Chapter-VIII

Human Interference on Fluvial Dynamics

8.1 Introduction

Channel conditions are highly influenced by the action of running water and human pressure on the floodplain. River habitat is the specific area where a flourished ecological landscape develops due to the channels form-process adjustment with the riparian biotic-abiotic assemblage. A process of covert interaction is always occurring to provide equilibrium between intake and release within a dynamic system like river. Channel hydro-geomorphology and its dynamics can bring transformations in the channel properties towards its behavioral changes by means of channel hydraulics and boundary condition. A micro scale detailing of channel and riparian properties with spot key check analysis was initiated by EU water frame-work directive (2000/60/EC) to access healthy ecological conditions of the rivers around the world by 2015. In this regard, the most suitable approach in form of River Habitat Survey (RHS) protocol was initiated in UK (1998) by Raven et al. (1997). The RHS is a system for assessing the character and habitat quality of rivers based on their physical structure (Raven et al. 1997, 1998). The principle is laid on the evaluation of the diversity, quality and modification of the morphological properties of the river ecological regime. The human interference on the rivers produces many negative consequences on a large scale. It gradually changes the planform, flow geometry, hydraulic parameters and channel ecosystem including riparian habitat. Human activity impacts on rivers in the following ways viz. river flow redistribution in time, spatial river flow redistribution, river flow withdrawal, physical disturbance of riverbeds, pollution, water clogging and thermal pollution (Govorushko, 2007). Channel flow redistribution is the direct impact of construction on the channels. The altering hydrological river regime causes impact on the channel bed form characteristics and on the existing channel process. The interaction between channel flow, flow regime and sediment transport aid in the determination of channel response to natural or man-induced changes (Tamang, 2013). The increasing population pressure on the channel is also disturbing the channel health (Richard et al., 1999) which can be accessed through the analysis of some physical, biological and chemical properties of the channel (Gore, 1985, Boon et al., 1992, Brooks and Shield, 1996). The changes in channel flow pattern and sediment regimes following catchment modification can markedly change the nature of channel (Bandyopadhyay et al., 2017). A river channel is a free flowing object that creates its own hydro-geomorphic regime. But, the anthropogenic pressure on the channel disturbs the flow pattern, bed form dynamics, bank formation, hydro-dynamics and most importantly the eco-system services from the river.

8.2 Methodology

8.2.1 The LULC (Landuse–cover) mapping has been carried out in GIS environment after the processing and supervised classification of TM sensor data (1991) and OLI-TIRS sensor data (2016) (Earth explorer). The change detection of LULC in the basin has been done on a temporal framework (1989 and 2017). Also the areal change detection from 1989 to 2017 has been carried out in GIS environment.

8.2.2 The *Gram Panchayat* and Mouza mapping of Mal block has been done under GIS environment supported by the District Census Handbook (Jalpaiguri), Villaege & Town directory (Census of India, 2011).The population density mapping (Persons km^{-2}) has been accomplished (GP & Mouza wise) to show the spatial variation of population pressure on the channel of Chel. The spatial variation of population and population density of river adjacent mouzas has been mapped under Q-GIS environment.

8.2.3 The channel encroachment on the floodplain has been shown after superimposition of temporal channel boundaries (1989 and 2017) on the mouza map of Mal Block (District Census Handbook, Jalpaiguri and Village & Town directory, Census of India, 2011).

8.2.4 The probable flood risk buffer (500 m) area has been prepared in the GIS environment along the river from Patharjhora to Rajadanga (confluence). The buffer has been generated on the basis of field investigation taking the most influenced area of flood water inundation along the course.

8.2.5 Impact of channel mining has been assessed from the superimposition of pre & post monsoon cross sections at Odlabari (2017-2018) at a streatch of 1000 m from up to down stream to address the changes in channel morphological and hydraulic parameters especially estimating changes in channel bed elevation, hydraulic mean depth and channel Depth-Width ratio. The vulnerable area of bed material extraction has been presented on the channel cross sections (pre and post monsoon) on the basis of field perception and presented in form of a model diagram. The estimation on the volume of extraction of bed materials has been carried out on the basis of successive field visits.

8.2.6 The discussion on channel management and its necessity has been accomplished from the secondary literatures. The human impact model on channel geomorphology has been discussed on the basis of Lóczy et al., 2008.

8.2.7 Other anthropogenic impacts on the channel have been identified from filed photographs.

8.3 Change in Landuse-cover pattern

Land use-cover change is one of the important factors characterizing the response of human activities to global change (Jia et al., 2018). Bork et al. (1998) investigated land-use change and its environmental effects for north of the Alps based on palynological and pedological data and demonstrated its strong imprint. Land-use and land-cover change clearly correlated with erosion rates (Haidvogl, 2018). Land use-cover change is the most direct manifestation of the impact of human activities on the earth's surface system and is very important in the global environmental change process (Lawler *et al*., 2014; Wulder *et al*., 2008; Mooney *et al*., 2013). Landuse-cover change within a river basin is the sign of human impact at large scale avoiding the ecological sustainability of the area. The human activities attributes the changes in the basin by deforestation, expansion of settlement and agricultural fields, channel mining activities, construction on slopes and on the channel. It has direct impact on the basin geo-hydrology and on natural environment. The scale of operation is significant in bringing certain changes within a frame of time. The spatio-temporal changes in LULC (Land use-cover) pattern of Chel basin have been detected from TM sensor data (1991) (Fig. 8.1) and OLI-TIRS sensor data (2016) (Fig. 8.2). The RS data have been used in the formation of supervised classification maps of LULC of Chel basin to identify the changes. The upper catchment of Chel above 300 m contour elevation is mainly covered by reserve and open forest lands viz. *Tista-Chel* reserve forest in the course of *Manzing khola*, *Sakkam* reserve forest on the left bank of Chel *Nadi*, *Rechela* reserve forest and *Pankhasari* reserve forest etc. The SOI topographical map G45E12 (1:50000) categorize the forest as dense mixed jungle. But below *Ambiok* tea garden, the natural vegetation mainly changes to degraded forest land especially in *Dalingkot, Fagu, Gorubathan* and Westner reserve forest. Below *Patharjhora* (in Jalpaiguri district) the landscape has been changed in to tea gardens viz. *Patharjhora, Syli, Raicharra, Nidam Jhora, Damdim, Rangamati, Betguri* (on the left bank) and *Turibari, Manabari and Odlabari* tea gardens (on the right bank) etc. Below *Targhera Hashkhali to Baragharia* mouza on the right bank of the channel, *Apalchad* reserve forest is situated. It acts as an active watershed (BM 126.7 m) between Chel and Tista river. The expansion of settlement encroached the area of *Apalchad* forest. From SOI topographical map 78B/9, in 1986 the *Apalchad* forest was inhabited by *Mech Basti, Magurmari basti* and *Sologharia* settlement. At the forest fringe of *Kailashpur* and *Anandapur* tea gardens was observed at expansion. The supervised classification presents the *Aplchad* forest as light green toned open forest because of its ongoing deforestation, it was no more a dense forest in TM sensor data of 1991. A massive change of the *Apalchad* forest region can be detected from the supervised classification map of 2016. The OLI-TIRS sensor data presents the forest as scattered vegetation which also proves the rapid deforestation at the region. Although, 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 $year^{-1}$. This slow rate of deforestation in the upper catchment causes the less probability of landslide occurrence. It is the main reason of low sediment yield of the Chel river at the piedmont. The expansion of cultivated land has been estimated as 16.44 km^2 which increases at a rate of 714.48 m^2 $year^{-1}$. The lower channel of Chel and its flood plain is mainly developing for the cultivation of paddy, potato, maize and Jute on both subsistence and commercial basis. The mouzas like *Nipuchapur, Purba Damdim*, *Teshimla* and *Rajadanga* etc are the places where crop cultivation is dominated. The occupied cultivated land in 1991 was 20.53% of the total basin and it was 27.73% in the year of 2016. So, the slow expansion of cultivable lands is the main character of the Chel basin. In 1991, only 9.72% land was occupied by human settlement. But in 2016, the settlement area was calculated as 14.45% of the total basin area. Still the basin is not heavily inhabited by the human beings. But, the significant settlements like *Odlabari, Damdim and Gorubathan* have impact on the hydro-geomorphology of the basin. The small tea gardens are largely influencing the LULC pattern of the basin. But one noticeable change has been observed in case of water body. It has declined by 32.04 km^2 in 23 years (Table 8.1). Because of human settlement and cultivation land occupancy, the water bodies and river channel have been greatly encroached over time. The width of the channel has also become narrow in 2016 map than 1991. The increase in number of dry days in North Bengal monsoon period causes the decay of many seasonal small jhoras on the left bank side of Chel river.

Table 8.1 Land use and land cover categories and their areal change over the year

Land use categories	Year	Area in sq.km	Year	Area in sq.km
Water body	1991	71.17	2016	39.13
Dense forest		54.91		49.58
Open forest		72.74		90.86
Bare soil		18.61		6.46
Cultivated land		64.87		81.31
Settlement		30.7		45.66
Total area	316			

Source: Calculated by the author.

8.4 Population pressure on the lower part of the channel (below Odlabari bridge)

From *Patharjhora* tea garden, the entire basin area falls under the administrative jurisdiction Mal community development block under Mal sub-division of Jalpaiguri district. Mal community development block has an area of 545.99 km^2. As per 2011 Census of India Mal CD Block had a total population of 299,556 of which 275,184 were rural and 24,172 were urban. The decadal growth rate of population was 12.9% in 2001-2011 and the annual growth rate of population was 2.1% as per the census report of 2011. There were 151,826 males and 147,730 females. The Mal block is consisting of 103 mouzas. As well Mal block is composed of 12 Gram Panchayat. As per 2011 census, Mal subdivision has a total population of 5,69,711 distributing in three blocks of *Mal*, *Matiali* and *Nagrakata* and in a single town namely *Mal*. The entire lower basin of Chel falls within *Mal* block. The Chel creates confluence with *Dharala* river at *Rajadanga* Gram Panchayat (GP). The Gram Panchayats (GP) wise population density (Fig. 8.3) distribution reveals high population density at *Lataguri* GP (985 person km^{-2}) and lowest population density at *Chapadanga* GP (351 person km^{-2}). Among the mouzas, *Odlabari* is carrying highest total population of 40,294 persons and the lowest total population has been found at *Teshimla* GP (14078 persons). After entering in Jalpaiguri district, the course of Chel passes through the mouzas namely *Patharjhora*, *Turibari*, *Manabari*, *Targhera*, *Purba Damdim*, *Nipuchapur, Baragharia, Kodalkati and Rajadanga*. These mouzas are the zone of direct influence of the channel flood. The channel oscillation within the mouzas is not high enough. From 1981 to 2016, the channel oscillation is confined within the adjacent mouzas not entered in to other mouzas. The *Odlabari* and *Dakshin Odlabari* census town having a population of 14194 and 4997 is situated along the course of Chel. Along the right bank of Chel, many tea gardens are situated namely *Mengless, Syli, Ranichera, Betbari, Damdim* and *Baitguri* etc which affects by the occasional monsoon flood of the channel. These tea gardens are often using the water resource from Chel river in plantation farming. In *Manabari, Turibari, Odlabari, Damdim* sites are familiar sites for the extraction of boulders from the channel beds. The mouza wise categorization of population density (Table 8.2) produces higher values than the previous mapping on same thematic aspect taking the *Gram Panchayats* only. The river passes through the densely populated mouzas which increases the importance of evaluation of human pressure on the channel. The mouzas with high population density above 892 persons km^{-2} are *Patharjhora, Damdim, Bainguri, Menglass tea garden, Baragharia, Neoranadi tea garden and kranti* etc (Fig.8.4). The inhabitants are getting ecosystem services from the channel also. Human societiy derives many essential goods from natural ecosystems through human activity in the natural environment (Alexander et al. 1997; Goudie 2000). The benefits that people obtain from ecosystems are usually referred to as ecosystem services (Costanza et al. 1995; MEA 2005).

