MORPHOMETRIC ANALYSIS OF KOSI RIVER SUB WATERSHED IN RAMNAGAR, UTTARAKHAND USING GIS AND REMOTE SENSING TECHNIQUES

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ABSTRACT

Evaluation of morphometric characteristics of watershed is the fundamental requirement for sustainable planning and development of its resources. Quantitative morphometric characteristics (viz. linear, relief and aerial) of Kosi river sub watershed in Ramnagar, Uttarakhand are evaluated by utilizing Cartosat-1 Digital Elevation Model (Carto DEM) with 30 meter resolution downloaded from BHUVAN (ISRO'S GEOPORTAL) using Arc Hydro tools in Arc GIS 9.3 software. Drainage map of the study area prepared reveals a dendritic drainage pattern with sixth order stream network comprising of a total of 315 numbers of streams. The length of the major sixth order stream of the sub watershed is 4.78 km. The average bifurcation ratio of the basin is 3.2 which is indicative of the fact that the drainage pattern is not influenced by the geological evolutions and disturbances in the recent past. The drainage density of 1.15 km/km^2 indicates impermeable subsoil material with dense vegetative cover and moderate mountainous relief with low infiltration. The elongation ratio of 0.62 infers that the basin is closer to a circular shape. In all, a total of 21 morphometric parameters including all aspects of the sub watershed have been evaluated and discussed in the present study. Hence, the study concludes that GIS techniques prove to be a competent tool in morphometric analysis which is further useful for planning rainwater harvesting and watershed management.

Keywords: *Morphometric analysis, Drainage characteristics, GIS and Remote Sensing, Aerial, Linear, Relief aspects*

I. INTRODUCTION

Watershed morphometric analysis provides the necessary parameters for the assessment of the ground water potential zones, identification of areas for implementation of water harvesting structures, water resource planning and management, surface runoff characteristics of the drainage system etc. In other words, morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect for the characterization of watersheds through the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms ([1],[2]). Morphometric analysis requires measurement of linear features, aerial aspects and gradient of channel network of the drainage basin ([3]).

Watershed characterisation for drainage networks can be achieved using traditional methods such as field observations and topographic maps or alternatively with advanced techniques using remote sensing and GIS ([4], [5]). In conventional methods, it is very tedious to evaluate the entire drainage network of the watershed from field observations due to their extent throughout the undulating terrain dispersed over vast areas. Morphometric analysis of many river basins and sub basins in different parts of the globe has been studied using conventional methods ([6]). However GIS technique has emerged as a potential tool in recent years for conveniently evaluating drainage characteristics. In Indian perspective, some of the recent studies on morphometric analysis using remote sensing and GIS technique have been carried out by Nautiyal ([3]), Srivastava ([7]), Nag ([8]), Kumar *et al.* ([9]), Mittal ([10]), Pareta ([11]), Srinivasa *et al.* ([12]) and Chopra *et al.* ([13]). More recently, Sharma *et al*. ([14]), Shakil ([15]), Magesh *et al.* ([16]) to name a few. Evaluation of morphometric parameters necessitates the analysis of various drainage parameters such as ordering of various streams, measurement of basin area and perimeter, length of drainage channels, drainage density, stream frequency, bifurcation ratio, basin relief and ruggedness number. In the present study, the remote sensing and GIS techniques have been implemented to work out the detailed quantitative analysis of morphometric parameters of Kosi river basin in the Ramnagar district, Uttarakhand and inferences are drawn to assess the behaviour of the study region towards varying climatic, hydrologic and lithological conditions.

