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## Morphometric analysis and prioritization of Garud watershed using remote sensing and GIS technology

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### Abstract

The quantitative analysis of morphometric parameters is found to be of immense utility in watershed prioritization for soil and water conservation and natural resources management at micro level. The present work is an attempt to carry out a detailed study of linear and shape morphometric parameters in four watersheds of Garud Catchment and their prioritization for soil and water resource management. The study area (Garud watershed) is located at Garud (Bajjnath), on Kausani-Bajjnath-Bageshwar route, near Bajjnath Temple in Bageshwar district of Uttarakhand state. The watershed drains into Gomti river at Garud (Bajjnath) and lies between 29°54'12" to 29°89'78" N latitude and 79°36'43" to 79°61'68" E longitude with 604 ha (6.04 km<sup>2</sup>) geographical area. The elevation varied from 1086 to 1700 m above mean sea level (msl). Topographic map (53 O/9) of 1964 on 1:50000 scale was utilized to delineate the basin boundary and drainage pattern was extracted from Digital Elevation Model (DEM), thus to identify precisely basin characteristics using Geographic Information System (GIS).

According to Strahler's system of stream ordering, the natural drainage system of watershed was classified and the main stream was found as 4<sup>th</sup> order stream. It showed that, the maximum frequency in case of first order stream was 34 and that for second, third and fourth order streams was found to be 8, 2 and 1, respectively. The stream length ratio ( $R_L$ ) was estimated to be 0.28 and 1.31 for II/I and III/II orders, respectively. The increasing trend in  $R_L$  from lower order to higher order indicated matured geomorphic stage and change from one order to another order in stream length ratio indicated late youth stage of geomorphic development of streams. In the present study, bifurcation ratio ( $R_b$ ) varied from 2.0 to 4.25 with an average of 3.42, which indicates that the value of  $R_b$  was not the same from one order to next order. The higher value of  $R_b$  indicated strong structural control on the drainage pattern. This showed its usefulness for hydrograph shape for watersheds similar in other respect. The bifurcation ratio between first and second order streams indicated the nature of head ward erosion. In the present case, the head ward erosion was moderate as bifurcation ratio was 4.25. The drainage density was found to be 3.48 km/km<sup>2</sup>. Lower drainage density of the basin (3.48 km/km<sup>2</sup>) indicates towards coarse drainage pattern. The coarse texture gives more time for overland flow and hence to ground water recharge. The circulatory ratio ( $R_c$ ), elongation ratio ( $R_e$ ) and form factor ( $R_f$ ) was estimated to be 0.45, 0.60 and 0.28 respectively, indicating them to be elongated in shape and suggesting flatter peak flow for longer duration. In sub-watershed GR-3 the stream length followed Horton's law. But in sub-watersheds GR-1, GR-2 and GR-4, the stream segments of various orders showed variation from general observation. This change may indicate flowing of streams from high altitude, litho logical variations and moderately steep slopes. The stream length ratio between different sub-watersheds showed an increasing trend from lower order to higher order indicating their mature geomorphic stage in sub-watersheds. The prioritization was carried out by assigning ranks to the individual indicators and a compound value ( $C_p$ ) was calculated. Watersheds with highest  $C_p$  were of low priority while those with lowest  $C_p$  were of high priority. Sub-watershed GR-4 with a compound parameter value of 2.22 received the highest priority, which consists of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio and the sub-watersheds GR-1 and GR-2 both have same  $C_p$  value as 2.55 received second priority. The sub-watershed GR-3 had highest  $C_p$  value as 2.67 received last priority. Highest priority indicated the greater degree of erosion in the particular sub-watershed and it became potential area for applying soil conservation measures. Thus soil conservation measures can first be applied to sub-watershed GR-4 and then to the other sub-watersheds depending upon their priority.

**Keywords:** Morphometric, prioritization, Garud, technology

### 1. Introduction

In the context of growing population and ever increasing demand for more food grain production, constrained by the finite and limited available land and water resources, the emphasis is on raising productivity of the land, both by intensifying the land use and by increasing crop yield per unit area. This calls for intensive agriculture based land and water management programmes. About 70% population, living in mountainous regions of Uttarakhand State, mostly depend on agriculture for their livelihood, but various climatic, geographical and socio-economic constraints have led to a dismal low agricultural productivity in the region.

