CHAPTER III

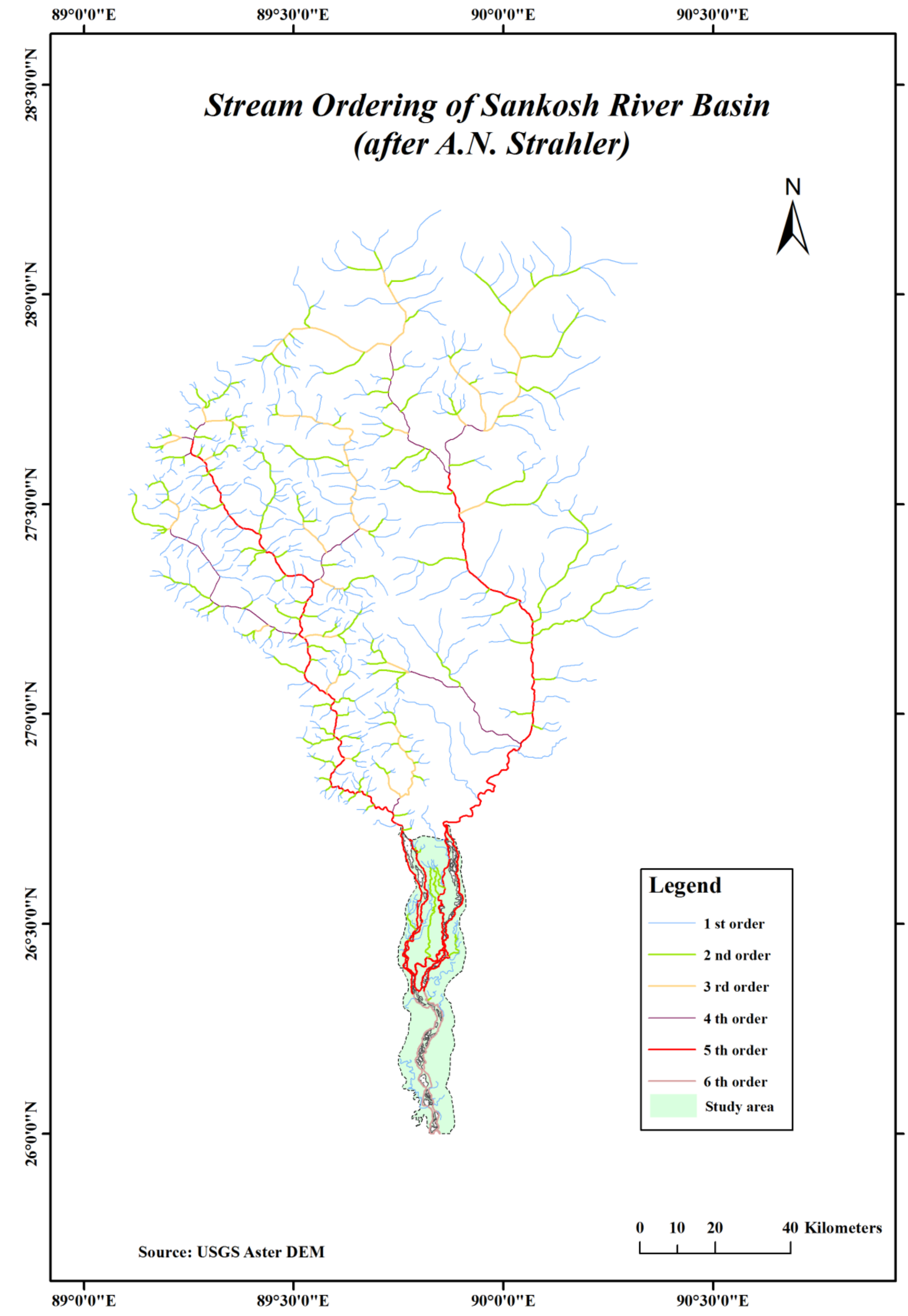
IDENTIFICATION OF ABANDONED CHANNELS

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 6^{th} 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.

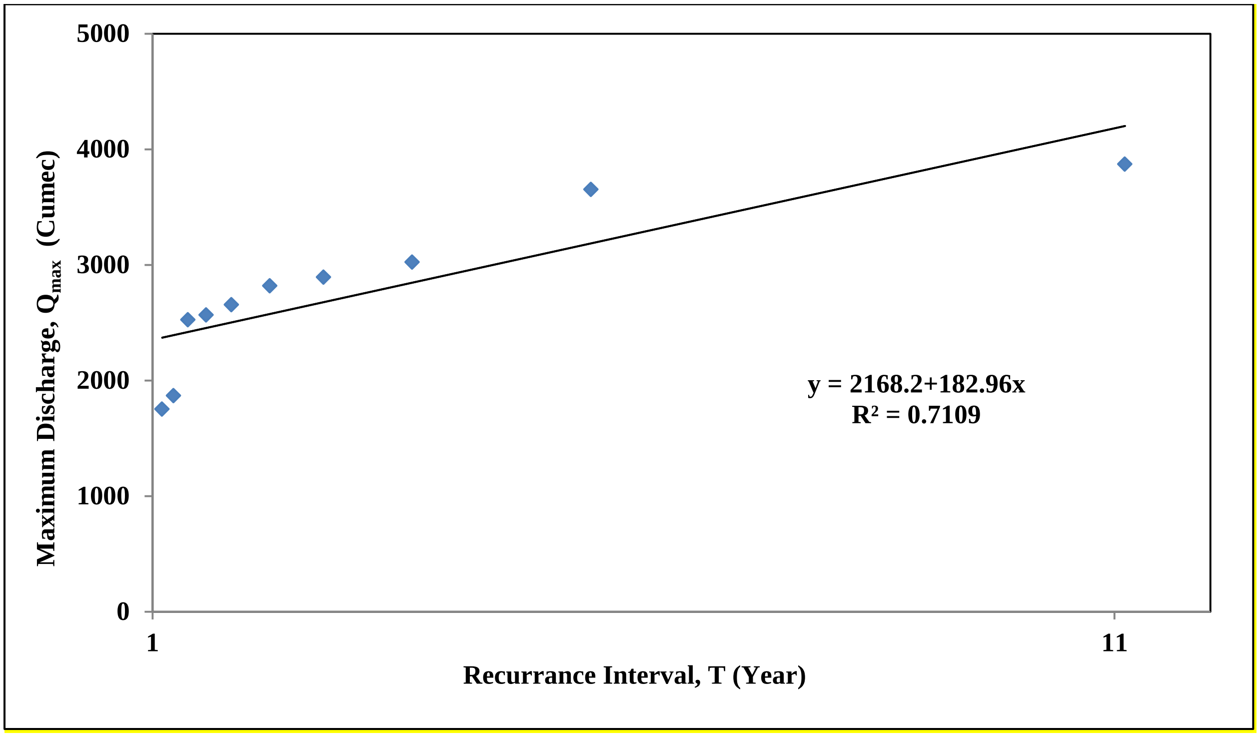


Figure 3.1 Flood Frequency Curve of Sankosh River for the Period of 1999-2008 at Gauge Station of Golokganj

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.

