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:

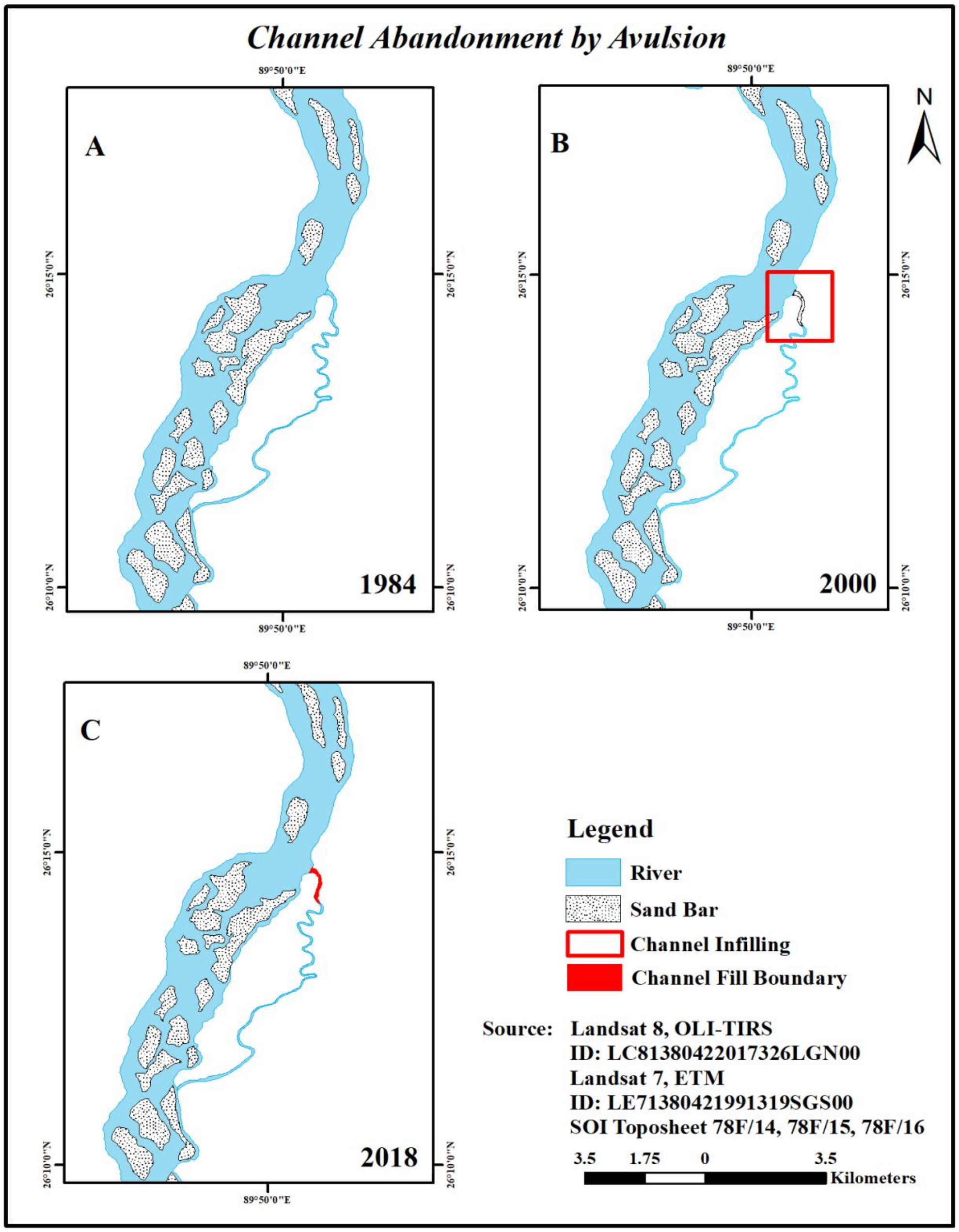
In the alluvial course of the river Sankosh, the river tries to maintain the state of equilibrium with well-balanced conditions of some important hydrological parameters such as the discharge, sediment load, sediment size and the slope. In this regard, it is mentioned that the changes of these parameters 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.