II. STUDY AREA

The kosi river catchment flowing through Ramnagar district of Uttarakhand state having an area of 1050 sq km and partially covering the forest area of Jim Corbet National Park has been selected as the study area as shown in Fig 1.
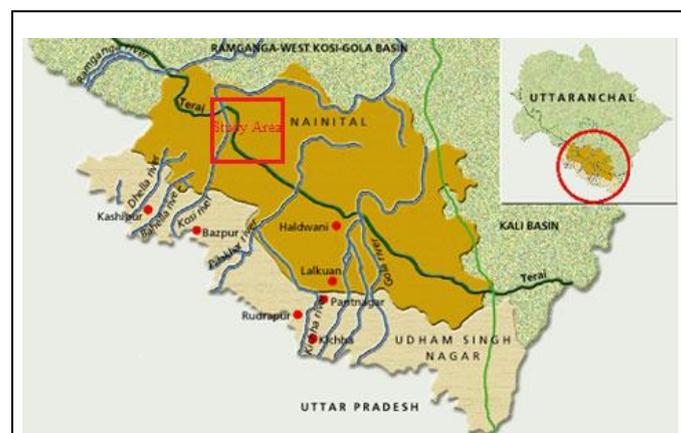

Fig. 1   Location of the Kosi river catchment with square box indicating the study area.

Kosi river originates from village Budha Peenath of Kausani region of district Almora, Uttarakhand. After traveling a distance of about 100 km in lower Himalayas with higher velocity, it emerges at Ramnagar district in Indo-Gangetic Plains, after which the velocity reduces considerably. After Ramnagar, it flows through the

famous rice-belt area of Kashipur, where a number of polluting industries discharge their highly polluted effluent into it. The study area is located between the longitude 79°10' to 79°38' N and latitude 29°32' to 29°50' E. Despite several geo-environmental constraints, the catchment has not escaped anthropogenic impacts, which continue to multiply with increasing pressure of population. The environmental impacts of the resource development process are therefore, of special significance in this ecologically sensitive mountain region where the steepness of slope and high rainfall, increases the susceptibility of the region to a variety of environmental hazards and natural risks. The terrain of the study area is hilly and undulating consisting of a number of ridges and valleys. The general climate of the area is tropical with four distinct seasons i.e. summer, monsoon post-monsoon and winter. May and June are the hottest months with day temperature rising as high as 43^0 C. The average annual rainfall in the area is 250 mm but, there is very high variability of rainfall within the area. The altitude of study area ranges from 300 m in southern part to 1205 m in north-eastern part.

III. METHODOLOGY

Quantitative morphometric analysis has been carried out by integrating remote Sensing data and GIS tools and correlating the basin characteristics with basin hydrology. Cartosat-1 Digital Elevation Model (Carto DEM) of October 2012 with 30 meter resolution downloaded in four tiles from BHUVAN (ISRO'S web GEOPORTAL) has been processed using Arc Hydro tools in Arc GIS 9.3 software. Subset image or sub watershed pertaining to the study area has been delineated which is then processed for the generation of flow direction, flow accumulation and finally drainage network map (Fig. 2) for evaluation and interpretation of the basin as well as stream characteristics. Basin perimeter and area are calculated and cross checked from the online measurement tool and satellite imagery available on Bhuvan webpage by overlaying the shape file of the study area.
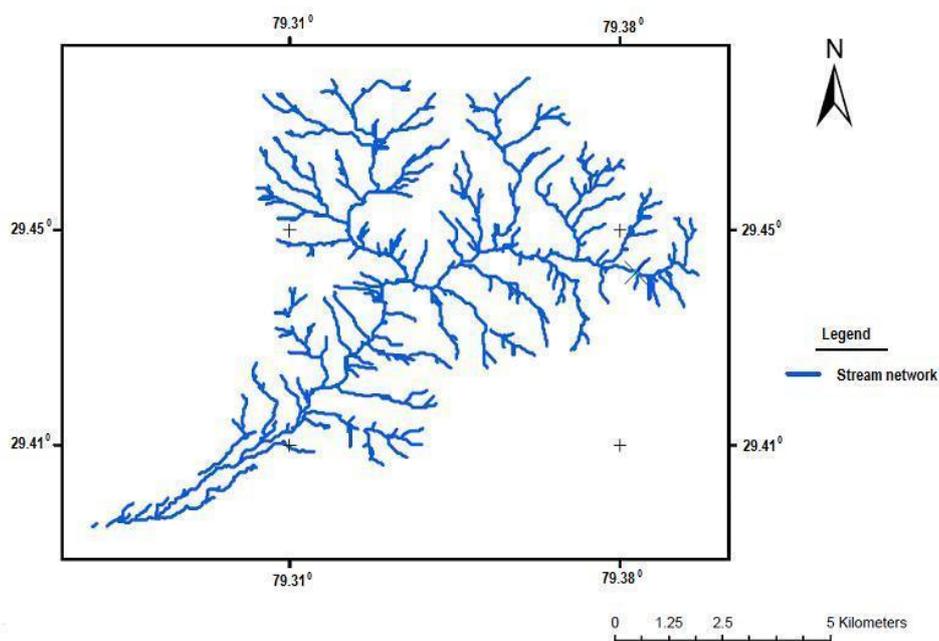