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Agriculture is largely (about 90%) rain-fed, and the farmers generally face severe soil-moisture stress at germination stage and large dry-spells during the subsequent growing period of winter (*Rabi*) and pre-monsoon crops due to erratic distribution of rainfall amount and intensity. Though the average annual rainfall in Uttarakhand is about 1547 mm, the agricultural productivity is adversely affected by non-availability of sufficient water at critical stages of crop growth due to mis-management of land and water resources.

Much of the environmental resource degradation is governed by mountain specificities, *viz.*, inaccessibility, fragility, marginality, diversity (heterogeneity), niche (natural suitability) and adaptability (human adaptation) apart from the growing population. They result in limited external linkages and replication of external experiences, slow pace of development, intraregional imbalances and underutilization of regional potential. As a result, it does not provide sufficient income levels to the people. This subsistence nature, which leads to low income and unstable income, which in turn lead to a sizeable out-migration of male members that leads to only women headed families behind, and the role of women in the household economy becomes more important. To reverse this order of deterioration of natural resources and support livelihood activities for the inhabitant's watershed management has been taken up as the functional and planning tool for conservation of natural resources and sustainable development.

A watershed is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. Watershed is a technical term used by the British to denote a common drainage point. It is a hydro-geological unit. In American terminology, it is referred to as Catchment Area. A watershed is an ideal unit for management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development. The watershed management concept recognizes the interrelationships among the linkages between uplands, low lands, land use, geomorphology, slope and soil. Soil and water conservation is the key issue in watershed management while demarcating watersheds. Watershed management is the practice of systematically and comprehensively protecting the quality and quantity of the land and water resources within a drainage basin.

Geo-informatics based Morphometric calculation is a new technique for watershed management. Geo-informatics is the combination of Remote Sensing, Geographical Information System and Global Positioning System (Bera and Bandyopadhyay, 2011) [2]. Remote sensing and GIS are integral to each other. The development of Remote Sensing is of no use without the development of GIS and vice versa. Remote Sensing has the capability of providing large amount of data of the whole earth very frequently, whereas G.I.S has the capabilities of analyzing a large amount of data within no time.

Morphometric analysis will help to quantify and understand the hydrological characters and their results will be useful input for a comprehensive water resource management and plans. Quantitative description of the basin morphometry also requires the characterization of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke, 1966;

Babar and Kaplay, 1998 and Obi Reddy *et al.* 2002) [3, 1, 11]. The Morphometric study of the drainage basin aims to acquire accurate data of measurable features of stream network. Drainage provides a basic to understanding of initial slope, inequalities in rock hardness, structural control, geological and geomorphologic history.

## 2. Materials and Methods

### 2.1 General Description of Study Area

The study area (Garud watershed) is located at Garud (Bajnath), on Kausani-Bajnath-Bageshwar route, near Bajnath Temple in Bageshwar district of Uttarakhand state, as shown in Fig. 3.1. The watershed drains into Gomti river at Garud (Bajnath) and lies between 29°54'12" to 29°89'78" N latitude and 79°36'43" to 79°61'68" E longitude with 604 ha (6.04 km<sup>2</sup>) geographical area. The elevation varied from 1086 to 1700 m above mean sea level (msl).

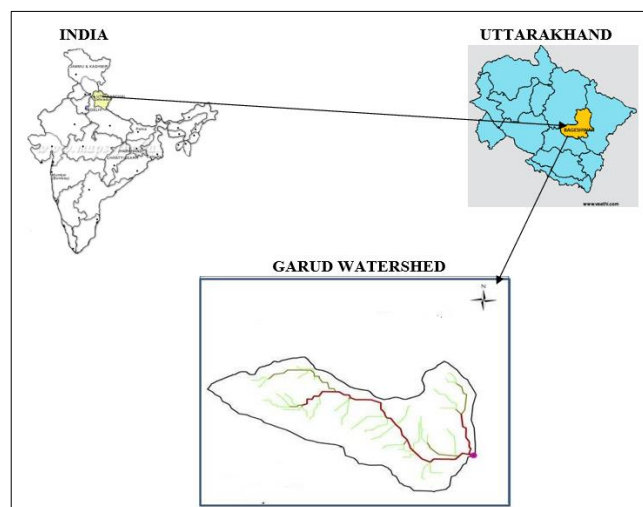


Fig 1: Index map of Garud watershed

The soil of the region was generally sandy-loam type with high organic matter content and acidic in nature. Soil was well drained with average thickness ranging from 0.1 to 0.5 m. The climate of the region is sub-tropical and humid with three distinct seasons. The average annual rainfall is about 1152 mm. The maximum and minimum humidity ranged are from 98 to 66 per cent and 67 to 25 per cent, respectively. The mean maximum and minimum temperatures were found to be 28.2 and -1.2 °C, respectively. In the study area major source of irrigation was canal (i.e. talihat canal network) in the form of small *guls* in the valley region and another source of irrigation was natural water streams at high altitude.

