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An assessment of factors influencing morphometry of the Himalayan rivers Chenab and Teesta

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ABSTRACT

Water resource is rapidly falling short to meet the needs of the population worldwide. The unjust anthropogenic activities have led countries to water stressed/scarce conditions, higher number of hydrological disasters such as floods, droughts and descending levels of groundwater. Being an alpine region, the trans Himalayan region is among the most susceptible regions of the world to the climate change. In this study, the comparative morphometric assessment was made of the eastern and western regions of the alpine zones of the Himalayas. Morphometry of the river basin is a step towards water resource management which provides baseline statistical data about river water. Both river basins were compared using morphometric parameters and further on the basis of 4th order watersheds. The study revealed significant differences in both the basins where the upper Chenab basin has a comparatively higher water discharge, more powerful geological control and lesser basin lag time. The upper Teesta basin demands more management strategies to cope up with higher soil erosion and floods.

Key words : *Himalayan rivers, Chenab basin, Teesta basin, Remote Sensing and GIS*

Introduction

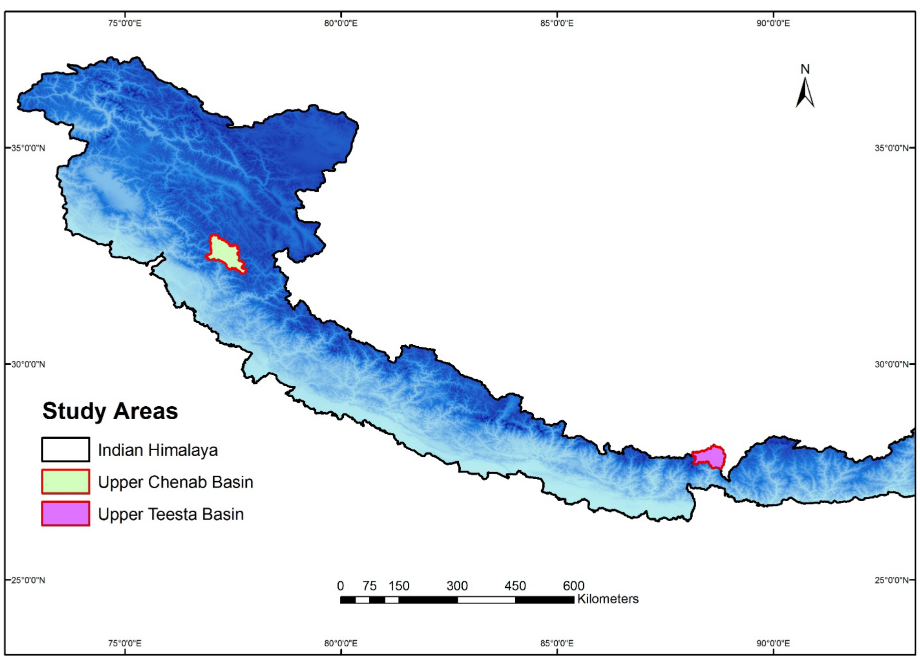
River, a simple definition would be a stream of water from a high-altitudinal source towards a low sink point, but the effects that river water leaves on the surroundings during this course are no less than magical. More often silently, then violently finding and carving its way through various topographical structures present over the earth. While some of these topographical structures are good at resisting the flow, and keep a check called geological and structural control of the basin, others are prone to the effects of flowing water and get easily washed along the course of the river. These high-altitudinal structures are usually mountain ranges from where the rivers of the world originate and however tough may these structures be, water is known to cut through even the mightiest mountains and forming huge canyons and valleys along the way by turning them into the large amount of sediment and silt which it carries along with it and deposits at the lows. It is not just the mountains which get affected by the rivers, but in a short period of time of human history, many civilizations of humans cherished along the banks of the rivers and vanished too along with the disappearance of the rivers. Rivers play a crucial role in the development of the morphology of the earth along its way. They are gentle and nurturing elements when they run silently and spread life, even around the most barren lands which it passes through and at the same time it may turn into such a fierce force which can uplift the greatest known settlements within a short period of time. Morphometric analysis of the rivers is the initial step towards understanding the possible effects and the extent of other parameters like environmental factors, underlying lithology, erosional forces, vegetation, etc. have on the rivers (Rai *et al.*, 2017). To start any study like this on the rivers one needs to start studying the basic unit, i.e. the watershed, which however can be divided into sub-watersheds of the large basin to perform the study more efficiently. These studies were initiated by R.E. Horton and A.E. Strahler in 1940s-50s (Horton, 1932; Strahler, 1957). They initiated by defining the various morphometric parameters which can be essential in understanding the fluvial process of the rivers which define the interaction of rivers with the land surfaces. After the introduction of remote sensing and GIS in past various studies have been carried out on various rivers to study and report their morphometric features (Saha *et al.*, 2016). Understanding the various morphometric features related to the shape of the basin helps to develop appropriate approaches for watershed resource management, which is the need of the hour as fresh water resources are reducing rapidly (Altaf *et al.*, 2013). Relating the morphometry with other factors such as environmental, hypsometric, vegetation distribution can help to better understand their relationships and advancing the effort for better understanding of the river system processes (Horton, 1932). In this the base line data for both the upper basins of the two rivers namely Chenab and Teesta have been generated and correlational analysis of the effect of environmental factors and hypsometry on the morphometry of river basin has been done. The information generated can be used as baseline data for future watershed management activities in these basins.

