Preface

The thesis is aiming to claim some hard work and originality as the author has tried to put forward some basin study aspects which is to some extent his brainchild and has tried to explore a parcel of landscape almost untouched from detailed studies. Some aspects definitely may invite intellectual debate but the author has put his best to clear the doubts and to clarify the debates. In most of the approaches the work has shown documentation of fact with pragmatic and academic amalgamation. Sometimes the implication of the analyses is self-evident and self explanatory to prove and vividly establish the reality. Not only this worker has a view to bridge the gap of study by taking some new and few modified techniques for understanding the situations better. His attitude and endeavor to study the geomorphology of Chel basin has been oriented more towards applied and advanced geomorphological approach.In the following paraphrases the author has amplified the know-how of the chapters as under:

In chapter I, the author has explained the introduction of the thesis by elaborating the major aims and objectives associated with the methodological approaches and prime hypothesis to be tested. He has also amplified the statement of problem and the data sources to build up the conceptual framework of the study. Detailed literature review has been elaborated by him.

Chapter II aims to understand the basic geomorphology and landscape configuration of the Chel basin. The tendency of the progressive shortening and upslope movement of the alluvial fan components have been observed through successive generations. Several tectonic units of Darjeeling Sub-Himalaya over thrusts successively towards the foreland tracts of fluvial cut and fill deposits and make the whole basin neo-tectonically unstable.The landscape of the piedmont area at *Patharjhora* is the manifestation of the propagating components of Main Frontal Thrust (MFT) within the alluvial fan depositions and thus controlling the braided behaviour of the channel.The average height difference of the profile is 1686 m. The basin expresses many exposures of tectonic upheaval with low entropy. The calculated relief ratio of the basin is 36.7 that represents a well developed drainage network with their erosional activity on the terrain and the attainment of high dissection of the upper catchment (lowest- 400 m) that reflects through the structural regularities of drainage network evolution.The analysis of longitudinal profile helps in revealing the act of complex process-response system on a channel's longitudinal profile. The sub-cycles of erosion reveals the complex short term changes in the profile.The basin has been preceded towards quasi-equilibrium as the Hypsometric Integral value of 48.56 indicates about its maturity. The maximum area of 78.99 km^2 falls under the relative height of 100 m and the area are occupied by the flat shallow foreland basin. The area is composed of five successive alluvial fans and gentle flood plain. The foreland basin is continuously filling with wash load carried from the upper catchment.The reason of tectonic instability and complex cycle of epeirogenic upliftments has been controlling the process of dynamic rejuvenation in this basin. In the Chel basin, the contribution of the 1st order streams to the whole network is 75.7 % which is far larger than the contribution of 2nd order streams (18.6%). The moderate value of basin elongation (0.5) with high bifurcation ratio (5.2) indicates the quick discharge of storm runoff with shorter lag period. But, the quick accumulation of the discharge on the piedmont surface often promotes large peaks in hydrographs. It also reduces the risk of flash flood occurrence although the risk of potential flash flood related to catastrophic rainfall events still persists in this basin.The irregular geometric progression is due to the influence of tectonic lines on the angle of bifurcation of the streams. The order-wise increase of basin area in Chel basin is progressively increase at smaller geometric fashion from 2nd order to 4th order and it shows higher increment for 1st to 2nd order and 4th to 5th order. The 3rd order basins are equally distributed on both the side of main channel of Chel.The morphometric variables are analyzed to understand the amount of variability and correlation due to the continuous fluvial cyclic action with differential impact. The terrain has been experiencing the alteration of fluvial processes in time scale.