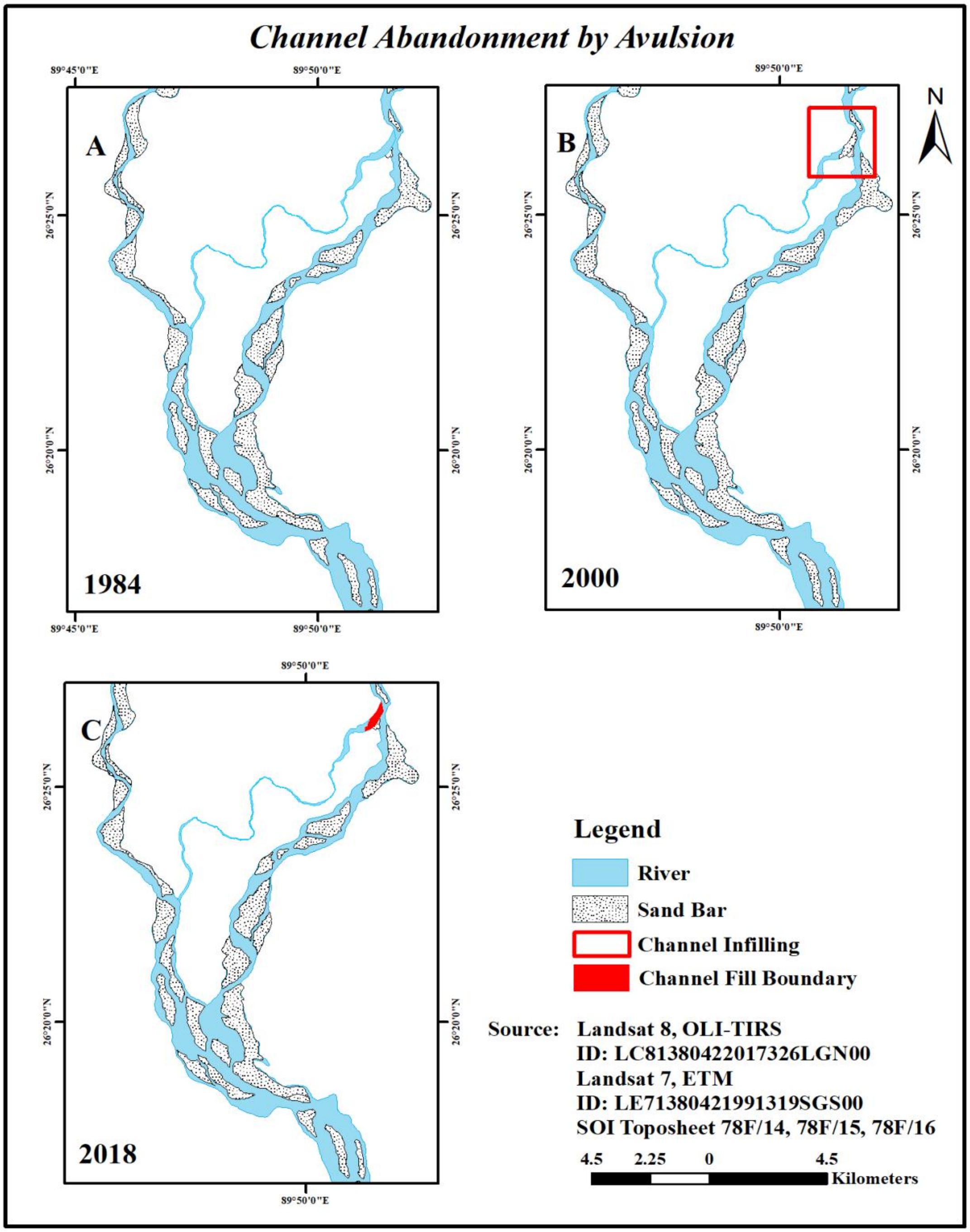
On the other hand, local avulsion has also occurred along the channel of Sankosh River in the study area near upstream and after flowing a few kms of distance, it again re-joins its parent channel at River Sankosh. (Fig: 4.1) Local avulsion has occurred by the process of incision during the peak flood 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.

