Chapter-I
Introduction

1.1 Introduction

The fluvial dynamics of a channel is associated with the mechanism governing the relationship between erosive power of the river, its bed load transportation and processes that are operating within the valley, alluvial plains and river beds. It is also related with the run-off pattern and changing nature of bed morphology. The alluvial channels exhibit a wide variety of morphological forms in response to the complex interaction with hydrological conditions (Ham, 2005). The Chel basin has been experiencing transformations and the channel processes are adjusting with the modified channel forms. The behaviour of the channel hydraulic parameters is more complex in alluvial streams where changes in discharge are associated with changes in the configuration of the bed (Leopold et al., 1964). The head streams namely *Mangzing, Sukha* and *Chel Khola* are the main sources of supply of water and sediment to the river Chel. The course of the river Chel on the piedmont tract of *Duars* is controlled by a distinctive fault line that aligned along the margin of the lower Chel fan surface and extends up to the *Tista* channel (Starkel et al., 2008). Loss of general slope along the foot-hill segment has lead bed aggradation in case of river Chel. This fluvial process is linked with the temporal variation of load-discharge ratio as recorded in the flood events between 1993 and 2000 (Starkel et al., 2008). The transformations of the river Chel has been connected with the flood dynamics within the channel as observed from the tendency of channel stabilization by means of the appearance of vegetated channel bars after the effect of major flood event at the river basins of lower Darjeeling Himalaya in 1968 (Starkel and Basu, 2000). Human activities and interferences (construction of embankments, bridges, sand and boulder extraction, deforestation and related landslides etc.) with the channel have impetus to modify the channel forms. The bed material extraction from the channel bed has impact on bar formations.

1.2 Study Area

The hilly part of the basin (total basin area 316 sq. km) rises above 2300 m a.m.s.l. Three small streams *Mangzing Khola*, *Sukha Khola* and the Chel Khola constitute the headwater catchment of the river Chel. The river Chel has been originated from the

Pankhasari Khasmahal on the *Kalimpong* ridge. At the south of *Mal Khasmahal* in Jalpaiguri district the Chel meets with *Neora* and takes the name of *Dharla* which ultimately falls into Tista. The basin is located within the extension of 26°41'N to 27°10'N and 88°39'E to 88°45'E.

1.3 Statement of problem

The channel form of the river Chel has been transformed during the period of last hundred years as revealed from the comparison of old SOI topographical maps and images. The changes in the channel dynamics and behavior is associated with the transforming situation on the flood plains i.e. the increasing population pressure and modification of the channel course. So, it is necessary to recognize the processes that govern the channel behavior and to understand the resultant morphological response over appropriate spatial and temporal scales (Ham, 2005). The catchment area has been witnessed with deforestation occurring over time and supplying load to the channel through landslides over the hill slopes coming down to the channel. As a result, aggradation is also increasing. The rainstorms of 1993, 1998, 2000 and 2002 have generated high discharge over the piedmont region of Jalpaiguri and Alipurduar districts that caused massive water spills and supplied load to the river bed. The flood of 1954 caused a damage of Chel road bridge (Roy & Sarkar, 2013). The rainfall records of *Kurti* TG and *Meteli* TG shows mean annual rainfall records of 4800.8 and 4291.3 mm respectively (Roy & Sarkar, 2013). The channel is experiencing ever increasing load during the rainy seasons of the past decades.

1.4 Objectives

The present study has been undertaken to fulfill the following objectives:

i. To assess the hydraulic parameters i.e. cross-sectional area, wetted perimeter, hydraulic mean depth, channel width-depth ratio, velocity, discharge, bank height etc. from cross-sections at several sites during 2016-2019.

ii. To assess the nature and degree of channel transformation.

iii. To assess the type and size of river load and downstream variation of their distribution.

iv. To assess the nature and extent of flood and bank failure and their impact on the channel form and process.

v. To assess the nature and extent of anthropogenic activities on the river Chel.