Materials and Methods

Study area

This study was an assessment of a comparative account of various parameters under study among the eastern and western river basins of the alpine zone, the study areas selected were the Upper catchments of two major rivers namely Chenab in the west and Teesta in the east region. The detail of the catchments under study is as follows:

The study was carried out for thirty-five 4th order sub-watersheds of Upper Chenab (Bhaga-Chandra) basin located at 32°.08′ N to 32°.99′ N and 76°.42′ E to 77°.42′ E in Lahaul–Spiti and Kullu district of Himachal Pradesh. Upper Chenab is the sub-basin of the Chenab basin. It lies on the northern ridge of Pir-Panjal range of the Himalayas with an elevation range between 2800 meters and 6500 meters above sea level with an average elevation of 4800 meters above sea level. The total area under study was 4123.72 km^2. Sixteen 4th order sub-watersheds of



Map 1. Study Area

Upper Teesta (Lachen-Lachung) basin are located at 27°.57′ N to 28°.12′ N and 88°.11′ E to 88°.88′ E in the North district of Sikkim. Upper Teesta is the sub-basin of Teesta basin, which rests along the north-eastern ridge of Kanchenjunga with an altitude range between 1500 m and 8118 meters above sea level with an average altitude of 4700 meters above ocean level. The total area under study was 2750.43 $km^{2.}$

Sampling

ArcGIS 10.3 was used to process the ASTER DEM (30m) data and the data for the respective study areas were extracted. The sinks in the DEM extracted area were filled and then further processed to get various maps of relief, slope and aspect. The extracted data was then used to delineate the drainage network of the study basins. From the data of elevation using minimum, mean, maximum values and the perimetric value of basins. Bioclim data was extracted for the study area and the various bioclimatic variables of temperature such as Annual Mean Temperature, Mean Temperature of Wettest Quarter, Mean Temperature of Driest Quarter, Mean Temperature of Warmest Quarter, Mean Temperature of Coldest Quarter and precipitation such as Annual Precipitation, Precipitation of Wettest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter, Precipitation of Coldest Quarter was also extracted. Data for Fresh Water Ecoregions of the World was extracted according to the areas under study. Regions of the study area were identified according to the Köppen-Geiger climate classification data. Soil maps were prepared after extracting form the Harmonized World Soil Database v 1.2 (HWSD) and variety of soil groups were accounted by using HWSD Viewer to identify them. All the permanent lakes of the regions were marked using the Google Earth High Resolution Imagery and their total area was accounted. Area under glacial and snow cover was accounted from the data. Correlation analysis was done among Morphometric, Hypsometric and Climatic variables using SPSS software.