### 2.2. Morphometric Analysis of Watershed

Morphological characterization is the systematic description of watershed geometry. For the study stream network along with their order was extracted from ASTER DEM 30 m through Arc-G.I.S software. Geometry of drainage basin and its stream channel system required the measurements of: (i). linear aspect of drainage network, (ii). areal aspect of drainage basin, (iii). relief aspect of channel network and contributing ground slopes. The first two categories of measurement were planimetric (i.e. projected upon a horizontal datum plane) and the third category compared the vertical inequalities of the drainage basin forms. The stream ordering is carried out using Horton's law. The fundamental parameters namely: stream length, area, perimeter, number of streams and basin length are derived from the drainage layer.

The morphometric parameters for the delineated watershed area are calculated based on the formula suggested by (Horton, 1945) [6], (Strahler, 1964) [18], (Schumm, 1956) [12], (Nookaratnam *et al.*, 2005) [10] and (Miller, 1953) [9] given in Table 1. Morphometric parameters like stream order, stream length, bifurcation ratio, drainage density, drainage frequency, relief ratio, elongation ratio, circularity ratio and compactness constant are calculated.

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, circulatory ratio and form factor have an inverse relationship with erodibility, 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. Prioritization rating of all the four sub-watersheds of Garud watershed is carried out by calculating the compound parameter values. The sub-watershed with the lowest compound parameter value is given the highest priority.

**Table 1:** Methodology adopted for computation of morphometric parameters

Sl. No.	Morphometric Parameters	Formula	Reference
1.	Stream order	Hierachial rank	Strahler (1964) [18]
2.	Stream length ( $L_u$ )	Length of the stream	Horton (1945) [6]
3.	Mean stream length ( $L_{sm}$ )	$L_{sm} = \frac{L_u}{N_u}$ Where, $L_u$ = Total stream length of order 'u' $N_u$ = Total number of stream segments of order 'u'	Strahler (1964) [18]
4.	Stream Length ratio ( $R_L$ )	$R_L = \frac{L_u}{L_{u-1}}$ Where, $L_u$ = Total stream length of order 'u' $L_{u-1}$ = The total stream length of its next lower order	Horton (1945) [6]
5.	Bifurcation ratio ( $R_b$ )	$R_b = N_u / N_{u+1}$ Where, $N_u$ = Total no. of stream segments of order 'u' $N_{u+1}$ = Number of segments of the next higher order	Schumm (1956) [12]
6.	Mean bifurcation ratio ( $R_{bm}$ )	Average of bifurcation ratios of all orders	Strahler (1957) [17]
7.	Length of main channel ( $L_m$ )	Length along longest water course from the outflow point of designated sub-basin to the upper limit of catchment boundary	
8.	Length of overland flow ( $L_g$ )	$L_g = 1/D * 2$ Where, $L_g$ = Length of Overland flow $D$ = Drainage Density	Horton (1945) [6]
9.	Basin length ( $L_b$ )	Distance between outlet and farthest point on the basin boundary	
10.	Basin perimeter ( $P$ )	Length of watershed divide which surrounds the basin	
11.	Fineness ratio ( $R_{fn}$ )	$R_{fn} = L_b/P$ Where, $L_b$ = Basin length, km $P$ = Basin perimeter, km	Melton (1957) [8]
12.	Basin/drainage area ( $A$ )	Area enclosed within the boundary of watershed divide	
13.	Drainage Density ( $D_d$ )	$D_d = L_u/A$ Where, $D_d$ = Drainage Density $L_u$ = Total stream length of all orders, km $A$ = Area of the Basin, $km^2$	Horton (1932) [5]
14.	Constant of channel maintenance ( $C$ )	$C = 1/D$ Where, $D$ = Drainage Density, $km/km^2$	
15.	Stream Frequency ( $F_s$ )	$F_s = N_u/A$ Where, $F_s$ = Stream Frequency $N_u$ = Total number of streams of streams of all orders $A$ = Area of the Basin, $km^2$	Horton (1932) [5]
16.	Circulatory Ratio ( $R_c$ )	$R_c = 4 * 3.14 * A/P^2$ Where, $R_c$ = Circularity Ratio $A$ = Area of the Basin, $km^2$ $P^2$ = Square of the perimeter, km	Miller (1953) [9]
17.	Elongation Ratio ( $R_e$ )	$R_e = 2 \sqrt{A} / L_b$ Where, $R_e$ = Elongation ratio $A$ = Area of the Basin, $km^2$ $L_b$ = Basin length	Schumm (1956) [12]
18.	Form Factor ( $R_f$ )	$R_f = A / L_b^2$ Where, $A$ = Area of the Basin $L_b^2$ = Square of Basin length	Horton (1932) [5]
19.	Unity shape factor ( $R_u$ )	$R_u = \frac{L_b}{\sqrt{A}}$ Where, $L_b$ = Basin length	

