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ORIGINAL ARTICLE

Hydrological Behavior of the Lower Course of the Lachung River Basin, North Sikkim

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ABSTRACT

Hydrological system of the Lachung River under crave changes due to eradicate pattern of rainfall, building of embankment, sand mining, construction of dams and barrages and roads. The stretch of the river is further affected by human activities. Local people collect sediment (in the form of stone and sand) from the river bed unscientifically. It has made the river bed very much irregular and undulating. The Lachung basin is located in the Upper North- Eastern reaches of the Teesta River in Sikkim. The area varies in terms of physical condition, such as Topography, Climate, Soil, Geology, Drainage and Vegetation. The prime objective of the study is to analysis the hydrological changes of lower course of Lachung river basin. Primary data were collected by using various field based instruments from different parts of the river. Satellite imageries have been used for preparing maps on temporal channel shifting of the River in GIS environment. The study reveals that due to human intervention landuse/ landcover has changed and also have impact on hydrological conditions.

Key words: *human intervention, hydrological changes, temporal channel shifting, landuse-landcover*

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INTRODUCTION

Hydrology studies is the movement of water on the earth's surface (Dingmans 2008).The main study components of hydrology are precipitation, surface waters such as river and lakes, soil water. These components are linked together using the concept of the hydrological cycle, which describes the movement of water between land and atmosphere. The basic principles of the hydrological cycle are as follows. When precipitation falls on the earth's surface, part of the water is evaporated from the soil, water surfaces and vegetation back to the atmosphere. Part of the water stays above the soil surface, forming rivers and lakes, and part of the water is infiltrated into the soil from where it seeps to rivers and lakes. The surface and soil water is then drained through rivers and other water bodies into the oceans, where water evaporates back into the atmosphere. The spatial unit, in which the hydrological analysis often occurs, is a river catchment or River basin. In studying hydrology the most common spatial unit of consideration is the catchment or river basin. Hydrology can be considered to be applied hydrology when the study of the Hydrological cycle is included to cover human or other "external" interferences. This means the consideration of climate variability, human water use, water infrastructure development and other water resources management activities together with the components of hydrological cycle. Water is a geomorphologic resources used by human for development, management and other purpose.The Himalayan Mountain where elevation ranges from 60m above mean sea level to 78000m within a north-south distance of approximately 197km (Hannah, *et. al.,* 2004). This extreme elevation combined with potential climate and land use change affects stream flow in this unique mountain headwater system (Ma, *et al.,* 2010). For example, monsoon precipitation account for 80% of total input to these mountain ranges (Sharma 1993) that may increases the risk of hydrological-related disaster such as flood and landslide in steep meandering channels. The risk is further enhanced by exposed rock without vegetation cover located at higher altitudes that increase surface runoff and sediment yield (Summerfield and Hulton, 1994; Ludwig and Probst 1998). These events reduce the water supply and hydro-electricity generation as transported sediment lowers storage capacity of downstream reservoirs (Monirul and Mirza, 2003). The south-Asian monsoon precipitation initiates from the south-eastern part of the himalayan ranges and weakens towards north-western part so it contribution is substantial in eastern himalayan region with glacier expansion during summer month (Asahi and Watanabe, 2004; Bookhagen, *et. al.,* 2005). The western region is predominantly influenced by winter westerlies causing snowfall at higher elevation with glacier advance during winter month (Barros *et al.,* 2006). These climate differences result higher snowmelt contribution (up to 50%) to the total annual eastern basin (25%) (Bookhagen and Burbank 2010). Therefore these Basin are likely to show different responses to continued climate changes that potentially differentiate melt water contribution to discharge of the rivers. Extensive human induced land use change is a major global research issues (Foley *et al*., 2005; Marshall and Shortle, 2005) that affect surface runoff and stream discharge due to changes in rainfall interception, evapotranspiration and surface soil hydraulicconductivity (He, *et al.,* 2008; Germer, *et al.,* 2009; Scheffler, *et al.,* 2011; Munoz-Villers and McDonnell 2013 ; Yan, *et al.,* 2013). Land use change also affects downstream water availability of mountain basin (He *et al.,* 2008; Nepat, *et al.,* 2014). The objective of the present study was to analyze the hydrological behavior of the lower course of the Lachung River in North Sikkim.

