PART-III

Chapter 5-Major outcomes and Conclusion

5.1 Major/overall outcomes of the study

- Analysis of the river over a 62-year period, using historical topographical maps, Landsat Images, DEMs complemented with extensive literature review and fieldwork, suggest that the river has changed its planform periodically. During1970s and 1980s, the river was much dynamic as suggested by much variability in planform indices but Channel length, mean channel width and braiding index all showing a decreasing trend over the years. Only sinuosity has recorded a negligible increase of 4.5%. Active channel area had seen a major spike between 1955 -1976 but then after it consistently seen decrease and has almost attained earlier value of 1955 during 2017. The study reach has experienced large spatio-temporal variation in the areas under erosion and accretion but the values are showing decreasing trend since early 2000s. Similarly channel gradually has attained the earlier width of 1955. These altogether is suggestive of the fact that the Chel River is gradually transforming itself from braided channel to straight one. River channel may have changed in a cyclical manner where paleochannels may be converted into a main channel as well as main channels may be converted into a paleochannel due to channel avulsion.
- Field measurements during pre-monsoon and post-monsoon of 2014,2015 and 2017 reveals the fact that the study reach of the Chel River is characterized by shallow multiple channels with asymmetric cross sections. There is great spatial and seasonal variability in velocity, discharge and sediment output. The flow is turbulent, non-uniform and overall sub-critical in nature.
- It is evident from channel configuration maps of the seven periods between 1955 and 2017 that the Chel River experienced several episodes on contraction, expansion, oscillation and straightening during the assessment period of 62years.

- Downward movements of confluence points can be asserted to the mechanism of aggradation in the confluence area. For example, Chel-Kumlai confluence and Chel- Neora have shifted downstream between 1976-1987 from A2-A3 and B2-B3 respectively (Table 4.3.2). Whereas erosion or avulsion near the confluence results in upward movement of the confluence points. Example- Chel-Kumlai confluence point moved upstream from A1 to A2 (4.3.2).

- Increase in channel confluence angle results increase in erosion and upstream movement of confluence points whereas downstream movement of confluence points can be triggered by decrease in the channel confluence angle.

- The temporal channel migration is oscillatory in nature rather than unidirectional. But a net westward progression of the main river has been recorded. Besides channel migration being temporally variable, it is also differed spatially, reflecting the controls implied by the structural confinements and physiographic elements at certain sections. The significant changes observed were -increased instability in terms of channel widening, increasing number of neck cut-offs, occurrences of avulsions, decreasing sinuosity, braiding intensity and overall westward movement of the river.

- One of the major outcomes of the study has been short-term prediction of channel Centerline and channel confluence junction angle dynamics using a linear regression method. Two zones of highest predictive centerline distance have been identified. If unrestricted the westward movement of the Chel will damage cultural elements (i.e., human habitation, agricultural lands and roads and infrastructures in the Zone-1 (near Odlabari town) and physical elements (i.e., natural vegetation) in the Zone-2 (Apalchand Reserve Forest). Therefore, investment of much focus and attention for proper bank strengthening and management works along these two reaches becomes suggestive and imperative too.

- Similarly, the prediction of channel confluence junction angle dynamics suggests that the Chel-Kumlai confluence junction angle will further increase and attain a value of 32 degrees by 2035. It implies greater erosion of bars and banks near the first confluence zone which consequently makes higher probability of movement of confluence point upstream. Contrary to this the Chel-Neora confluence junction angle zone is likely to experience greater aggradation in the near future as suggested by the decreasing predicted junction angle values. Increase in sedimentation brings stability and the confluence point will move downstream. Thus, predictive confluence junction angle variability analysis suggests that the Chel will experience increased instability in reach near the Chel -Kumlai confluence zone and the stability will increase near Chel-Neora confluence zone.