Fig. 2   Drainage network map of the study area (Kosi river sub watershed).

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IV. RESULTS AND DISCUSSION

The first step in the quantitative analysis of drainage basin is the designation of stream order to the drainage network. The term "stream order" is a measure of the position of a stream in the hierarchy of tributaries. In the present study, the channel segments are being ranked according to Strahler's stream ordering system i.e. the 1st order streams are the one having no tributaries. The 2nd order streams have tributaries only of 1st order streams, where two 2nd order channels join a segment of 3rd order and so on. From the drainage map of the study area, a dendritic drainage pattern is identified with sixth order stream network as shown in Fig. 3.
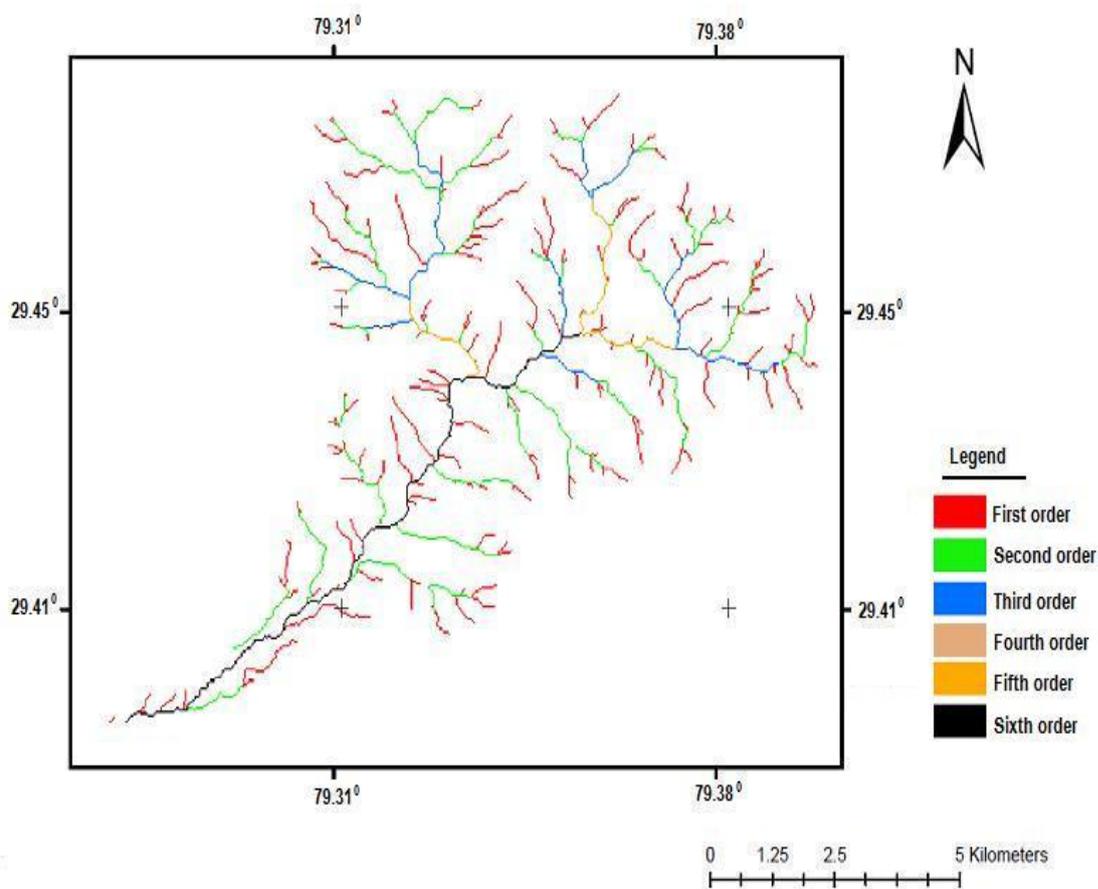

