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Morphometric Analysis of Upper Karha Watershed in Semi-Arid Area, Western Maharashtra, India

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Abstract – In the present work, an attempt has been made to study the quantitative geomorphological analysis of the Upper Karha watershed of Karha River Basin, Western Maharashtra, India. The study involves conventional top sheets, Geographic Information System (GIS) and Remote Sensing technique which are proved to be of immensely helpful to evaluate and compare linear relief and aerial morphometric features of a watershed.

Morphological characteristics of the drainage line as appear in shape ,size, number, order, length, D_d, S_f, R_b, F_s, T, R_c are derived to trace its usefulness for surface development. Upper Karha watershed is basically 6th order drainage and mainly dendritic to sub dendritic. Drainage density and texture of the drainage basin is 3.13 km/km^2, 17.591 respectively. The drainage frequency of Upper Karha watersheds is 4.31 whereas the bifurcation ratio ranges from 3 to 5.

Keywords- Upper Karha River, Watershed. Morphometry, Bifurcation Ratio, DEM, GIS.

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1. INTRODUCTION

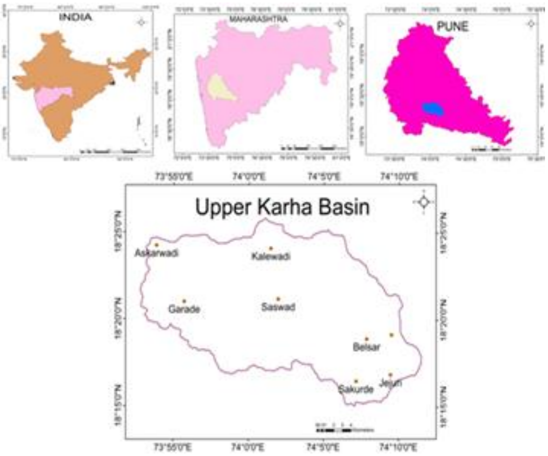
The demand for water has increased over the years due to that, the assessment of quantity and quality of water of its best use in necessitated.

The available surface and ground water resources are inadequate to satisfy the growing water demands due to fast urbanization and increasing population and varying climate conditions. Identification and outlining of various ground features like surface and subsurface structures, geomorphic features and their hydraulic characteristics could serve as direct or indirect indicators of the presence of ground and surface water. The understanding of geomorphic conditions is a key factor in depicting the hydrological characteristics of hard rocks.

Quantitative morphometric analysis helps in through understanding of drainage network patterns and overall role played by lithology and structural geology in the development of watershed. The morphometric parameters of a watershed are reflective of its hydrological response to a respectable extent and may be useful in synthesizing its hydrological behavior [Zende et al., 2011].

2. STUDY AREA

The study area lies in western part of state of Maharashtra is bounded by Latitude 18^0 15’ to 18^0 25’ N and longitude 73^0 52’ to 74^0 11’ E falling partially in Survey of India topographical sheet no. E 43H/15 and E43I/3 on the scale 1:50,000 (Figure No.1). It covers a total area of 399 km ^{2} and includes part of Pune district in Maharashtra. The average annual rainfall increases from 400 millimeter to 575 millimeter. Geology of the area is dominantly covered by basaltic rock. The area has suffered plenty by tectonic movement within the past as proved by lineaments association with hills located in the western side of study area [Singh S.R., 2006].



3. METHODOLOGY

Entire study area is delineated from rectified mosaic using Survey of India topographical maps no. E 43H/15 and E43I/3 on the scale 1:50,000 on regional projection (WGS 1984 UTM Zone 43 N). With the help of Arc-GIS software drainage network was digitized (Figure No.2) and stream order was calculated using the technique proposed by Strahler (1964). Arc-GIS 9.3 software is used for computing all morphometric parameters (Table - 1).