- The study reveals the fact that middle reach is highly unstable followed by moderately unstable upper reach and comparatively stable lower reach.
- The overall planform seems to be highly influenced by the seasonal and annual variability in discharge and consequent variability in sediment flux. It seems especially most likely be influenced by the amount of discharge during the peak flow period in each year, although a lack of discharge data means that the effect of inter-annual variation in discharge on morphodynamics could not be analyzed here. But it is a fact that the area receives one of the highest rainfalls along the whole Himalayan range and every year, at the piedmont, the Teesta discharge may reach 3000–5000 m^3s^{-1}, but every dozen of years, during devastating floods, discharge can be 3–4 times higher (Wiejaczka 2016). That largely cause transformation of the channel morphology, riverbed aggradation (Starkel 1972; Starkel et al. 2008). Further SWAT 2012 analysis for the estimation of flow out (discharge) and sediment out flow found a strong correlation between the flow out and sediment out from all the sub-basins. Major peaks in flow out and sediment out were observed during 1980s and 1999-2000. Therefore, it is not difficult and wrong to infer that this massive rainfall amount and its variability during both normal and heavy monsoonal years are largely influencing the planform of River Chel.
- The Chel basin area falls within the meizoseismal zone of 1934 Bihar-Nepal, the 1950 Assam Earthquakes and belongs to the zone-IV in the seismotectonic map of India. The 18th September 2011 Sikkim earthquake and 2015 Nepal earthquake

had epicenters in the north of this zone. With its upper portion flanked on the outer Himalayan surface and rest on the Himalayan foreland, Chel River basin has a typical straddle like situation and is tectonically disturbed due to its proximity to major Himalayan faults. Frequently recorded major earthquake events which were felt well in the basin are testimony of the tectonically active nature of the region to which the basin belongs to.

- Morphotectonic study using SRTM DEM based geomorphic indices, suggests that the Chel river basin has undergone differential level of neotectonics activity and the river has adjusted with the ongoing tectonics. Among all indices, the drainage basin asymmetric factor (Af) of 40.31 and the transverse topographic symmetric factor (T) clearly suggests that the basin is asymmetric and is tilted towards the south-west direction. This very well comprehends the asymmetric cross profiles and have influenced river to flow along the right bank to a greater extent rather than the other.
- Wiejaczka, 2016 have measured the incision rate of river Chel at the Himalayan margin at Mukti bridge near Gorubathan and have given a figure of 1cm year^{-1} which is very close to the estimated rate of channel incision for Siwaliks in central Nepal (Lave´ and Avouac 2001). Considering negligible amount of anthropogenic activity or sediment mining around Mukti bridge near Gorubathan, the incision in the Chel River near Himalayan margin can be attributed to the prevailing neotectonics of the region.
- Apart from physical factors (i.e. neotectonics, rainfall, discharge and sediment flux), anthropogenic factor has emerged as one of the major factors intervening the planform dynamics of River Chel. With less literacy and a higher percentage of SC and ST population, the basin portrays all the characteristics of social backwardness which implies higher exploitation of existing natural resources. Presently the dwindling Tea industry of the region is also forcing the local population to get engaged in the sediment mining process. The same reason is driving locals for coal mining in the nearby Lish and Gish basins. There has been

a decrease in land under natural cover and an increase in land under anthropogenic activities except for tea gardens.

- Extensive sediment mining, construction of small length Rail and road bridges (as hydrotechnical structures) and embankment extension has been identified as major anthropogenic activities influencing the planform to a great extent.
- Twin bridges at Odlabari are disrupting the natural state of hydrological and geometrical properties of the upstream and downstream section of the bridge. The twin bridges have constricted the channel to such an extent that there is large scale variation in the elevation surface, velocity, transport capacity and erosion and deposition in the upstream and downstream of the bridges.
- There has been three times extension in the length of the embankments and now covers almost 58.1% of the total active channel length of 71kms combining both banks. It has constricted the flood plain and has disconnected the main channel from its flood plain to a large extent. It reduces the elevation gap between embankments or natural levees and river channel bed due to constant aggradations, the threshold level of bank full discharge and increasing the likeliness of embankment breaching even in low flow.
- Among all, massive sediment mining can be considered biggest anthropogenic factor for the fact that it is held responsible for incision of channel beds by an average of 5cm year^{-1} in the piedmont of the Chel (Wiejaczka 2016). This implies that the volume of the material extracted by human is greater than delivery of the material carried down from Himalayas. This incision process is contrary to aggradation process and rates of 3cm year^{-1} and 0.5 cm year^{-1} in the very vicinity of piedmont Lish and Gish rivers (Wiejaczka 2016). The similar trend towards incision the river channel in the foreland of the Darjeeling Himalayas is noticed on the Balason river (a right-bank tributary of the Teesta River), where the volume of extraction has been much greater than the annual river replenishment volume (Tamang 2013).