Fig. 3   Pattern of stream ordering of the study area (Kosi river sub watershed).

In all 21 morphometric parameters are computed in the present study which include linear, aerial and relief parameters such as stream order, stream length, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, relief ratio and ruggedness number etc . The input parameters for the present study such as area, perimeter, elevation, stream length etc. are obtained from digitized coverage of drainage network map in GIS environment and the values are presented in the Table 1.

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Table 1. Morphometric parameters of Kosi river basin

S. No.	Morphometric Parameters	Formulas	Obtained Values	References
1	Basin Area, km^2	Total Basin Area (A)	83.81	[17]
2	Basin Perimeter, km	Length of watershed divide which surround the basin (P)	64.66	[17]
3	Length of the basin, km	Distance between outlet and farthest point on basin boundary (L_b)	19.22	[17]
4	Drainage density, km/km^2	D_d= L/A Where, L=Total length of streams, A= Area of basin	1.15	[17]
5	Total Number of Stream (N_u)	Hierarchical order	315	[1]
6	Stream Length (L_i)	Total Length of the stream (Km)	96.46	[17]
7	Mean Stream Length (L_{sm})	$L_{sm}=L_u/N_i$; Where, L_i=Total stream length of a given order, N_i=Number of stream of next order	13.67	[17]
8	Stream length Ratio (R_L)	$R_L= L_i/ L_{i-1}$ Where, L_i= Total stream length of order (u), L_{i-1}= total stream length of next lower order	0.74	[17]
9	Bifurcation ratio (R_b)	$R_b = N_i/ N_{i+1}$ Where, N_i=Number of streams present in given order, N_{i+1}= total streams of next order	3.2	[17]
10	Stream Frequency (F_s)	$F_s = \Sigma N_i/A$, Where, N_i= number of stream segments of	3.76	[17]
11	Length of overland flow	$L_o=1/(2 \times D_d)$ Where, D_d is Drainage density	0.43	[17]
12	Form factor	$R_f=A/(L_b)^2$ Where, L_b=Basin length	0.23	[17]
13	Elongation ratio	$R_e=\sqrt{(2/ L_b) \times (A/\pi)}$	0.54	[20]
14	Circularity ratio	$R_c=2\pi (A/P^2)$	0.67	[21]
15	Compactness constant (C_c)	$C_c = 0.2821 \times P/ A^{0.5}$	1.99	[17]
16	Texture ratio	$T=N_1/P$ Where, N_1=Total number of first order stream	3.79	[17]
17	Infiltration Number (I_f)	$I_f = F_s \times D_d$	4.33	[22]
18	Relative relief (R_R)	$R_R = H \times P$ Where, H = Watershed relief,	13.91	[23]
19	Relief ratio (R_r)	$R_r = H/L_b$	0.011	[1]
20	Ruggedness number (R_N)	$R_N = H \times D_d$	0.247	[23]
21	Constant of channel	C=1/D, D=Drainage Density,km/km^2	0.87	[24]

4.1 Linear aspects of the study area

The linear aspects of a channel system deal with the quantitative analysis of landform in a watershed area, where the surface runoff flowing over a long period of time tends to modify the surface geometry of the area (Horton, [17]). Linear aspects of channel system include plani-metric measurements that are projected upon a horizontal datum plane and are discussed in the subsequent sections.