AREA AND PEOPLE

Physical background of the study area contains geology, climate, natural vegetation and soil**.** Lachung is a small town located in the North Sikkim district and is near the border with Tibet. It has central longitude and latitude value of 88.65°E and 27.61°N. The word Lachung means "small pass". The town is approximately 125 km from the capital Gangtok. Lachung is at an elevation of about 9,600 ft or 3,000 m above sea level. Most of the people of the state reside near Mangan, the district headquarters which is about 2,000 feet (610 m) above sea level. Further north the elevation increases with the vegetation turning from temperate to alpine to tundra. Temperatures range from about 25° to below-40° in the extreme high reaches where the altitude is in excess of 6,000 meters. Kanchenjunga is the highest peak at over 8,000 m, straddling its western border with Nepal and can be seen clearly from the town of Singhik. According to the 2011 census North Sikkim district has a population of 43,354 roughly equal to the nation of Liechtenstein. This gives it a ranking of 634th in India (out of a total of 640). The district has a population density of 10 inhabitants per square kilometre (26/sq mi). Its population growth rate over the decade 2001-2011 was 5.66%. North Sikkim has a sex ratio of 769 females for every 1000 males, and a literacy rate of 77.39%. The people are mainly of Lepcha and Bhutia descent. Other groups include the Tibetan community. It also has one of the lowest populated regions of the state.

MATERIALS AND METHODS

Hydrological data are collected from the CWC as well as from Field survey using Total Station and GPS. Rainfall data of the concerned station are collected from the Gangtok Meteorological Office and Horticulture Department of the Government of Sikkim and published literatures. Basic literatures related to hydrology, climate, soil, geology, and geomorphology have been collected from government and non-government organizations. The Survey of India (SOI) topographical maps (77/12, D/16, 78A/9, A/10 and A/13) of 1:50,000 scale and Googleimage has been used for the demarcation of the Lachung River basin to UTM WGS 1984 45 Northern Hemisphere projection through GIS 9.3 Software. Hydrological data set from the secondary as well as the field survey will be plotted through Origin v 8.0 software to obtain the sequential changes of the Parameters. Monthly values of different parameters have been plotted for each year individual followed by the superimposition of such annual graphs in order to detect the nature of changes of individual parameters. Five Cross Sections prepared through direct field survey along the CWC Gauge station for the river. This fixation in reduced level was necessary to incorporate major lateral changes along both the bank which were not at the same height. However in case of bed height the base level was considered following standard gauge height fixed by Central Water Commission. To study area the satellite images of different time period have been downloaded from USGS. The spaceborne thermal emission and Reflection Radiometers(ASTER), Global Digital Elevation (GDEM) are used to delineate the boundary of the study area and ASTER GDEM tiles were mosaicked and than treated further using the standard GIS techniques to delimit Lachung River basin. The study area was than extracted and superimposed by the other necessary features layer. Three period Landsat TM, ETM, ETM+ (i.e. 2000.2009.2015) have been used for preparing maps.The satellite images in digital formatfor the whole area between 2002,2009 and 2015 from Landsat5 TM (spatial resolution 30 m) and Landsat 7ETM+ *(*spatial resolution 15m*)* have been analysed to compare changes in the study area. Landsat 7 ETM+has been used after merging the panchromatic image with 15m resolution and further enhanced and compared with Topographical maps of previous periods. This enhanced image of fine resolution gave the better view of channel changes and subsequent geomorphic implication. There has been further supplementation in the form of satellite imagery from Google Earth.Merging with high resolution Imageis carried on for better mapping and presentation. All temporal data were registered carefully in Remote Sensing environment involving ERDAS Imagine software and further processing has been carried on for product generation to the GIS Environment involving Arc GIS software. Finally, after careful processing of rectification, enhancement and edge matching technology, spatio-temporal shifts of confluence points were extracted and mapped in the GIS environment.

