participation in Agriculture

Plate 2: Women Participation in Fishing

Plate 3: Paddy field adjacent to Kamandanga beel

Plate 4: Vegetable cultivation adjacent to Purba Charra

Plate 5: Fishing in Naya Chhara

Plate 6: Paddy Cultivation nearby Khalishamari Beel

Plate7: Fish collection from Kamandanga beel

Plate 8: Food and Fodder Collection from Nayachara

Plate 9: Water lilly (local food) cultivation in Khalishamari beel

Plate10: Traditional paddy drying process

Plate 11: Measurement of cross section at Falimari

Plate12: Measurement of cross section at Barobisha

Plate13: Stream bank failure at Barobisa

Plate14: Stream bank failure at Falimari

Plate15: Visit at office of Central Water Commission.

Plate16: Interview with local villager at Kamandanga beel.

Plate17: ICDS centre at Purba charra.

Plate18: Higher secondary School at Kamandanga.

Appendix II: Data Tables and Calculations

Table a: Participation of Local People at Different Livelihood.

Name of Village	Agriculture	Business	Service	Fish Trade	Fish Catching	Fishing Net Making	Collecting other resources from channel	Daily Wage labor	Total
Pokalagi	47	23	8	24	33	9	11	22	177
Kamandaga	56	25	13	23	31	7	14	42	211
Chagolia	42	13	6	19	27	4	12	17	140
Schoolghutu	46	14	8	21	41	5	13	18	166
Falimari-West	61	19	7	27	42	0	19	25	200
Majerdabri	51	18	8	11	39	6	19	53	205
Falimari-East	67	23	18	31	36	12	27	26	240
Tamarhut	74	31	11	29	29	7	23	39	243
Kukiladanga	56	19	26	23	28	6	16	20	194
Dewaguri-II	36	9	10	12	26	5	13	15	126
Hawraipet-II	39	14	10	19	27	0	14	16	139

Cont…

Name of Village	Agriculture	Business	Service	Fish Trade	Fish Catching	Fishing Net Making	Collecting other resources from channel	Daily Wage labor
Pokalagi	26.55	12.99	4.52	13.56	18.64	5.08	6.21	12.43
Kamandaga	26.54	11.85	6.16	10.90	14.69	3.32	6.64	19.91
Chagolia	30.00	9.29	4.29	13.57	19.29	2.86	8.57	12.14
Schoolghutu	27.71	8.43	4.82	12.65	24.70	3.01	7.83	10.84
Falimari-West	30.50	9.50	3.50	13.50	21.00	0.00	9.50	12.50
Majerdabri	24.88	8.78	3.90	5.37	19.02	2.93	9.27	25.85
Falimari-East	27.92	9.58	7.50	12.92	15.00	5.00	11.25	10.83
Tamarhut	30.45	12.76	4.53	11.93	11.93	2.88	9.47	16.05
Kukiladanga	28.87	9.79	13.40	11.86	14.43	3.09	8.25	10.31
Purni	28.57	7.14	7.94	9.52	20.63	3.97	10.32	11.90
Pub Maragadadhar	28.06	10.07	7.19	13.67	19.42	0.00	10.07	11.51

Table b: Gauge level of River Sankosh during different time period.

Date	Gauge level in mGTS	Date	Gauge level in mGTS	Date	Gauge Level in mGTS
25-Jul-15	45.9	1-Jun-16	45.5	1-Jun-17	45.1
27-Jul-15	45.8	4-Jun-16	45.1	4-Jun-17	45.3
29-Jul-15	45.7	10-Jun-16	45.5	7-Jun-17	44.9
31-Jul-15	45.9	13-Jun-16	47.1	13-Jun-17	44.8
2-Aug-15	46.5	16-Jun-16	45.5	16-Jun-17	45.6
4-Aug-15	46.3	19-Jun-16	47.2	17-Jun-17	45.2
6-Aug-15	46	22-Jun-16	46.2	19-Jun-17	45.6
8-Aug-15	46.6	25-Jun-16	45.8	22-Jun-17	46.3
12-Aug-15	47.2	1-Jul-16	48.1	25-Jun-17	45.7
16-Aug-15	47.4	4-Jul-16	47.5	28-Jun-17	45.5
18-Aug-15	46.4	7-Jul-16	48.2	1-Jul-17	46.3
22-Aug-15	46.5	10-Jul-16	46.1	4-Jul-17	46
26-Aug-15	47.4	16-Jul-16	45.8	6-Jul-17	46.9
30-Aug-15	47.2	19-Jul-16	45.7	7-Jul-17	46.1
3-Sep-15	47	22-Jul-16	46.5	10-Jul-17	47.5
5-Sep-15	46.8	25-Jul-16	46.1	13-Jul-17	47
8-Sep-15	46	28-Jul-16	45.9	16-Jul-17	45.6
11-Sep-15	46.1	6-Aug-16	45.8	31-Jul-17	46.4
14-Sep-15	45.9	30-Aug-16	46.4	3-Aug-17	46.1
17-Sep-15	45.7	2-Sep-16	45.8	12-Aug-17	48.9
21-Sep-15	46.8	5-Sep-16	45.7	15-Aug-17	47.2
23-Sep-15	46.4	23-Sep-16	45.5	18-Aug-17	47
27-Sep-15	46	26-Sep-16	47.8	30-Aug-17	46.4
29-Sep-15	45.6	29-Sep-16	45.4	2-Sep-17	46.8
01-Oct-15	45.2	11-Oct-16	45.2	29-Oct-17	44.9