Stream ordering in accordance to Strahler ([1]) is allocated to the drainage network map which revealed the stream network of the study area to be of sixth order. The total number of first order streams are evaluated as 245, 49 second order streams, 14 third order streams, 4 fourth order streams, 2 fifth order and 1 sixth order stream. The computed value of the mean bifurcation ratio for the present basin is found to be 3.2 which is fairly high and indicates that the drainage pattern is not influenced by the geological conditions.

To obtain the mean length of channel L_i of order i, the total length of streams of that order is divided by the number of streams N_i of the same order. The total length tends to decrease with the increase of stream order, while the mean length tends to increase with the increase in stream order. The total length of the first, second, third, fourth, fifth and sixth order streams are 49.57 km, 12.68 km, 7.91 km, 11.61 km, 9.91 km and 4.78 km, respectively. The mean length of the streams from lower to higher order is obtained as 0.202 km, 0.259 km, 0.565 km, 2.91 km, 4.955 km and 4,781 km, respectively. Results indicate that the total length of stream increases with decrease of the stream order and average length of the stream increases with increase in the stream order.

The length of overland flow affects both the hydrologic and physiographic development of drainage basins (Horton, [17]). During the evolution of the drainage system, length of overland flow is adjusted to a magnitude appropriate to the scale of the first order drainage basins and is approximately equal to one half the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams. The length of overland flow for the present study area is 0.43 km and is associated with moderate runoff and fairly high infiltration.

4.2 Areal aspects of the study area

Areal aspects of drainage basin include measurement of areal elements such as basin, area, basin length, basin perimeter, shape, drainage density, constant of channel maintenance, stream frequency, form factor, circulatory ratio, elongation ratio, compactness constant, Infiltration Number, and texture ratio in a systematic way and are illustrated in Table 1. The total area of the basin selected under the present study is 83.81 km^2, whereas the basin perimeter computed is 64.66 km. The values of form factor (R_f), circulatory ratio (R_c) and elongation ratio (R_e) are 0.23, 0.67 and 0.54 respectively. The high value of circulatory ratio as compared to the elongation ratio indicates that the study area is approaching towards the circulatory shape (Singh *et al.,* [18]). Also, the low value of form factor signifies that the watershed has a shorter lag time and a higher peak flow. Flood peaks of such circulatory basins finds tough to manage as compared to elongated watershed (Pandey *et al.,* [19]).

The drainage density is an indicator of quantitative measure of the average length of stream channel to the area of the watershed and therefore, provides at least some indication of the drainage efficiency of the basin. Further, it gives an idea about the physiographical properties of the underlying soils. Low value of drainage density D_d is an indication of the region having permeable subsoil material under vegetative cover and it also indicates the watershed has low relief (Strahler, [1]). The drainage density of the study basin is 1.15 km/km^2 which is low and indicates that the area has highly resistant or highly permeable sub-soil material. The constant of channel maintenance which is indicative area of the basin surface needed to sustain unit length of stream channel was found to be 0.87 sq km/ km for the study area which is an indication of the number of square km of basin area required to sustain one linear kilometre of channel.

Horton ([17]) defines drainage texture or texture ratio as the total number of segments of all order per perimeter of that area. Schumm ([20]) classified drainage density into five different textures. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage. On the basis of this classification, the texture ratio (R_t) for Kosi basin study area is computed as 3.79, which falls under coarse to very coarse drainage texture. The compactness coefficient is independent of size of watershed and dependent only on the slope. The compactness coefficient of the study area is 1.99.