Table 8.2 GP-wise population density of Mal block

Sl No.	Name of Gram Panchayat	Total Population	Area (km^2)	Population Density (person km^{-2})
1	Bagrakot	35318	72.81	485
2	Odlabari	40294	65.55	615
3	Rangamatee	34072	56.78	600
4	Rajadanga	35374	91.94	385
5	Damdim	28037	48.27	581
6	Tesimla	14078	18.52	760
7	Kumlai	24252	40.26	602
7	Changmari	19020	43.12	441
8	Kranti	23826	31.31	761
9	Chapadanga	1458.31	41.58	351
10	Moulani	14857	19.13	777
11	Lataguri	15845	43.12	441

Source: Calculated by the author (Based on 2011 census, Govt. of India).

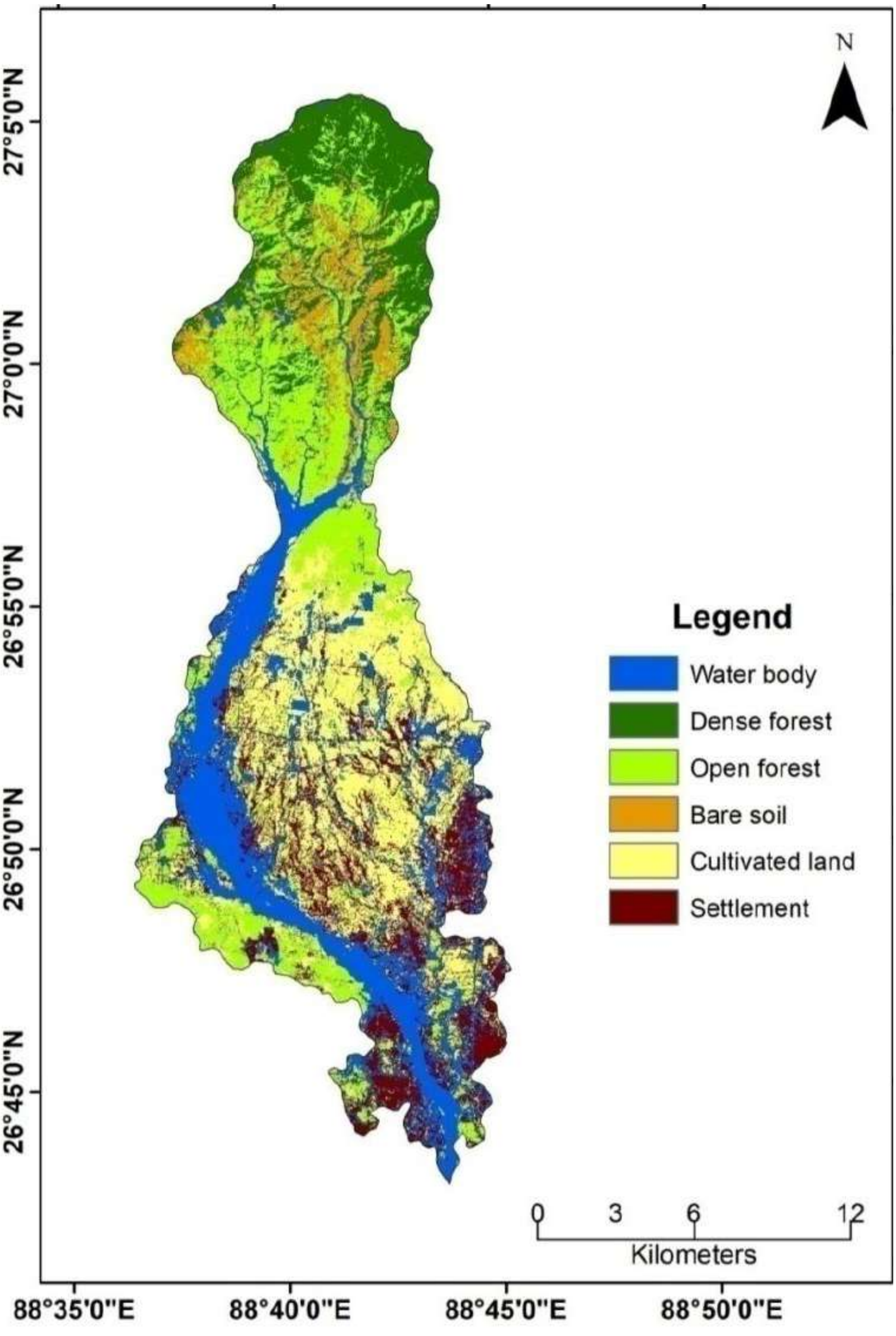


Figure 8.1 Landuse-cover map of Chel basin 1991.

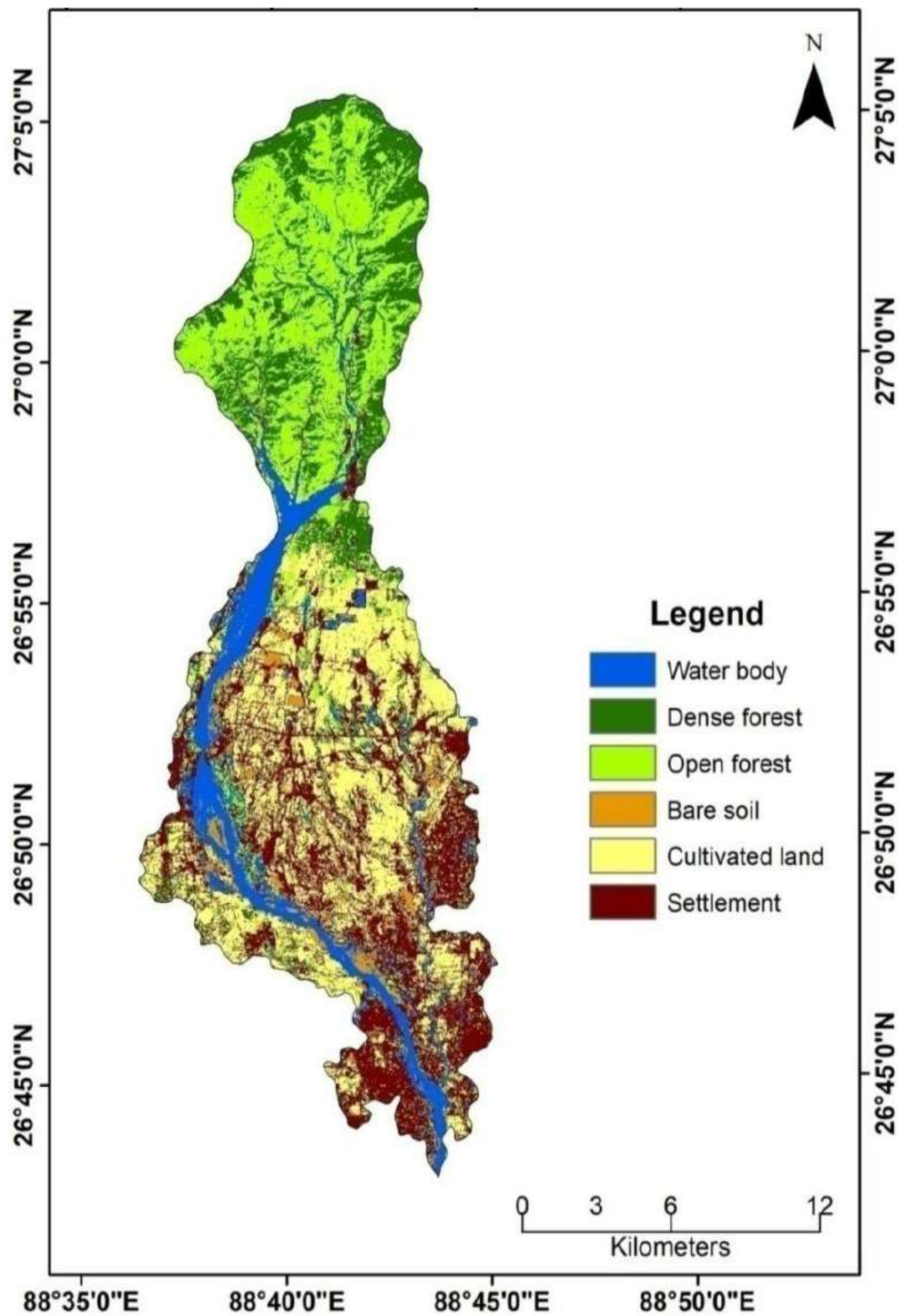


Figure 8.2 Landuse-cover map of Chel basin 2016.

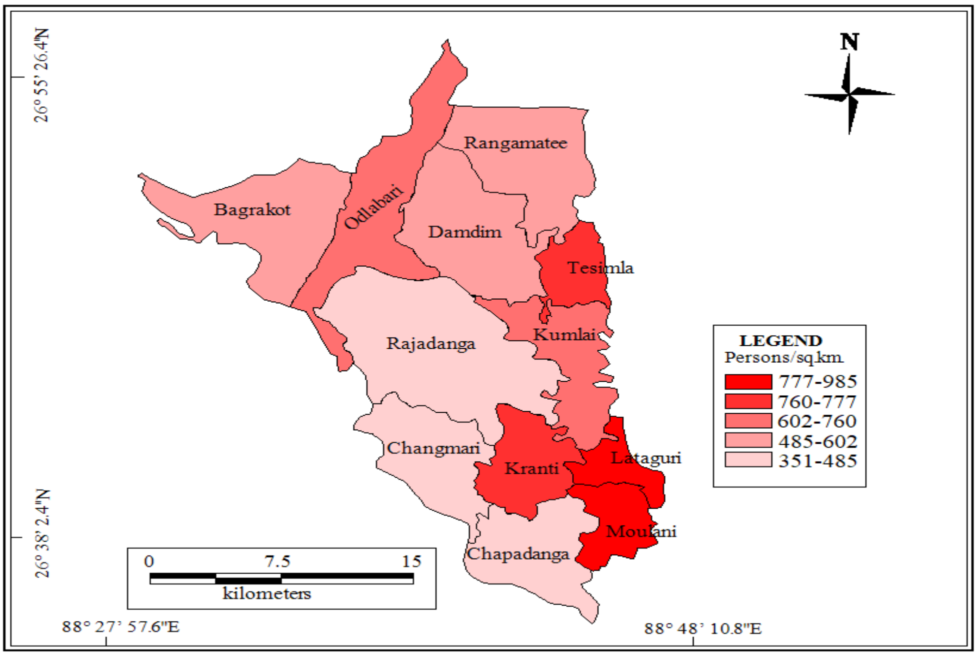
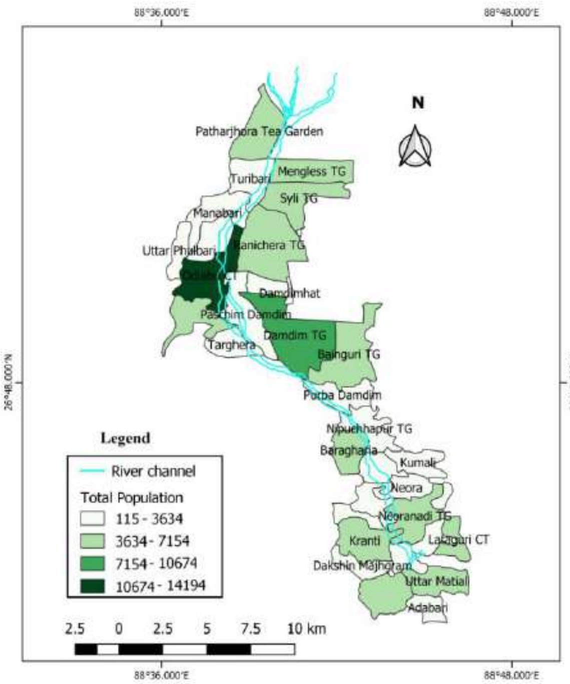


Figure 8.3 Gram panchayat wise population density map of Mal block.