Table 1: Nature of data with respective date and resolution

Nature and types of Data	Acquired date	Resolution
SOI-Topographical Maps	78A/9, 78A/10, 78A/13, 7 8A/14	1:63,360,1:50,000
Landsat 5 TM +	2002	30m
Landsat 7 ETM+	2009	15m
Landsat 7 ETM	2015	30m
Google Earth	2015	With Zoom, 10m

DRAINAGE

Lachung river basin has its source in a lake, deep in the mountains of the Himalaya near the Indo-China border. From there, the river flows down in a south-westerly direction and joins with another unknown river at a place just above the Lachung village. The river continues its course downwards through the ethereal Lachung valley till it meets River Lachen near Chungthang. After the confluence, it takes the name of River Teesta and flows further down. The River Lachung is a perennial river. The Rangeet and the Teesta which form the main channels of drainages run nearly north south. It gets its water from the melting waters of snow in the mountains of the Himalayan Range. The water in the river is maximum in summer and monsoon. The rainfall also adds to the water content. During the months of winter, the water line turns slim. River Lachung is one of the main tributaries of River Teesta in north, the other tributary being River Lachen. The two meet near a town Chungthang.

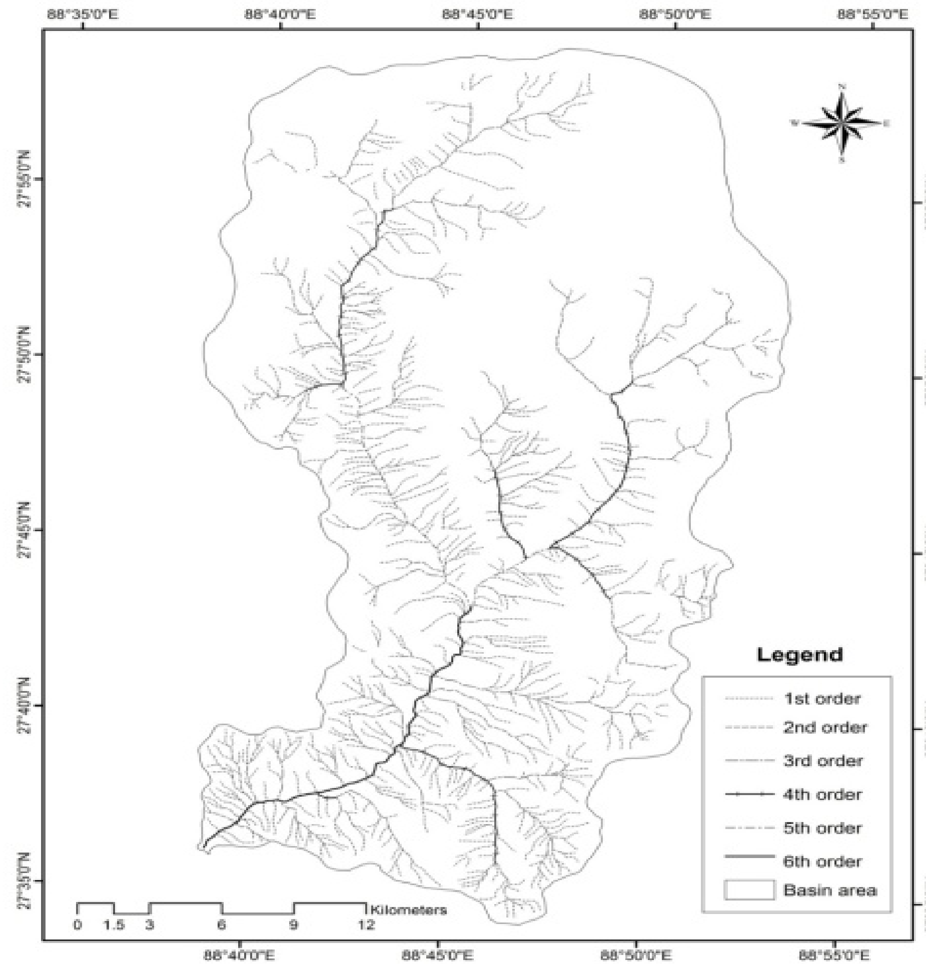


Fig.1. Drainage of Lachung river basin

DRAINAGE DENSITY

R.E Horton (1945) define drainage density as the "a ratio of total of total length of all stream segment in a given drainage basin to the total area of that basin". Drainage density is simply the total channel length divided by the total area of the basin. Drainage density=Total length of stream/unit area. The drainage density is very high in the southern part of the basin cover an large area of 260sq km. high drainage density cover an area of 247 sq km, moderate cover a area of 210 sq km and very low cover an small area of basin i.e. 9 sq km.

Stream Network:

The drainage area is identified as an area which contributes water to a particular channel or set of channels. Whereas, the drainage network is the pattern of tributaries and master streams in a drainage basin as delineated on a planimetric map.

Stream Order:

Stream order is a measure of the position of a stream in the hierarchy of tributaries. In this study, Strahlar's method of stream ordering is followed. The Lachung River Basin is drained by 6th Order of streams.

Bifurcation Ratio:
Bifurcation ratio (R_b) is the ratio between the number of streams of a given order and number of streams of the next higher order. The equation is followed to calculate the bifurcation ratio is:

$$R_b = N_u/N_{u+1}$$

Where, N_u= Number of a stream of a given order
N_{u+1}= Number of streams of the next higher order

Table 2: Number of stream and Bifurcation ratio

Stream order	Total number of stream (Nu)	Bifurcation ratio(Rb)	Average
1st order	630	4.41	3.79
2nd order	143	4.33	
3rd order	33	4.71	
4th order	7	3.5	
5th order	2	2	
6th order	1		