Results and Discussion

Quantitative morphometry

Stream Order (S_O): The highest stream order of both the basins is 6 but Upper Chenab has two catchments of stream order 6 which indicates the higher discharge of sediment load in the Chenabriver. Higher stream order is associated with greater discharge, and higher velocity (Howard, 1990). According to the Horton's law of stream numbersthe total number of stream segments decreases with stream order and any deviation indicates that the terrain is typified with high relief and/or moderately steep slopes, underlain by varying lithology and probable up-lift across the basin (Costa, 1987). Here in both the basins we see a deviation from the normal distribution of stream segments with respect to the stream order and hence both the basins have probable up-lift across the basin, which falls in line with the fact that The Himalayas are still rising and both these basins lie in the Himalayan region.

Bifurcation Ratio (B_R): Here for all the catchments of both the basins the bifurcation ratios do not remain constant from one order to another which is probably because of the variation in the watershed geometry and lithology, however for all watersheds it lies in the range of 2 to 6. If the basin shows small variation in the mean bifurcation ratio for different regions on different environment, it shows that powerful geological control dominates in basin (Strahler, 1957).

Mean Bifurcation Ratio (M_{BR}): The average of all bifurcation ratio values of all orders is the mean bifurcation ratio. For sub-watersheds of the Upper Chenab basin, it was in the range of 2.58 to 5.12 and an overall value of 4.21 for the whole basin while for the sub-watersheds of the Upper Teesta basin it was in the range of 3.03 to 5.45 and an overall value of 4.48 for the whole basin. Higher mean bifurcation values are the characteristics of structurally more disturbed watersheds with a prominent distortion of

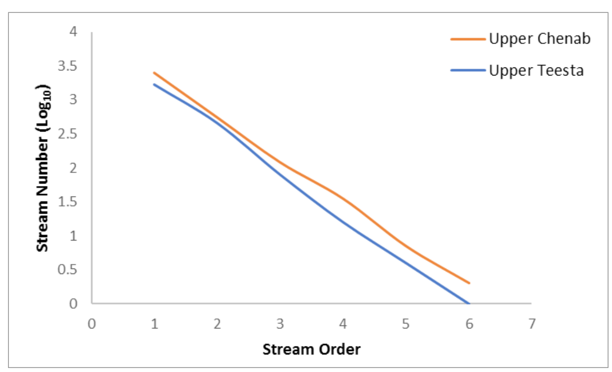


Fig. 2. Relation between stream order and stream number for Upper Chenab and Upper Teesta basin.

drainage pattern and vice versa (Strahler, 1957).

Stream Length (S_L) / Mean Stream Length (M_{SL}): Normally the total length of stream segments is the maximum in case of first order streams and it decreases as the order increases, but here we see 17 sub-watersheds out of 35 of the Upper Chenab basin and 6 sub-watersheds out of 16 of the Upper Teesta basin do not follow this distribution and hence reaffirm that the area is not underlain with uniform lithology and probably basin upliftment is going on. Also, there are more number of sub-watersheds in the Upper Chenab basin and the total stream length of all the orders of this basin is greater than the Upper Teesta basin, therefore the longer travel times (Nag, 1998) makes the former basin hydrologically very active than the latter one. Stream length showed a positive correlation with ruggedness number and mean slope while negative correlation was shown with minimum elevation in the Upper Chenab basin. It shows positive correlation with stream frequency, circularity ratio in the Upper Teesta basin.

Length of Overland Flow: Length of overland flow is a very important independent variable affecting both hydrologic and hydrographic development of drainage basins (Luo and Harlin, 2003). Here all the sub-watersheds of both basins show values ranging from 0.30 – 0.50 and the overall value for Upper Chenab basin is 4.44 while for the Upper Teesta basin it is 4.43 which indicates that both basins are nearly equally gently sloping and flow path lengths. It showed negative correlation with drainage density and stream frequency in the Upper Chenab basin and in the Upper Teesta basin negative correlation with drainage density, minimum precipitation (annual, driest quarter, wettest quarter, warmest quarter, and coldest quarter).