4.3 Relief aspects of the study area

Relief aspects are an important factor in understanding the extent of denudational process undergone within the watershed and an indicator of flow direction of runoff. The relief (H) of the study area is 215 m from which Relative relief (R_R), Relief ratio (R_r) and Ruggedness number (R_N) are calculated as 13.91, 0.011 and 0.247 respectively, thereby indicating the relief of the study area having moderate slope. Also, the low ruggedness value of the area reflects that it is less prone to soil erosion and comprises of moderate to thick vegetal cover. Plot of logarithm of number of streams against stream order is plotted as shown in Fig. 4, which reveals a linear relationship having $R^2 = 0.974$, satisfying the Horton's law i.e. the number of streams decreases in geometric progression as the stream order increases.
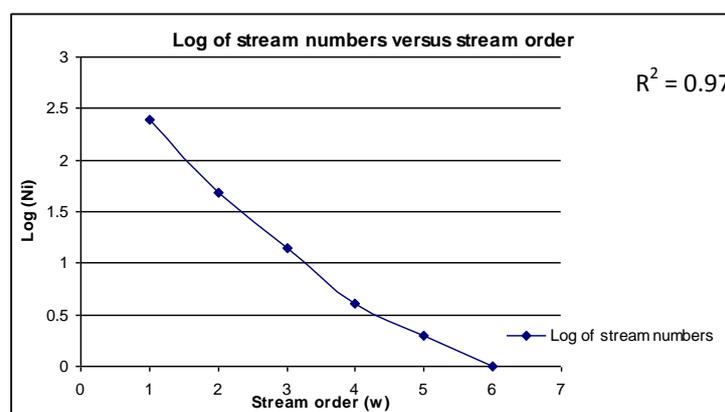

Fig. 4   Plot between stream order and logarithm of stream number.

Also, a plot of logarithm of stream length versus stream order is plotted which again reveals a linear relationship as shown in Fig. 5, with $R^2 = 0.76$, thereby indicating the existence of geometric progression between stream length and stream order as per Horton ([17]).
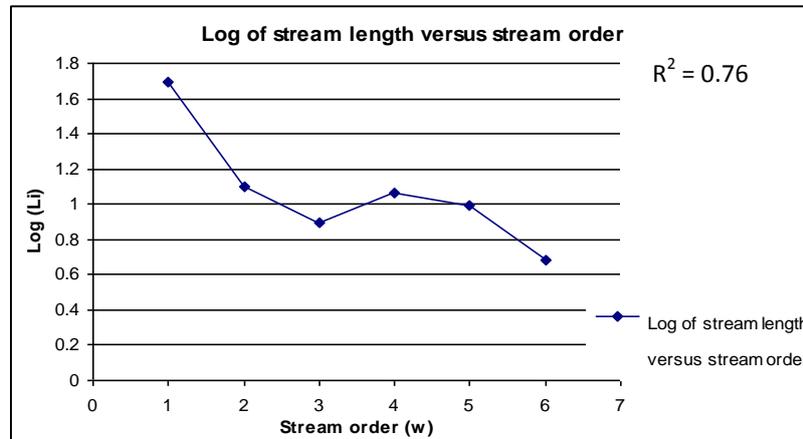

Fig. 5   Plot between stream order and logarithm of stream length.

V. CONCLUSIONS

Quantitative analysis of morphometric parameters of Kosi river sub watershed has been car ried out using CartoSat-1 DEM in GIS framework. Results from the analysis indicates that the shape of the sub watershed approaches towards circulatory and having low drainage density, moderate relief ratio and fairly high infiltration rate. The bifurcation ratio lying within the range of 3.0 to 6.0 (i.e. $R_b = 3.2$ for the present study) infers that the study area has suffered less geological disturbance. Also, the low ruggedness value of the area (viz. 0.247) reflects that it is less prone to soil erosion and comprises of moderate to thick vegetal cover with moderate land gradient. Plots of stream order versus stream number and stream length indicates the existence of geometric progression thereby satisfying Horton's law of stream numbers and lengths respectively. Results reported in the study shall further be useful in developing functional relationships between morphometric parameters and hydrological variables. Similar studies in conjunction with high resolution satellite data help in better understanding the landforms and their processes and drainage pattern demarcations for watershed level planning and management and efficiently installing rain water harvesting systems.

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