		A = Basin area	
20.	Watershed shape factor ( $W_s$ )	$W_s = L_m/D_c$ Where, $L_m$ = Length of main channel $D_c$ = diameter of circle having same area as that of watershed	Wu <i>et al.</i> (1964)
21.	Drainage Texture (T)	$R_t = N_u/P$ Where $N_u$ = Total no. of streams of all orders P = Basin perimeter, km	Horton (1945) [6]
22.	Total relief (H)	Maximum vertical distance between the lowest (outlet) and highest (divide) points on the valley floor of a watershed	
23.	Relief Ratio ( $R_h$ )	$R_h = H/L_b$ Where, H = Total relief of the basin $L_b$ = Basin length	Schumm (1956) [12]
24.	Relative relief ( $R_p$ )	$R_p = H/P$ Where, H = Total relief P = Basin perimeter	Melton (1957) [8]
25.	Ruggedness number ( $R_n$ )	$R_n = H * D$ Where, H = Total relief, km D = Drainage density, km/km <sup>2</sup>	Melton (1957) [8]

### 3. Results and Discussion

#### 3.1 Morphometric Characteristics of the Watershed

Arc-G.I.S v9.3 software was used for the digitization, computation and output generation of the drainage network of the watershed. The results of Morphometric study are summarized in Table 2.

##### 3.1.1 Linear aspects

Classification of stream is important to index the size and scale of the watershed. According to Strahler's system of stream ordering, the natural drainage system of watershed was classified and the main stream was found as 4<sup>th</sup> order stream. It showed that, the maximum frequency in case of first order stream was 34 and that for second, third and fourth order streams was found to be 8, 2 and 1, respectively. It was also noticed that there was decrease in stream frequency with the increase in stream order. This satisfies the Horton's law of stream numbers, the number of stream segment of each order form an inverse geometric sequence with order number. This stream order is used in the study of other characteristics of watershed.

The number of streams of various orders in the watershed was counted and their length from outlet to drainage divide was measured with the help of Arc-G.I.S v9.3 software. Stream length was computed on the basis of the law proposed by Horton (1945) [6] for the watershed. The total length of stream segments of first, second and third order streams was found to be 12.72, 3.54, 4.61 km, respectively. It also showed that the total length of stream segments was maximum for the first order streams. This was satisfying Horton's second law.

The mean stream length for the watershed was also measured as per Starhler (1964) [18] method and it was found to be 0.37, 0.44 and 2.31 km for first, second and third order streams, respectively. The stream length ratio ( $R_L$ ) was estimated to be 0.28 and 1.31 for II/I and III/II orders, respectively. The increasing trend in  $R_L$  from lower order to higher order indicated matured geomorphic stage and change from one order to another order indicated late youth stage of geomorphic development of streams (Singh and Singh, 1997) [13]. Horton (1945) [6] considered the bifurcation ratio ( $R_b$ ) as an index of relief and dissections. The value of  $R_b$  normally varies between 3.0 and 5.0 and is a useful index for hydrograph shape for watersheds similar in all other respects. In the present study,  $R_b$  varied from 2.0 to 4.25 with an average of 3.4 and was not the same from one order to next order. The higher value of  $R_b$  indicated strong structural control on the drainage pattern. This showed its usefulness for hydrograph shape for watersheds similar in other respect.

An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed (Singh, 2003) [14]. The present study indicated that the watershed chosen for the study was not circular in the shape and would produce delayed peak flow. The bifurcation ratio between first and second order streams indicated the nature of head ward erosion. In the present case, the head ward erosion was moderate as bifurcation ratio was 4.25.