Hypsometric analysis

Hypsometric Index: In Upper Chenab basin, the HI values are from 4.60 to 0.63 where sub-watershed B10 has > 0.6 HI (young) and in Upper Teesta basin from 0.44 to 0.51. The HI values < 0.30 indicate old basins, 3.0 - 0.50 indicate mature and > 0.60 indicate unstable, actively uplifting basin (Altýn and Altýn, 2011). Here the Upper Chenab basin (HI=0.52) and Upper Teesta basin (HI=4.92) both are mature basin. It showed negative correlation with Maximum elevation in the Upper Chenab basin and in the Upper Teesta basin positive correlation with circulatory ratio.

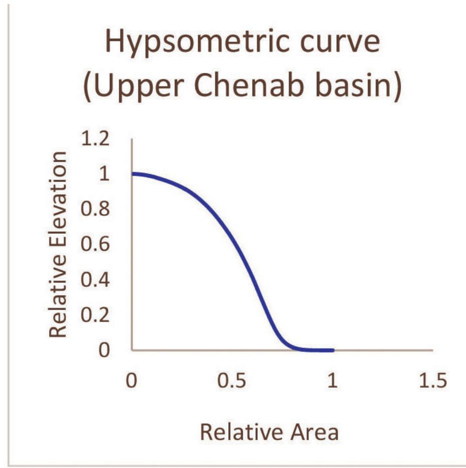


Fig. 3(a). Upper Chenab basin

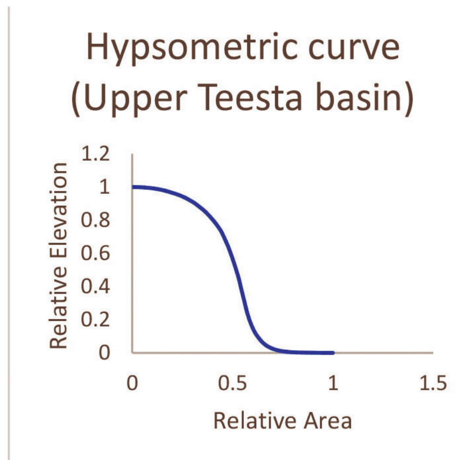


Fig. 3(b). Upper Teesta basin

Hypsometric Curves: Two types of Hypsometric Curves are obtained plotting the relative area of the basin against relative elevation of the basin i.e. Convex for young basin and Concave for old basin (Demoulin, 2011). The hypsometric curves for Upper Chenab basin and Upper Teesta basins areas are both sigmoid shape indicating that these are mature basins as shown above.

Conclusion

Both the basins upper Chenab and upper Teesta are undergoing probable upliftment which is further strengthened by the fact that the Himalayas are rising range of mountains and both these basins area located in the Himalayan region. The Upper Chenab basin has higher discharge than the Upper Teesta basin. The inference from the values of bifurcation ratio comes out to be that there is a more powerful geological control existing in the Upper Chenab basin than the Upper Teesta basin also, the Upper Chenab basin is structurally less disturbed and hydrologically more active than the Upper Teesta basin. Some similarities were also noted among the two basins as both the basins have gentle slopes, have fine coarse drainage texture, are oval in shape, are mature basins, have shorter time lags due to low relief and impermeable surface but comparatively the Upper Chenab basin has lesser basin lag time than the Upper Teesta basin. The intensity of erosion in the Upper Teesta basin is little higher than the Upper Chenab basin. This comparative study clearly indicates that among the basins Upper Chenab basin has higher chances of floods as it has higher discharge, is hydrologically more active and have shorter time lag for peak flow under the similar environmental and vegetational conditions and will need more management in case of adverse conditions whereas the Upper Teesta basin has higher erosional intensity and it needs more management in handling the higher sediment load this river will pass down.

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