Table c: Abandoned Channel based Different Livelihoods and their Participation Rate

Percentage of People Engaged in Different Economic Sectors							
Livelihood Option	**Khalishamari Beel**	**Kamandanga Beel**	**Purbachaara**	**Nayachaara**	**Tama Nadi**	**Avulsed Abandoned Channel**	**Average**
Agriculture	59.29	56.54	52.90	49.29	56.38	59.10	55.58
Agricultural Labour	10.80	15.84	20.00	15.81	8.64	13.72	14.14
Fishing	20.00	16.45	15.66	19.84	18.93	13.00	17.31
Food and Fodder Collection	3.57	3.59	3.61	5.69	4.12	4.47	4.18
Livestock	2.14	2.08	2.41	3.71	6.58	4.23	3.53
Others	4.20	5.50	5.42	5.66	5.35	5.48	5.27
Total	100.00	100.00	100.00	100.00	100.00	100.00	

Appendix III: Questionnaire

DEPARTMENT OF GEOGRAPHY & APPLIED GEOGRAPHY
UNIVERSITY OF NORTH BENGAL
ACCREDITED BY NAAC WITH GREAD ‘A’
P.O North Bengal University, Dist. Darjeeling, PIN-734013.

Survey Schedule

- Name of the Village ………………………………………………
- Name of the Gram Panchayat ……………………………………
- Name of the Block …………………………………………………
- Name of the District ………………………………………………
- Name of the State ………………………………………………….

A. GENERAL INFORMATIONS:

Sl. No.	Name of the Households (Starting from the head of the households)	Sex (M/F)	Age	Education	Caste	Religion	Marital Status:	Category: (BPL/APL)
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								

C. SOCIO-ECONOMIC INFORMATION:

1. Family Type: Nuclear/Joint
2. Land Ownership Details: i) Household…………………………. ii) Cultivable…………………………
3. Type of House: Kuccha/Pucca/Semi-Pucca
4. Electric Facility: Yes/No
5. Household aminities: TV/Cycle/Mobile/Fan/Radio/Others………………………………………………
6. Sources of Drinking Water: Well/Tube well/Public Tap/Others……………………………………..
7. Sources of Fuel: Wood/Coal/Keroseen/Gas/Others………………………………………………………….
8. Toilet Facility: Yes/No
9. Drainage Facility: Yes/No
10. Primary Occupation of the Family:……………………………………………………………….
11. Secondary Occupation of the Family:…………………………………………………………….
12. Number of Earning Member of the Family:………………………………………………………
13. Monthly Income of the Family (Rs.):……………………………………………………………..
14. Monthly Expenditure of the Family (Rs):
    Maintainance…………………Developmental……………………Luxarious…………………………