1.5 Hypothesis

The following hypothesis will be tested:

a. Materials resulting from bank failure may have impact on the channel form and thereby on the hydraulic parameters.
b. Anthropogenic activities could have affected the channel form.
c. Occasional floods may have impact on the channel form.
d. Increasing load in the channel may have affected channel avulsion and related geomorphological changes in the bed and bank of the river.

1.6 Methodology

Conventional survey techniques shall be applied for the assessment of parameters i.e. cross-sectional area, wetted perimeter, hydraulic mean depth, channel width-depth ratio, velocity, discharge, bank height of the river Chel at different sites during pre and post monsoon periods during 2016-2019. Longitudinal profile will be drawn based on SOI topographical maps (1: 50,000). Discharge will be calculated by 'Area-Velocity' method (Chow, 1959 & *Mu*treja, 1990*)* based on field survey. Water level will be recorded during pre and post monsoon periods (2016 to 2019). The following sites have been selected for carrying out the field study:

Site 1: Below the Junction of the three small rivers namely Sukha Khola, Mangzing Khola and Chel at an elevation of 285 m at *Patharjhora* and a distance of 11 km from the source of the river.

Site 2: Beside *Manabari* Tea garden at an elevation of 212 m at a distance of 15 km from the source of the river.

Site 3: At *Odlabari* NH-31 Bridge at an elevation of 166 m at a distance of 20 km from the source.

Site 4: Near *Apalchad* at an elevation of 90 m at a distance of 37 km from the source.

Site 5: Near *Rajadanga* at an elevation of 80 m at a distance of 46 km from the source.

An attempt would have been made to analyze channel transformation during the past hundred years based on SOI topographical maps, cadastral maps, tea garden maps and satellite images under GIS platform.

Suspended sediment load will be measured at the sample sites in pre and post monsoon months by 1 liter sample bottle (Chow, 1959) whereas size distribution will be determined by sieving technique in laboratory. Bed material size will be measured by using slide caliper at the field sites.

An attempt would be made to analyze river bank stability I bank failure based on GPS survey technique (both pre and post monsoon) during 2016-2019 to draw the bank lines and the rate of bank erosion will be measured by the superimposition of the temporal (2016-2019) bank lines under GIS environment. Impact of flood will be studied by identifying the changes in the channel hydraulic characteristics from the constructed channel cross-sections.

Temporal Landuse-Cover mapping has been done to detect the changes within the basin due to anthropogenic activities. The study of channel encroachment has been carried out on a temporal framework (1989 & 2017) and the amount of lateral oscillation has also been calculated. The effect of channel movement on the adjacent mouzas with 1km flood risk buffer zone analysis has been carried out in GIS environment. The effect of channel bed mining on fluvial dynamics has been carried out from the drafted cross sections (pre & post Monsoon) at various stations and the analysis of seasonal variation of channel mean bed height has been measured. Also the estimation of extracted total volume of channel material load has been carried out from the count of total numbers of trucks that collects bed material at Odlabari site on a particular day excepting the monsoon months.

1.7 Data Source

The important data sources are SOI topographical maps 78 A/8, A/12, B/5, B/9 (scale 1: 50,000), Landsat TM sensor (1990), ETM+ sensor (2000) and OLI-TIRS sensor data (2017) (Earth Explorer- free source), temporal Google Earth images (free source) and Bhuvan (free source) satellite data, DEM (SRTM data of 90 m and ASTER data of 30 m spatial resolution- free source), USGS topographical map (NG 45-8, scale 1: 2,50,000), District Census handbook of Jalpaiguri district (2011, Part-XII-A, Series-20 & XII-B, Series-20), overview of Census 2011 (GOI) and cadastral maps etc. Rainfall records will be collected from the tea-gardens (Ambiok tea garden, upper and lower *Fagu* tea garden, *Meenglas* tea garden, *Damdim* tea garden, *Syli* tea garden etc.-

daily and mean monthly records), IMD and Water Portal of India (mean annual and monthly records) and from secondary sources (Water portal, GOI & Office of the Additional Director of Agriculture, North Bengal Region, Jalpaiguri, Dept. of Agriculture). The land use-cover maps of the Chel basin has been prepared from above mentioned satellite imageries after its processing in GIS environment. Moreover field investigations and selected review of literatures will be the major sources of data (Geological & Mineral Map of WB, 1999, Seismo-tectonic map of GSI, 2000, Soil map from NBSS & LUP, Kolkata).