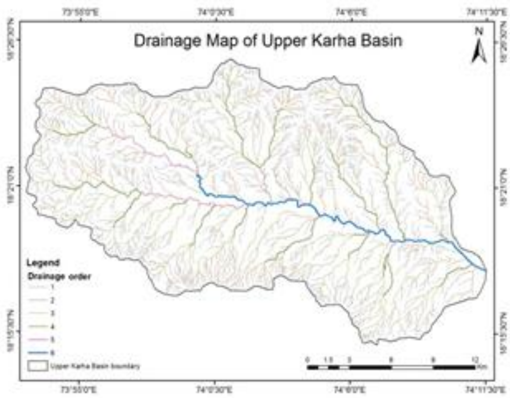


Fig.2 Drainage map of Upper Karha Basin

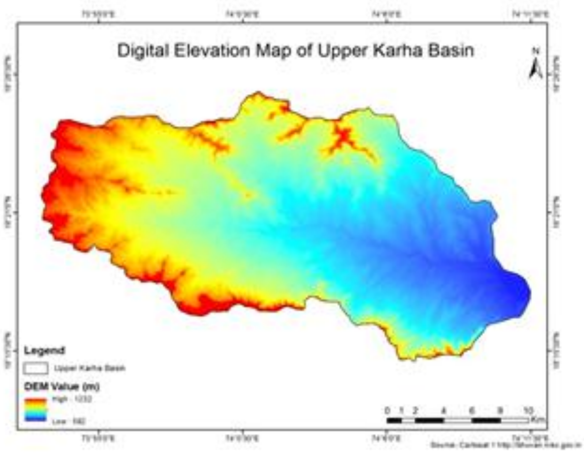


Fig.3 DEM of Upper Karha Basin

Table 1. Formulae used for computation of morphometric parameters

SN.	Mophometric Parameters	Formula	Reference
1	Stream order	Hierarchial rank	Strahler (1964)
2	Stream length (L_u)	Length of the stream	Horton (1945)
3	Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$ Where, L_{sm} = Mean stream length L_u = Total stream length of order 'u' N_u = Total no. of stream segments of order 'u'	Strahler (1964)
4	Stream length ratio (R_L)	$R_L = L_u / L_u - 1$ Where, R_L = Stream length ratio L_u = The total stream length of the order 'u' $L_u - 1$ = The total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (R_b)	$R_b = N_u / N_u + 1$ Where, R_b = Bifurcation ratio N_u = Total no. of stream segments of order 'u' N_u+1 = Number of segments of next higher order	Schumn (1956)
6	Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
7	Relief ratio (R_h)	$R_h = H / L_b$ Where, R_h = Relief ratio H = Total relief (Relative relief) of the basin (km) L_b = Basin length	Schumm (1956)
8	Drainage density (D)	$D = L_u / A$ Where, D = Drainage density L_u = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932)
9	Stream frequency (F_s)	$F_S = N_u / A$ Where, F_S = Stream frequency N_u = Total no. of streams of all orders A = Area of the basin (km2)	Horton (1932)
10	Drainage texture (R_t)	$R_t = N_u / P$ Where, R_t = Drainage texture N_u = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
11	Form factor (R_f)	$R_f = A / L_b^2$ Where, R_f = Form factor A = Area of the basin (km^2) L_b^2 = Square of basin length	Horton (1932)
12	Circularity ratio (R_c)	$R_C = 4 * Pi * A / P^2$ Where, R_c = Circularity ratio Pi = 'Pi' value i.e., 3.14 A = Area of the basin (km2) P^2 = Square of the perimeter (km)	Miller (1953)
13	Elongation ratio (R_e)	$R_e = 2 / L_b$ Where, R_e = Elongation ratio A = Area of the basin (km2) Pi = 'Pi' value i.e., 3.14 L_b = Basin length	Schumn (1956)
14	Length of overland flow (L_g)	$L_g = 1 / D * 2$ Where, L_g = Length of overland flow D = Drainage density	Horton (1945)

4. RESULTS AND DISCUSSION

The understanding of geomorphic conditions is a key factor in depicting the hydrological characteristics of hard rocks. Quantitative morphometric analysis helps in through understanding of drainage network patterns and overall role played by lithology and structural geology in the development of watershed. The morphometric parameters of a watershed are reflective of its hydrological response to a respectable extent and may be useful in synthesizing its hydrological behavior [Zende et al., 2011]. In the present study, quantitative analysis of the basin characteristics has been computed from linear (unidimensional), areal (two dimensional) and relief (three dimensional) aspects (Table 1), details of which have been discussed below.

Linear aspects

In the present studies linear aspects include Stream order (u), stream number (Nu), Bifurcation ratio (Rb), Length of overland flow (Lg), Stream length (Lu), Mean stream length (Lsm), Stream length ratio (Rl)

Linear aspect of drainage basin includes stream order; stream length and length of overland flow are the most common attribute. Stream ordering is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold et al. 1964). The number of stream in various order is countered and total number of segment (N_u) in each order (u) was computed on basis of Horton (1945) method as modified by Strahler A.N. Stream order in this drainage basin are numbered up to 6th order (Figure No. 2).

Stream length (L_u)

Stream length (L_u) has been computed based on the law proposed by Horton (1945). Stream length is indicative of chronological developments of the stream segments including interlude tectonic disturbances (Magesh et al. 2013). Longer length of stream is advantageous over shorter length in the fact that water collects from wider area and better options for construction of a bund along the length are available. It is observed form (Table 4) that LSM value is 0.378. Stream length ratio and analysis is given in Table 3.