D. TOPIC RELATED QUESTIONS

I) AGRICULTURAL STATUS

15. Are You Involved in Agriculture? Yes/No
    If Yes Then
    i) Directly
    ii) Indirectly
16. From How Many Years You Have Been Engaged in Farming?
    ……………………………………………………
17. In Which Land You Cultivate? Own Land/Husband's Land/Others……………………………………………….
18. If You Cultivate in Your Land or Other's Land then what is the Area of that Land? ………………….
19. If You Cultivate Other's Land then You are: Main Worker/Marginal worker/Non Worker
20. Are You the Only Member in Your Family Who Involved in Agriculture? Yes/No
21. Does the Agriculture is the Main Source of Income in Your Household? Yes/No
22. Do You the Primary Bread Winner in your Family? Yes/No
23. Have Your Family Taken any Land for Agriculture on Lease or Rent? Yes/No
    If Yes then
    i) Which Purpose?...
    ii) How Much You Pay for This?...........................
24. What Type of Crops You Cultivate? Food Crops/Cash Crops/Others
25. What Type of Agricultural Activity You have done in the Field? Harvesting/Land Preparation/weeding/Others
26. How Many Hours You Work in the Field Per Day? 2-3 Hours/4-6 Hours/More Than
27. What is the Distance of Agriculture Land from Your House? Within 1 Km/Within 5 km/More Than
28. Generally which Tool You Use for Plaguing Your Land? Plough with Oxen/Tractor/Both/Worker does not Require Plaguing
29. What Kind of Seeds You Use for Farming? Local Seeds/Traditional Seeds/Hybrids Seeds/Foreign Seeds
30. From which Area You Collect Seeds? Market/Agriculture Office/Panchayet Office/Others
31. Which of the Following Means of Irrigation are Present in Your Land? Cannel/Own Pump/Tube Well/Pond/River/Govt. Tube Well/Others
32. Are You Faced Any Problem in Related With Irrigation during Cultivation? Yes/No
    If Yes then, What Type of Problem You Faced? ……………………………………………………
33. What Type of Fertilizer You have been Used for Agriculture? Organic Fertilizer/In organic Fertilizer
34. What Type of Soil You Mainly Found for Agriculture?...................................
35. In Which Market You Sale you're Produces? Local Market/Village Market/Others
36. Does there have Any Middle Man Who Take the Produce to the Market? Yes/No
37. Distance of Market from Your House……………………………………………………….
38. Mode of Communication for Selling Produces: i) In Case of Local Market………………. Ii) In Case of Others Market…………………
39. Are You Related With Any Other Non Firm Economic Activity? Yes/No

    If Yes What Kind of Activity it is ……………………………….

40. Do You have any Fishpond: Yes/No
    If Yes, Then
    i) What Is the Area? ……………………………………………………………
    ii) What Type of Fish You Cultivate?..
41. Do You have Livestock?
    If Yes, Then
    i) Small Livestock: Goat/Pig/Sheep/Others
    Ii) Large Live Stock: Oxen/Cattle

42. What are the Leading Sources: NGOs/Formal Lender/In Formal Lander/Bank/Financial Institutions/Friends/Relatives/Group Based Microfinance/Others
43. Do you have any others Land which are not Used for Agricultural Purpose? Yes/No
If Yes, Then What Purpose? ……………………………………………………………….
44.

VARIATION ON CLIMATIC PARAMETER & EVENTS (BASED ON FGDs/PRA)												
MONTHS												
EVENTS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1)Temperature:												
Hotness >												
Coldness >												
2)Rainfall Pattern:												
Normal >												
Rain storm >												
3)Wind:												
Normal Wind												
Storm												
Hail Stromes												
Hot Winds												

	CLIMATIC HAZARDS & EVENTS (BASED ON FGDS/PRA)												
SL NO.	MONTHS												
1. Drought													
2. Bank Erosion													
3. Storms													
4. Floods													
5. Heat Waves													

SEASONAL CALENDER FOR DIFFERENT CROPS												
CROPS	MONTHS											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

45.

NAME OF AGRICULTURE PRODUCES AND THEIR RATES	
PRODUCES	RATES

II) ECONOMIC CONDITION OF AGRIAN FAMILY

46. Are Your Economic Conditions Improved After Engaged in Agriculture?
    If yes, then How?..
47. Do You Think Your Involvement in Agriculture Improve the Economic Condition or Living Standard of Your Family? Yes/No
48. How Much Money Got from Selling Your Production?..
49. What is the Frequency of Selling Your Production? Daily Basis/Weekly Basis/Once in a Month/Twice in a Month
50. If You are a Agricultural Labourer then What is the Wage Rate? Daily Basis……………/Weekly Basis…………….. /Month Basis………..
51. Are You Satisfied with Your Wage? Yes/No
52. If You Cultivating in Your Own Land then
    What is the Expenditure Behind the Agriculture?......................................
    And How Much Benefit You Get Back?...
53. Do You Have Any Saving Account After the Involvement to the Agriculture Sector? Yes/No
54. Do You Connected with Any Self Help Group? Yes/No
    If Yes, Then How? …………………………………………………….
55. Do You have Taken Any Loan from Any Bank for Betterment of Your Livelihood? Yes/No
    If Yes, Then What Purpose? ……………………………………..
56. Do You have at least One Recurring or Fixed Deposit in Any Bank or Post Office? Yes/No
57. Have You Heard The Name of NABARD? Yes/No
58. Did You Get Any Help of Getting Loans from NABARD? Yes/No
59.