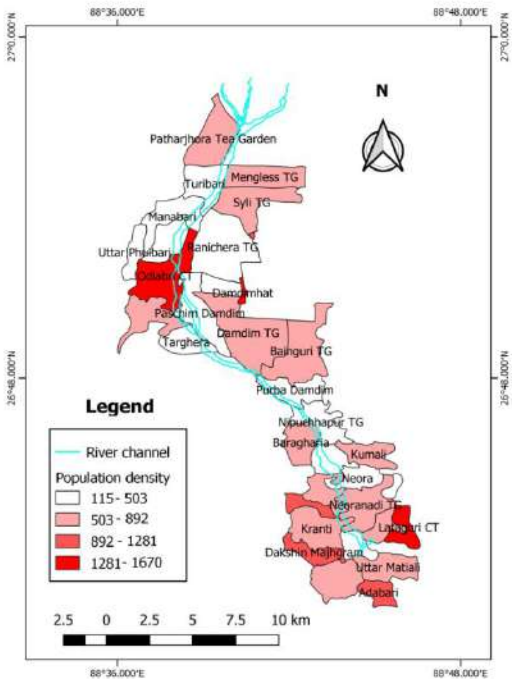


Figure 8.4 **Spatial distribution of total population within adjacent mouzas of Chel river (Mal block).**

Figure 8.5 **Spatial distribution of population density within the adjacent mouzas of Chel river (Mal block).**

(**Note:** Odlabari census town has also been included)

The channel has been used for regular bathing, laundry activities, boulder extraction, fishing and irrigational purposes. Among various uses, the channel material extraction at *Manabari, Odlabari* and *Damdim* sites are hampering the natural ecology of the channel including riparian vegetation, in-stream biota. The human occupancy is raising the chances of channel habitat deterioration in the future. The upper catchment is mostly belonging to the virgin ecosystem of Neora valley national park, *Rechela* reserve forest and *Pankhasari* reserve forest. The oocurence of extreme rainfall events cause structural changes along the river banks. The *Pathatjhora* tea garden, *Manabari* Chel colony, *Odlabari* census town, *Targhera* (beside *Apalchad*) and *Rajadanga* are the most vulnerable areas of regular flood inundation and bank erosion. Especially, the river course below *Apalchad* forest is the most affected site of bank erosion. The bed material extraction at *Patharjhora, Manabari*, *Odlabari* and *Apalchad* makes the channel highly unpredictable by hydraulic nature and causes the frequent changes of the channel form. The high near bank stress causes massive bank erosion during high water stage and gradual flood plain encroachment at *Patharjhora* (4335 population) and *Manabari* tea garden (2147 population). During 2017 monsoon, *Rajadanga* (1323 population) and *Kranti* (5961 population) villages were highly affected by flood in Chel river.

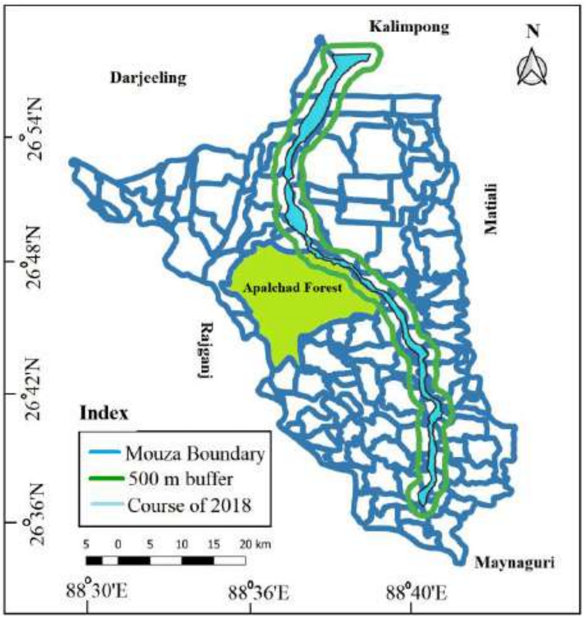


Figure 8.6 The 500 m buffer zone along the banks of Chel on mouza map of Mal Block (2017 channel).

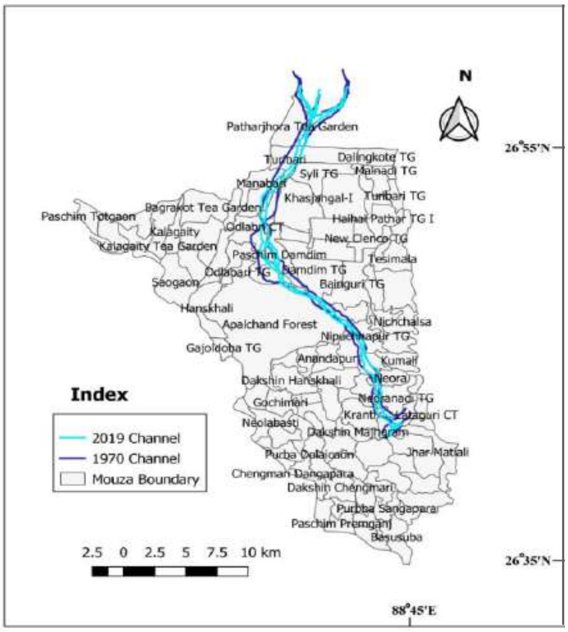


Figure 8.7 Channel encroachment within adjacent mouzas.

8.5 Discussion on temporal channel encroachment (1990 to 2017) and affected mouzas

The channel encroachment process is a natural behaviour of foothill channels especially on piedmont surface. The channel encroachment study has been accomplished from temporal satellite image analysis. The temporal scale of study has been selected from 1990 to 2017 from Landsat TM sensor (1990) 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 width and c. characterization of the channel oscillation over time. The analysis on channel transects at 24 stations has been carried out in the GIS environment to detect the sites with changes along left and right banks (Fig. 4.15, chapter-IV). But, the Chel river does not show any significant change over time. The limit of channel encroachment has been only confined within the adjacent mouzas namely *Patharjhora, Turibari, Manabari TG, Syli TG, Dakshin Odlabari census town, Targhera, Damdim, Bainguri TG, Purba Damdim, Nipuchapur TG, Bargharia and Rajadanga*. The magnitude of channel encroachment is not high enough below *Odlabari* bridge. The river course is duly controlled by neo-tectonics in the upper catchment. The channel oscillation within the basin is the result of extreme rainfall events and occasional flood dynamics of the channel since time immemorial. The previous flood events left the imprint on the flood plain that the channel had faced massive channel winding or oscillation over time. The signs of cannel avulsion and old channel courses are clearly visible from the temporal satellite images which have been discussed in the earlier chapter.

Now, the focus of the study is to quantify the changes along the banks on temporal framework (1989 and 2017) (Fig. 8.8). It particularly aims to know the nature of Man-River interaction process which controls the fluvial dynamics. On the piedmont surface, the magnitude of channel encroachment is comparatively lower than part below *Manabari* tea garden. The channel at *Patharjhora* shows frequent avulsion especially during the storm rainfall phases of 1993, 1994, 1998 and 2000 on the piedmont. The channel encroachment is relatively confined within 500 m buffer zone on flood plain. The channel winding mechanism did not influence beyond the influence zone of 500 m beside the banks (Fig. 8.6). The main channel of Chel leaves many anabranches on the left bank (2016) and after 2007 it came towards the left bank. In 1989, the channel encroached in the mouzas like *Paschim Damdim, Damdim TG, Targhera and Purba Damdim*. The average channel width of Chel in 1989 was 911 m and in 2017 it is measures as 736.59 m (Fig. 8.9). In the lower stations below *Odlabari,* the channel in 1989 shows higher width than 2017 (Fig. 8.8). It bears the evidence of channel narrowing process which connects decreasing extreme rainfall events, forest cover in upper catchment and increasing human interferences with the river.

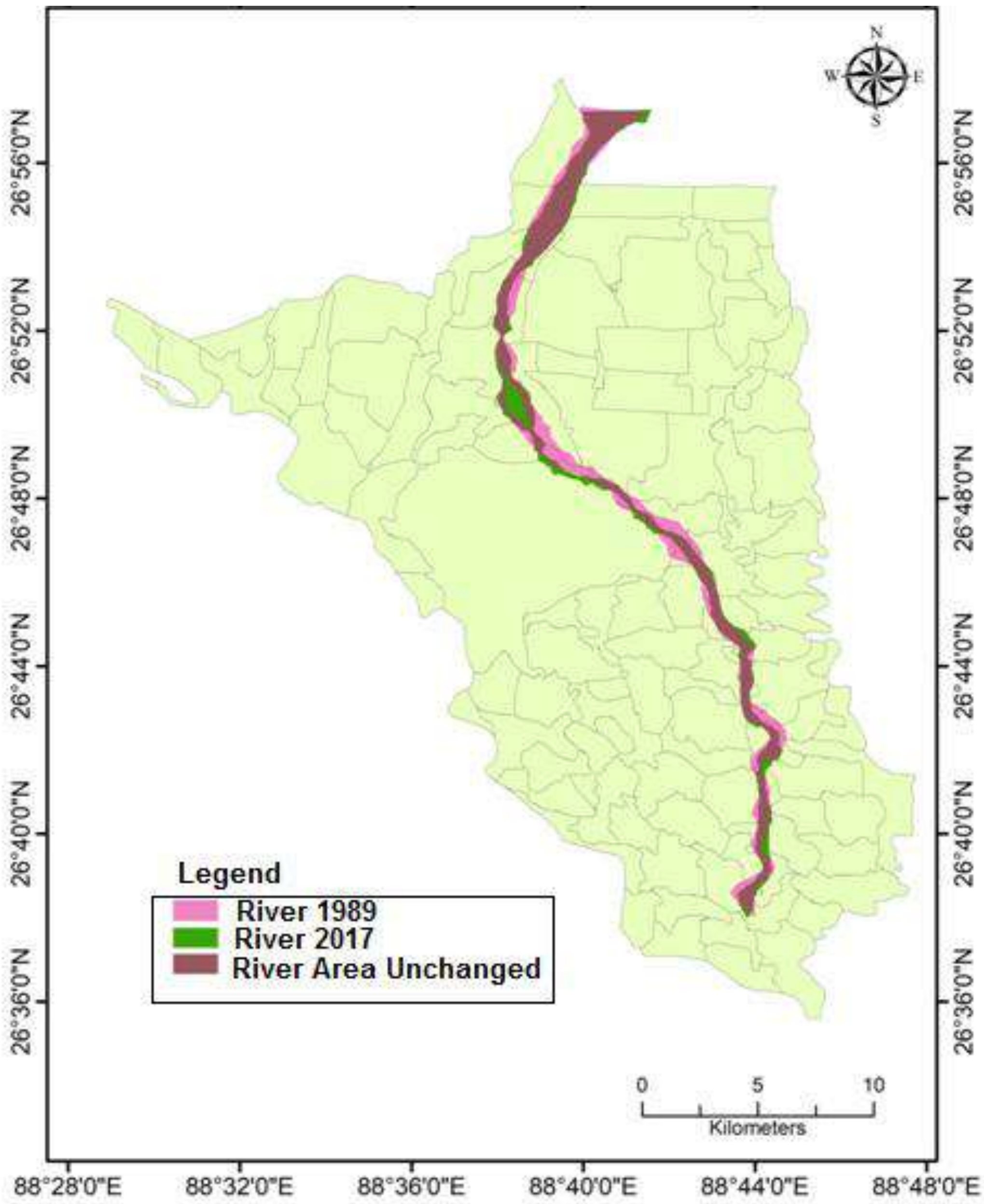


Figure 8.8 Channel encroachment analysis.

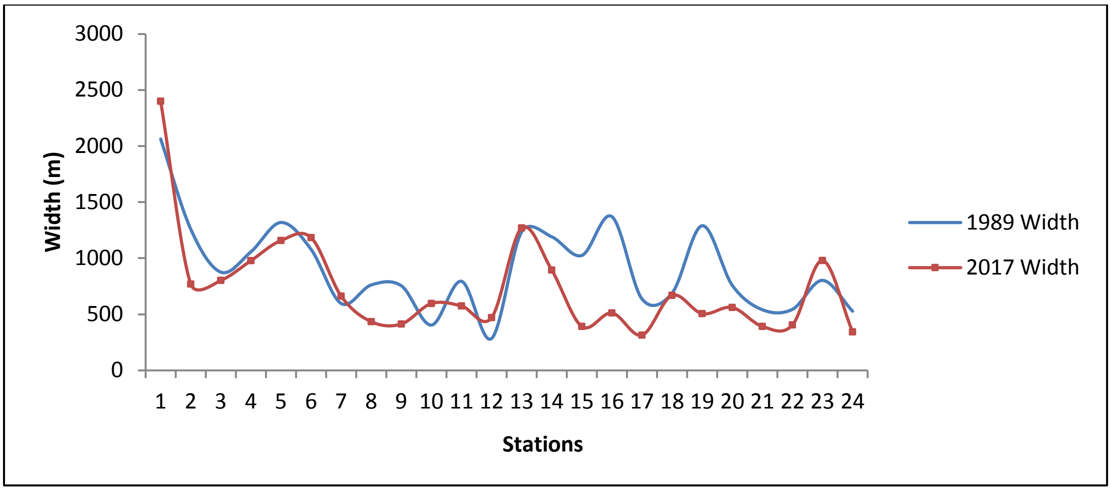


Figure 8.9 Temporal variation in channel width.