Stream order (u)

Stream ordering (u) refers to the determination of hierarchical ranking of the stream within a drainage basin. Stream number (Nu) refers to the total number of stream segments of the order 'u'. Stream order (u) 1^{st} order and 2^{nd} order streams are mostly in high elevation with moderate slope while higher order stream occurred in low elevation with deep dissects. The high number of first order streams depicts terrain complexity and compact bedrock. The variation in order and size of the basin is largely due to physiographic and structural conditions of the region (Sreedevi et. al.2009) generally, higher the order, longer the length of stream as is observed in the nature.

Bifurcation ratio (R_b)

The number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order. According to Strahler (1957), in a region of uniform climate and stage of development, the R_b tends to remain constant from one order to next order. The Bifurcation ratio is an indicative tool for the shape of basin. Elongated basins have low R_b value whereas circular basins have high R_b value. R_b Value of upper Karha watershed is 4.207. It is varies from order to order. Lowest R_b value is 3.809 which indicate lowest land flow and discharge due to plain area with gentle slope (Table 2).

Table - 2 Stream Analysis of Upper Karha River Basin

Stream Order	Stream Number Nu	Nu Cumulative	Stream Length (Km)	Stream Length Cumu. (Km.)	Length Ratio	Mean Stream Length	Bifurcation Ratio	Mean Bifurcation Ratio	Mean Length Ratio
1	1289	1289	727.382	727.382	-	0.564	3.929	4.207	0.378783723
2	328	1617	257.263	984.645	0.353	0.159	4.1		
3	80	1697	165.046	1149.691	0.641	0.097	3.809		
4	21	1718	76.664	1226.355	0.464	0.044	4.2		
5	5	1723	25.106	1251.461	0.327	0.014	5		
6	1	1724	2.679	1254.14	0.106	0.001	-		

The length of over land flow (L_g)

The length of over land flow is the length of water over the ground slope before it becomes concentrated into a definite stream channel (Horton, 1945). It is the length of water over the ground before it gets concentrated into definite stream channels and affects both hydrologic and physiographic development of drainage basin (Ajaykumar, et. al. 2016). The length of over land flow is one of the most important variables affecting terrain development of drainage basin. The length of overland flow (L_g) is about equal to one half of the reciprocal of drainage density, i.e. one half of the Constant Channel Maintenance (Horton, 1945). The shorter the length of overland

flow, the quicker the surface runoff will enter the stream. In the present study, the length of overland flow is 0.21. It indicates that the runoff is more due to short length of over land flow.

Stream length (Lu)

Stream length (Lu) The plot (Figure No.4 A&B) of logarithm of stream length (ordinate) as a function of stream order (abscissa) yields a set of points lying essentially along a straight line fit following Horton's law (1945) of stream length. The straight line fit indicates that the ratio between L_u and u is constant throughout the successive order of basin and suggests that geometrical similarities are preserved in basins of increasing order. Deviation from its general behavior indicates that the terrain is characterized by high relief and /or moderately steep slopes, underlying by varying lithology and probable uplift across the watershed (Singh and Singh, 1997).

Areal aspects

Form factor (R_f)

Form factor (R_f) has direct regard to stream flow and shape of watershed. Upper Karha watershed has high R_f, value of 0.25. This shows that the drainage basin is moderately elongated in nature with less side flow for shorter duration and high main flow for longer duration.

Circulatory ratio (R_c)

It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region. The circulatory ratio (R_c) is influenced by the length and frequency of stream, geological structure, land use / land cover, climate, relief and slope of the basin. The R_c value is 0.523. Greater the value more is the circularity ratio, which indicates that watershed is elongated in nature. Constant Channel Maintenance (C) for this watershed is 0.318 which leads us to believe high structural disturbance, steep to very steep slope with high surface runoff.

Drainage density (D_d)

Horton (1932) defined drainage density (Dd) as the length of streams per unit area divided by the area of the drainage basin. Drainage density (D_d) is an important indicator of land form. It provides a numerical measurement of landscape dissection and runoff potential. It also indicates closeness of spacing of streams. In present study, drainage density (D_d) is determined to be 3.135 is an important indicator of land form. It provides a numerical measurement of landscape dissection and runoff potential. It also indicates closeness of spacing of streams.

Drainage frequency (D_f)

Horton (1945) defined stream frequency (Fs) as the ratio between the total numbers of segments cumulated for all orders within a basin and the basin area. Drainage frequency (D_f) in the study area is 4.31 and it indicates the low relief and growth of new channel or lengthening of existing stream. There are total 1724 stream segments of high orders. Highest order i.e. 6th order stream is nothing however main rivers in the study area.