PAIR WISE RANKING FOR WOMEN LIVELIHOOD OPTION						
Livelihood Option	Livestock	Stich	Cultivation	Labour	Handicraft	Small Business
Livestock						
Stich						
Cultivation						
Labour						
Handicraft						
Small Business						

III) ADVANCED AGRICULTURAL TECHNOLOGY

60. Are You Using Advanced Technology in Agricultural Field? Yes/No
61. Do You Operate the Machines By Yourself? Yes/No
    If No, Then Who Helps You? …………………………………………….

62. Do Advanced Technology Helps You For Increase Your Production? Yes/No
63. From Which Source You Get the Information of Weather? TV/Radio/Internet
64. Do You have Kisan Card? Yes/No
65. Do You have KisanVikashPatra(KVP)? Yes/No
66. Do You Know the Kisan Call Centre Number? Yes/No
67. Do You Have Any Membership Card in Farmers Club? Yes/No
    If Yes, Then what is the Name of that Club? ……………………………………………….

IV) GOVERNMENT ASSISTANCE/AGRICULTURE DEPARTMENT ASSISTANCE FOR AGRICULTURE

68. Do You Get Information or Help Related to Agricultural Matter Like Soil Test, How to Use Fartilizer etc. from Agriculture Dept. or Local Panchayat Office? Yes/No
69. In Your Area or Locality Does Govt. has Created Any Crop Purches Centre? Yes/No
70. In Your Locality Does the Govt. or Agriculture Dept. has established any Agriculture Training Centre?
71. Do You Know Any Govt. Scheme Which Related With Agriculture? Yes/No
    If Yes, Then What? ……………………………………………………………………………
72. Does Local Panchayat Help or Encourage Women for Agriculture or Allied Activities? Yes/No
73. Do You heard the Name of MGNREGA? Yes/No
74. Are You a Worker of MGNREGA? Yes/No
75. Do You have Job Card of MGNREGA? Yes/No

V) SOCIO-CULTURAL INFORMATION

76. What are the Source of Your Refreshment? ....
77. What do You do in Free Time? …………………………………………………
78. Do You Observe Any Programme Related With Agriculture? Yes/No
    If Yes, Then What Kind of Programme that is? ……………………………..
79. Do You Observe Nobanno? Yes/No
80. Do You do Social Forestry? Yes/No
81. Do You have Ration Card? Yes/No
82. Do You have Voter Card? Yes/No
83. Do you have Adhar Card? Yes/No
84. Do You have PAN Card? Yes/No

B. HEALTH ISSUES

95.

HEALTH ISSUES	
DISEASE FACED BY FAMILY MEMBER IN LAST SIX MONTHS	a. Fever/Cough b. Diarrhea c. Skin Diseases d. Jaundice e. Dengue f. Measles g. Chicken Pox h. Any Other
DISEASE CAME FROM AGRICULTURE FIELD	
HEALTH SCHEME OR HEALTH INSURANCE OF THE FAMILY MEMBER	a. Employees State Insurance Scheme b. Community Health Insurance Scheme c. Through Nationalized Insurance Camp d. Private Health Insurance e. No Scheme for Family Member
PLACE OF TREATMENT OF FAMILY MEMBERS	a. Govt. Hospital b. Private Hospital/Clinics

	c. NGOs Health Centre d. ICDS e. Vaidh/Homeopathy f. Household Remedy g. Local Primary Shop h. Not Required
FREQUENCY OF VISIT ANY HEALTH CENTRE	a. Once in a Week b. Once in a Month c. Once in Six Months d. Once a Year e. Did not Visit
HABITS OF DRINKS OR SMOKING	a. Yes b. No
OVER ALL FAMILY HEALTH IN LAST TWELVE MONTHS	a. Good b. Fairly Good c. Not Good
NUMBER OF DATH IN CASE OF AGRICULTURE IN LAST ONE YEAR	a. In case of Male………………. b. In case of Female…………….