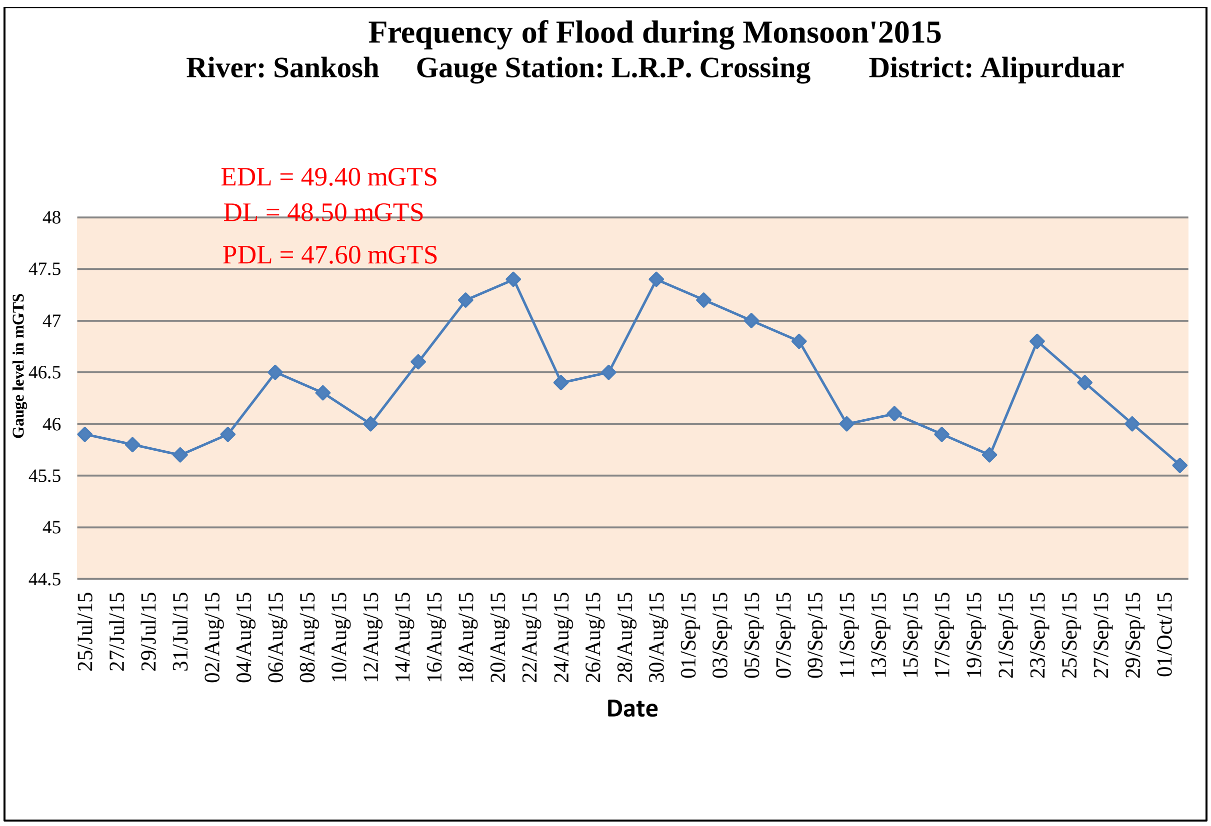


Figure 3.2: Frequency of Flood during Monsoon'2015

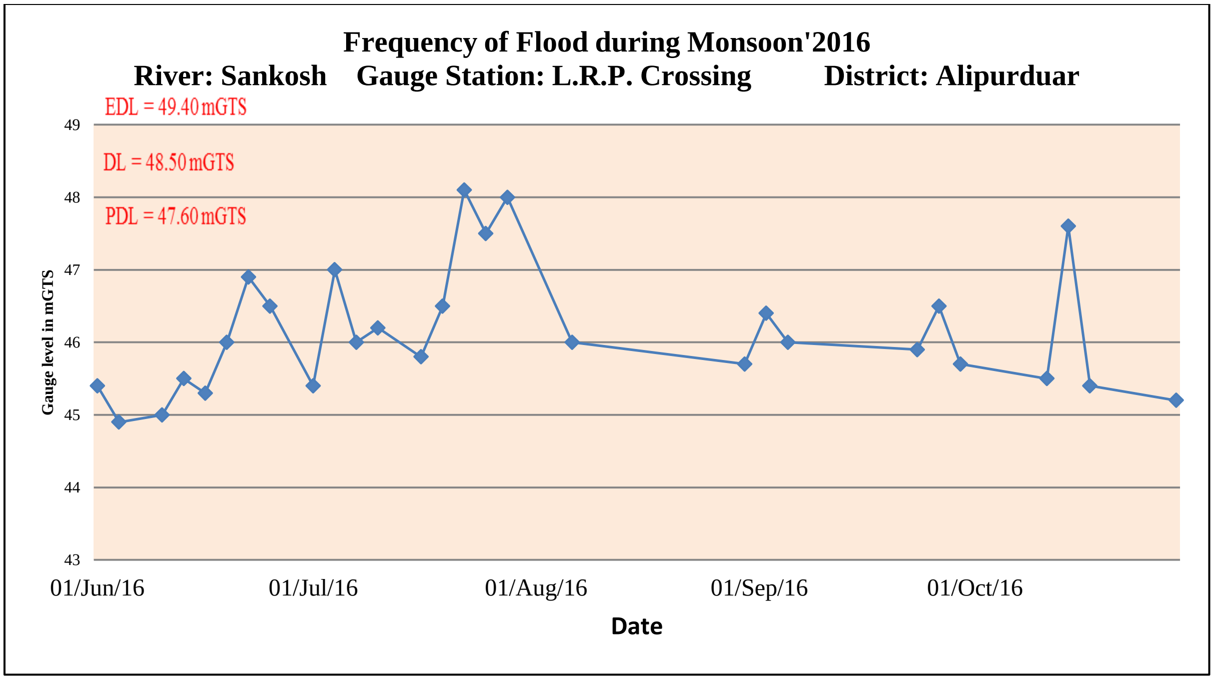


Figure 3.3: Frequency of Flood during Monsoon'2016

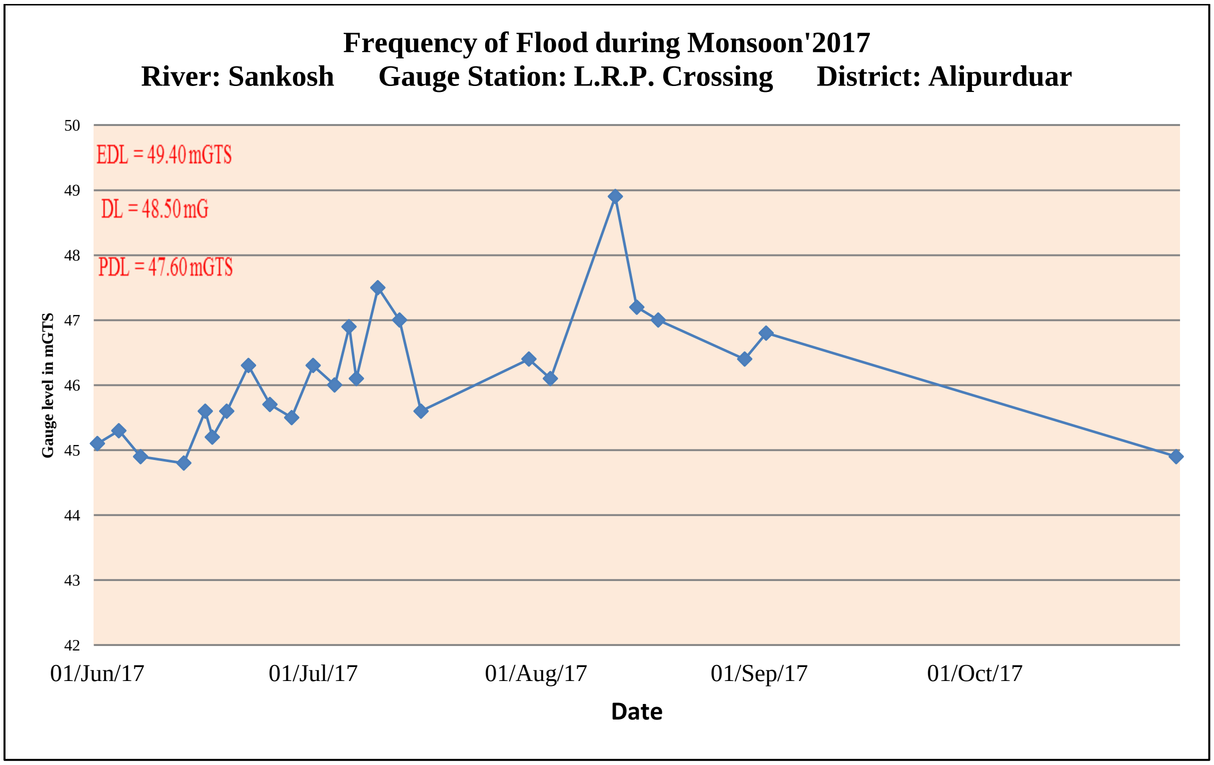


Figure 3.4: Frequency of Flood during Monsoon 2017

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.