In the area under study, length of main channel, basin length and basin perimeter were found to be 5.1, 4.63 and 13.02 km, respectively. The fineness ratio was found to be 0.39. Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels. This factor relating inversely to the average shape of the channel is quite synonymous with the length of the sheet flow to a large degree. Generally higher value of  $L_g$  is indicative of low relief resulting delayed runoff, where as low value of  $L_g$  is an indicative of high relief resulting quicker surface runoff. The length of over land flow for Garud watershed was 0.140 km, indicating delayed yield.

##### 3.1.2 Areal aspects

Areal aspect of morphometric study of the watershed includes the description about arrangement of areal elements, law of stream area, relation of stream area to stream length, relation of area to discharge basin shape (form factor, circulatory ratio, elongation ratio, compactness coefficient, drainage density etc.)

The areal aspects of different geomorphologic parameters were considered which represented area and were computed using the mathematical formulae given in Table 1. Drainage area represents the area enclosed within the boundary of the watershed divide. It is probably the single most important characteristic for hydrologic design. Using Arc-G.I.S v9.3 software, the drainage area of watershed was found to be 604 ha (6.04 km<sup>2</sup>).

Lower drainage density of the basin (3.48 km/km<sup>2</sup>) indicates towards course drainage pattern. The course texture gives more time for overland flow and hence to ground water recharge. A low value of drainage density indicates a relatively low density of streams and thus a slow stream response (Singh *et al.*, 2004) [15]. The constant of channel maintenance (C) was found to be 0.29 km<sup>2</sup>/km, which was the reciprocal of drainage density. It indicates that magnitude of surface area of watershed needed to sustain unit length of stream segment.

Horton (1932) [5] introduced stream frequency or channel frequency ( $F_s$ ) which was ratio of number of stream segments



of all orders per unit area. From Table-2, it can be observed that the  $F_s$  varied from 0.33 to 5.629 for orders III to I. Using Melton's (1957) [8] equation, stream frequency of the watershed was found to be 7.45 per  $\text{km}^2$ .

The circulatory ratio ( $R_c$ ) was estimated to be 0.45, according to definition given by Miller (1953) [9]. As basin shape approaches to a circle, the circulatory ratio approaches to 1. The elongation ratio ( $R_e$ ) for the study area was found to be 0.60. A circular basin is more efficient in the discharge of runoff than an elongated basin (Singh and Singh, 1997) [13]. The value of  $R_e$  approaches to 1 as the shape of the basin approaches to a circle and varies from 0.6 to 1.0 over a wide variety of climatic and geologic regimes. Typical values are close to 1 for areas of very low relief and are between 0.6 to 0.9 for regions of strong relief and steep ground slope. The lowest value of  $R_e$  ( $< 0.5$ ) indicates high relief and steep slope while very high values of  $R_e$  ( $\geq 1$ ) indicates plain land with low relief and low slope. The estimated value of  $R_e$  was not closer to 1 and it indicates study area was elongated. The form

factor ( $R_f$ ) was found to be 0.28 as per definition given by Horton (1932) [5] and unity shape factor ( $R_u$ ) for the selected watershed was 1.88. The watershed shape factor ( $W_s$ ) for selected watershed was found to be 1.83.

In the present study, drainage texture ratio was found to be 3.46, as per definition given by Horton (1945) [6]. Drainage density of the study area was of coarse texture, since drainage density ranged between 2 to 4 as per relationship of drainage density and texture given by Smith (1950) [16].

### 3.1.3 Basin relief aspects

The results related to basin relief aspects are presented in Table 2. In the present study, total relief was found to be 0.61 km. The relief ratio ( $R_h$ ) was found to be 0.25. The  $R_h$  normally increased with the decreasing drainage area and size of the sub-watersheds of a given drainage basin (Gottschalk, 1964) [4]. Lower value indicates the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope.