- Overall, it can be said that the piedmont of Chel River basin is witnessing planform dynamics in response to overlapping of natural and anthropogenic factors. The rate of human activities in the basin is all likely to increase further in the future. If proper efforts are not taken towards limiting and maintaining an optimum scale of human interventions in the basin, then it would be even difficult to discern or isolate the natural and anthropogenic causes and their relative role in the channel planform dynamics of the Chel River.

5.2 Conclusion

Each part of the Earth is characterized by a particular set of hydrological, morphological and ecological set up. Social and economic potentiality as well as opportunities depends on the diversified geophysical set up. Margin and piedmont of Eastern Himalayas is unique in terms of geological origin, morphological attributes and hydro dynamic behavior. The inner and northern parts of this belt experience mass movements whereas the middle and lower parts are dominated by extensive aggradation of sediments and its arrangement and re-arrangement by numerous sub-parallel rivers flowing out southwards from the Himalayas. The rivers flowing over this highly unstable region display highly dynamics characteristics. Human interventions are also influencing this natural dynamic behavior of rivers of the region.

The present study area, Chel River Basin, is a proper and typical representative unit of the Eastern Himalayan margin and piedmont region as the area has distinct assemblage of natural elements (highest rainfall along the Himalayan margin, consequent high sediment flux, active neotectonics etc.) and cultural elements (high population with social backwardness, LULC change, extension of channel embankments, extensive sediment mining etc.). Thus, today the collective actions of both these elements are shaping fluvial morphology or channel dynamics of the rivers of the region.

The information extracted from time-series satellite sensor data of Landsat archives, USGS coupled with SOI topographical maps and extensive fieldworks formed the foundation for reconstruction of planform dynamics of the Chel River from 1955 to 2017. The analysis of the data has given valuable information and insights into the morphological processes or changes that has happened historically and is ongoing at present and thus gives a picture of evolutionary mechanism of channel dynamics of a small Eastern Himalayan piedmont river.

The research observations and cause effect analysis depict that the planform evolution or channel dynamics of rivers flowing over this piedmont environment has a close connection with the active neotectonics, intensity of hydro-dynamic forces and different hydro-meteorological conditions of the region. Highly variable discharge and copious amount of sediment flux is directly shaping the planform. Anthropogenic intervention has been identified as another very important factor influencing the dynamism of the channel. In a nutshell, it can be said that the documented dynamism of Chel River has been particularly in response of the natural forces coupled with the human modifications.

The huge data base generated in this study has increased understanding of the behavior of the river Chel in particular and rivers flowing through the piedmont of eastern Himalaya in general. The progressive westward migration of main channel potentially threats erosion of fertile lands under agriculture, tea plantations and forests. Thus, threatening livelihood of riparian human population as well as the sustenance of riparian flora and fauna.

The presented results are of great importance in the context of overall management and policy planning for future prevention of bank erosion, course changing and loss of properties for receiving sustained ecological services. Thus, it would be of immense help to decision makers and local planners alike. The overall scenario demands a healthy and effective marriage of academics, planners and decision-makers for the sustainable management and restoration of this naturally highly dynamic zone. Lastly, the findings and scenario presented in this thesis can be considered as a typical representation of channel planform dynamics in response to natural and human factors along the margin and Piedmont (Terai and Dooars) belt of Darjeeling-Sikkim-Bhutan Himalaya.

Future planform dynamics studies incorporating detailed discharge data, sediment regimes, bed material size, channel geometry and rainfall data would enable greater understanding of the morphological evolution of the Chel river. The results thus computed will be much more robust. Prediction of planform dynamics based on past locations of the planform as derived from the time series satellite sensor data can be another important field of study and be achieved through geostatistical modelling. The forecasted planform dynamics of the river system can be coupled with risk maps of the region to produce vulnerability maps which can lead to development of a decision support system for the benefit of planners and decision makers towards better management of the river system and formulate a framework for disaster preparedness and mitigation planning.

The present study has employed manual data extraction technique wherein on-screen digitization of satellite images and topographical maps was largely done. However, the whole process is very tedious and time consuming, therefore automatic detection of river morpho dynamics should be explored in the future studies.