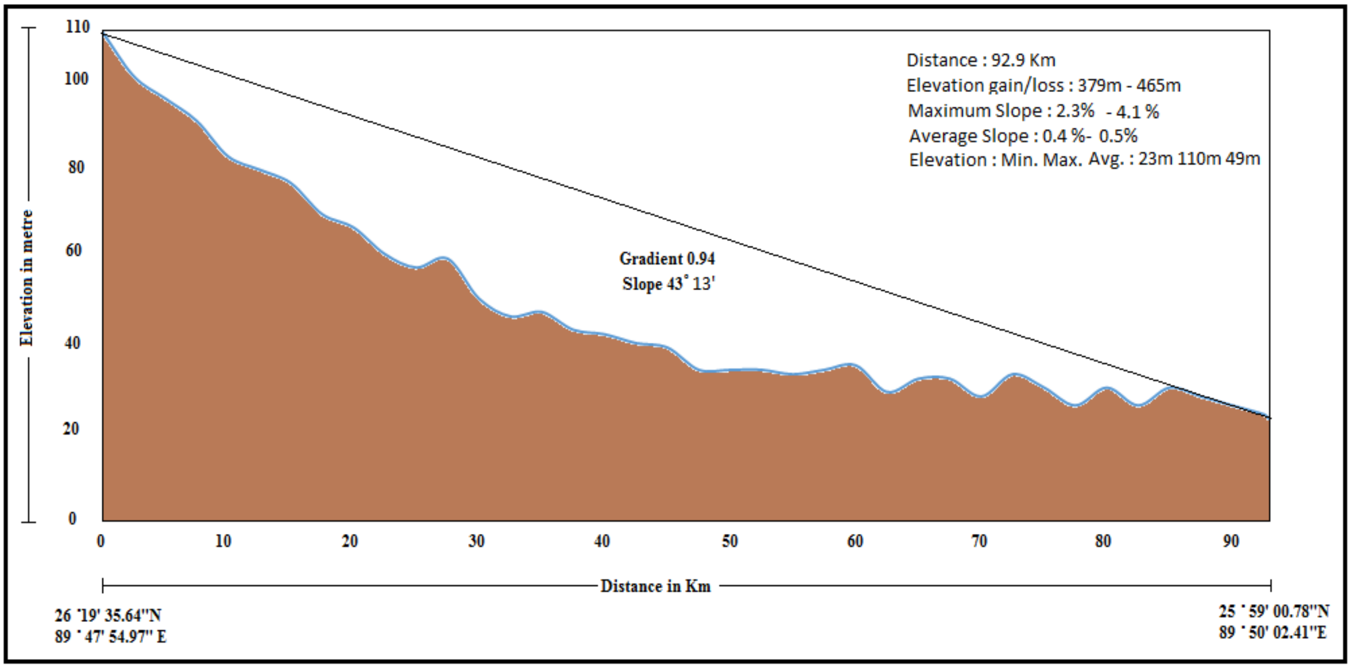


Figure 3.5: Long profile of Sankosh River from Indo-Bhutan border to Indo-Bangladesh Border

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.

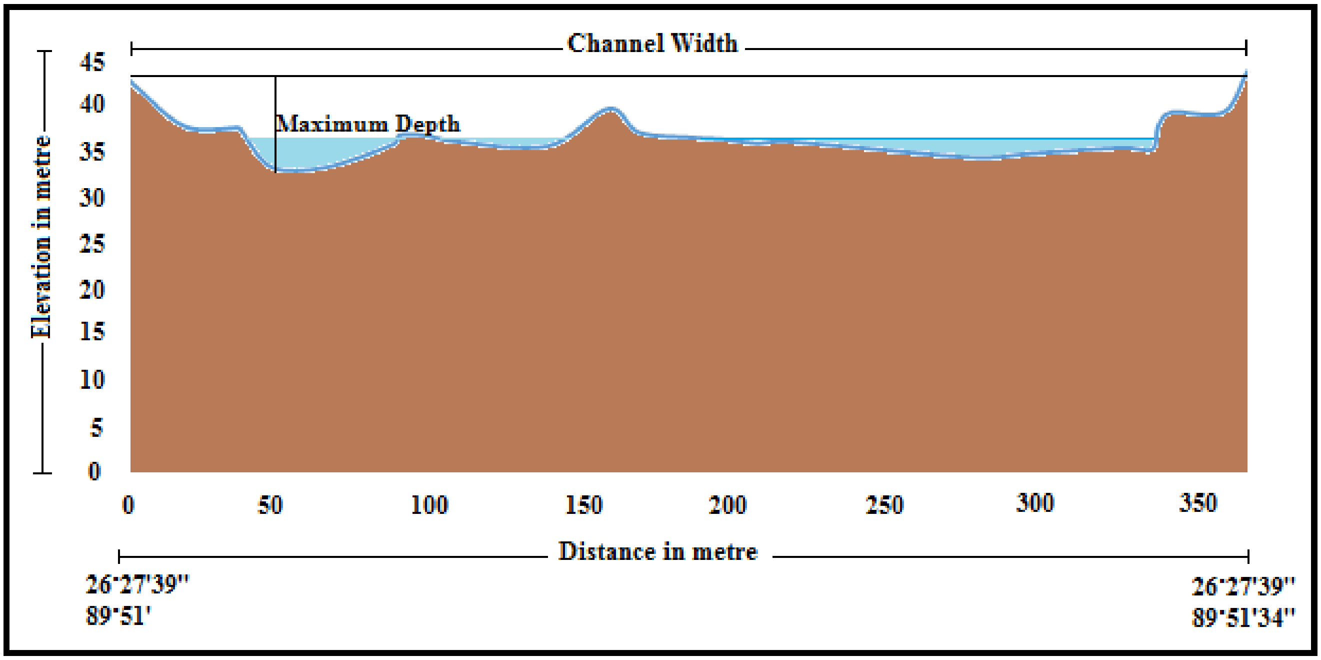


Figure 3.6: Cross Profile at Upstream Gauge Station at Barobisha

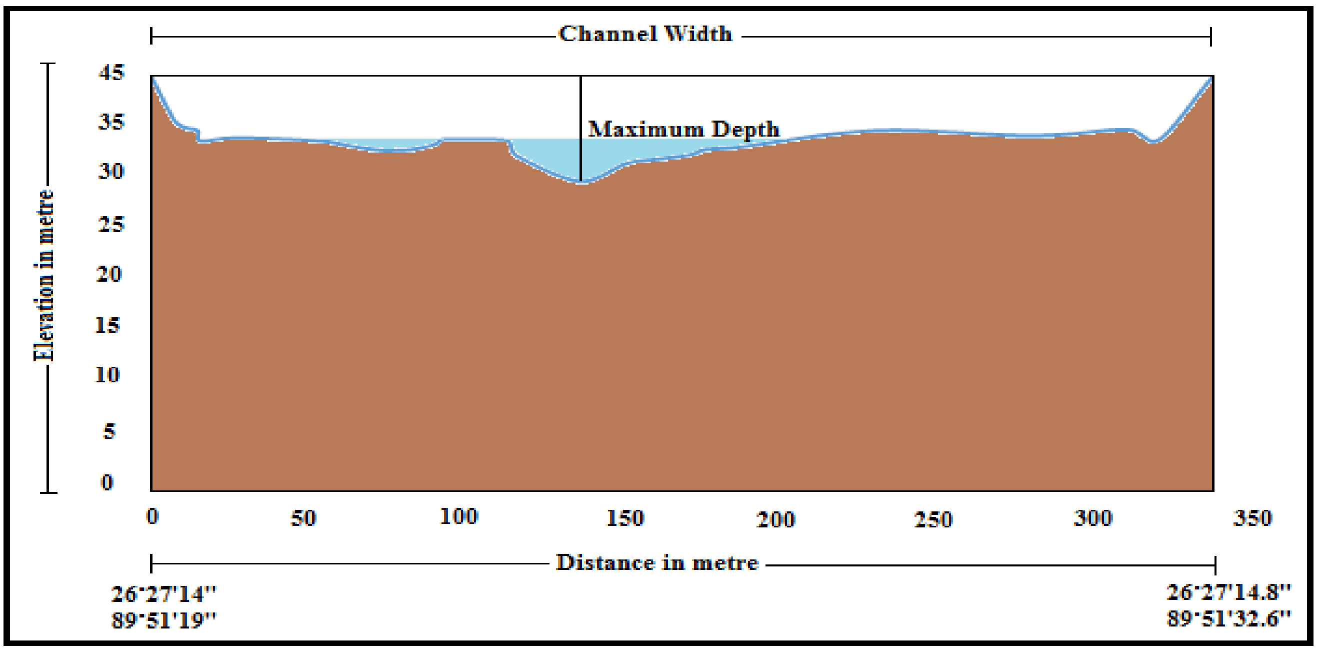


Figure 3.7: Cross Profile at Midstream Gauge Station at Falimari

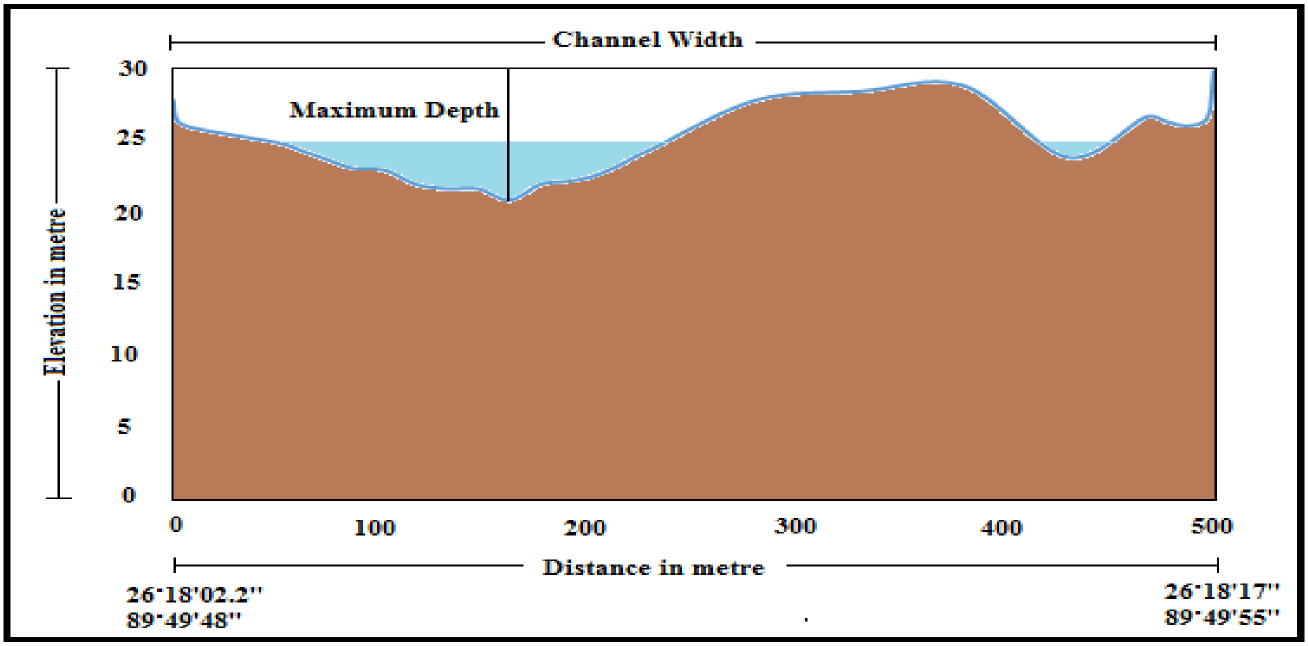


Figure 3.8: Cross Profile at Downstream Gauge Station at Koimari.