1.8 Review of the previous works

The foothill geomorphology of Darjeeling Himalaya and its transformations have been discussed by Starkel et al. (2008) and Nakata (1972). Starkel et al. (2008) elaborated the evolution of the part of Sikkimese-Bhutanese piedmont zone as well as the evolution of the great variety of rivers flowing through it. They also stated about the nature of fluvial dynamics that is highly controlled by the structural activities and the shifting of the zone of aggradation. They added the effect of anthropogenic factors that has accelerated the sediment loading and aggradation within the streams. Nakata (1972) indentified the fragments of old *Gorubathan* surface which is covered with boulders (>2m) and elevated above the Chel river channel. Starkel et al. (2008) identified the presence of neo-tectonic crustal movements within the stretch of the piedmont zone between Chel and Jaldhaka-Diana river system. Nakata (1972) provided a vivid description about the formation of fluvial fan surfaces, terraces and their deposits on the piedmont tract of the North Bengal. He observed the anomalies of the drainage pattern above the old fan surface as some streams of tectonic origin have been retarding the free flow passages of N-S directed rivers. He identified number of neo-tectonic signs in form of small isolated rounded hills on the left bank of the Chel near *Gorubathan* which is composed of gneissic boulder and gravel ranging up to 3 m in diameter. He also observed the tendency of increase in the height of the river beds from the outlets of the rivers on the elevated fan surface of the *Rangamati* formation. The development and fluvial mechanism of the river system on the Sikkimese-Bhutanese piedmont tracts have been discussed by Sing (1992), Jain and Sinha (2003). Later on, Starkel et al. (2008) classified river Chel as coming down by dissecting the lower Darjeeling Himalaya and has been aggrading at the foothills.

The studies on river dynamics and associated geomorphological changes at the foot-hills of Sikkimese-Bhutanese Himalaya have been discussed by Starkel and Sarkar in 2002, Chakraborty and Dutta in 2013. The changes in channel form, processes and characteristics have been discusses by Charlton (2008), Leopold et al. (1964), Morisawa (1968), Knighton (1984) and Chorley (1969). Leopold et al. (1964) observed the variations in the hydraulic characteristics of the channel cross-section i.e. mean velocity, mean depth and mean width of flowing water at different discharges. Charlton (2008) opined about the adjustments to the channel form occur as a result of fluvial processes that always operates between channel form, flow and sediment transport. The techniques of stream gauging are elaborated by Raghunath (2010) and Chow (1959). The study on channel hydraulics and forms has been discussed in engineering manual of US army corps in 1993. The assessment on drainage network analysis has been accomplished by Doornkamp & King (1971), Singh (2007) and Chorley (1969), Panda (2013) and Nayer (2013). The works on bank erosion have been discussed by Rosgen (2011), Toriman et al. (2012), and Saha (2013). The mechanism and nature of the channel avulsion has been discussed by Field (2001) and Slingerland (2003). The work on morphodynamics of alluvial channels has been carried out by Ham (2005) and Cencetti et al. (2005). Ham (2005) said that the channel morphodynamics is connected to the downstream variability of sediment transfer and this study is associated with the relationship between sediment transfer and channel deformation. He also stated that the floodplain modification and channel instability along wandering rivers are directly related to the downstream transfer and storage of coarse alluvial sediment. Goudie et al. (1990) commented on the cross-sectional geometry of a channel and assumed it as water prism beneath the morphologically defined Bankful stage. He also studied various channel bed forms by considering the gradient of the channel derived from the long profile of short reaches. The planform geometry of multi-thread channels has been discussed quantitatively by following various empirical equations of Brice (1960), Kansky (1963), and Smith (1970). The techniques of channel velocity determination by following Velocity-Area discharge estimation method and Manning's equation have been elaborated by Chow (1959), Goudie et al. (1990), Mutreja (1986) and British standard institution (1964). Leopold et al. (1964) supported the Chezy's equation to relate water velocity with the roughness condition of the channel boundary, slope and depth of flow. The typical values of Manning's n have been mentioned by Graf (1971), Gregory and Walling (1973). The changes in the hydraulic characteristics of a channel cross-section as a function of discharge variation have been discussed by Leopold et al. (1964) and they established a power relationship in between the pairs of discharge at a given section and the width, mean depth and mean velocity of the moving water within the channel. Leopold et al. (1964) remarked on the shape of the channel as it is the function of flow and character of the sediment in motion within the channel. Similarly, Charlton (2008) stated that the form of a channel is largely a function of the water and sediment supplied to it. Henderson (1961) highlighted that the channel form stability is attached with the transmission of flow and the stability of the banks. All such literatures furnished herewith will be helpful for this study.