Chapter III aims to understand the existing water/hydrological regime of the Chel basin. The occasional flood persists for a short duration in the channel. The study reveals that the channel receives 250 to 300 mm monsoonal monthly average (July-August) rainfall and maximum greater than 1800 mm isohyets line encompasses a major part of Chel basin. The range of channel runoff at Odlabari site ranges between 1284.21 to 152.22 Ha m day^{-1} and it enhances the channel discharge greater than 150 m^3sec^{-1}. But the highest rainfall of a single day does not causes similar maximum runoff at a gauging station due to the effect of basin lag. From 2015 to 2017, the null hypothesis of similar trend of occurrence between rainfall and runoff has been nullified with due variation in channel runoff seasonally. The temporal (2015 to 2017) trend of channel gauge height variation indicates the occasional flood peaks above 2.5 m gauge height from the level of zero RL (Reduced Level). In 2016, the maximum stage of 2.9 m has been observed at a discharge of 145.69 m^3 sec^{-1}. The rational formula has been applied for the small 3rd order sub basins to detect the peak and average runoff yield from each sub basins. The probability of 2 years and 10 years peak runoff rate estimation produces results of average 162.79 and 212.60 m^3 sec^{-1} respectively which are responsible for occasional flood in the channel. Gambel's (1941) flood frequency analysis reveals the increasing trend of probable flood discharge with lapse of years as 148.87 m^3Sec^{-1}, 158.58 m^3Sec^{-1} & 179.95 m^3Sec^{-1} in 5, 10 & 50 years.

Chapter IV aims to understand the channel behaviour of Chel. Channel behavior of Chel is related with the existing channel processes that lead to frequent changes in the water and sediment flow pattern of the river. River patterns express an additional mechanism of channel adjustment which is related to channel gradient and cross-section. Channel behavior changes frequently downstream due to the supply of discharge as related with the gradual decrease in the slope. The pattern of channel bar formation is related with the supply of sediment from the up-stream. On the piedmont surface, the channel exhibits high braiding and avulsion through channel anabranches which seems to become active especially during the monsoon months. The formation of central bar mechanism appears to be more typical of situations where bed shear stress is above the threshold for movement.

Chapter V aims to know the downstream variation of hydraulic geometry and their seasonal adjustments. The channel processes at a cross-section is significantly related with the changes of width (w), mean depth (d), sediment-water discharge (Q_s, Q), water velocity (v), bed and channel boundary roughness, sediment caliber etc. The pre and post monsoon drafted cross sections at *Patharjhora, Manabari, Odlabari, Apalchad* and *Rajadanga* reaches shows no progressive trend of changes of channel hydraulic parameters and erosions leads to set back sedimentation at the sites. But, the average change in bed heights characterizes the tendency of active channel erosion which dominates on channel deposition over the years (2015-2018). The adjustments of the hydraulic parameters are dependent of the discharge fluctuation of the channel.

Chapter VI aims to understand the nature of sediment distribution at downstream direction. The variety of channel load can be identified on the basis of sediment shorting process entirely related with the flow of water. The channel flow is the main driving force acting along the channel bed slope to carry the sediment load further downstream. The shorting of the load is from up to downstream causes by the variable flow energy acting within the channel. The mobility of fine sediment particles within the water is related with the critical components of water shear stress on the particles, immersed weight of particles, component of drag and the function of gravity on a slope. The study of Grid sampling (Wolman, 1954) has been conducted from *Patharjhora* at a regular interval of 2 km up to *Rajadanga* site. The flood water driven boulders are of 4096-2048 mm and their position is found scattered on the bed. Above the confluence of Chel-Mal river near *Rajadanga* (24-26 km downstream), the channel bed form are featured by the settling tendency of suspended load during the recession of monsoon discharge and from bank failures. During the recent flood year of 2017, the average monsoon discharge (Q) of 60.89 m^3 s^{-1} supports average suspended sediment load (Q_{SL}) of 85.91 tons day^{-1} which is quite synonymous in nature and relation. The relation of suspended sediment transport and channel discharge maintains the hydro-sediment regime characteristics of the channel.

