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Prioritization based on Morphometric Analysis in Alaknanda Basin

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PRIORITIZATIONBASEDONMORPHOMETRICANALYSISINALAKNANDABASIN

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I. Introduction

All economies are facing a basic problem that is scarcity of resources. Along with scarcity of resources unlimited human wants is reason for diminishing resources. Scarcity is the situation in which resources are insufficient to meet the human wants. This state of affairs calls for economizing of resources i.e., making optimum use of available resources and allocation of resources i.e., assigning scarce resources in such a manner so that maximum wants of the society are fulfilled. This makes the scenario clear that for sustainable development we need to conserve, economize, allocate and manage resources appropriately. Land and water resources are the prime resources which forms the basis for others, so in this study our spotlight will be the same, and thus watershed is the ideal unit for the management of these. A watershed is a hydrological facet which generates runoff by itself as a product of precipitation. Though, the runoff hose down depends upon morphology of the watershed. Morphometric analysis of drainages is an important feature for categorization of watershed. The major objectives of the study include morphometric analysis and prioritization of sub-watersheds for Alaknanda river basin of Uttarakhand state of India using remote Sensing and GIS techniques.

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II. Study Area

The Alaknanda Basin is extended between 30.0˚N to 31.0˚N and 78.45˚E to 80.0˚E, encompasses an area about 10882 Km², and represents the eastern part of the Garhwal Himalaya. Out of the total area of the basin, 433 km² is under glacier landscape and rest of 288 km² is under fluvial landscape. The total number of villages is approximately 2310. The land under agriculture is 644.22 Km², which is 5.9 percent of the total geographical area while only 64.8 Km² (0.6%) land is under the horticultural crops. The study area involves seven districts, Uttarkashi, Rudraprayag, Chamoli, Bageshwar, Pithoragarh, Tehri Garhwal and Pauri Garhwal.

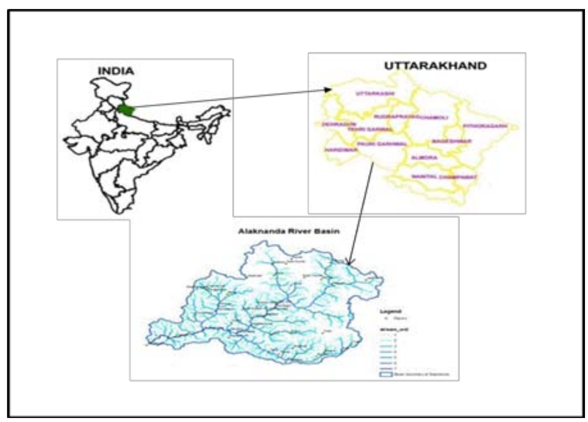

Figure 1

III. Materials and Software Used

Remote sensing technique with visual interpretation approach was adopted for creation of various thematic maps. Morphometric analysis requires delineation of all drainage network which is achieved in GIS environment using ASTER 30 m DEM. Stream order upto 7th have been delineated for the study. Calculation of the basic parameters (i.e., area, perimeter, stream order, stream length and stream number) of each sub-watershed analysis is carried out separately using the Remote sensing & GIS approach. Other parameters like bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio and compactness ratio have been computed with the help of standard formulae suggested by (Horton, 1945), (Strahler, 1964), (Schumm, 1956), (Nookaratnam et al., 2005) and (Miller, 1953) given in the table 1.

Table 1: Morphometric Parameters

Morphometric	Parameters	Formula Reference
Stream order	Hierarchical rank	Strahler (1964)
Stream length (Lu)	Length of the stream	Horton (1945)
Mean stream length (Lsm)	Lsm = Lu / Nu where Lu = Total stream length of order 'u' Nu = Total number of stream segments of order 'u'	Strahler (1964)
Stream length ratio (Rl)	Rl = Lu / Lu1 where Lu = Total stream length of order 'u' Lu1 = The total stream length of its next lower order	Horton (1945)
Bifurcation ratio (R_b)	Rb = N_u/N_{u+1} Where N_u = Total no. of stream segment of order 'u' N_{u+1} = Number of segment of the next higher order	Schumm (1956)
Drainage density (D_d)	$D_d = L_u/A$ Where D_d = drainage density, L_u = total stream length of all orders & A = area of the basin,(km^2)	Horton (1945)
Stream frequency (F_s)	F_s N_u/A Where F_s = Stream frequency, N_u = total number of streams of all orders & A = area of the basin,(km^2)	Horton (1945)
Circulatory ratio (R_c)	$R_c = 4 * TT * A/P^2$ WhereR$_c$ = circularity Ratio, TT= TT value i.e., 3.141, A = area of the basin, km² & P^2 = square of the perimeter, km	Miller(1953)
Elongation ratio (R_c)	R_c $(4*A/TT)^{0.5}/L_b$ Where R_c = elongation ratio, A = area of the basin, km^2, TT = TTvalue i.e., 3.141 & L_b = basin length, km	Miller (1953)
Form factor (F_f)	$F_f = A/L_b^2$ Where F_f form factor, A = area of the basin, km^2 L_b = basin length	Schumm (1956)
Drainage texture (T)	$T = N_u/P$ Where N_u = total no. of streams of all orders P = basin perimeter, km	Horton (1945)
Compactness constant (C_c)	$C_c = 0.2821\ P/A^{0.5}$ Where C_c = Compactness Ratio A = Area of the basin, km^2 P = basin perimeter , km	Horton (1945)