The texture ratio (T)

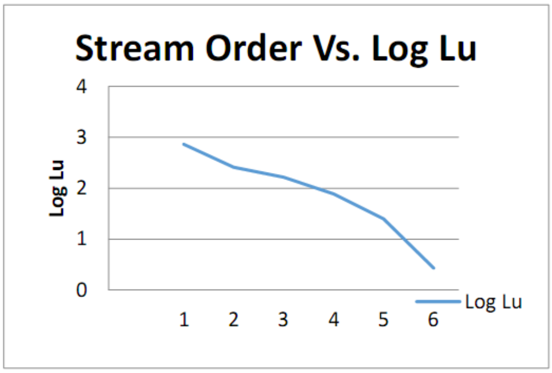
The texture ratio (T) depends on the underlying lithology, infiltration capacity and relief aspect of the terrain [Zende et al., 2013]. In the study area, texture ratio (T) is 17.591 and categorized as moderate to fine texture in nature.

Relief aspect

It comprises of Basin Relief (B_h), relief ratio, relative relief and ruggedness number (R_n). Relief aspect of the watershed plays an important role in drainage development, surface and subsurface water flow, permeability, landform development and associated features of the terrain. Study area shows basin relief (B_h) more than 283m (Figure 3) and it indicates low infiltration with high runoff.

Bifurcation ratio (R_b) and Ruggedness number (R_n)

Bifurcation ratio (R_b) and Ruggedness number (R_n) indicate the structural complexity of the terrain in association with relief and drainage density (Table - 4).



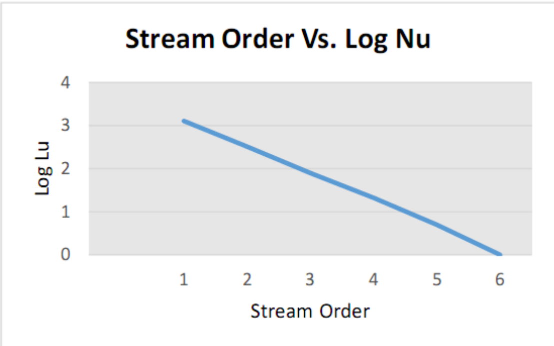


Fig. 4 Regression of logarithm of number of streams versus stream order

CONCLUSION

Quantitative morphometric analysis of Upper Karha watershed has been carried out for linear, areal and relief aspects using GIS applications. The study shows that terrain is formed from mainly basaltic rock and exhibits dendritic to sub dendritic drainage pattern and is classed as extremely sloping and high runoff zone that give rise to high drainage discharge. Application of Morphometric approach revealed that there are total 541 streams grooved with each other from order 1st to 6th sprawled over 399 Km^2 area of the catchment. Detailed study of upper Karha watershed provides a helpful direction for surface runoff and helps in natural resource development. Bifurcation ratio ranges from 3.809 to 4.207 indicates that the drainage basin is covered by impermeable sub surface and high mountainous relief. Circulatory ratio R_c value is 0.523 which indicates that watershed is elongated in nature; elongation ratio shows watershed has high slope and high peak flow. Texture ratio provides an idea about infiltration capability and relief aspect of terrain. Thus, study shows that the morphometric analysis using GIS and Digital Elevation Model (DEM) (Figure No.3) helps to perceive complete terrain parameters that result in finalization of watershed development designing and management with regard to water conservation [Zende et al., 2013].

Areal, Linear and Relief properties for the quantitative analysis of morphometric parameters using GIS software is found to be of huge utility in drainage basin, elevation, watershed prioritization for soil and water conservation, flood prediction and natural resources management.

Table - 3 Linear aspect of drainage network of Upper Karha Basin

Stream Order	Number of stream (N_u)	Total length of stream (km) L_u	Log N_u	Log L_u
1	1289	727.382	3.11025292	2.86176255
2	328	257.263	2.51587384	2.41037733
3	80	165.046	1.90308999	2.217605
4	21	76.664	1.32221929	1.88459148
5	5	25.106	0.69897	1.39977752
6	1	2.679	0	0.42797271

Table - 4 Morphometric Analyses

Watershed	Morphometric Parameters	
UPPER KARHA	A (Km^2)	400
	P (Km)	98
	Lu	1254.14
	Lsm	0.378
	Rbm	4.207
	Rh	0.25
	Dd	3.135
	Rf	0.25
	Rt	17.591
	Rc	0.523
	C	0.318
	Lg	0.159
	Fs	4.31

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