Chapter VII aims to understand the occurrence of occasional flood process vis-à-vis bank failure at the studied reaches. The peak flood discharge from the 3^{rd} order basins has been estimated by using Rational method (less than 12 sq. km watersheds) (Mutreja, 1990) and Kirpich equation (1940) of time concentration estimation of runoff. The 10 years probability of peak runoff rate shows greater results for sub basin wise analysis. The 10 years probability of peak runoff for both the left (LB) and right (RB) bank sub basins of Chel yields similar i.e. greater than 106 m^3 sec^{-1} peak runoff rate. But, the 2 years probability of peak runoff generation from both sides contributes 86.7 and 76.01 m^3 sec^{-1} peak runoff rate. The total volume of peak runoff rate is calculated as 212.60 m^3 sec^{-1} for 10 years and 162.79 m^3 sec^{-1} for 2 years of probability. The BEHI rating discloses the intensity of bank erosion ranges from moderate to very high from mountain outlet to confluence. But, the comparative share of moderate bank erosion is observed greater than other categories. The very high category of bank erosion in BEHI is observed at *Patharjhora, Manabari* (comprises reach 1) and *Rajadanga* (reach 7). The BEHI potentiality categorization is more comprehensive than NBS in this study. In linear regression function BEHI scores are capable of explaining 60.6% of variation in NBS single parametric score. The total erosion volume of the basin from BEHI model has been calculated as 4668.65 ton $year^{-1}$ and the average annual rate of erosion has been calculated as 1.124 tons m^{-1} $year^{-1}$.

Chapter VIII aims to know the nature of human interference on the fluvial system of Chel. Channel conditions are highly influenced by the action of running water and human pressure on the floodplain. Channel hydro-geomorphology and its dynamics can bring transformations to the channel properties towards its behavioral changes by means of channel hydraulics and boundary condition. Land use/cover change is the most direct manifestation of the impact of human activities on the earth's surface system as well on fluvial systems. The spatio-temporal changes in LULC (Land use-cover) pattern of Chel basin have been detected from TM sensor data (1991) and OLI-TIRS sensor data (2016). The rate of deforestation is still much slower in the upper catchment. Only 5.33 km^2 dense forest area had been changed from 1991 to 2016. So, the rate of estimated deforestation in the upper catchment from RS data is calculated as 213.2 m^2 $year^{-1}$. The channel encroachment study has been accomplished from the channel buffer analysis of 500 m on the mouza map. The temporal scale of study has been selected from 1989 to 2017 from Landsat TM sensor (1989) and OLI-TIRS sensor data (2017). The channel encroachment study keeps the main objectives like – a. nature of channel's lateral expansion within a mouza, b. temporal variation in channel's width and c. characterization of the channel's oscillation over time. In 1989, the channel affected the mouzas like *Paschim Damdim, Damdim* TG, *Targhera* and *Purba Damdim*. The increases or decrease in channel width changes with the same rhythm as the changes in bank lines. So, the channel encroachment on adjacent mouzas is dependent on the temporal width variation of the channel cause by the triggering effects like high discharge, occasional flood events, frequent avulsion, evolution of ephemeral channels, and excessive channel bed mining. The channel bed material extraction also alters the nature of occasional flood in the channel. The present study focuses on the effect of daily sand and boulder extraction from the river bed. At *Patharjhora*, boulders greater than 2048 mm in size from the mid channel bars are extracted on a regular basis. The *Manabari* and *Odlabari* sites, the mid channel excavation is predominant where large cobbles ranges from 64-256 mm are extracted from the elongated boulder levee deposits after monsoon periods. It is also visible that the extraction of very coarse to coarse gravels (16-64 mm) is high from the mid channel bar deposits at *Odlabari* site. The average estimated volume of sediment extraction per year from the Chel river (*Patharjhora, Manabari, Odlabari* *and Apalchad*) has been calculated as 4.6 to 6.9 million cubic meters annually. The estimated sediment extraction from *Patharjhora, Manabari, Odlabari* and *Apalchad* are $4.6*10^4$ m^3 $year^{-1}$, $4.0*10^4$ m^3 $year^{-1}$, $61*10^4$ m^3 $year^{-1}$ and $3.7*10^4$ m^3 $year^{-1}$ respectively. Channel management for Chel appears as to control the sudden toll of floods, heavy bank erosion and engulfing tendency of adjacent flood plain, water resource utilization and most importantly preservation of the ecological variety of the forest lands at the upper catchment. But still, the rise of population pressure on the channel causes the ultimate threat to the channel of Chel. As well the main threat to the channel appears in form of excessive sediment extraction from the channel which causes the rapid alteration of the channel flow and sediment regime.

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