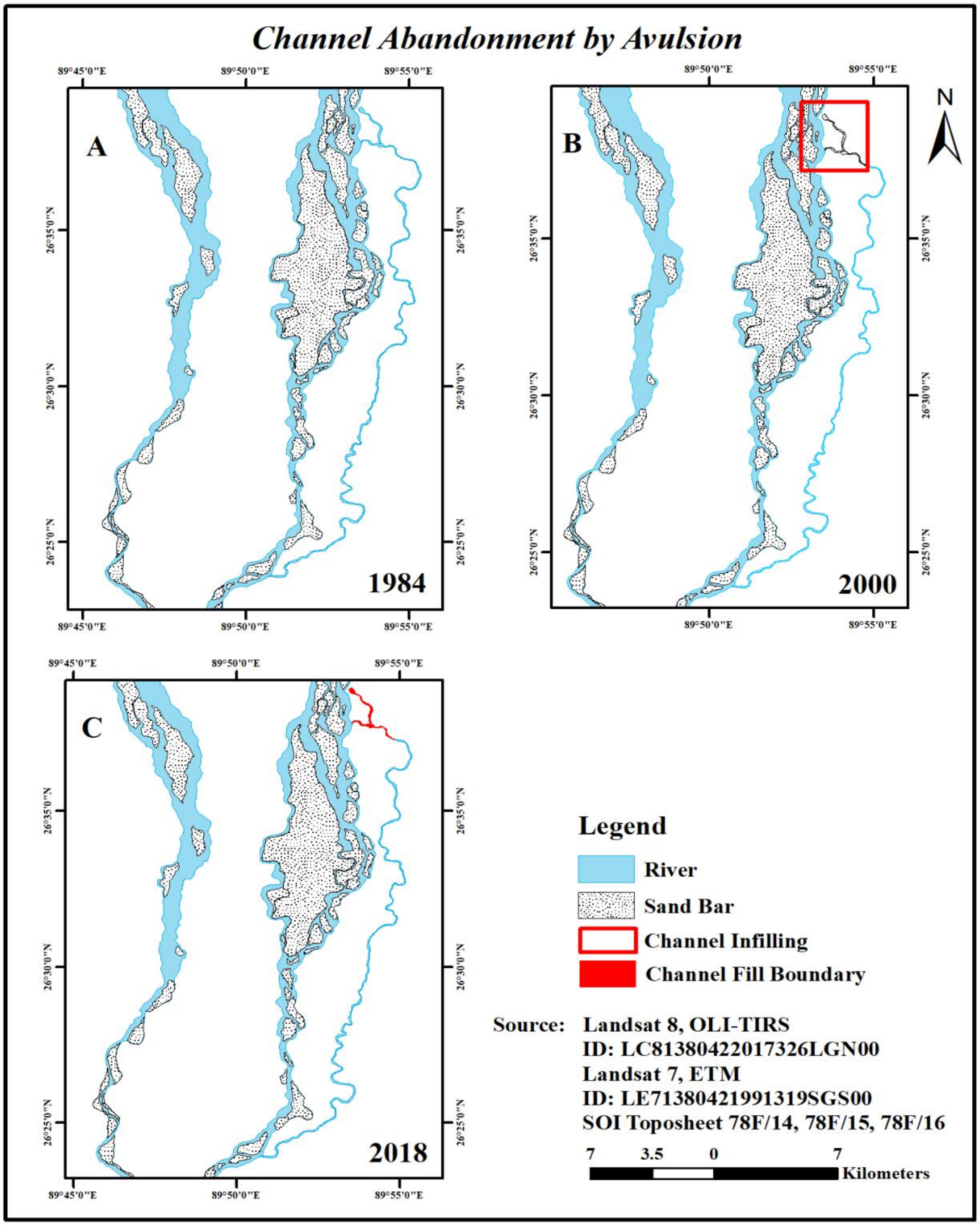
From the above mentioned mechanisms of channel avulsion in the Sankosh river, resulted by the process of aggradation on the channel regime after rain induced high flow, it can be said that the 1st hypothesis '**Abandoned channels