**Table 2:** Morphometric analysis for Garud watershed.

#### A. Linear aspects

Stream order	Number of streams ( $N_u$ )	Stream length in km ( $L_u$ )	Mean stream length in km	Stream length ratio ( $R_L$ )			Bifurcation ratio ( $R_b$ )		
				II/I	III/II	IV/III	I/II	II/III	III/IV
I	2	3	4	5			6		
I	34	12.723	0.374	0.278	1.304	0.035	4.25	4	2
II	8	3.539	0.442						
III	2	4.614	2.307						
IV	1	0.163	0.163						

#### Linear aspects contd.....

Mean bifurcation ratio ( $R_{bm}$ )	Length of the overland flow ( $L_g$ ) in km	Basin length ( $L_b$ ) in km	Basin perimeter (P) in km	Finess ratio ( $R_m$ )	Length of main channel ( $L_m$ ) in km
7	8	9	10	11	12
3.417	0.14	4.630	13.02	0.39	5.066

#### B. Areal aspects

Drainage/basin area (A) in $\text{km}^2$	Drainage density ( $D_a$ ) in $\text{km}/\text{km}^2$	Constant of channel maintenance (C)	Stream frequency ( $F_s$ ) per $\text{km}^2$	Circulatory ratio ( $R_c$ )
1	2	3	4	5
6.04	3.478	0.29	7.45	0.45

#### Areal aspects contd....

Elongation ratio ( $R_e$ )	Form factor (Rf)	Unity shape factor ( $R_u$ )	Watershed shape factor ( $W_s$ )	Drainage texture ratio (T)
6	7	8	9	10
0.60	0.28	1.88	1.83	3.46

#### C. Relief aspects

Total relief (H) in km	Relief ratio ( $R_h$ )	Relative relief ( $R_p$ )	Ruggedness No. ( $R_n$ )
1	2	3	4
0.614	0.133	0.047	2.14

The relative relief ( $R_p$ ) was found to be 0.047, as per definition given by Melton (1957) [8]. It indicates general steepness of the basin from summit to outlet.

In the present study, ruggedness number was found to be 2.14 km. This number represents that if drainage density is increased, keeping relief as constant, then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

### 3.2 Prioritization of Sub-watersheds

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes. The present study demonstrates the usefulness of G.I.S. for morphometric analysis and prioritization of the sub-watersheds of Garud watershed of Bageshwar district. For that, Garud watershed having area of about 604 ha was divided into four sub-watersheds (i.e. GR-1, GR-2, GR-3 and GR-4) having areas 94.4, 158.9, 260 and 92 ha, respectively (Fig.2)

### 3.2.1 Stream numbers and orders

The sub-watershed wise length of streams of different orders, their total length and mean length is given in Table 3. It is revealed that the drainage network of the Garud Catchment was characterized by total length of 20.99 km. The stream length was computed on the basis of the law proposed by (Horton, 1945) [6], for all the 4 sub-watersheds. Generally, the total length of stream segments decreased as the stream order increased. In sub-watershed GR-3, the stream length followed Horton's law. But in sub-watersheds GR-1, GR-2 and GR-4, the stream segments of various orders showed variation from general observation (Table 3). This change may indicate flowing of streams from high altitude, litho logical variations and moderately steep slopes.

The sub-watershed wise drainage length given in the table revealed that GR-3 constituted the highest proportion of drainage length of 9.44 km (44.97%), followed by GR-2 which is 5.15 km (24.52%), while the lowest contributors were GR-4 and GR-1 contributing 3.61 km (17.20%) and 2.78 km (13.33%). It was also observed that mean stream length of sub-watersheds increased with the increase in stream orders, except GR-2. The stream length ratio between different sub-watersheds showed an increasing trend in the stream length ratio from lower order to higher order indicating their mature

geomorphic stage in sub-watersheds.

### 3.2.2 Linear parameters of sub-watersheds

The Linear parameters include drainage density ( $D_d$ ), stream frequency ( $F_s$ ), bifurcation ratio ( $R_b$ ), drainage texture ( $R_t$ ), length of overland flow ( $L_g$ ). The drainage density in the Garud sub-watersheds exhibits a close range in its values from 2.96 km/km<sup>2</sup> (lowest) in GR-1 to 3.92 km/km<sup>2</sup> (highest) in GR-4. Drainage density ( $D_d$ ) shows the landscape dissection, runoff potential, infiltration capacity of the land, climatic conditions and vegetation cover of the basin. The high value of drainage density indicated that the region was composed of impermeable sub-surface materials, sparse vegetation and high mountainous relief.

In Garud watershed the lowest stream frequency was found in GR-1 (6.35) and the highest stream frequency was found in GR-4 (8.69). The present high stream frequencies were indicative of high relief and low infiltration capacity of the bedrock pointing towards the increase in stream population with respect to increase in drainage density. It was found that, the watersheds having large area under forest and the area having more agricultural land had high drainage frequency. High value of drainage frequency produces more runoff in comparison to others.