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

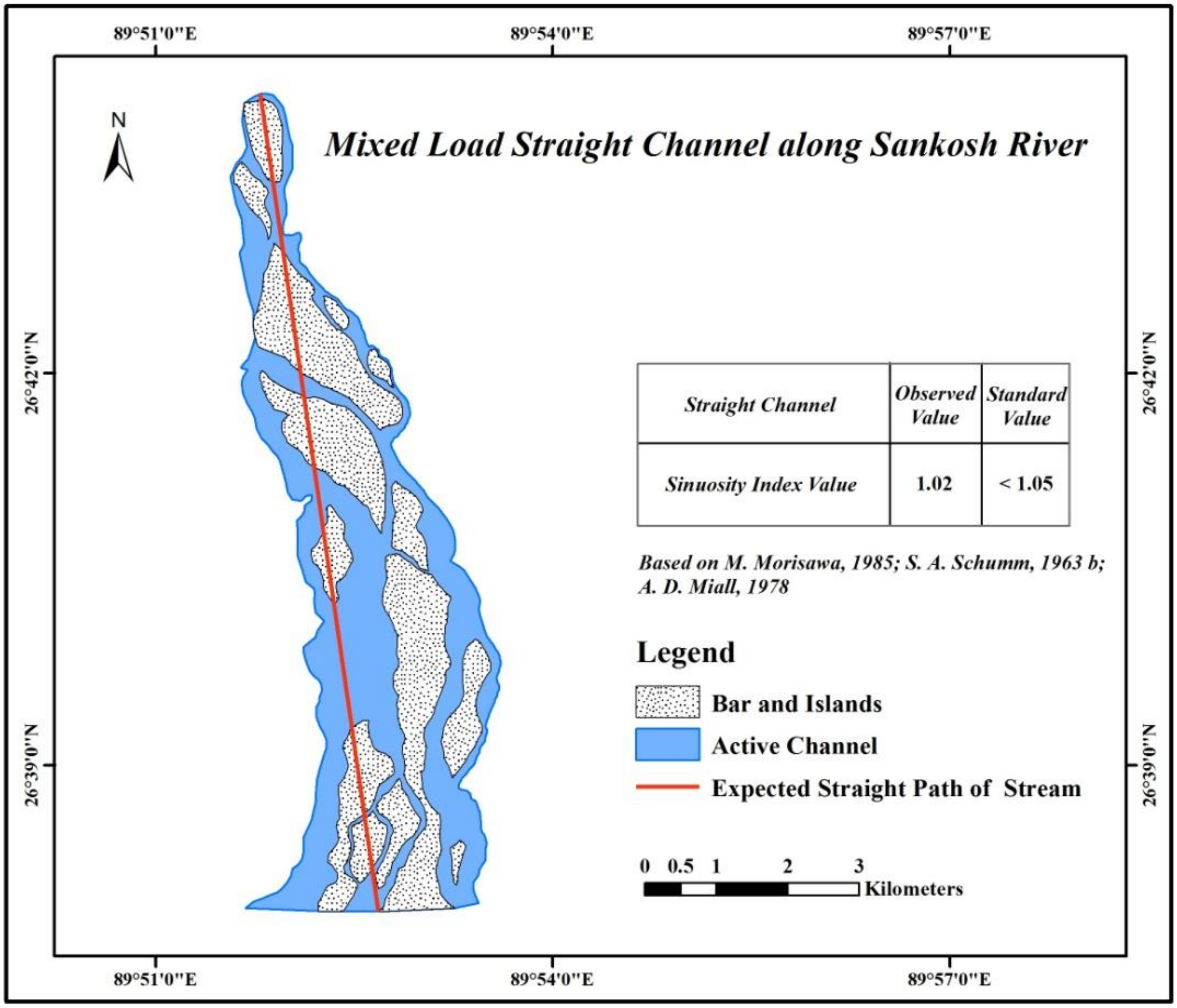
An alluvial channel when Sinuosity index is between 1.05 and 1.5 is called sinuous channel, is found in the lower portion of straight pattern of River Sankosh.

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.

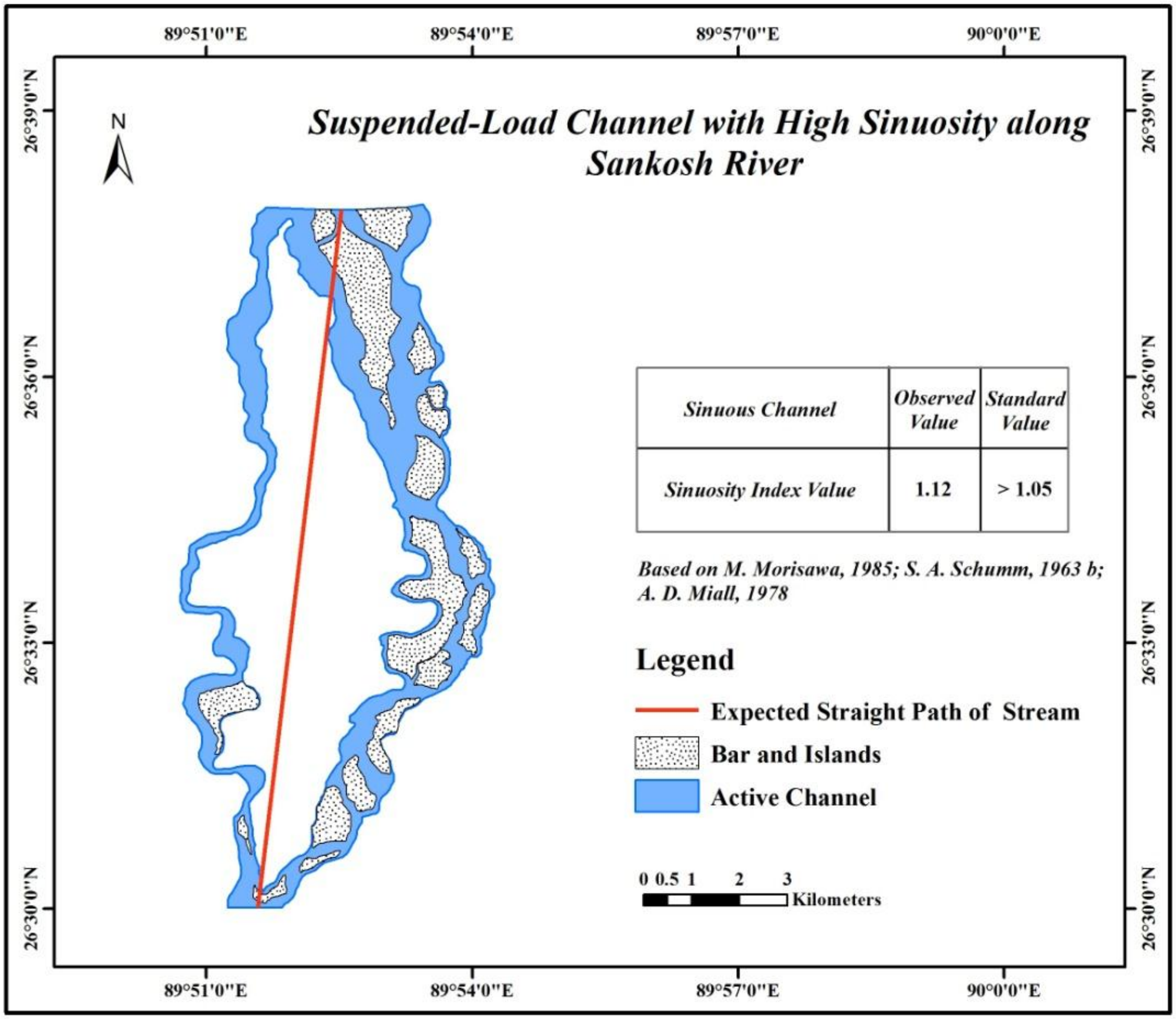
3.2.6.4 Bed- Load Channel (Braided)

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.