occur where stream bed aggradations cause the stream to overflow with rain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

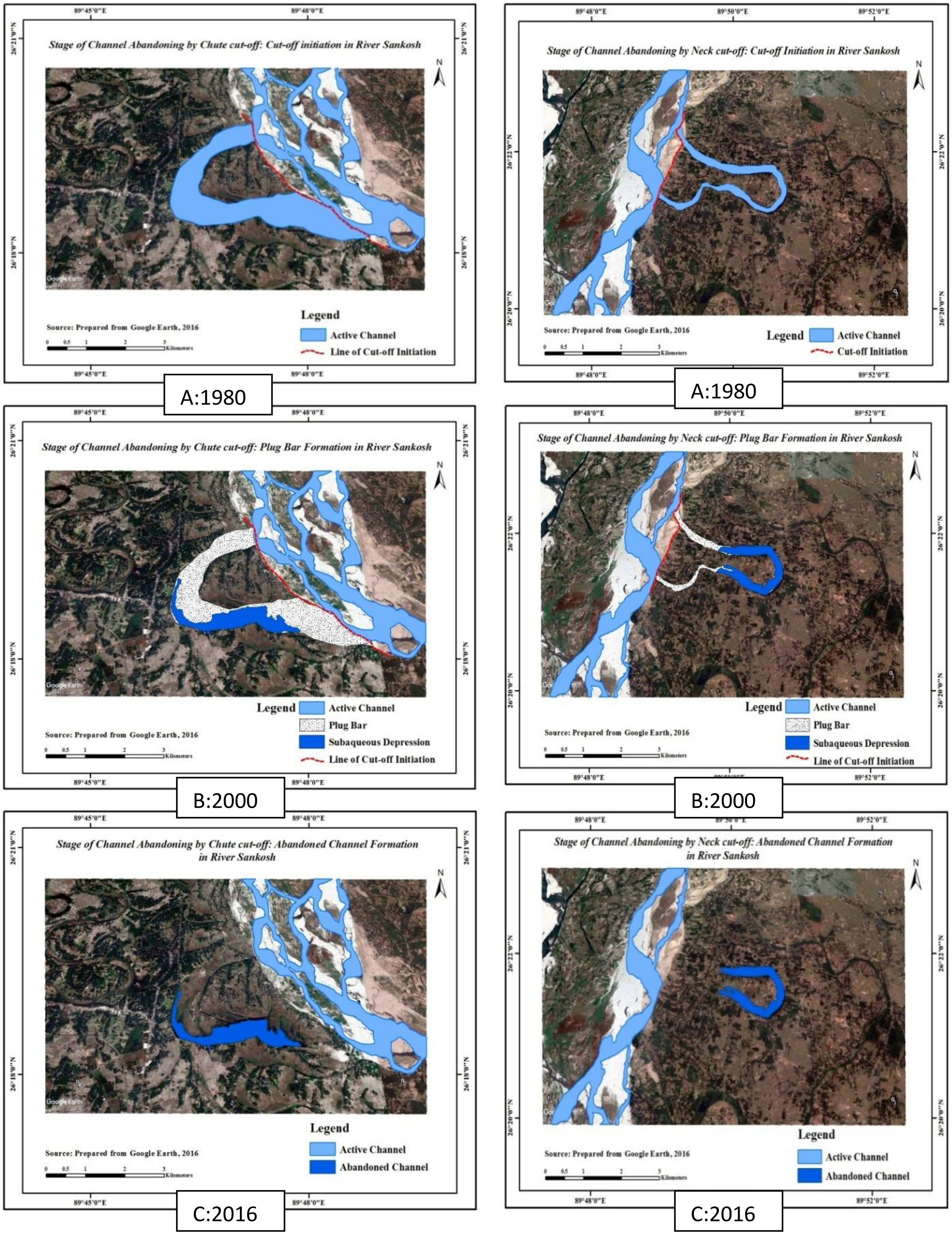
4.3.3 Plug bar and Point bar formation:

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).