8.6 Impact of channel mining on channel morphology and hydraulic geometry

Rivers are a key source of ecosystem services such as water, food, energy, rocks, etc. (Postel and Thompson 2005; Wang et al. 2009; Auerbach et al. 2014; Rasul 2014). Within those ecosystem services, the extraction of river bed material is one of particularly important types of human activity in river ecosystems (Gregory, 2006; Wohl, 2006, Wiejaczka et al., 2018). Analyzing anthropogenic landforms according to economic activities, the most spectacular examples of direct and intentional landscape transformation are probably found in mining landscapes (Bell, 2011). The effect of channel mining directly effects in-stream geomorphology and channel hydraulic parameters. 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. The most vulnerable sites of bed material extraction are *Patharjhora*, *Manabari*, *Odlabari* (Plate: 8.11 & 8.12) and beside *Damdim* tea garden. By removing sediment from the channel, in-stream material extraction disrupts the preexisting balance between sediment supply and transporting capacity, typically inducing incision upstream and downstream of the extraction site (Kondolf 1997; Jia et al. 2006; Huang et al. 2014). At *Patharjhora* site, the excessive bed mining also leaves an imprint on the channel thresholds for avulsion. The changes greatly hamper the seasonal channel water levels. Mass-scale in-stream extraction by local communities leads to a progressive degradation of river ecosystems (Wiejaczka et al., 2018). The pre and post monsoon cross-sectional study at selected stations reveals the areal aspect of channel bed material extraction for a time being. Tamang and Mandal (2015) shows that the supply of material by surges during the monsoon season did not always compensate for the losses resulting from mass scale extraction of river bed material during the dry season. The extraction of bed materials is also responsible for infringement of the river adjustment between the channel geometry and its sediment capacity (Martin-Vide et al., 2010). The channel bed of Chel river shows large changes from average bed level before and after the bed mining activities (Fig. 8.9). The study of the cross-sections of the selected stretch of a river shows that the effect of extraction activities is quite visible on the mean bed elevations (Tamang, 2013).

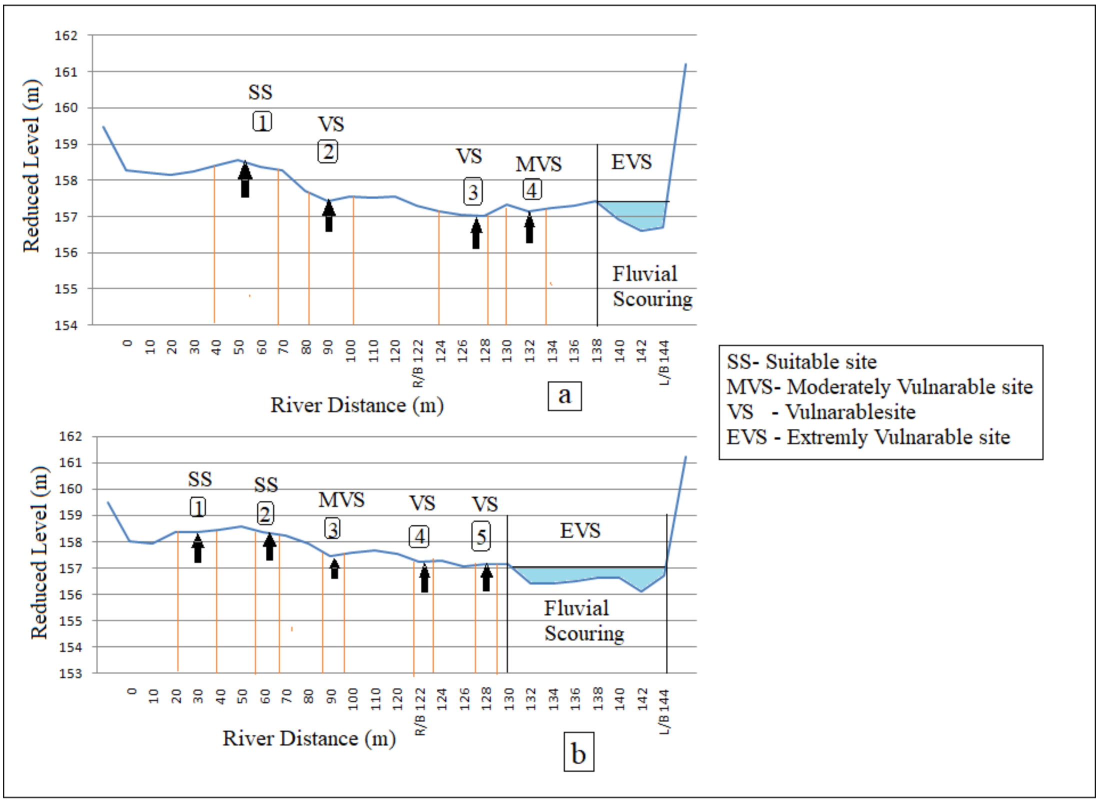


Figure 8.10 Model of channel cross section presentation for determining the vulnerable and suitable areas of bed materials extraction: a. Identification of vulnerable sites of mining form 2016 post monsoon cross section, b. Identification of vulnerable sites of mining form 2017 post monsoon cross section.

The following channel cross sectional study of mean bed elevation has been carried out to find out the volume of extraction of bed materials from the selected reaches viz. *Patharjhora, Manabari* (Plate: 11) and *Odlabari* (Plate 12) and beside *Apalchad* forest (Plate 10). The average bed height variation (Table 8.4) causes the fluctuation of channel gauge heights. So, the natural state of stage-discharge relationship is highly interrupted by the cannel bed mining activity. It causes stand-still water in the big scours in the channel and it indicates the degradation of the channel ecosystem. The major effect of channel bed material extraction is related with the seasonal bar dynamics. The boulder levees, mid channel bars, cross or transverse bars are the natural sediment architecture of the channel. At *Patharjhora*, boulders greater than 600 mm in size are extracted on a regular basis from the mid channel bars. 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 variation in sediment deposition is very common after the recession of monsoon discharge. At *Apalchad* reach, the sediment shorting indicates the relative fineness of the deposition. The site is suitable for extraction of sediment ranges from very fine gravel (2-4 mm) to very coarse gravel (32-64 mm). The amount of sediment extraction cannot be replenished by the deposition of next high discharge within the channel. Somewhere, it causes the stagnancy of water within the large scours in the channel. It greatly hampers the running water ecosystem. 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 $year^{-1}$, $6.1*10^4$ m^3 $year^{-1}$ and $3.7*10^4$ m^3 $year^{-1}$ respectively (field survey).

8.7 Effect on channel morphology: A case study of 1 km stretch at Odlabari

The bed material extraction process from river channel has combined morphological and hydrological impact on the channel at a particular site. It causes the changes in the flow regime of the channel, sediment movement process, flux of sediment generation in water, bed forms, bed roughness, bed gradient and hydraulic depth of the channel. The mining sites are unpredictable in terms of water holding capacity during high discharge. The frequent behavioral adjustments of hydraulic parameters and its natural rhythm become sluggish. In general, bed materials extraction from the active river bed may trigger changes in many factors governing fluvial processes, disturb the sediment balance and alter the erosion and sedimentation patterns (Lopez, 2004). The channel bar forms get highly instable at the mining sites. At *Patharjhora*, the bed material extraction causes the lateral instability of the channel and occasionally promotes high near bank fluvial stress during monsoon discharge. It is noticeable that there is clear link between channel avulsion and lateral instability of the channel due to bed mining. The channel avulsion after 2007 at *Patharjhora* not only caused by devastating capability of flood water but also there is less effect of bed mining behind this. The channel at *Odlabari* NH bridge is highly affected reach of bed material extraction. The 1000 m stretch has been selected with 200 m interval (A, B, C, D & E) (Fig. 8.11) up to downstream to prepare pre and post cross sections of 2017 and 2018 (Fig. 8.12). The main objective is to find out the effect of channel morphological changes occurred along the cross sections at the vulnerable mining site. The results of analysis are presented as follows:

8.7.1 The frequent changes in the channel bed elevation and mean bed elevation are important to know the impact of mining. It causes scours in the channel bed that is not always get replenished by the sediment supply. The channel flow remains concentrated within the same portion and causes the narrowing of cross section.

8.7.2 In 2018, the pre and post monsoon difference in the mean bed elevations at different stretches are 0.320 m at A, 0.481 m at B, 0.359 m at C, 0.225 m at D and 0.386 m at E. Comparatively maximum bed elevation change from pre to post monsoon has been noticed during 2018 (Fig. 8.12).

8.7.3 The drafted cross sections are presenting the irregular means of mining which spreaded throughout the cross section even not leaving the left bank thalwegs. The extensive mining form the mid channel bars is visible at post monsoon cross section of B and pre monsoon cross section of E.

8.7.4 The maximum erosion or scouring has been observed at post monsoon cross section C as 7.88 m (Fig. 8.12 c). The total amount of bed scouring within 1000 m stretch is calculated as 28.019 m in pre monsoon and 29.779 m in post monsoon cross sections of 2017. As well it is 24.944 m in pre monsoon and 27.552 m in post monsoon cross sections in 2018.

8.7.5 The hydraulic mean depth of the channel shows its hydraulic efficiency of water and sediment load movement. The hydraulic mean depth is calculated for the effective cross sectional segment. The higher value of hydraulic mean depth indicates the bed scouring by natural and anthropogenic means. The hydraulic radius is higher compared to the sections with deposition replenishing the extraction volume (Tamang, 2013). The maximum hydraulic mean depth has been calculated for both post monsoon condition at C cross section 0.92 m in 2017 and 0.93 m in 2018 (Fig. 8.14). The lowest hydraulic mean depth has been found for B cross section i.e 0.53 m during pre monsoon time. It reveals that increment in hydraulic mean depth during post monsoon time causes increase in hydraulic energy, channel velocity and continues erosion. But the mining related increment in channel hydraulic mean depth causes irregularities in channel energy slope, changes channel gradient, flow of water along previous thalwegs and creates whirlpools of water.

8.7.6 The Depth-Width ratio of a channel indicates the retainment of hydraulic efficiency of a channel which adjusted through changes channel mobility, erosion and deposition. In the ratio, if we consider the width is not changing (as only 2017 & 2018 time frame has been considered), then increase in channel depth causes increase in the ratio. So, in post monsoon condition the maximum ratio value is 0.008 (Fig. 8.15) which indicates the phase of bed scouring or erosion. This process is not only the result of fluvial erosion as well combines the effect of channel bed material extraction. At A and C cross sections the high value of the ratio in 2018 indicates ongoing bed material extraction process.