IV. Methodology

The step wise methodology is as follows:

1. Drainage has been digitized individually as separate segments for each stream order.
2. Delineation of basin, sub-watershed and micro-watershed has been done in Arc GIS environment.
3. Calculation of number and length of streams of every order for each sub-watershed have been done.
4. Computation of all eight Morphometric parameters.
5. Linear parameters are directly proportional to erodibility whereas shape parameters are indirectly linked, hence priority is marked accordingly.
6. All parameters are assumed to have equal weights. The average rank for all sub-watersheds is computed. Final rank has been assigned in ascending manner.

V. Results and Discussion

Morphometric parameters are significant and useful to identify a variety of hydraulic characteristics of drainage basin, i.e., shape, stage of stream, permeability of bed rock, health of streams, as well as help to compare with lithological distinctiveness (Yadav et al. 2014). In the present study, morphometric analysis of the parameters, such as stream order, stream length, bifurcation ratio, drainage density, stream frequency, circulatory ratio, form factor, elongation ratio, texture ratio, compactness coefficient and area, perimeter, basin length, number of stream and total stream length of the twenty two sub-watersheds has been conceded out using the mathematical equation and their results are précised in below tables.

a) Stream order

The ‘‘stream ordering’’ is the initial step of morphometric analysis which is based on the delineated streams and their branching proposed by (Strahler 1964). Table 2 points out that there are twenty two sub-watersheds, out of these three sub-watersheds are seventh ordered (SWS-6, SWS-13, SWS-21), one fourth ordered sub-watershed i.e., SW-2, out of remaining eighteen, nine are fifth ordered (SWS-3, SWS-4, SWS-5, SWS-7, SWS-8, SWS-11, SWS-14, SWS-18, SWS-22) and rest are sixth ordered (SWS-1, SWS-2, SWS-9, SWS-10, SWS-12, SWS-15, SWS-16, SWS-17, SWS-19) sub-watershed.

b) Stream length

According to Horton’s second law (1945), the stream length characteristics of the sub-watersheds authenticate the ‘‘laws of stream length’’, which affirm that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio (Horton 1945).

In general, logarithms of the number of streams of a given order, when plotted against the order, the points lie on a straight line (Horton 1945). Most drainage networks show a linear relationship with a small deviation from a straight line (Chow 1964). Generally, the total length of different order streams decreases with stream order. Deviation from its common behavior indicates that the terrain is characterized by high relief and/or moderately steep slopes, underlain by varying lithology and probable uplift across the basin (Singh and Singh 1997). The values of stream length according to their orders are shown in Table 2.

c) Stream length ratio

Stream length ratio (SLR) is the ratio of the mean length of the one order to the next lower order of the stream segments. All the values of stream length ratio are presented in table 2.

d) Bifurcation ratio

The bifurcation ratio imitates the geological as well as tectonic characteristics of the watershed (Gajbhiye et al. 2014). Lower value of Rb indicates the partially disturbed watershed without any distortion in drainage pattern (Nag 1998). In this particular area, the value of mean bifurcation ratio varies between 1.764 and 9.96.

e) Stream frequency

It is also known as drainage frequency or channel frequency; it is directly related to stream population per unit area of the watershed (Horton 1932). It point to the close correlation with drainage density value of the sub-watershed. Stream frequency of the all sub-watershed can be reviewed from Table 3. Higher value of stream frequency shows the high runoff. In this study, SW-12 formed more runoff as compared to other sub-watersheds; however, values vary from 5.785 to 6.665.