REMARKS:

DATE: …………………………..   SIGNATURE OF THE INVESTIGATOR…………………………….

Appendix IV: Abbreviations

EDL= Extreme Danger Level

DL= Danger Level

PDL= Primary Danger Level

MGTS=Multi-gigabit Transceiver

BMP= Best Management Practices

SQ. =Square

KM =Kilo Meter

CM =Centimeter

GPS= Global Positioning System

GIS= Geographical Information System

SI= Sinuosity Index

CUMEC= Cubic Meter per Second

ICDS = Integrated Child Development Services

Appendix V: Publications

1. Barman, D. C., Bhattacharya, S.K., (2018) Management Strategies of Abandoned Channels of the Sankosh River Basin in India, *RESEARCH REVIEW International Journal of Multidisciplinary*, *Volume-3 Issue-3.*
2. Barman, D. C., Bhattacharya, S.K.,(2020) Analysis of meander cutoff mechanism of the formation of abandoned channel of Sankosh River, India. *INDIAN JOURNAL OF SPATIAL SCIENCE, SPRING ISSUE, 11(1) 2020PP.7-16*
3. Barman, D. C. (2020) Socio-Economic Importance of Abandoned Channel: A Case Study of KhalisamariBeel of Sankosh River in India. *GEOGRAPHY IN THE 21ST CENTURY: EMERGING ISSUES AND THE WAY FORWARD*, 175.

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Analysis of Meander Cut-off Mechanism for the formation of Abandoned Channels of Sankosh River, India

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Abstract

The Sankosh river in its lower course is found to have a tendency to meander over floodplains in order to balance the transport of its water and sediment load. As a result, both the neck and chute cut-offs develop and are considered to be the main mechanism of abandoned channel formation. The neck cut off occurs due to the continuous deposition of sediments on the convex bank and sediments curved out of the concave bend. As a result, the sinuosity of the meander increases, thereby forming a narrow neck. The convoluted meander bend at the neck remains in the threshold level of instability unless naturally, the neck disappears due to the crossing of the limit of threshold. Eventually, a straight channel is formed, creating a cut-off. When the cut off is sealed from the main channel by sediment deposition, an ox-bow lake is normally formed and left as an abandoned channel. On the other hand, chute cut-off occurs when successive high flows develop a chute across the inner part of a point bar which starts to flow as straight channel decreasing the sinuosity of the main river course on that part. Thus, the former sinuous course becomes detached as an abandoned channel. Thus, channel sinuosity is reduced with increase in velocity and gradient in flow and discharge through chute and neck leaving cut-offs that lead to the development of abandoned channels.

Introduction

Meander cut-off is a general process for the development of an alluvial channel or meandering stream. In general, a meandering channel is characterized by some deeps (pool) at the concave slope of bends and shallow fills (riffle) at the convex slope of bends along its course. A pool is characterized by a water surface profile less than the mean (stream) gradient and by finer bed material, whereas a riffle has a water surface slope steeper than the mean stream gradient and is composed of coarser bed material (Morisawa, 1985). Consequently, the most meandering channels having sinuosity index value >1.5 is defined as bends facing down valley and traverse downstream from a geometric viewpoint.

Objectives

The aim of this research is to study the meander cut-off mechanism for the formation of abandoned channels in the course of the Sankosh river, India

Methodology

Empirical and quantitative techniques of geomorphology have been applied according to the requirement. Relevant maps have been prepared by using geo-spatial techniques on the Remote Sensing and GIS platform. Inferences have been derived from systematic compilation, processing and classification of information (generated by sample survey) and data.

The Study Area

The Sankosh river is one of the major rivers of North Bengal and Assam in India. It traverses through the mountains of Bhutan and then flows through the undulating plains of North Bengal and Assam and finally enter into Bangladesh to meet the Brahmaputra river. The Khalisamari Beel, located in the Chagalia village of Dhubri district of Assam, is an abandoned channel of Sankosh river. It was disconnected by the process of chute cutoff for a long time. It occupies about 212 bighas of land with a mean ground elevation of about 32m a.s.l. The length of this abandoned channel is around 8 km from the Chotto Guma to Kaimari village. The depth of water in this abandoned channel is about 5 - 6m during the rainy season and 3 - 4m in the dry season and is affected by flood in the rainy season (fig.1).