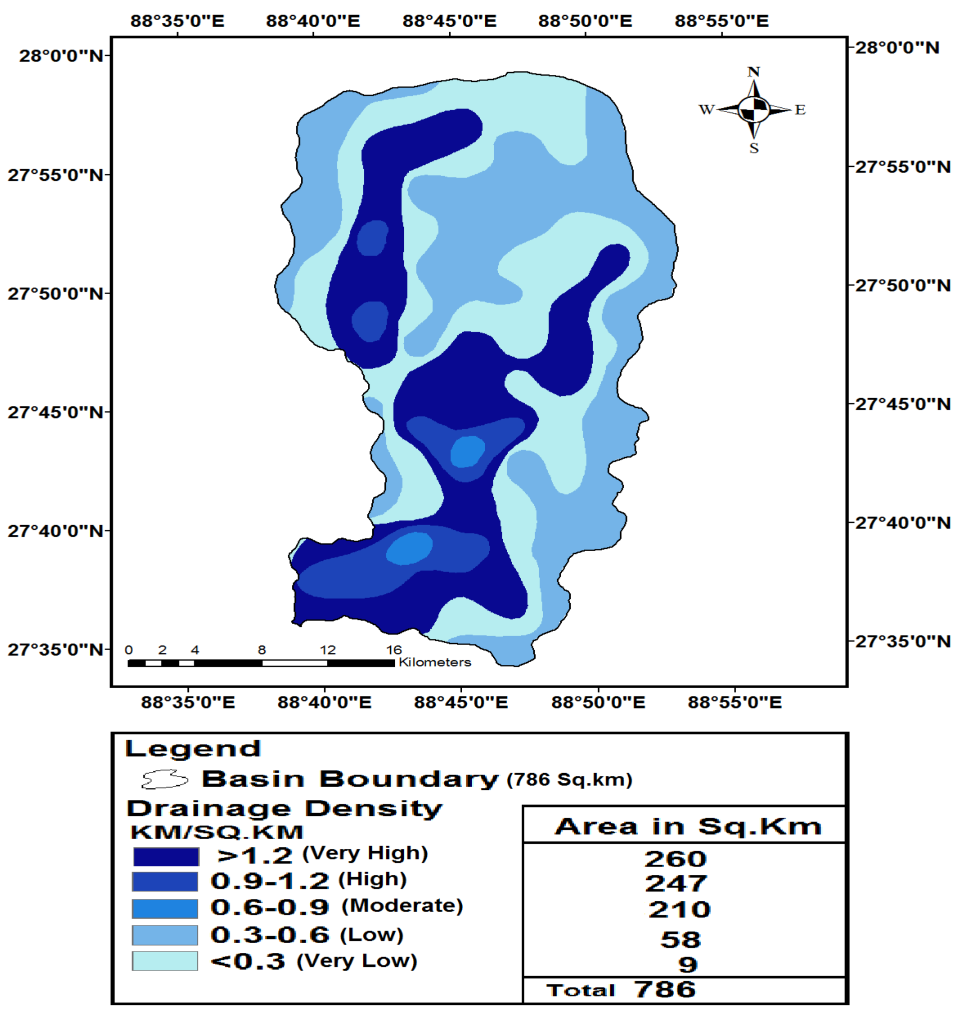


Fig. 2: Drainage density of LachungRiver basin

From the above table it is clear that, bifurcation ratio varies from one order to the next order. There are 4.41 times as many 1st order segments as 2nd order, 4.33 times as many as 2nd order segments as 3rd order, 4.71 times as many as 3rd order segments as 4th order, 3.5 times as many as 4th order segments as 5th order and 2 times as many as 5th order segments as 6th order. The average value of Bifurcation ratio (R_b) i.e. 3.79 is the representative value of the whole series of the Lachung River Basin. According to the above table, the R_b values vary between 2 to 4.71. This range of variation of R_b values of the Lachung river basin indicates that there is a limited influence on the distortion of drainage pattern in the basin. The mean value of R_b i.e. 3.79 indicates that the nature of discharge of the Lachung River Basin is high during flood.

TEMPORAL CHANNEL SHIFTING OF LACHUNG RIVER BASIN

The changing of river course is due to presence of structural weakness, in stability and sudden change of hill sides lope and steep channel gradient. Flash flood and landslides in remote areas of North Sikkim due to very high meanannual rainfall for several daysand simultaneous melting of snow accumulated on high mountain peakregion affect the course of river. The neo-tectonic network of transverse and parallel fault sand line aments parallel to the Himalayan axis are considered to be major contributing factors to the in stability of this region. Any movement or adjustment along the sestructuralele