The patterns of Channel Plan form Dynamics (CPD) of Chel basin in relation to the variety of flow conditions and sediment regimes has been discussed by Knighton & Nanson, 1993; Kumar et al., 2007. The alluvial fan litho-facies of Chel including various categories viz. clast supported gravels, stratified gravels, cross stratified gravels, poorly shorted gravels, massive gravel, pebbly sand and mud etc. has been highlighted by Mandal et al., 2016.

The effect of catastrophic rainfall in shaping the morphology of Darjeeling Himalaya has been elaborated by Starkel, 2008, Dutta, 1966 & Sarkar, 2012.

The downstream changes and seasonal adjustments of channel hydraulic geometry has been discussed by Leopold et al., 1964, Hikin, 1981, Lacey, 1929, 1933, 1946, 1958 and Lane, 1937.

The variety of channel flow conditions and flood dynamics has been discussed by Brierley et al., 2010 & Fryirs et al., 2010; Cheng-Wei Kuo., Chi-Farn Chen., Su-Chin Chen., Tun-Chi Yang. & Chun-Wei Chen, 2017. Further, the nature of channel load movement and its deposition under a particular flow condition has been elaborated by Hickin, 1995. Shield (1936) stated the causative factors for grain movement in a channel. The nature of downstream Bed load movement has been discusses by Leopold et al, 1964, Bagnold, 1954 & Hickin, 1995. The particle size distribution in a channel and its downstream variation has been highlighted by Julien, 1998. The unit suspended discharge (Qs) in channels has been discussed by Julien, 1998 & Hickin, 1995. Dietrich, 1982 & Tamang, 2013 discussed the sediment particles mode, rate and distance of transport by shearing forces of the flow.

Raghunath, 1985, Chow et al, 1964 & Knighton, 1998 discussed the nature of flood occurrence and its effect on a river basin. Mutreja, 1990 studied the determination of peak flow contributed in form of channel runoff from the micro basins. Gumbel (1941) discussed the probability of flood occurrence within a basin. Bryant et al. 1995, Sinha et al., 2014 & Allen, 1965 discussed the effect of channel flood in determination of avulsion threshold of the channel. Reddy, 2008 & Tamang et al., 2017 discussed the techniques of suspended sediment yield from the upper catchment of Chel basin.

Rosgen 1996, 2001, 2006, 2008a, b, 2001, 2006 studied and discussed the effect of Bank erosion hazard and its effect on channel form bay using BEHI and NBS indices.

Raven et al. 1997, 1998 & Tamang, 2013 discussed the effect of human interference on the channel. Haidvogl, 2018, Jia et al., 2018, Bork et al. 1998, Lawler et al., 2014, Wulder et al., 2008 &Mooney et al., 2013 discussed the effect of land use-cover change in relation to soil erosion rate, human settlement expansion in basin etc. Alexander et al. 1997, Goudie 2000 & Costanza et al. 1995 analyzed the eco-system services of a channel with flowing water and how the services modify due to channel degradation. Kondolf 1997, Jia et al., 2006 & Huang et al., 2014 elaborated the effects of in stream mining or bed material extraction on a channel planform dynamics. Gregory, 2006; Wohl, 2006 & Wiejaczka et al., 2018 analyzed the channel ecosystem degradation due to boulder extraction.