Findings and Discussion

Formation of Meander Cut-off and Channel Abandonment

In the lower course of river Sankosh (lower course), there are several meandering cut-offs in the form of abandoned channels, also called oxbow lakes. Its formation process through meandering chute cut-off is illustrated in fig.2 in a schematic manner. The three stages of abandonment that can be distinguished are:

Cut-off Initiation: According to Lewis and Lewin (1993) and Hooke (1995), the triggering of the cut-off occurs when the majority of the river discharge is diverted from the meander and starts to flow along the newly activated channel which has developed diagonally as chute over the plug bar by the process of sediment deposition. It must be mentioned here that the entrance of the two meander bends to the chute of the Sankosh river has shrunk due to channel infilling to initiate the process of plug bar formation which is responsible for separation of the chute from the meander ends, the active channel earlier (fig. 3).

***Plug-Bar Formation*:** The plug bar is defined as a bed sediment bar formed at the entrance of a bifurcation channel, hindering flow into a channel (Fisk,1947; Gagliano and Howard,1984; Hooke,1995). In the downstream section of the Sankosh channel near the inner bends of Khalisamari Beel, the plug bar has been perpetuated by bedload supply. With the steady supply of bed load, it appeared to stop the channel flow because of the channel fill and cut-off occurred from the crest of the bends. Thus, channel deposition not only caused shallowing but also narrowing as well as shrinkage of the meander bend in the study area.

Disconnection: The disconnection of the channel begins with no continuous flow of discharge carrying sediment load (Willem Toonen et. al. 2012). In study area, the discharge was no longer being carried regularly through the chute. Depending on the maturity of the plug bar and the proximity to the active channel, a flood may temporarily cause a diversion of discharge through the chute delivering a pulse of suspended sediment. As a result, the chute is disconnected from the network of the active main channel of the Sankosh River and finally, the chute cut-off occurred which now remains as an abandoned channel. Thus, the disconnection of the meander bend with the main channel occurred only after the completion of plug bar formation. This disconnected stretch of meander bend is recognized as chute cut-off that eventually became an abandoned channel in the study area.

Conclusion

Thus, a highly meandering course of the Sankosh river developed on the right bank near the village of Falimari, Cooch Behar district, West Bengal and Koimari and Khalishamari villages, Dhubri district, Assam. It is evident that a meander chute cut-off was initiated with the deposition of sediments at the inner part of the bend and it was gradually increased with the occurrences of successive extreme bankfull discharge. As a result, meander channel entrances near the inner bends are responsible for more and more bedload supply. This initiated the formation of plug bar in the downstream section of the Sankosh river channel near the inner bends of Khalisamari Beel and finally, the plug bar formation has been completed by bedload supply and with more bed load appeared to stop the inner channel flow and resulted in cut-off from the crest of bends.

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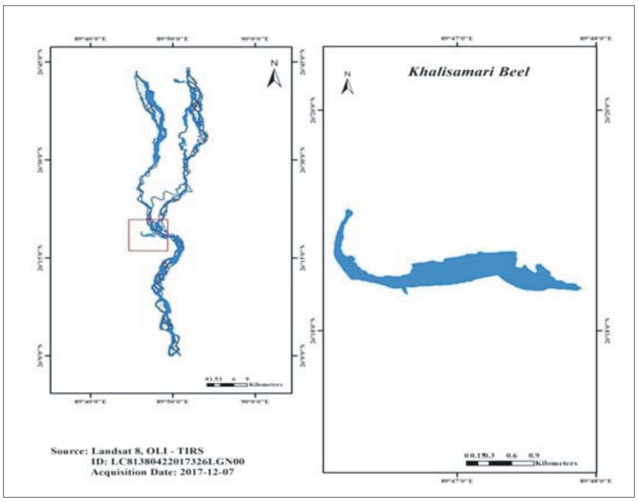