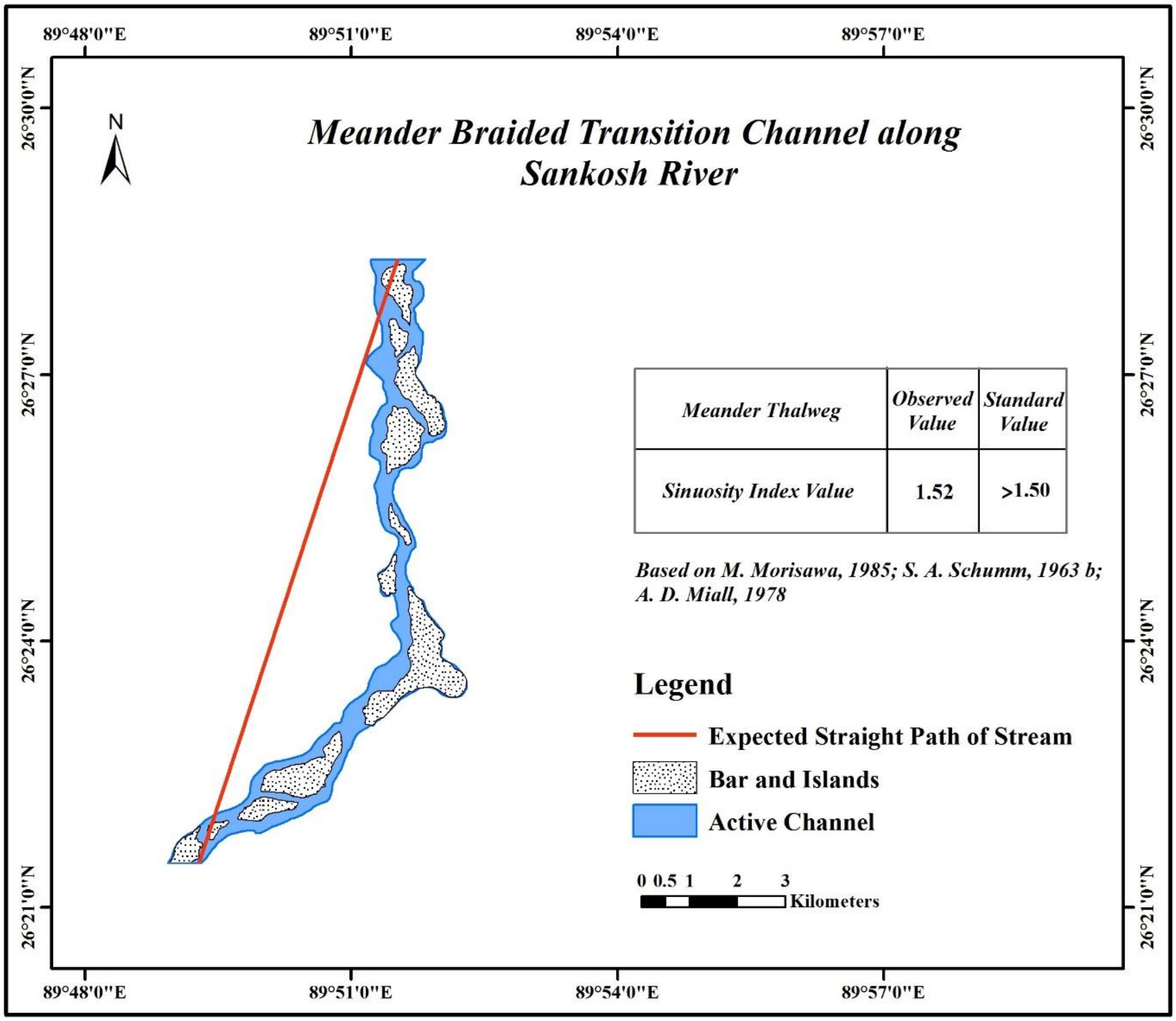
Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

Map 3.2 Mixed Load Straight Channel along Sankosh River



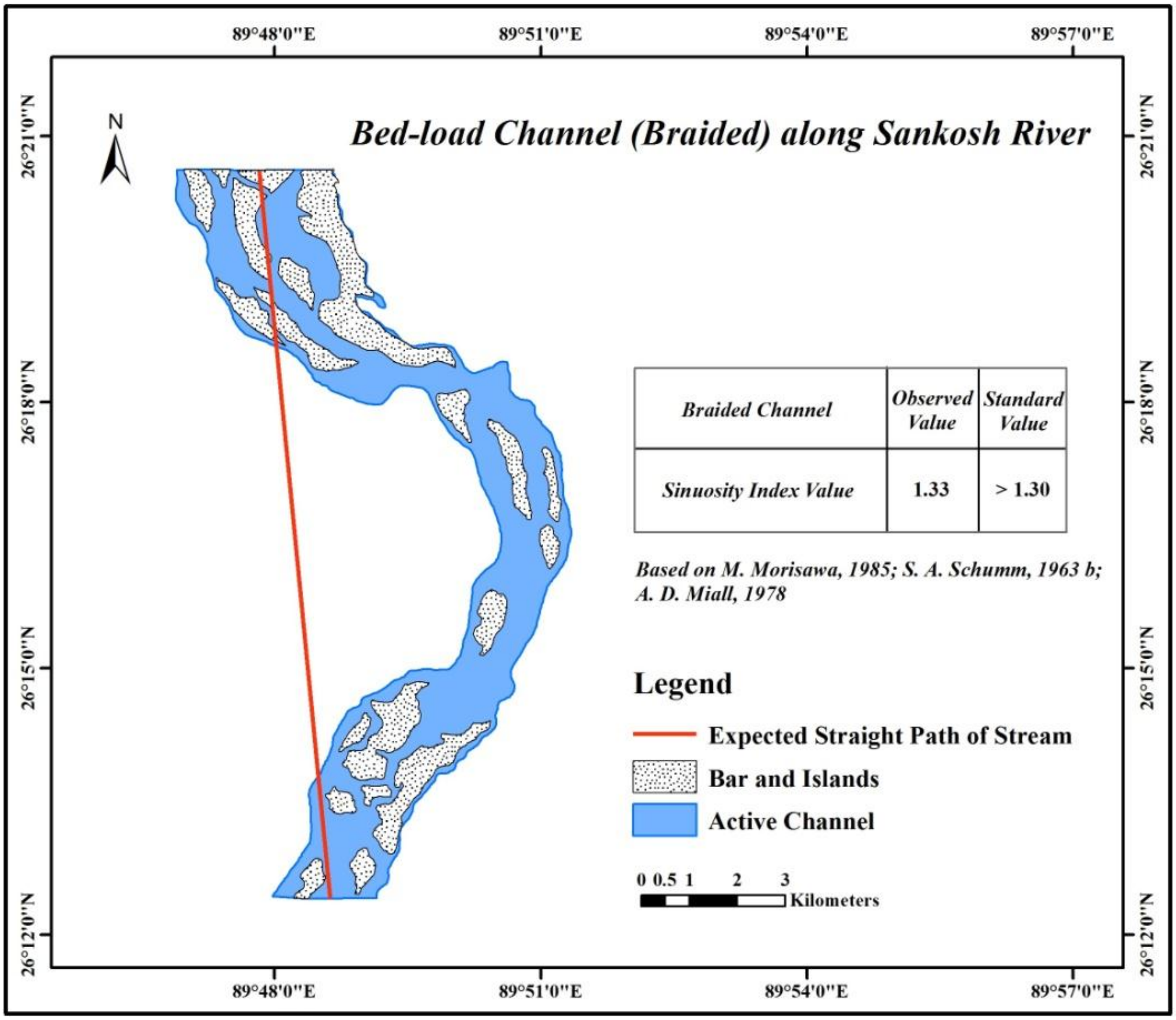
Source: *Landsat 8, OLI-TIRS,* ***ID:*** *LC81380422017326LGN00,* ***Acquisition Date:*** *2017-12-07*

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:

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

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:

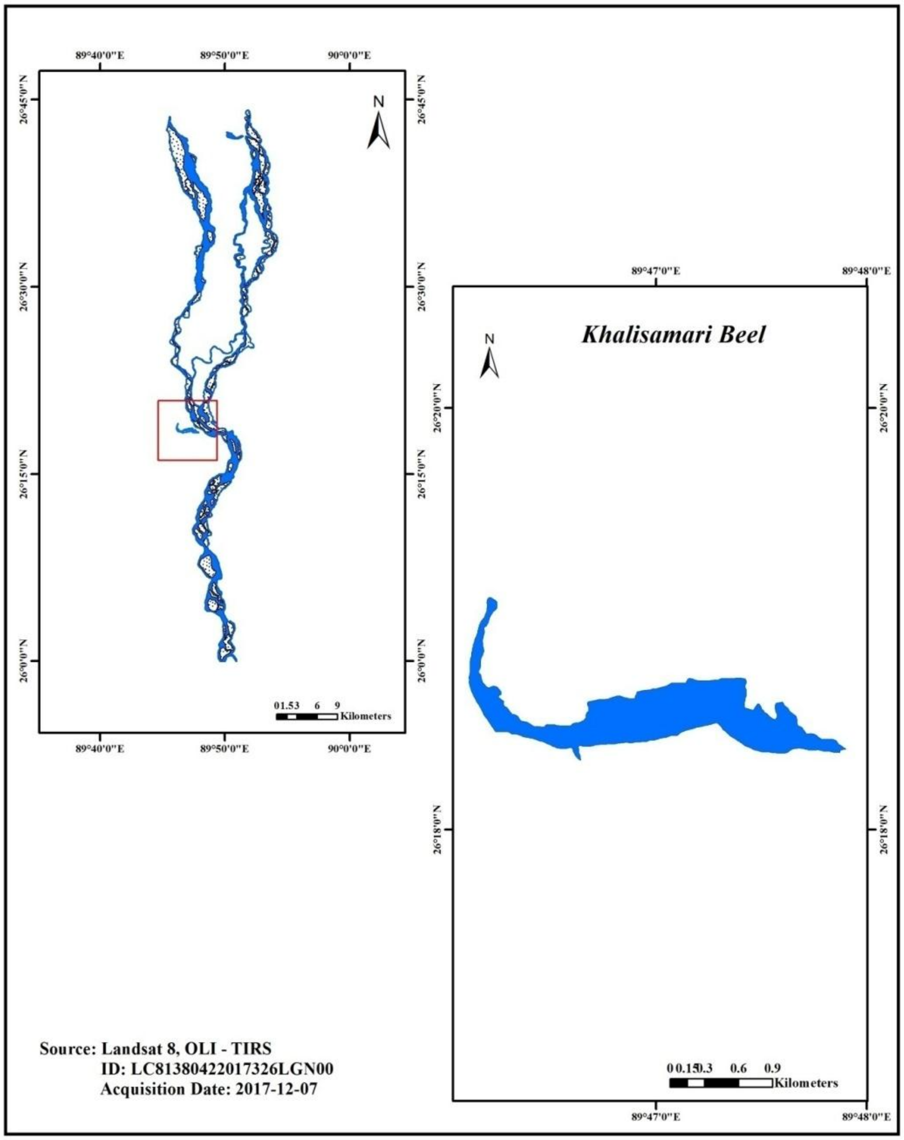
I. Oxbow lakes, formed by single meander bend neck or chute cutoff (Fisk,1947; Lewis and Lewin, 1983, Hooke, 1995)
II. Channels abandoned over multiple meander lengths, left inactive due to an upstream avulsion (Smith et al., 1989; Stouthamer and Berendsen, 2000)

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:

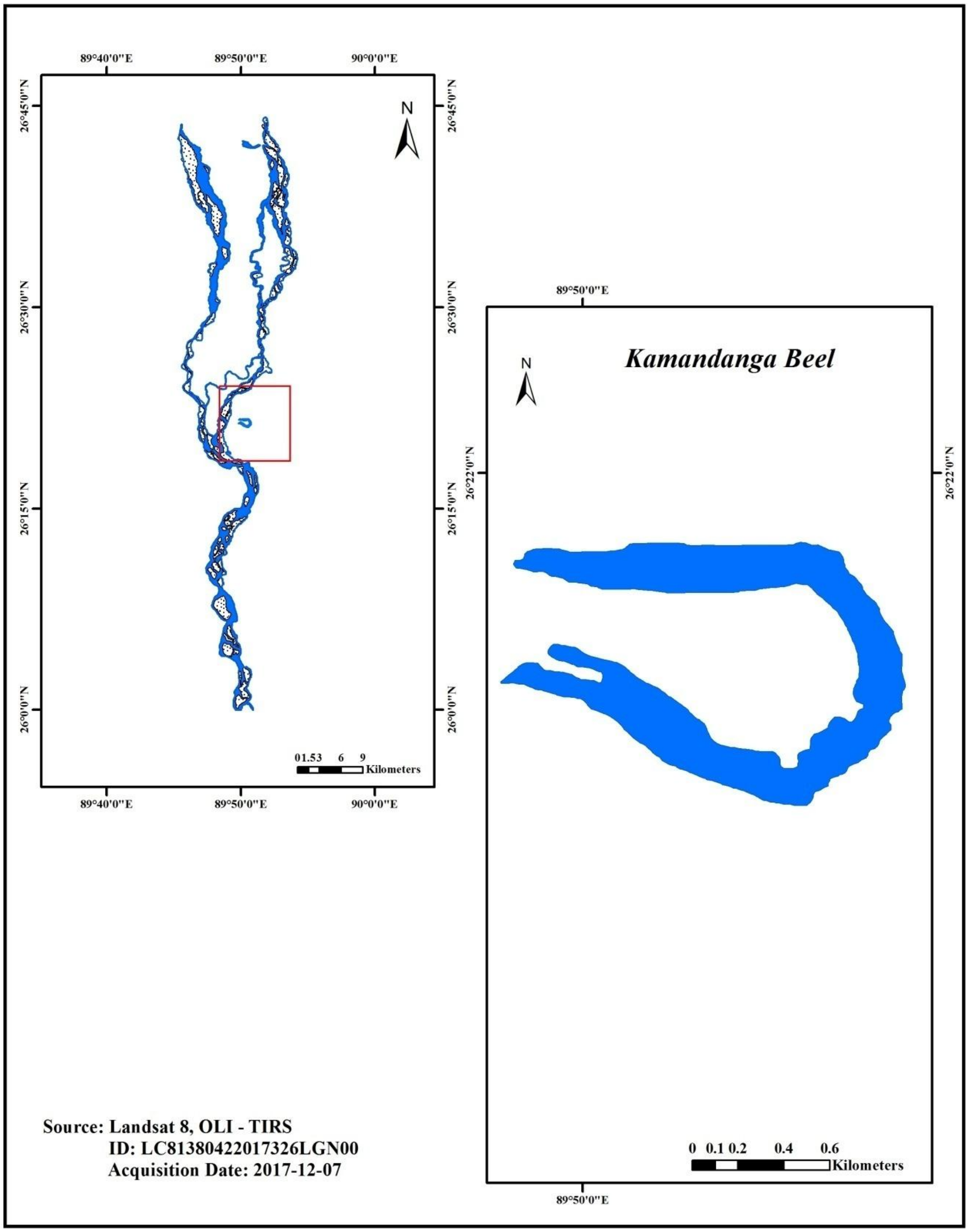
A semi-circular, curved shaped perennial abandoned channel formed by meander cut-off named Purbachara (Map 3.8) is located at Schoolghutu village of Kokrajhar district of Assam. Geographically it is located in the left bank of Sankosh river at 26̊ 21’latitude and 89̊ 53’ longitude. The length of this 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:

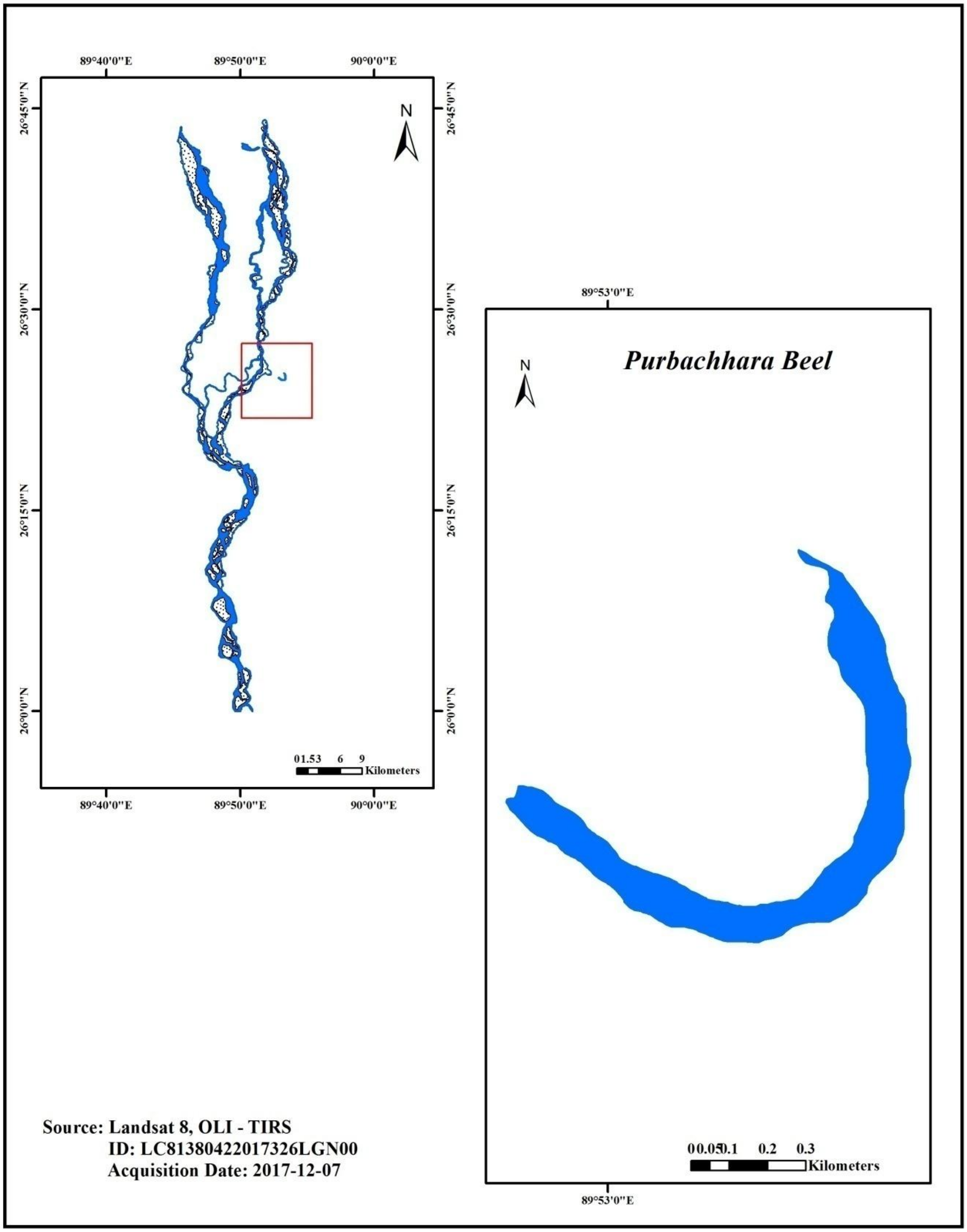
Numerous meander cut-offs i.e. neck and chute cut-offs are also found in both the banks of Sankosh River in the study area. Ghirtinga beel, a meander cut off is situated in the left bank of the Sankosh River near the village Ramnathpur of the state of Assam. It was formed due to the neck being cut off 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).

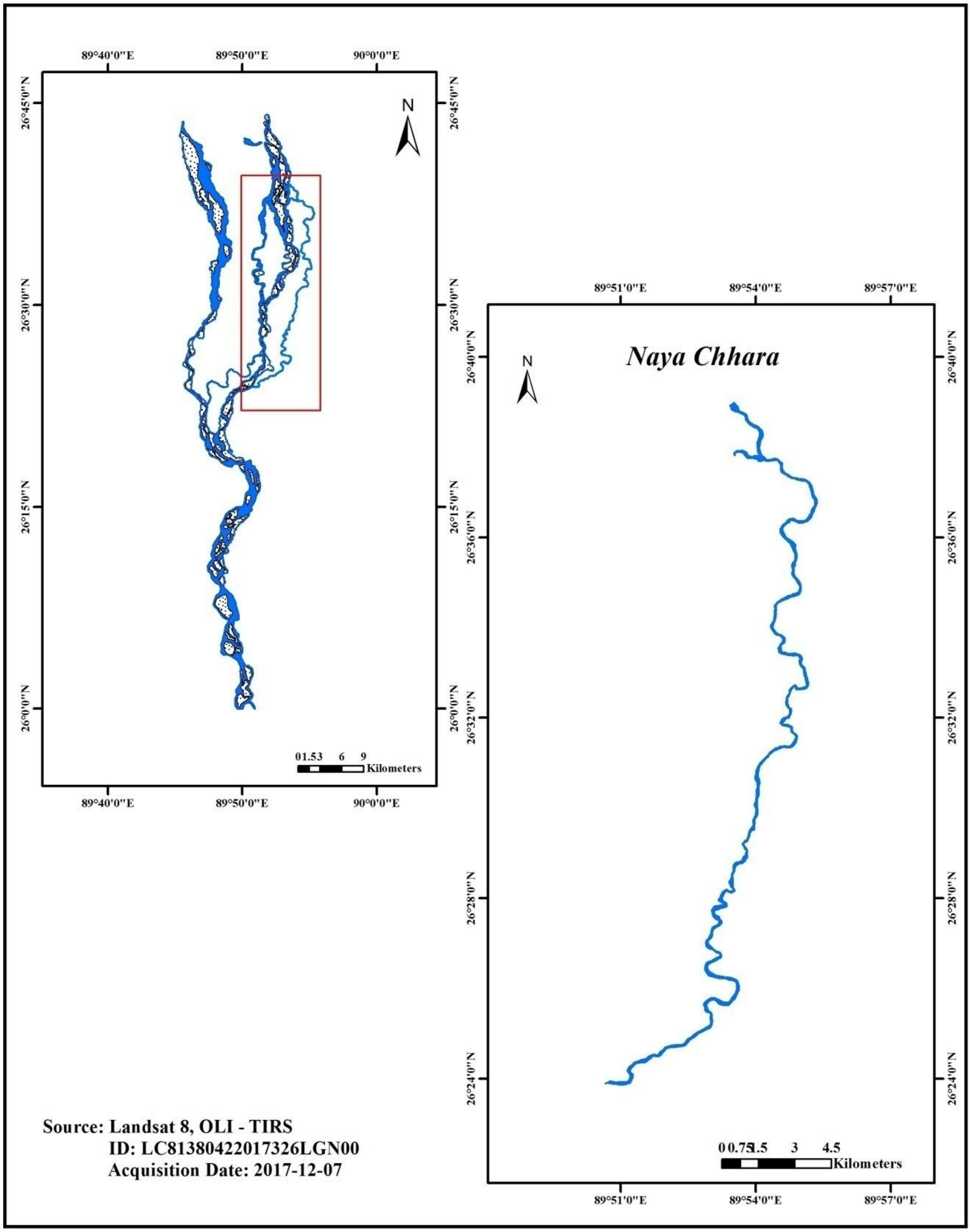
In the study area, it is evident that two types of channel avulsions have been identified. Out of these two types, one is recognized as local channel avulsion at the upstream reach and another is recognized as partial channel avulsion at the middle stream reach. Both types of channel avulsions have occurred 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:

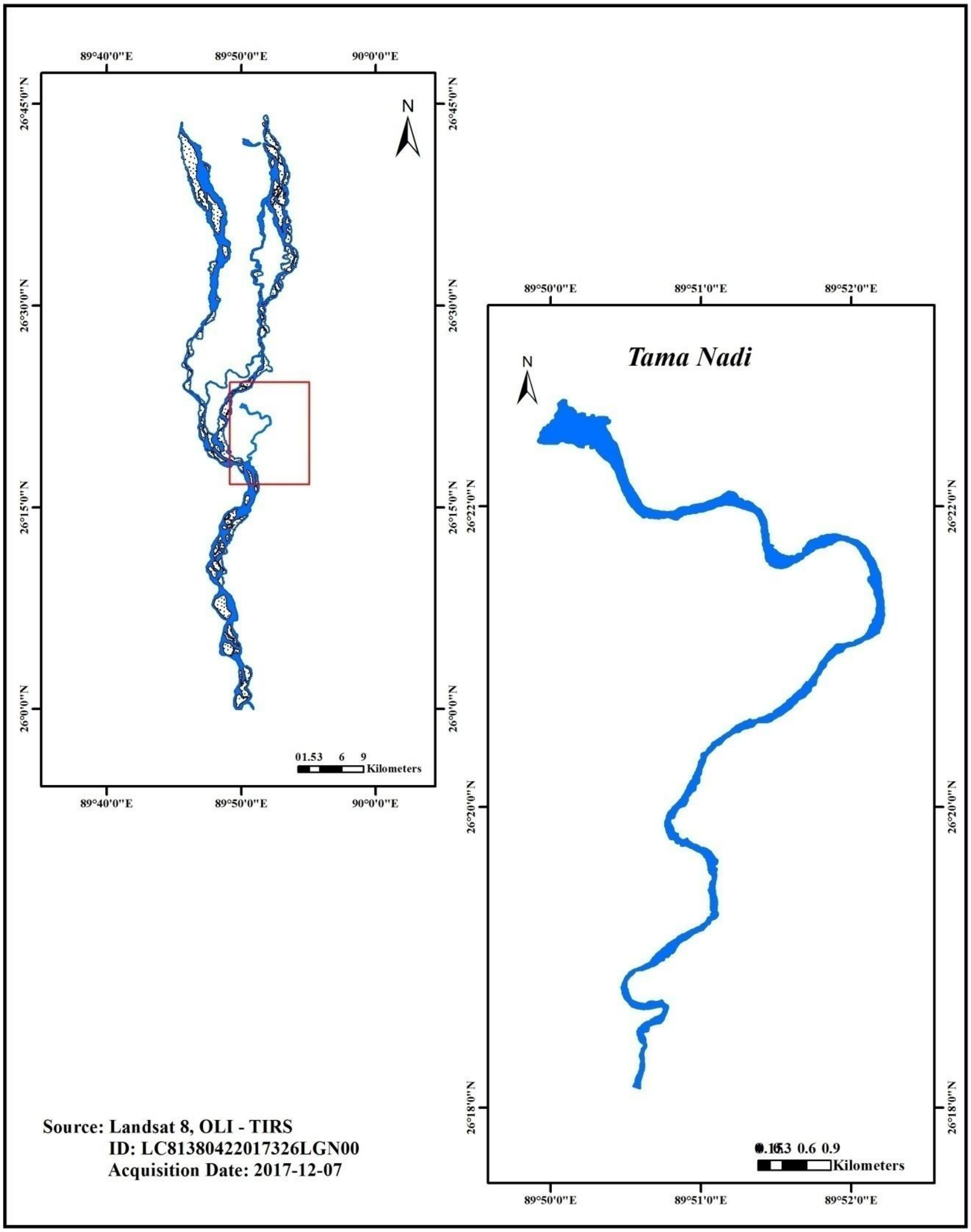
An avulsed channel Nayachhara (Map 3.9) of Sankosh river is found at the Fulkumari village of okrajhar district of Assam in the left bank of the main channel. Due to siltation and dense forest cover, this avulsed channel disconnected with the main river and now flows a few km to the south direction and 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:

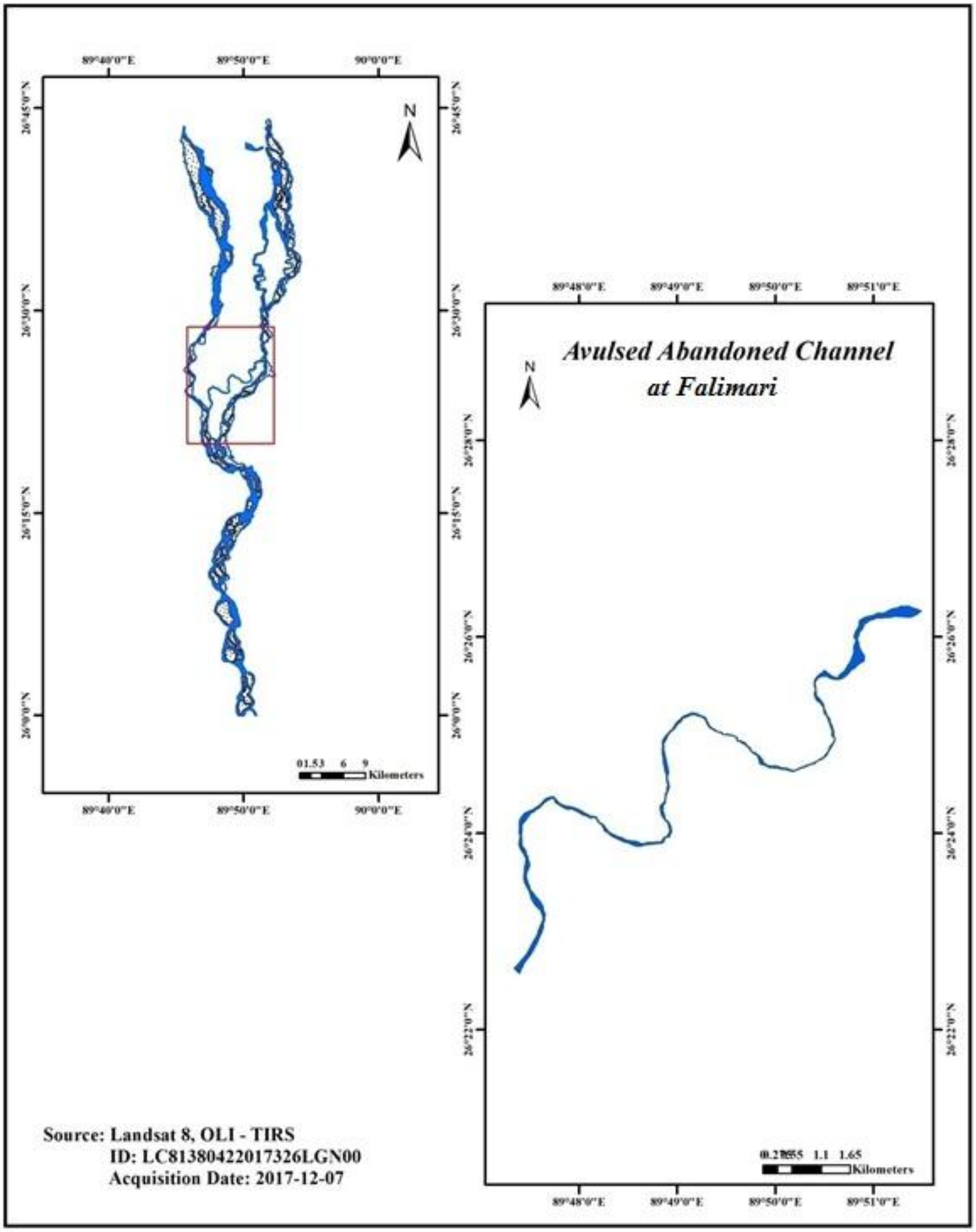
A locally avulsed abandoned channel is found in the middle stream reach of Sankosh River of the study area. It has been observed that Tamanadi (Map 3.10) has formed due to channel infilling at the entrance. The total length of this avulsed abandoned channel is about 13 km. It is noticed that the entrance 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:

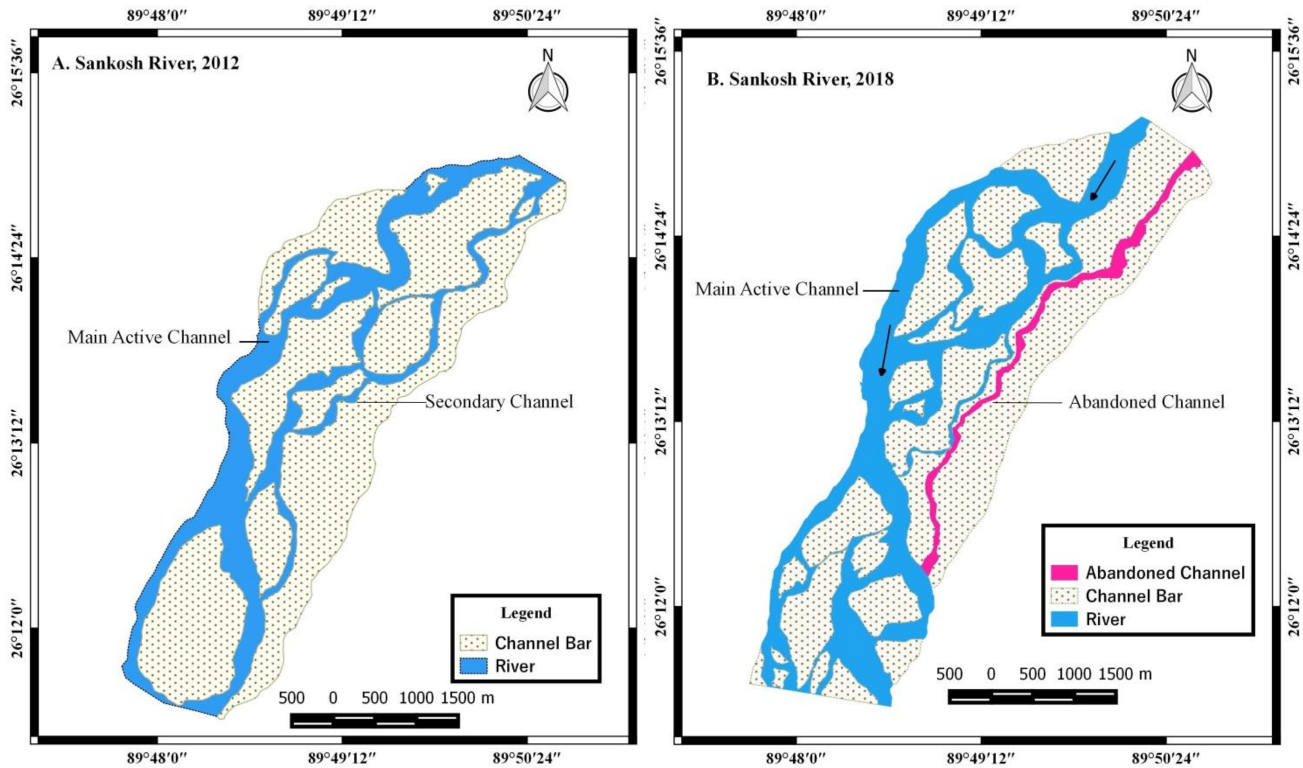
A partial avulsed abandoned channel (Map 3.11) is found in the middle course of the Sankosh River at Majerdabri, Falimari village of Cooch Behar district of West Bengal. The left flow of Sankosh River was called Gadadhar at that time and on the other hand right flow of Sankosh was the main flow of Sankosh 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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