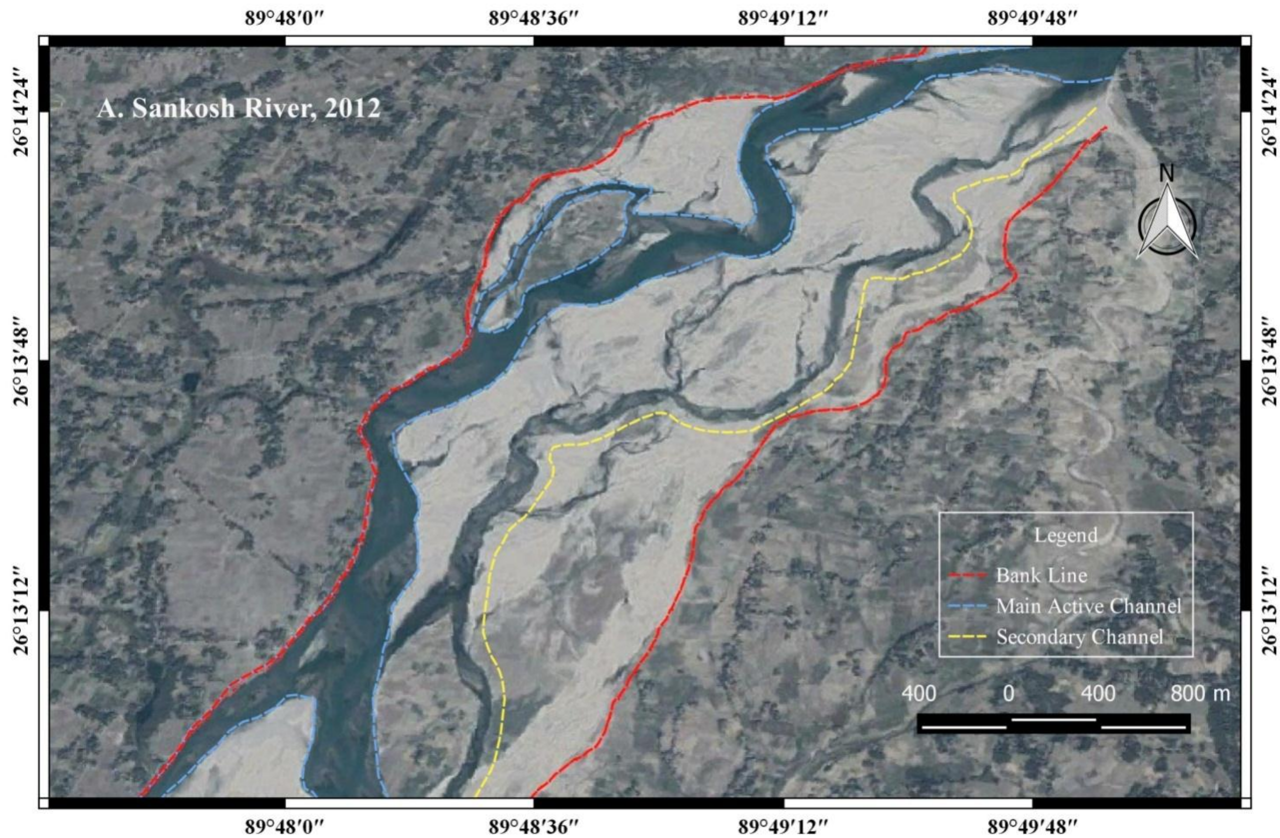
River by aggradation on one bank and rapid erosion on the other, which makes torturous meander bends unstable and cut off takes place with significant reduction of sinuosity when meander threshold is crossed. Therefore, the