Fig.1: Location of the Study Area

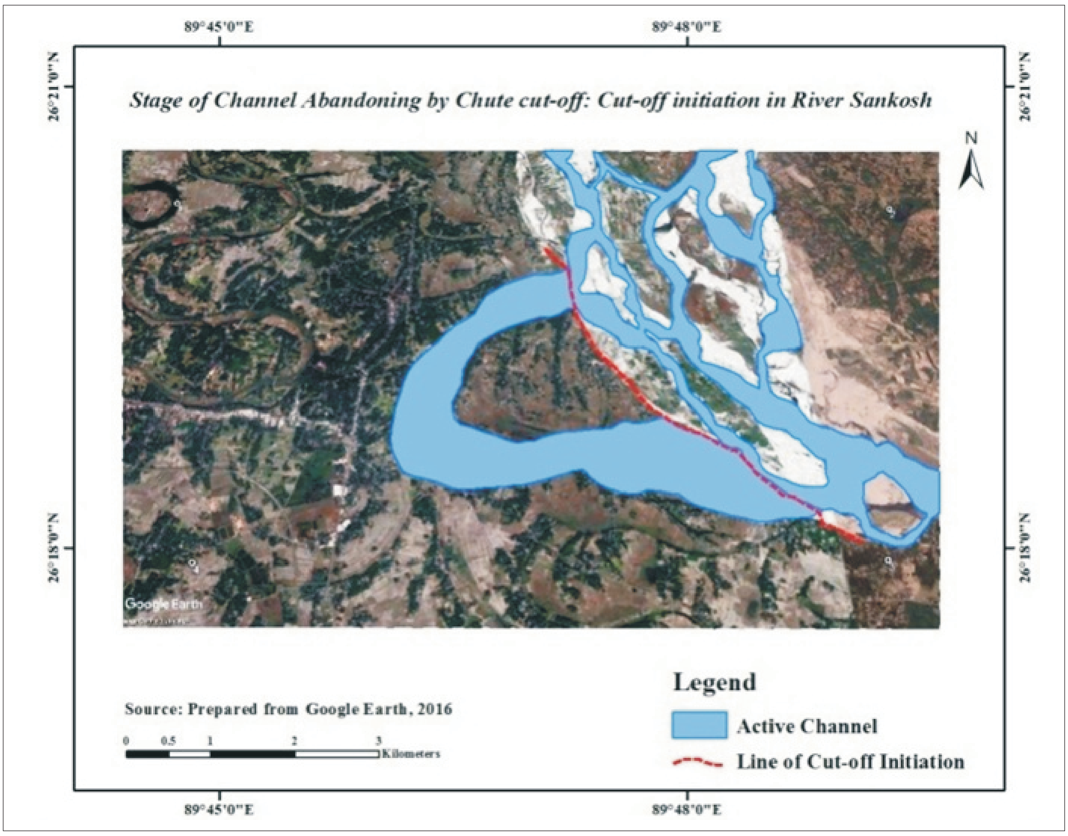

Fig.2: Cut-off Initiation in 1970

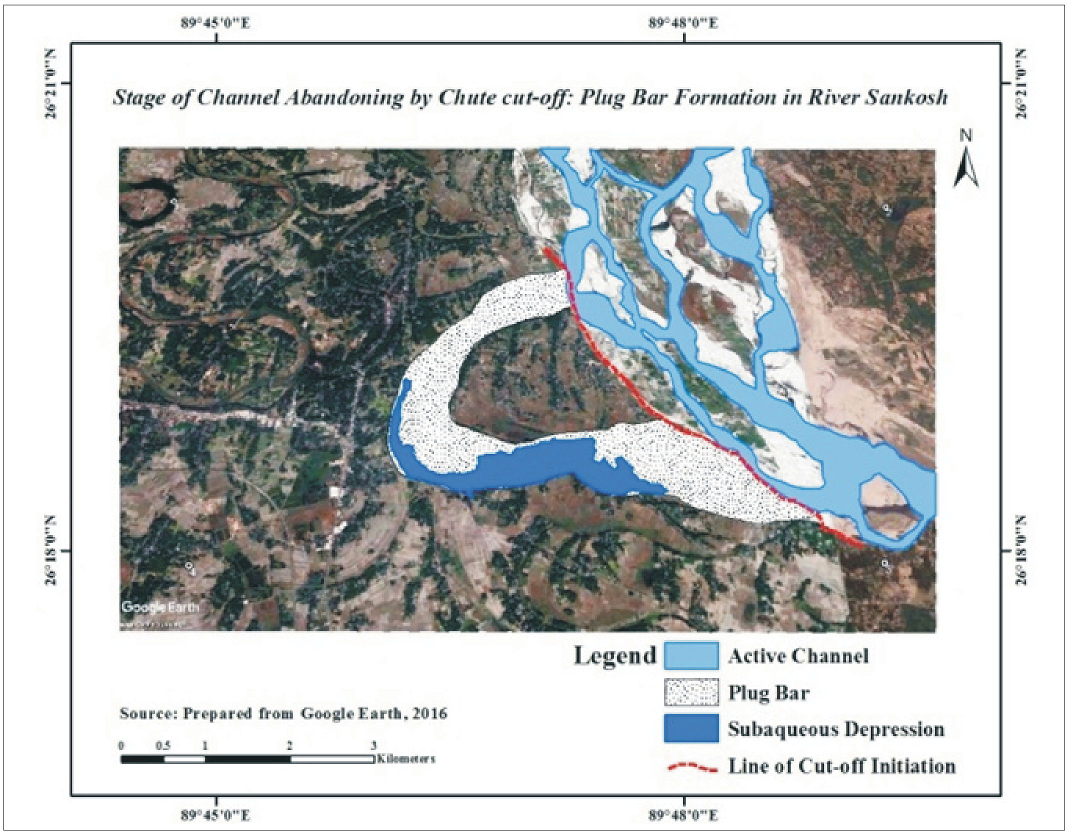