ments will have an effect on river morphology and channel changes of the area. Tectonic activity is still expressed in the network of river channels where junction so streams follow latitude in a fault lines as with the lower courses of rivers Latching. Alluvial courses are very sensitive indicators of channel change and can readjust to variation in hydrology, sediment load and active tectonics (Schumm, *et al*., 2000). Lateral shifting is a type of change of immense importance which can be detected by its asymmetric position in the river valley and the evidences of its spatio-temporal shift in one direction (Schumm, *et al.,* 2000). Eroded materials from up lifted parts are deposited in the down faulted depression sleadingtoagg radiations and shifting of rivers. Bursting of artificial embank mention the riversmayalso cause floods in theregion, so, soil erosionis also remarkable in the catch ment area of the rivers due to high deforestation and un scientificcultivation on the hills lopes. The silts and debris'sthus, collected, are carried by the rivers from the hills and simultaneously are deposited on their river beds. Thus, gradual rise of riverbeds results asevere bankerosion, channel degradation, and diversion with marked changes of channel pattern. Three different time period of satellite images i.e.2002, 2009, and 2015 have been digitized and superimposed in GIS environment to show the temporal change of river course. In 2002 the river width and the amount of water accumulation is more in relation to the intensity of rainfall distribution and temperature in Lachung.