hypothesis 2 '**Channel abandonment has positive relation with instability threshold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

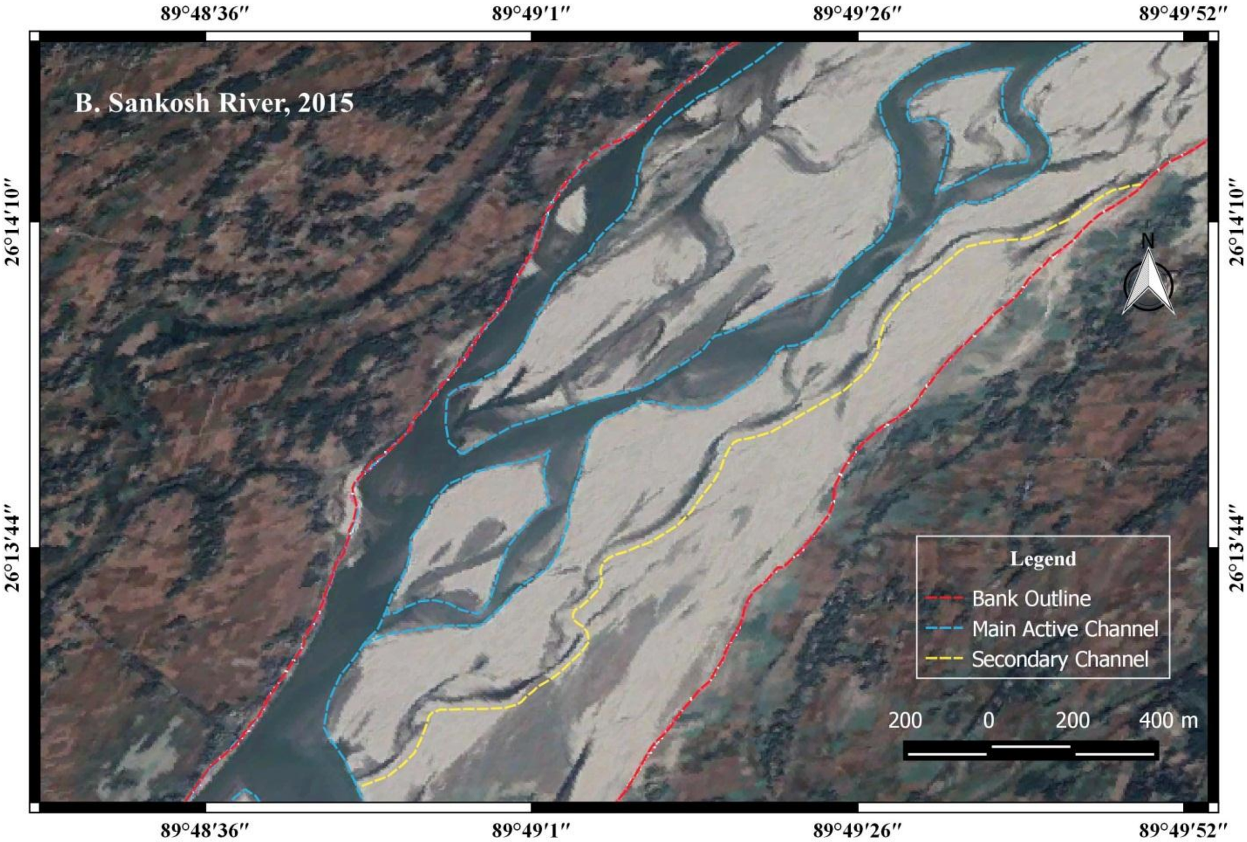
4.4.1 Braiding and abandonment:

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.