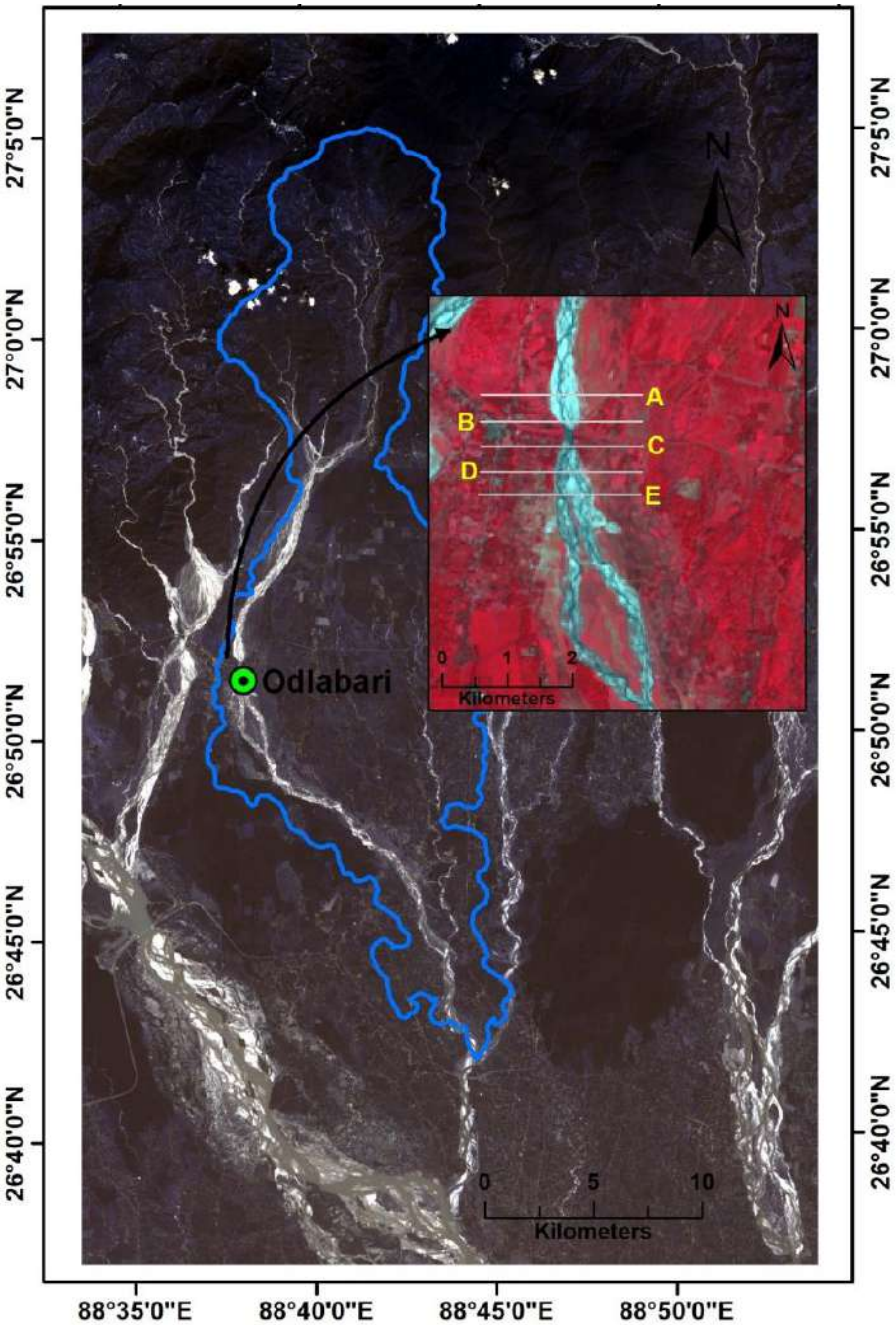


Figure 8.11 Design of channel cross sections at 1000 m stretch near Odlabari NH 31 Bridge (200 m interval).