CROSS SECTION AND DISCHARGE OF LACHUNG RIVER BASIN

Cross section data represent the geometric boundary of the stream. These are required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, roughness, and at hydraulic structures. Four cross section have been taken within about 500m stretch from the Military Coronation Bridge towards downstream. The area is just like bottle neck shape of which the narrow part of upstream is near the bridge and it further widen downstream and again it has been narrow further downstream near Lachung town. Cross-section has been taken with dumpy level, measuring tape and ranging road from left to right bank across the stream at different part of it. The river bed is full of boulder, pebbles as well as sand within this stretch the river is protected by embankment along its both side. Some indication of flood as well as shifting of the course are found within this stretch .The present coronation bridge was located about above 300m downstream and it was hanging bridge due to flash flood the hanging bridge was broken and the remnant of the bridge is still lying on the right bank of the river. After the breaking of the hanging bridge a new coronation bridge was constructed 20m downstream from the present constructed bridge. The stretch of the river is further affected by human activities. Local people collect sediment (in the form of stone and sand) from the river bed unscientifically. It has made the river bed very much irregular and undulating. Some stone barriers have been constructed in the form of T-bridge and embankment for two purposes:-

1. First for sand quarrying.

2. Second for protected settlement fury of the flood.

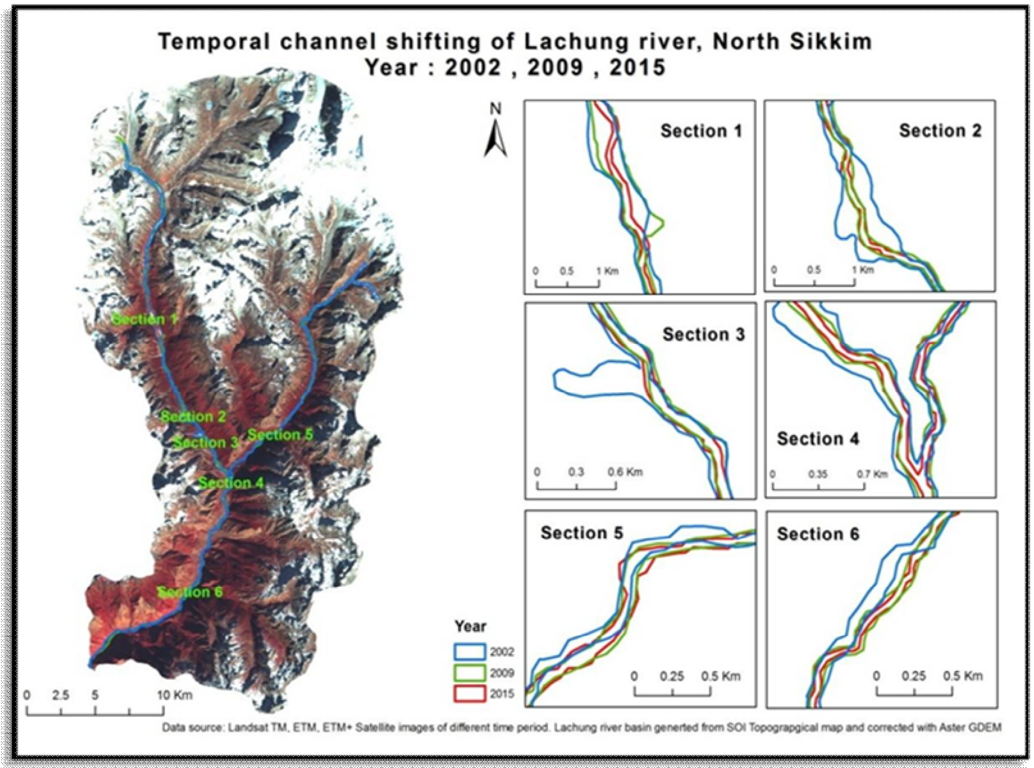
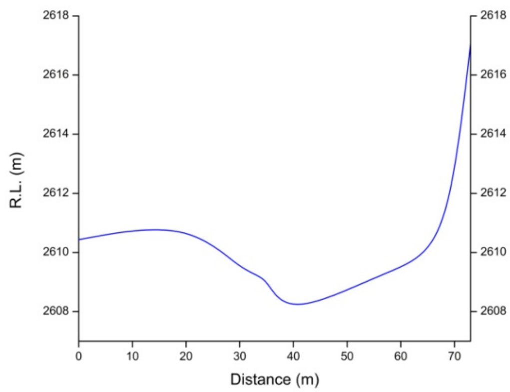
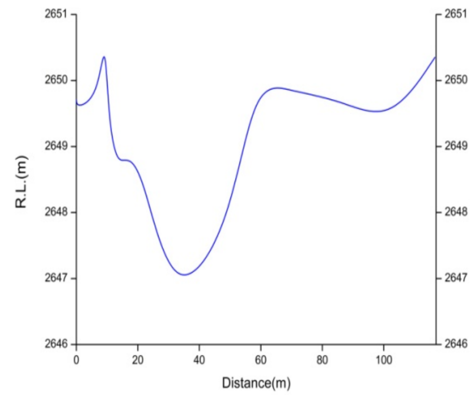