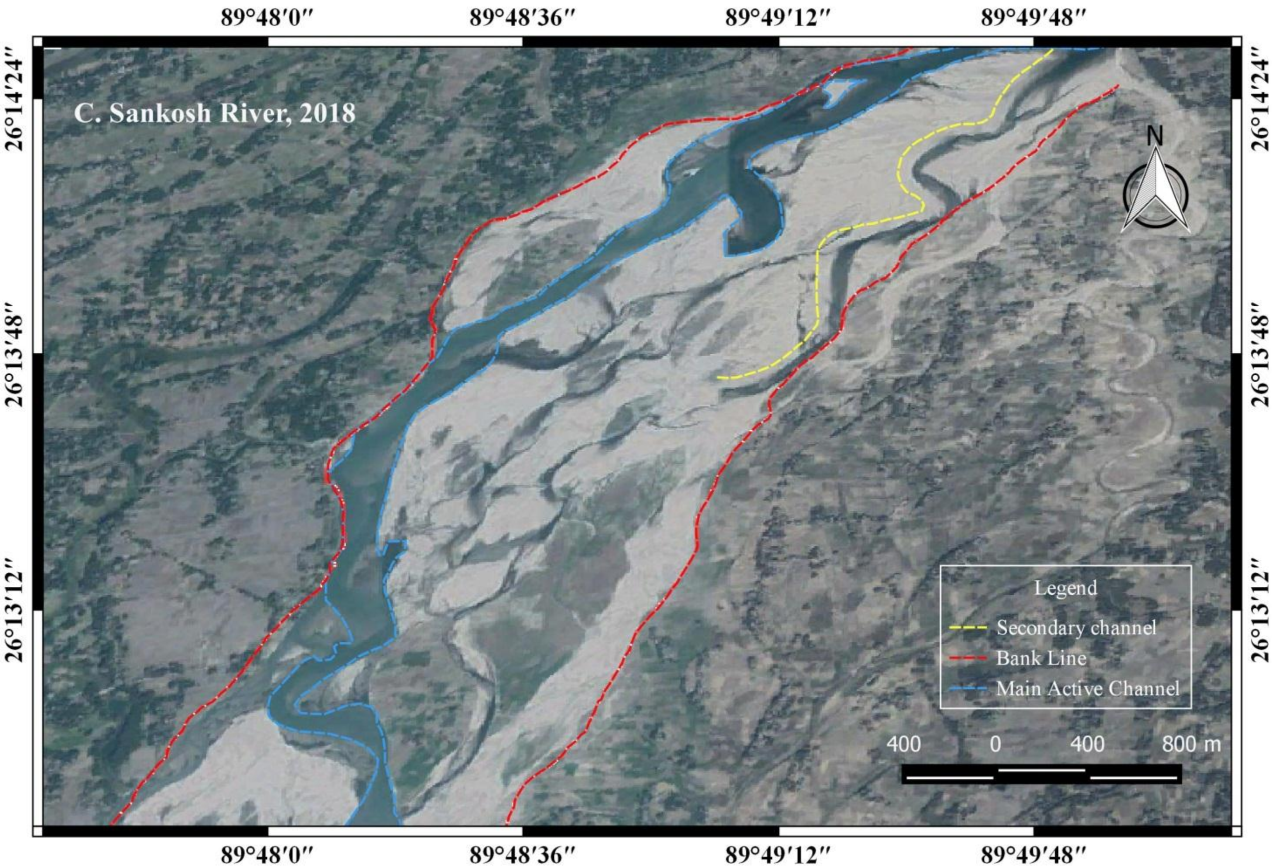
Source: Google Earth, 2016

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.

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

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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