Fig.3: Formation of Plug Bar in 2000

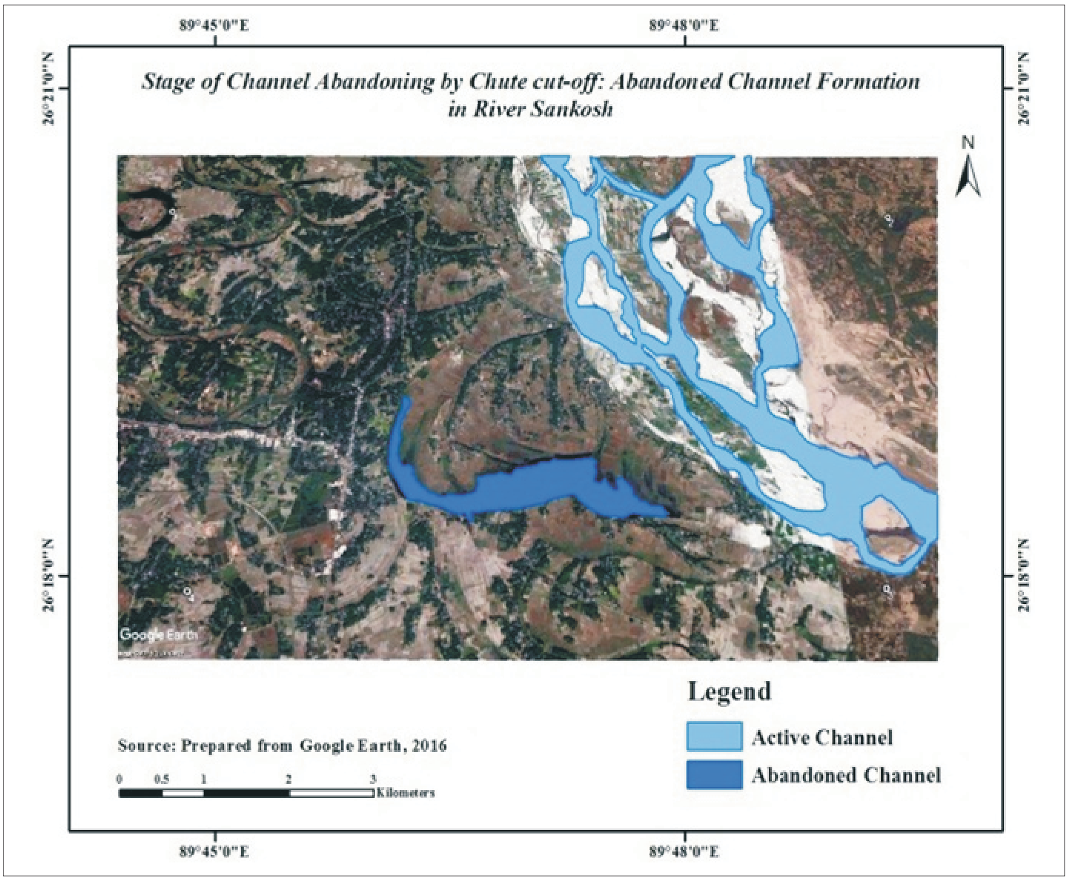

Fig.4: Disconnection of Chute cut-off in 2018

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