Fig. 3: Temporal Trend of Channel Shifting

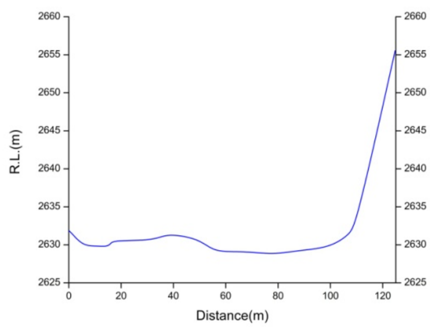
The left bank has highly been eroded by river (concave bank) and the slope has almost become vertical. The right bank topography is the lower part of alluvial fan of which big alluvial corn is located. It is composed of conglomerate and partly it is cover with vegetation. A First order tributary is flowing across that alluvial fan from the small cascade and meeting at right angle. The embankment has been constructed from the bridge till the end of Lachung town. Along the right bank further downstream towards Lachung town. Landslide has been accrued during 2011 earthquake and severely affected the road. For the supply of debris from slide right bank of the river have become almost vertical. 2011 Sikkim earthquake with the magnitude of 6.9 hit Sikkim on 18th September with its epicenter located at 27.72 N, 88.06 E, near India- Nepal border about 68 km NW of Gangtok and at a focal depth of 19.7 km. as reported by USGS. Several places and town were affected badly in north and east district of Sikkim, such as Lachung, Chungthang, Mangan, Phodong, Gangtok, Dikchu, and Singtam. About 100 death and loss of property was about Rs 1 lakh crore. More than 300 landslides occurred all over the state and disturbed the road connectivity to major town like Mangan, Chungthang, Lachung and even NH31A is the main route connectivity Sikkim and West Bengal. Huge rockslide damaged several housing units in Lachung affected the Lachung river basin.