**Table 3:** Morphometric parameters for sub-watersheds  
A. Linear aspects

Sub-watersheds	Stream orders	Number of streams ( $N_u$ )	Stream length ( $L_u$ ) in km	Mean stream length in km	Stream length ratio ( $R_l$ )		Bifurcation Ratio ( $R_b$ )		Mean bifurcation ratio ( $R_{bm}$ )
					II/I	III/II	I/II	II/III	
1	2	3	4	5	6		7		8
GR-1	I	5	1.389	0.28	1.01	0	5	0	5
	II	1	1.41	1.41					
GR-2	I	9	3.289	0.36	0.15	2.66	3	3	3
	II	3	0.508	0.17					
	III	1	1.35	1.35					
GR-3	I	17	6.83	0.4	0.21	0.83	5.66	3	4.33
	II	3	1.42	0.47					
	III	1	1.19	1.19					
GR-4	I	5	1.73	0.35	0.49	1.23	2.1	0.81	1.45
	II	2	0.84	0.42					
	III	1	1.04	1.04					

Linear aspects contd.....

Length of the overland flow ( $L_g$ ) in km	Basin length ( $L_b$ ) in km	Basin perimeter (P) in km	Fineness ratio ( $R_{fm}$ )	Length of main channel ( $L_m$ ) in km
9	10	11	12	13
0.17	1.82	5.5	0.33	1.82
0.15	2.24	5.83	0.36	2
0.14	2.34	7.31	0.31	2.25
0.13	1.83	4.87	0.46	2.23

B. Areal aspects

Drainage/ Basin area (A) in km <sup>2</sup>	Drainage density ( $D_d$ ) in km/km <sup>2</sup>	Constant of channel maintenance (C)	Stream frequency ( $F_s$ ) per km <sup>2</sup>	Circulatory ratio ( $R_c$ )	Elongation ratio ( $R_e$ )	Form factor ( $R_f$ )	Drainage texture ratio (T)	Compactness coefficient ( $C_c$ )
14	15	16	17	18	19	20	23	24
0.944	2.96	0.34	6.35	0.39	0.6	0.28	1.09	1.59
1.589	3.24	0.31	8.18	0.59	0.63	0.32	2.23	1.30
2.60	3.63	0.27	8.07	0.61	0.77	0.48	2.87	1.28
0.92	3.92	0.25	8.69	0.49	0.59	0.27	1.64	1.43

**Table 4:** Prioritization of sub-watersheds

Sub-watershed code	Linear parameters					Shape parameters				Compound parameter ( $C_p$ )	Final priority
	( $R_{bm}$ )	( $D_d$ )	( $F_s$ )	(T)	( $L_g$ )	( $R_f$ )	( $R_c$ )	( $R_e$ )	(C)		
GR-1	1	4	4	4	1	2	1	2	4	2.55	2

GR-2	3	3	2	2	2	3	3	3	2	2.55	2
GR-3	2	2	3	1	3	4	4	4	1	2.67	3
GR-4	4	1	1	3	4	1	2	1	3	2.22	1

In present study the sub-watershed GR-1 had highest bifurcation ratio (5) followed by GR-3 (4.33). An elongated watershed had higher bifurcation ratio than normal and approximately circular watershed (Singh, 2003) <sup>[14]</sup>. Low  $R_b$  value indicates less structural disturbance and the drainage patterns have not been distorted, whereas, high  $R_b$  value indicates high structural complexity and low permeability of terrain.

The hypothesis that the bifurcation ratios within a given region tend to decrease with increasing order does hold well except the bifurcation ratio of 4<sup>th</sup> and 5<sup>th</sup> order where it registers the highest bifurcation ratios (Kanth and Hassan, 2012) <sup>[7]</sup>. The bifurcation ratio between first and second order stream indicated the nature of head ward erosion. The values showed that, the head ward erosion was more in GR-3, followed by GR-1.

The lowest drainage texture (T) of 1.09 was found in GR-1, while the highest was in GR-3 (2.87). Based on the values of T Smith (1950) <sup>[6]</sup> classified the texture as: < 4 Coarse, 4-10 Intermediate, 10 -15 Fine, >15 Ultra Fine (bad land topography). The drainage texture of the sub-watersheds in

Garud watershed was very coarse. The length of overland flow of Garud watershed was found to be 0.14 km. It is highest in GR-1 (0.17 km), while as the lowest value was found in GR-4 (0.13). Higher value of  $L_g$  is indicative of low relief and where as low value of  $L_g$  is an indicative of high relief.