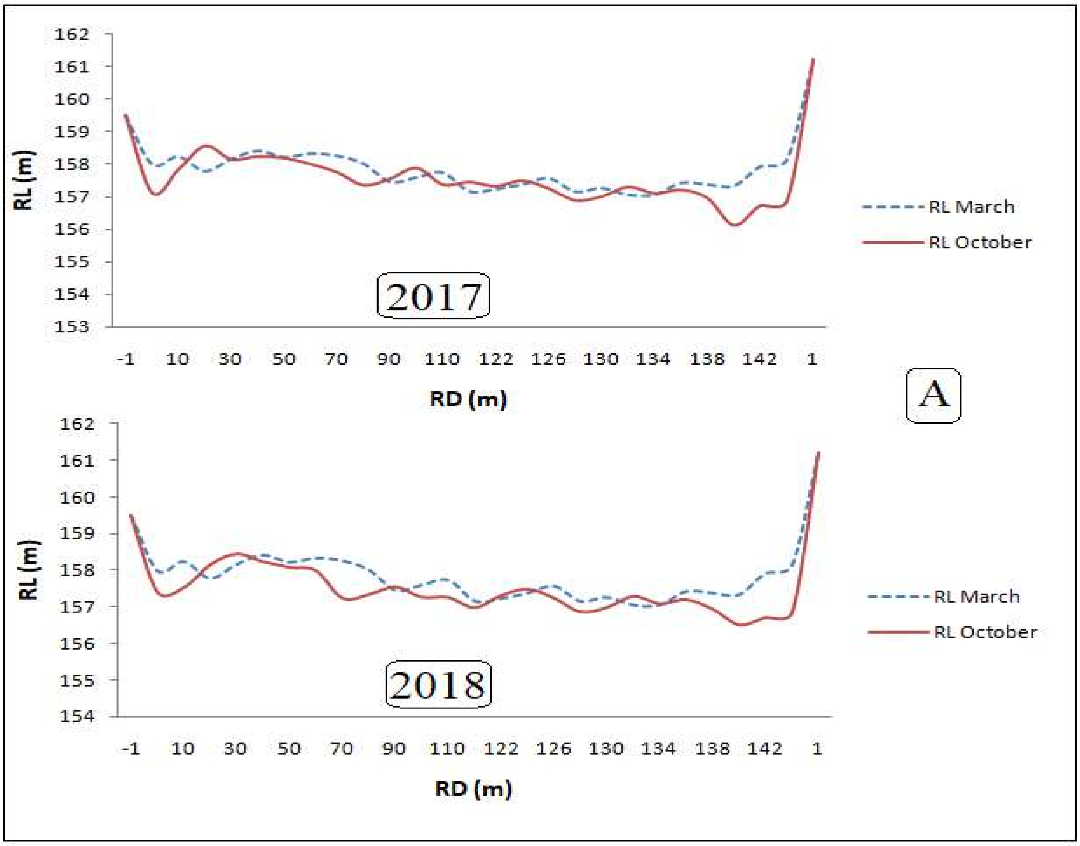


Figure 8.12 a

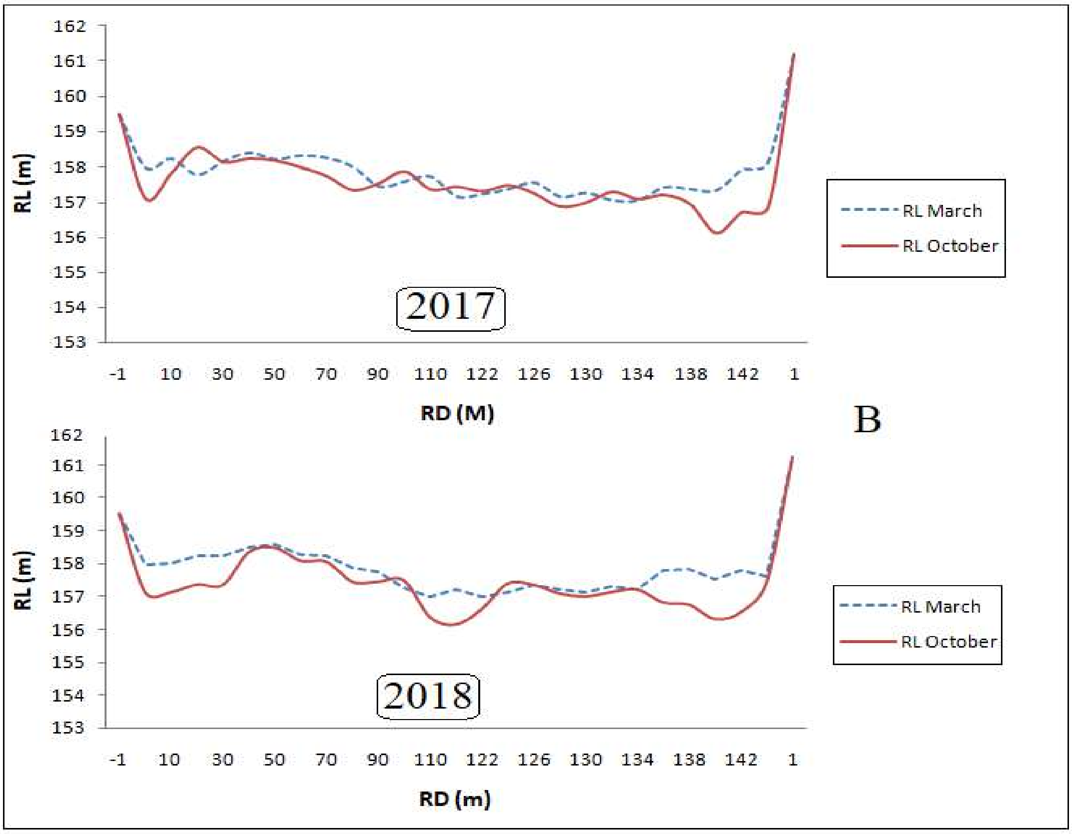


Figure 8.12 b

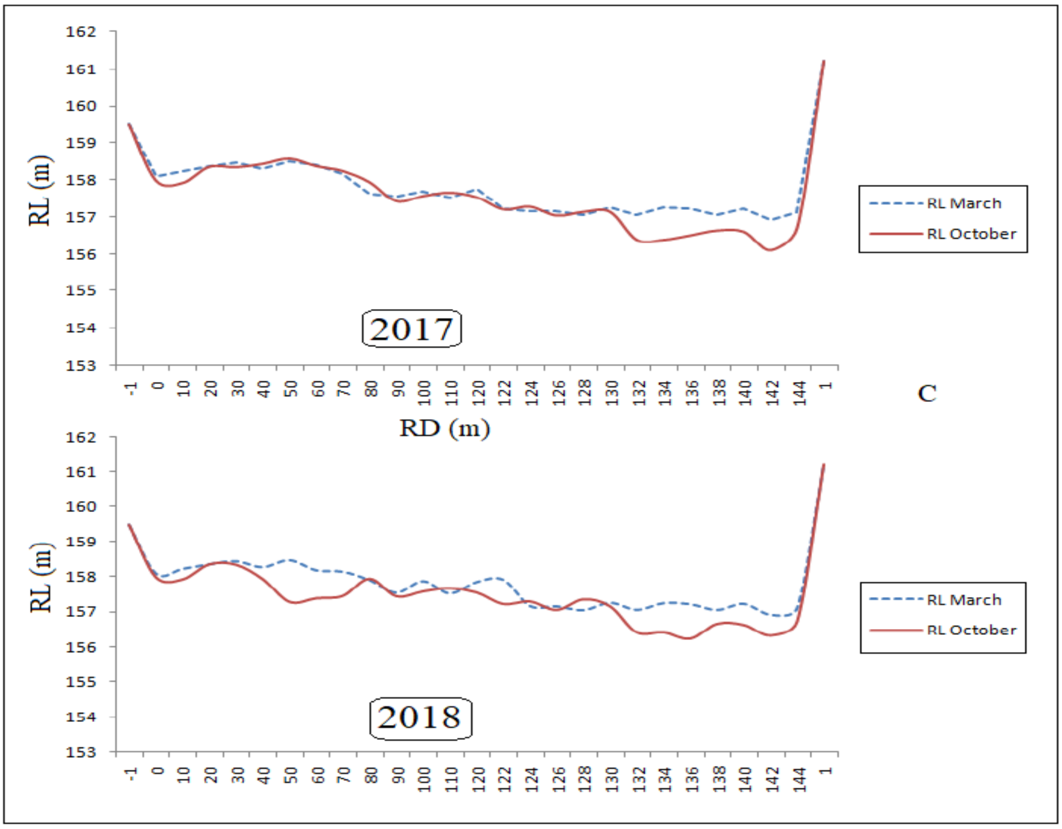


Figure 8.12 c

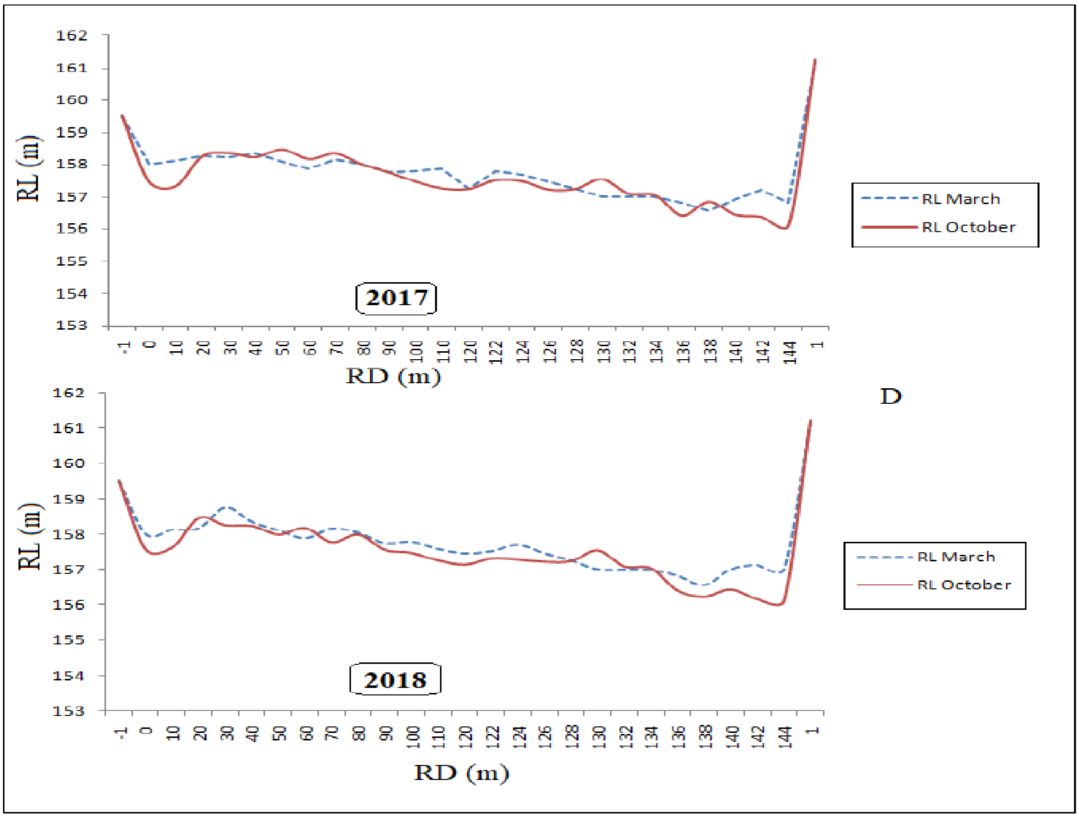


Figure 8.12 d

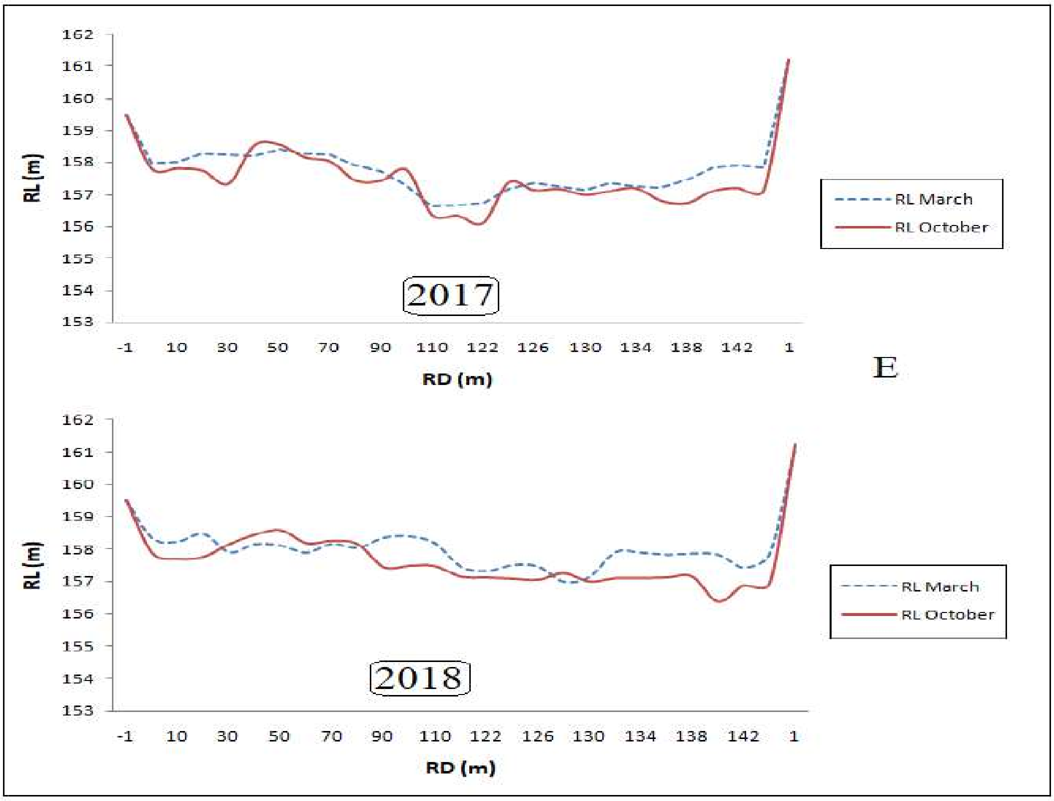


Figure 8.12 e

Figure 8.12 Cross-sections along the selected stretch (1000 m) at 200 m interval showing the changes in bed elevation during pre-monsoon and post-monsoon condition from 2017 to 2018. (Reference: Appendix Table 50 & 51).

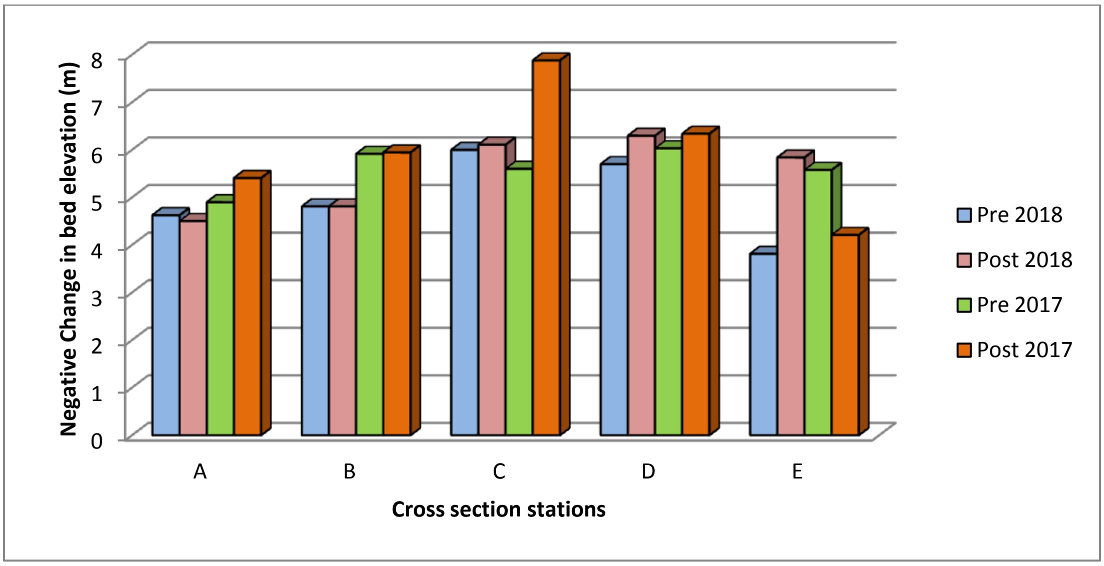


Figure 8.13 Pre & post monsoon negative change in channel bed elevation at cross sections.

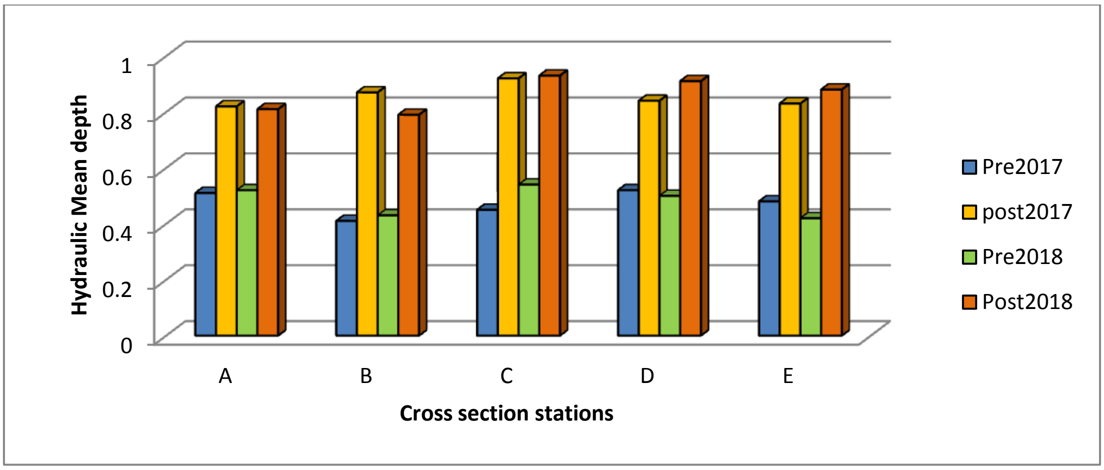


Figure 8.14 Pre & Post monsoon changes in channel hydraulic mean depth (m) at cross sections.

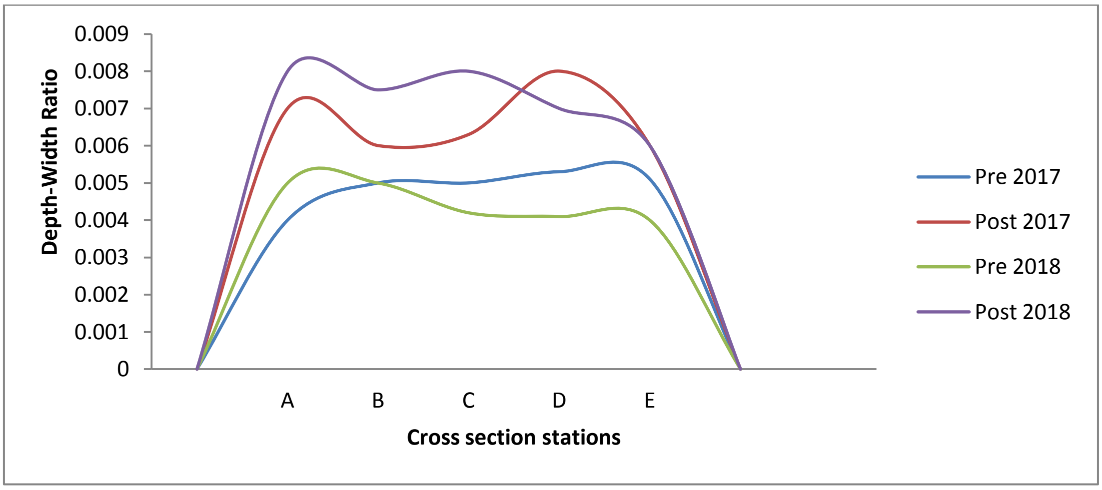


Figure 8.15 Variation in Pre & Post monsoon Depth-Width ratio at cross sections.

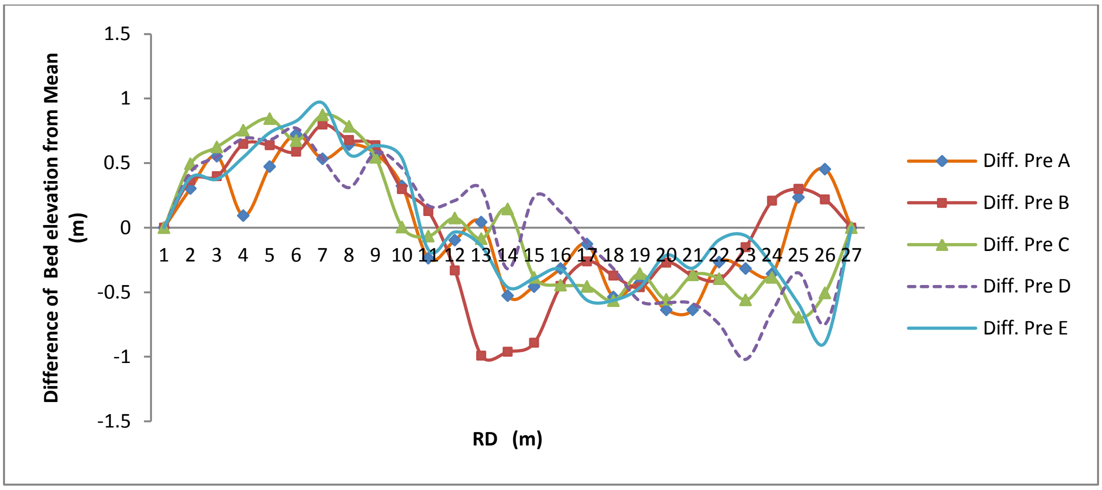


Figure 8.16 Pre monsoon difference of channel bed elevation (m) form Mean bed elevation (m) in 2017.