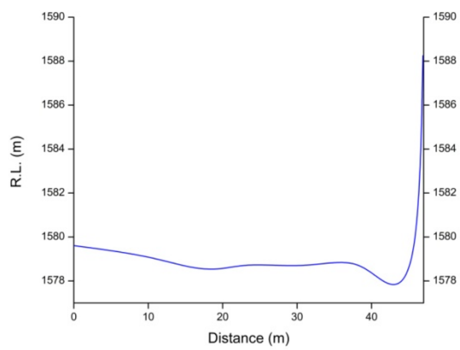
Cross-section 1



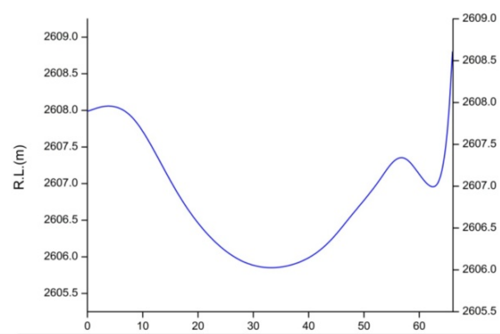
Cross-section 2



Cross-section 3



Cross-section 4



Cross-section 5

Cross Section 1:
First cross-sectionhaven been taken near the coronation bridge. Stream Width was measured with measuring tape, stretched from left to right bank. Elevation at a distance of 10 m to 20 m of the river is steep. Depth of stream is more at 30 m to 40 m, within these narrow steam velocity of the river is very high .In right bank the slope became lower but in left bank the slope is almost vertical. Altitude is 2644 m and instrument height is 1.287m.

Cross Section 2:
At 0 to 10 m the elevation of area is low and the river bed has rise. River bed is full of boulder and pebble. Depth of Stream in this section is at 60 m to 90 m. Left bank is eroded and is vertical. Altitude 2632 m and instrument height is 1.362 m.

Cross Section 3:
River bed has rise steeply from 0 to 20 m. But left bank has gradually decreased its height. Depth of the stream is maximum at 30 m to 50 m. Altitude is 2611 m and instrument height is 1.363 m.

Cross Section 4:
In this section width of the river increased and steepness in both side of bank have reduce. Depth of stream is more at 30 m to 40 m and water accumulation is more in it. Altitude of area is 2609 m and instrument height is 1.312 m.

Cross Section 5:
This cross-section was taken in the lower course of the stream near chumthang. River bed has become almost horizontal. This section is highly affected by flood and lots of debris materials carried down from the upstream is deposited here. Width of the stream increase during the monsoon period and in non monsoon period the river become very narrow.

CONCLUSION

Present study has been carried out to analyze and interpret the hydrological changes of the lower course of Lachung river basin. As the River morphology have change due physical factors and human intervention. Depth of the river has been reduced due to huge amount of sediment deposition. During monsoon period the volume of water increases. In a changing climate, river basins with limited summer precipitation but abundant snow and glacier melt-water are affected severely by reductions and seasonal alterations in annual stream flows. However, high altitude glacio-hydrological observations and investigations to address the linkage between the timing of glacier changes and river runoff fluctuations remain ambiguous, particularly in the northwestern Himalayan region. In this context, the hydrological regime of lower part of Lachung river basin have under changes due to eradicate pattern of rainfall, building of embankment, sand mining, construction of dams and barrages and roads the morphology of the river have change. Northern part of Lachung river basin, covered with snow is an important variable for fresh water availability in the dry season, particularly for the high altitude glaciated basins where it nourishes glaciers but, if it melts abruptly, then it causes natural disasters such as floods or avalanches throughout the melting process. Similarly, early melting may produce flash floods and/or seasonal shifting and low water availability in the dry season. Therefore, snow cover dynamics play a vital role in the hydrological characteristics of the basin. Towards the right bank the width of the river is narrow and landslide has occurred during 2011 earthquake and severely affected the road. For the supply of debris from slide right bank of the river have become almost vertical. Channel confluences specially for the rivers with high to very high seasonal discharge(both water and sediment), marked variation in altitudenda sudden fallofslope from mountain to plain course for manimportant component of the river systems asthey in fluence the morphology and hydrology of the reaches upstream and downstream of the confluence. The dynamic soft he confluence point saffects the availability of water in different reache sand the pattern of sediment dispersal around the confluence zone. Eroded materials from uplifted parts Lachung river basinare deposited in the down faulted epressions leading to agg radation sand shifting of rivers.

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