### 3.2.3 Shape parameters of sub-watersheds

The shape parameter includes form factor ( $R_f$ ), shape factor ( $B_s$ ), circulatory ratio ( $R_c$ ), elongation ratio ( $R_e$ ) and compactness coefficient ( $C_c$ ). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated watershed with low form factors have lower peak flow of longer duration. Garud watershed had a form factor of 0.28 and it was found highest in GR-3 (0.48) and the lowest in GR-4 (0.27), indicating them to be elongated in shape and suggesting flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

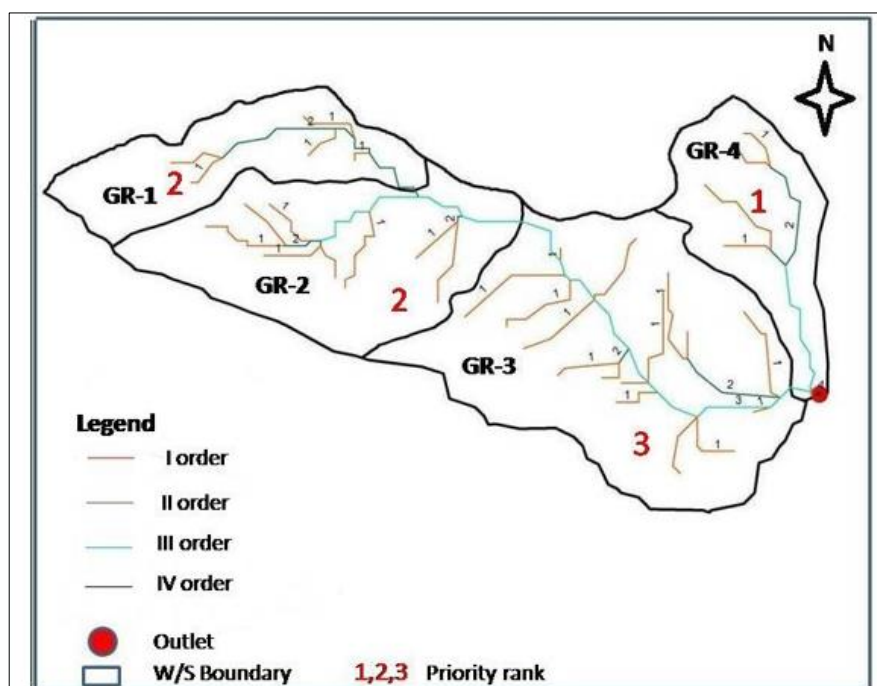


Fig 2: Sub-watershed and priority map of Garud watershed

Circulatory ratio ( $R_c$ ) is defined as the ratio of basin area to the area of circle having the same perimeter as the basin and is dimensionless. It is helpful for assessment of flood hazard. Higher the  $R_c$  value, higher would be the flood hazard at the peak time at the outlet point. GR-1 had the lowest circulatory ratio of 0.39, and it was the highest in GR-1 (0.61) indicating that all the watersheds represent an elongated shape. Sub-watershed GR-3 had the highest elongation ratio of 0.77 and the lowest of 0.59 was found in GR-4, which indicates high relief and steep ground slope. Compactness coefficient ( $C_c$ ) is used to express the relationship of a hydrological basin with that of a circular basin having the same area as the hydrologic basin. It was highest in GR-1 (1.59) and the lowest in GR-3 (1.28).

### 3.2.4 Assigning priority to sub-watersheds

The final result is shown in Table 4. The prioritization of Garud watershed was done by assigning ranks to the individual indicators and a compound value ( $C_p$ ) was calculated. Sub-watersheds with highest  $C_p$  value were of low priority while those with lowest  $C_p$  value were of high priority. Sub-watershed GR-4 with a compound parameter value of 2.22 received the highest priority and the sub-watersheds GR-1 and GR-2 both have same  $C_p$  value as 2.55 received second priority. The sub-watershed GR-3 had highest  $C_p$  value as 2.67 received last priority. Highest priority indicated the greater degree of erosion in the particular sub-watershed and it became potential area for applying soil conservation measures. Thus soil conservation

measures can first be applied to sub-watershed GR-4 and then to the other sub-watersheds depending upon their priority. The final prioritized map of the study area and prioritization ranks of sub-watersheds is shown in Fig. 2.

#### 4. Conclusion

The study depicts the utility of Remote Sensing and GIS technique in prioritizing micro-watershed based on morphometric analysis which could be valuable for watershed management practices.

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