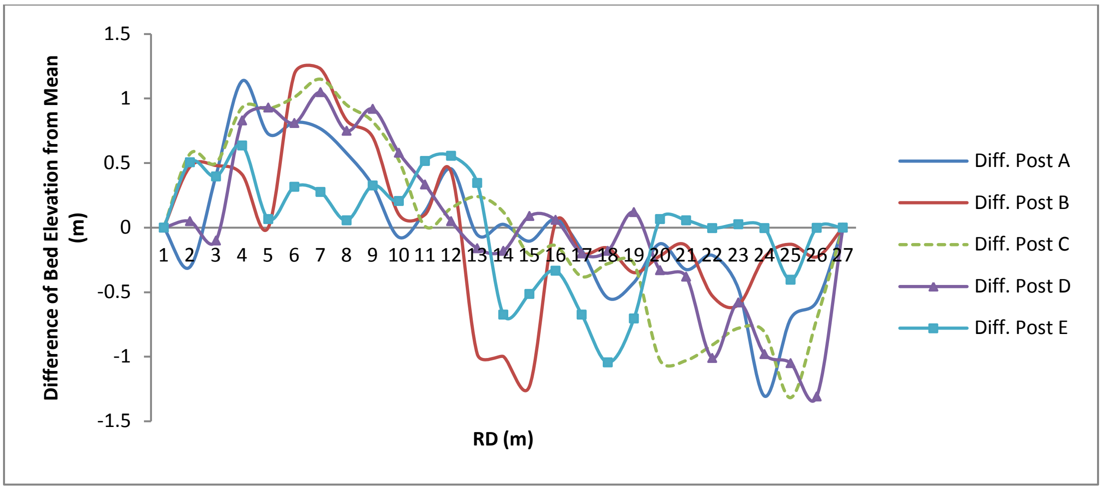


Figure 8.17 **Post monsoon difference of channel bed elevation (m) form mean bed elevation (m) in 2017.**

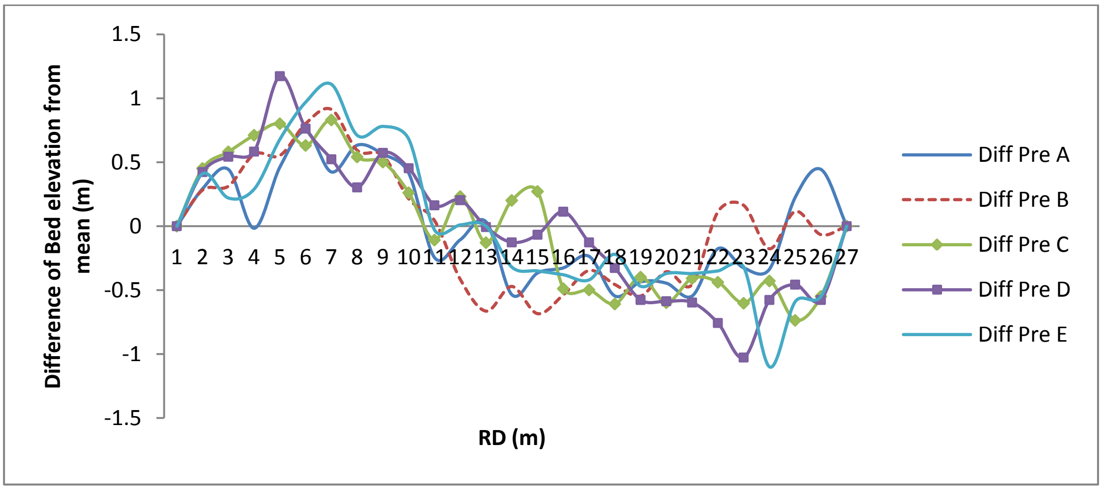


Figure 8.18 **Pre monsoon difference of channel bed elevation (m) form mean bed elevation (m) in 2018.**

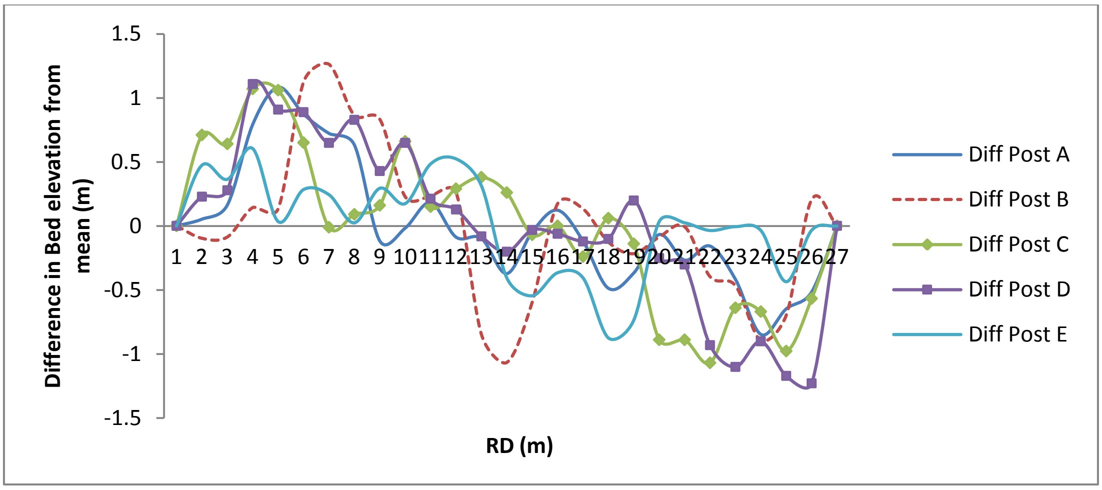


Figure 8.19 **Post monsoon difference of channel bed elevation (m) form mean bed elevation (m) in 2018.**

8.8 Towards sustainable channel management: A solution

The seeds of the term "Sustainable development" were perhaps first sown at the time of the Cocoyoc Declaration in the early 1970s. By 1980, the World Conservation Strategy (IUCN, 1980) emphasized the need for conservation of living resources to achieve sustainable development (Patel, 2012). The evolution of river uses and related ecological conditions, especially in recent decades, has been utilized to show the impact of humans on river ecosystems (Haidvogl, 2018). Rivers provide ecosystem services that have attracted humans for millennia. The Italian geologist Antonio Stoppani (1873) found human action comparable to other landscape shaping forces and was the first to speak of an 'Anthropozoic era' (Crutzen, 2006). In order to delimit the period when human action prevailed, Paul J. Crutzen (2006) introduced a new term 'to emphasize the central role of humankind in geology and ecology by proposing to use the term "Anthropocene" for the current geological epoch' (Crutzen, 2006: 13, Lóczy et al., 2014). Along with human uses, the resultant ecological impacts increased exponentially, especially after the 1950s (Haidvogl, 2018). The increasing capacity to substitute for river ecosystem services, regardless of distance, eliminated the need to harmonize a large variety of different uses (Jakobsson 2002). The increasing population pressure in the basin enhances the need of river water dependency for various purposes. Human action, as summarized most comprehensively by Goudie (2006), takes place at micro, meso and macro scales and influences geomorphological processes (Gregory and Walling, 1987, Lóczy et al., 2014). The classification of human impact on river environment came from the classical work of Martin Haigh (1978). He classified the human impact on channel geomorphology as – a. Directly human-induced processes – like construction; excavation or hydrological interventions and b. Indirectly human-induced processes – like acceleration of erosion and sedimentation; ground subsidence; slope failure and earthquakes triggered (Fig. 8.20). Water management was a basic condition for the survival of the first civilizations in Egypt, Mesopotamia, the Indus and Ganga valleys and in China and has never ceased to be a necessity ever since (Lóczy et al., 2014).

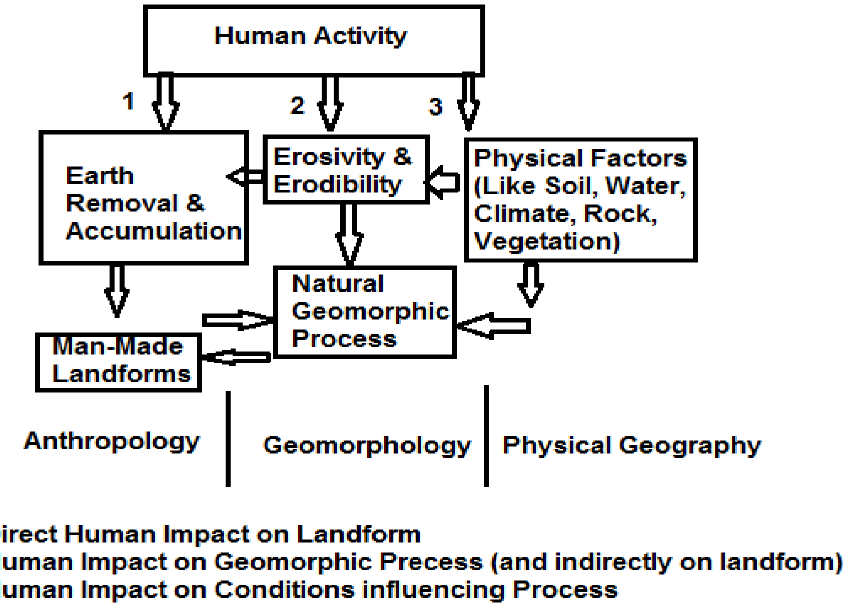


Figure 8.20 The 'human impact' model (Lóczy, 2008).

8.9 Channel management: A prior necessity

Channel management is defined as a course of action that achieves the needs of human to manage channels for flood risk and land drainage purposes, that has due regard of the needs of ecology and wildlife. In some situations, this can be met by allowing natural channel-forming processes to establish (Channel Management Handbook, 2015). 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. The management should not be confined within engineering solutions in form of dyke, embankment, spur and check dam construction rather it should proceede towards finding some sustainable techniques of restoration and protection. The channel performance within the valley indicates the most favorable idea for analysis and planning. The ability of channel to maintain its natural fluvial dynamics is importent for flood risk assessment, water resource management and surface drainage regulation etc. Channel management takes place at multiple scales. The channel management includes how water level regime and sediment are moving, how the bed and banks are being shaped, and what other local influences there are (local scale) (Channel Management Handbook, 2015). This includes land uses pattern analysis, geology and soils of the basin, and other issues. The quality of the channel habitat is maintained by the existing healthy fluvial process like flow regulation, ground water recharge, flow pattern, bar formations, bank architectures and riparian growth of vegetation. The long term effect of any obstruction in the existing flow and sediment regime of the channel causes the channel habitat degradation which bound to be a fact of both climatic shifts and anthropogenic pressure on the basin. So, the strategies and necessity of channel management of Chel discloses the following points:

8.9.1 Maintenance of un-regulated surface runoff.

8.9.2 Maintenance of overall surface drainage within the whole basin.

8.9.3 Protection of the riparian eco-system from excessive avulsion and high sedimentation which ultimately leads to edaphic drought.

8.9.4 Increasing water storage capacity and related managemental plans for the tea gardens.

8.9.5 Leaving the vulnerable site (human settlement infested) for river bed mining and finding alternative virgin sites for bed material extraction within the prescribed limit by the competent authorities.

8.9.6 In-stream extraction of bed materials from below the water level of a stream generally causes more changes to the natural hydrologic processes than limiting extraction to a reference point above the water level which should be followed strictly (Tamang, 2013).