f) Drainage Density

Drainage density relies upon both climate & physical characteristics of the watershed. It is a basic length scale in the landscape, which is renowned to be the transition point between scales where unstable channel forming processes capitulate to stable diffusive processes (Tarboton et al. 1992). Drainage density is influenced by a variety of factors, among which resistance to erosion of rocks, infiltration capacity of the land and climatic conditions ranks high (Verstappen 1983). As per Langbein (1947) theory, the significance of drainage density is a factor which determines the time of travel by water within the watershed. In this study area, drainage density of sub-watersheds varies from 0.453 to 1.723.

g) Circulatory ratio

Circulatory ratio (Rc) is prejudiced by the length and frequency of the stream, geological structures, land use land/cover (LULC), climatic variability, relief and slope of the sub-watersheds (Patel et al. 2013). In this area, circulatory ratio ranges from 0.265 to 0.614.

h) Form factor

The smaller value of the form factor shows maximum elongation of the basin whereas the high value of form factor illustrate high peak in short duration and vice versa. In this study area, the value of form factor varies between 0.161& 2.333 (given in table 3), which demonstrates that the SW-17 is most elongated.

i) Elongation ratio

The values of elongation ratio can be grouped into three categories, namely circular (<0.9), oval (0.9–0.8) and less elongated (>0.7). In the Alaknanda basin, elongation ratio varies between 0.453 (SW-17) and 1.723 (SW-14).

j) Texture ratio

Texture ratio depends upon properties of lithology of the basin, infiltration of the soil and relief aspect of the terrain (Vijith and Satheesh 2006). In this area, the texture ratio of the sub-watersheds lies between 10.261and 53.411. The lower values of texture ratio show that the basin is plain with lower degree of slopes and vice versa.

k) Compactness Constant

A circular shaped watershed is the most risky from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin (Ratnam et al. 2005; Javed et al. 2009). Its values range from 1.275 to 1.939.

l) Prioritization of sub-watersheds

On the basis of above mentioned 22 watersheds analysis using morphometric parameters, prioritization is accomplished of Alaknanda Basin. Drainage prototype of watershed refers to geospatial association among the streams and its slope, soil type, rock resistance, structural and geological status of the basin. The study lays emphasis on the prioritization of the sub-watersheds on the basis of morphometric analysis.

The final score of entire twenty two sub-watersheds and their ranking are shown in Table 4. High priority indicates the higher degree of erosion at specific sub-watershed. therefore, it is necessary to improve the soil conservation measures according to the priority scores. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility, higher the value, more is the erodibility. Hence for prioritization of sub-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility (Nooka Ratnam et al., 2005), lower the value, more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. The prioritization was carried out by assigning ranks to the individual indicators and a compound value (Cp) was calculated. Watersheds with highest Cp were of low priority while those with lowest Cp were of high priority.

The sub-watersheds has been categorized into nine classes as extremely very high, extremely high, very high, high, medium, low, very low, extremely low & extremely very low. To archive for management point of view, the conservation practices or measures are suggested as per their final priority.

VI. Conclusions

The quantitative morphometric analysis was completed for twenty two sub-watersheds of Alaknanda basin using the remote sensing and GIS techniques. Landscape morphology is a utility of drainage, climate, and structure of a particular basin region. The present paper has demonstrated morphometric analysis based on numerous drainage parameters. The drainage density values of entire twenty two sub-watersheds are below 5 enlightening that the subsurface strata are permeable, and characteristic feature is coarse. The linear aspects, i.e., stream order, bifurcation ratio, stream length and aerial aspects such as drainage density (Dd), stream frequency (Fs), form factor (Rf), circulatory ratio (Rc) and elongation ratio (Re) have been carried out on the foundation of soil erosion. The usual methods of morphometric analysis are time consuming and error prone, so in its place GIS technique has been used for more consistent and accurate judgment of similar parameters of watersheds. However, geological field authentication also agrees with the present morphological-based prioritization. The morphometric analysis of twenty two sub-watersheds shows the dendritic drainage pattern and the variation in stream ratio is due to changes in slope as well as topographic features of the area. It was found that the SWS-13, SWS-19 and SWS-21 shows very higher erosion and soil loss-prone areas. Hence, immediate soil erosion control measures are required in these sub-watersheds to safeguard the land from further erosion. Higher runoff might also affect the sediment per unit volume. The deviation in bifurcation ratio among the sub-watersheds is described to the difference in topography and geometric development. The stream frequencies for all sub-watersheds of the region exhibits direct proportionality with the drainage density values indicating the increase in stream population with respect to increase in drainage density. Drainage density is very coarse to coarse texture. Elongation ratio shows that particular sub- watershed possesses circular shape, while the remaining marks elongated pattern. The present study is important for erosion control, watershed management, land and water resources planning and future potential related to runoff study.

Figure 2: Final priority map of Alaknanda Basin

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