8.9.7 In-stream extraction of gravel below the deepest part of the channel (thalweg) generally causes more changes to the natural hydrologic processes than limiting extraction to a reference point above the thalweg (Tamang, 2013).

8.9.8 Kondolf, et al (2001) suggested the suitable methods of channel bed material extraction viz. Bar scalping or skimming, Dry-Pit Channel Extraction, Wet-Pit Channel Extraction, Bar Extraction, In-stream Gravel Traps etc.

8.9.9 No extraction of minerals shall be allowed within 200 m of both sides of any river bridge or culvert over any waterway or from any embankment and structural works of the irrigation and waterways department (West Bengal Minor Minerals Rules, 2002, Schedule V).

8.9.10 Preparation of sites of channel water storage during monsoon months to be used as a source of irrigation water during dry periods.

8.10 Strategic river management

It needs to get concern from the previous and ongoing human impacts on the river channel. The managemental site purely relies on the human perception of the channel habitat modification and degradation. The basic strategies are sited below (Channel Management Handbook, 2015)-

8.10.1 Economic Strategies- to understand the economic justification for investment in flood risk management.

8.10.2 Structural Solutions- to consider where built defenses are appropriate to manage flood, control water levels, provide navigation, and retain water for irrigation.

8.10.3 Environmental Performance- to enable the river management to endure and to best manage all the demands on the river system, for breeding fish to flood water management.

8.10.4 Policy advice and stakeholder management- to ensure that communities work with and understand their river environments.

8.11 Conclusion

River channels provide eco-services to the human beings. But, overexploitation of hydrological resources from the channel causes threats to the aquatic eco-system and overall habitat of a channel. The rise of population pressure on the channel causes the ultimate threat to the channel of Chel. The channel is tectonically controlled at the head part. It shows high fluvial dynamics with the slow and mature adjustment of the channel. The channel has to bear the sudden flood risk and associated morphological changes on the adjacent flood plain (mainly within piedmont surface). At the lower part, the channel leads towards quasi-equilibrium condition and shows meandering trajectory. The main threat to the channel is excessive sediment extraction from the channel which causes the rapid alteration of the channel flow and sediment regime. So, the sustainable river management is applicable in reducing occasional flood risk, assessment of the flood recurrence, preservation of ecological diversity and decreasing the unscientific tendency of channel bed mining. The redline guidance (Castro, et al 2006 & Tamang, 2013) of channel extraction by following strategies like extraction permit based on measured annual replenishment, establish an absolute elevation below which no extraction may occur, extraction of bed materials from the downstream portion of the bar, retaining vegetation buffer at edges of water, against river bank and long term monitoring may reduce the threat of uncontrolled changes in channel hydrological regime. The Chel river is a potential site of water resource and its future utilization. The basin encourages eco-tourism (Plate: 8.8), home-stay tourism and international trade of delicious tea. Above *Gorubathan*, the basin is still virgin and zone of Eastern Himalayan bio-diversity hot-spot (*Neora* Valley National Park). Human imprint is rapidly modifying the landuse and land-cover aspect of the basin with rapid deforestation in the upper catchment. The water resource should be utilized in agricultural activities. As well it should directly contribute in developing Intergrating Watershed Management programme. The focus should be placed on implementing sustainable river management programmes to utilize the water resource with proper action plans.

Plate 8.1 Bridge construction across the river channel at Odlabari (2018).

Plate 8.2 Old bridge across the river at Upper Fagu (2018).

Plate 8.3 Human settlement (Chel Colony) on the right bank at Odlabari (2017).

Plate 8.4 Destructed old rail bridge after the flood of 1975 at Odlabari site (2017).

Plate 8.5 Presence of the concrete wall of burning ghat at the right bank of Chel at Odlabari (2018).

Plate 8.6 Destructed boulder net spur at high flow stage on the left bank of Chel at Odlabari (2018).

Plate 8.7 **Boulder wall construction in front of seasonal paddy field on the flood plain of Chel at Patharjhora (2019).**

Plate 8.8 **Upper Fagu eco-tourism spot on the right bank of Chel (2019).**

Plate 8.9 **Boulder pitched embankment of the left bank of Chel at Rajadanga (2017).**

Plate 8.10 **Marks of truck tiers on the destroying of mid channel bar at Apalchad reach (2018).**

Plate 8.11 **Stone breaker women on the bed of Chel at Manabari site (2018).**

Plate 8.12 **Truck transportation of extracted bed materials at Odlabari site (2018).**

8.12 References & Bibliography

Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Woodwell, G.M., (1997). Ecosystem services: benefits supplied to human societies by natural ecosystems, vol 2. Ecological Society of America, Washington, DC.

Auerbach DA, Deisenroth DB, McShane RR, McCluney KE, Poff NL(2014) Beyond the concrete: Accounting for ecosystem services from free-flowing rivers. Ecosyst Serv 10, pp.1–5.

Bandyopadhyay S., De S.K. (2017). Introduction. In: Human Interference on River Health. Advances in Asian Human-Environmental Research. Springer, Cham, pp. 1-14. DOI. 10.1007/978-3-319-41018-0_1

Banerjee, A. N., (2007).The West Bengal Minor Minerals Rules, 2002 Also the Mines and Minerals (Development and Regulation) Act, 1957 (as amended up-to-date), Tax 'N Law, Kolkata, pp. 3–29.

Boon, P.J., Calow, P., Petts, G.E., (1992). River conservation and management. Wiley, Chichester, p.470.

Brookes, A., Shields, F.D. (1996). River channel restoration: guiding principles for sustainable projects. Wiley, Chichester, p.433.

Castro, J., Mullan, A., Livermann, A., Barco, J., and Hansen S., (2006). Sediment removal from active stream channels in Oregon: considerations for federal agencies for the evaluations of sediment removal actions from Oregon streams, US Federal Interagency, pp. 42-62.

Census of India (2011). District Census Handbook, Jalpaiguri, Directorate of Census Operations, West Bengal, Series-20, Part XII-A.

Census of India (2011). District Census Handbook, Jalpaiguri, Directorate of Census Operations, West Bengal, Series-20, Part XII-B.

Census of India, (2011). District Census Handbook, Jalpaiguri, Directorate of Census Operations, West Bengal, Series-20, Part XII-B.

Census of India, (2011). District Census Handbook, Jalpaiguri, Directorate of Census Operations, West Bengal, Series-20, Part XII-A, p. 129.

Census of India, (2011). Overview of Census 2011, Government of India.

Costanza, R., Darge, R., Groot, R., Farber, S., Grasso, M., Hannon, B.,Limburg, K., Naeem, S., Dutta, M., (1995). River Balason: A study ofriver behavior under human influence in the foothills of Darjeeling. Himalayan Paryavaran 3, pp.18–21.

Crutzen, P., (2006). The Anthropocene. In: Ehlers, E. and Krafft, Th. (eds), Earth System Science in the Anthropocene: Emerging Issues and Problems. Springer Verlag, Berlin, pp. 13–18.

Gore JA (ed) (1985). The restoration of rivers and streams. Butterworth, Stoneham, 280.

Goudie, A., (2000). The human impact on the natural environment. MIT press, Oxford.

Govorushko, S. (2007). Effect of Human Activity on Rivers, pp. 465-470.

Gregory, K.J. and Walling, D. (eds) (1987) Human Activity and Environmental Processes. John Wiley and Sons, Chichester.

Haidvogl G., (2018). Historic Milestones of Human River Uses and Ecological Impacts. In: Schmutz S., Sendzimir J. (eds) Riverine Ecosystem Management. Aquatic Ecology Series, vol 8. Springer, pp. 19-39. https://doi.org/10.1007/978-3-319-73250-3_2.

Haigh, M. (1978). Evolution of Slopes on Artificial Landforms. Department of Geography, University of Chicago, Chicago. (Research Paper 183).

Huang, M.W., Liao, J.J., Pan, Y.W., Cheng, M.H., (2014). Rapid channelizationand incision into soft bedrock induced by human activity—Implications from the Bachang River in Taiwan. Eng Geol 177, pp.10–24.

Jakobsson, E. (2002). Industrialization of rivers: a water system approach to hydropower development. Knowl Technol Policy 14, pp. 41–56

Kirpich, Z. P. (1940). Time of concentration of small agricultural watersheds. Civil Engineering, 10(6), p.362.

Kondolf, G. M., Smeltzer, M. and Kimball, L., (2001). Freshwater Gravel Extraction and Dredging Issues. Washington Departments of Fish and Wildlife, Ecology, and Transportation, Olympia, pp. 15- 21.

Kondolf, G.M., (1997). PROFILE: hungry water: effects of dams and gravel mining on river channels. Environ Manag 21, pp. 533–551.

Kondolf, G.M., (1997). PROFILE: hungry water: effects of dams and gravel mining on river channels. Environ. Manag. 21, pp.533–551.

Lawler, J. J., Lewis, J. D., Nelson, E. *et al.*, (2014). Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences, 111(20), pp.7492–7497.

Lóczy, D. (2008). Az emberi társadalom és a geomorfológia. Alkalmazott geomorfológia (Human society and geomorphology: applied geomorphology). In Lóczy, D. (ed.), Geomorfológia (Geomorphology) II. Dialóg Campus Kiadó, Budapest – Pécs., pp.395–431.

Martín-Vide, J.P., Ferrer-Boix, C., Ollero, A., (2010) Incision due to gravel mining: modeling a case study from the Gállego River, Spain. Geomorphology 117, pp. 261–271.

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC.

Mooney, H. A., Duraiappah, A., Larigauderie, A., (2013). Evolution of natural and social science interactions in global change research programs. Proceedings of the National Academy of Sciences, 110(1), pp. 3665–3672.

Ning, J., Liu, J., Kuang, W. et al., (2018). Spatiotemporal patterns and characteristics of land-use change in China during 2010–2015**.** J. Geogr. Sci. 28: pp. 547-562. https://doi.org/10.1007/s11442-018-1490-0

Patel, P.P., (2012). An exploratory geomorphological analysis using modern techniques for sustainable development of the Dulung river basin, Unpublished thesis, under the supervision of Dr. Ashis Sarkar, Dept. of Geography, Calcutta University, pp. 1-2.

Postel, S.L., Thompson, B.H., (2005). Watershed protection: Capturing the benefits of nature's water supply services. Natural ResourcesForum. Blackwell Publishing, Ltd, Hoboken.

Rasul, G., (2014). Food, water, and energy security in South Asia: a nexusperspective from the Hindu Kush Himalayan region. Environ Sci. Policy 39, pp.35–48.

Raven, PJ et al., (1998). Quality Assessment using River Habitat Survey Data, Aquatic Conservation: Marine and Fresh Water Ecosystems 8, John-Willy & Sons Ltd., pp. 485, 487, 489.

Richard H, Norris M, Martin CT (1999). What is river health?. Freshwater Biol 41. Blackwell Science Ltd, pp 197–209.

Stoppani, A., (1873). *Corso di Geologia* II. Cap. xxxi. Sec. 1327.Milano.

Tamang, L., (2013). Effects of boulder lifting on the fluvial characteristics of lower Balason basin in Darjeeling district west Bengal, Un-published Ph.D. thesis, Dept. of Geography & Applied Geography, NBU, under the supervision of Deepak Kumar Mandal, pp. 107-132.

Wang, C., Meer, P.V.D., Peng, M., Douven, W., Hessel, R., Dang, C., (2009). Ecosystem services assessment of two watersheds of LancangRiver in Yunnan, China with a decision tree approach. AMBIO38, pp. 47–54.

Wiejaczka, Ł., Tamang, L., Piróg, D. et al., (2018). Socio-environmental issues of river bed material extraction in the Himalayan piedmont (India), Environ Earth Sci. 77 (718). Pp. 1-9. https://doi.org/10.1007/s12665-018-7897-1

Williamson, P. et al., (2015). Channel Management Handbook, 2015, Report-SC110002, Environment Agency, Horizon House, Deanery Road, Bristol, BS1 9AH, pp. I-IV.

Wohl, E., (2006). Human impacts to mountain streams. Geomorphology 79, pp. 217–248.

Wulder. M. A., White, J. C., Goward, S. N. *et al.*, (2008). Landsat continuity: Issues and opportunities for land cover monitoring. *Remote Sensing of Environment*, 112, pp. 955–969.