Quantitative Morphometric Analysis of Adhala basin, Ahmednagar Maharashtra Using Arc-GIS Tool

V. P. Mandale[1], R. D. Bansod[2], V. N. Barai[3], S. B. Nandgude[4], B. K. Gavit[5], J. B. Shinde[6]

[1]Research Scholar, Dept. of Soil & Water Conservation Engineering, Dr. ASCAET, MPKV, Rahuri, Maharashtra, India.
[2]Professor (SWCE) &, Head Agril. Engineering Section, College of Agriculture, Pune, Maharashtra, India.
[3]Associate professor, Dept. of Soil & Water Conservation Engineering, Dr.ASCAET, MPKV, Rahuri, Maharashtra, India.
[4]Professor &, Head, Dept. of Soil & Water Conservation Engineering, Dr. ASCAET, MPKV, Rahuri, Maharashtra, India.
[5] Associate professor, Dept. Agril. Engineering College of Agriculture, Nandurbar, Maharashtra, India.
.[6]Ex-Associate Professor, Department of Agronomy, Post Graduate Institute, MPKV, Rahuri, Maharashtra, India.

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ABSTRACT

Advancement of technology in natural resource planning has brought new hopes for sustainable development. Sustainable development can be achieved by the micro level planning and management at watershed scale. Watershed is the basic land unit for water resource management and support for human as well as other living beings and is vulnerable to unfavorable weather events and climatic conditions. In present study, the morphometric characteristic of Adhala river basin was done. The Adhala river basin is one of the major tributaries of Pravara river which rises in the North of Akole at Deothan in Ahmednagar district of Maharashtra. It extends between 19°32'40" N to 19°43'02" N latitudes and 74°10'15"E to 74°48'18" E longitudes and encompasses an area of 216.17 km2. DEM data were used to calculate the flow accumulation, stream networks, morphometric characteristics and also delineation of watershed using ArcGIS watershed delineator tools. The more emphasis is given to evaluate all the morphometric parameters which are basically categorized in three aspects viz; linear, areal and relief. Strahler's stream ordering techniques & analysis were followed. The results of the morphometric study showed that the trunk stream order was found to be of 6th order having 3145 numbers of streams in the basin, also total length of the streams was found to be 985.20 km. Lengths of streams indicate flatter gradient of the basin. Bifurcation ratio indicates elongated shape of the basin. Drainage density of Adhala basin was 4.54 km/km2 indicating high drainage densities, circularity ratio was 0.17 and indicated moderate to high relief. Infiltration number was 65.97 indicating low infiltration capacity and very high surface runoff. Relief aspect showed that absolute relief was 552 m and relief ratio was 0.02 indicating overall low relief due to highly elongated basin. The geoprocessing techniques employed in this study will assist in planning & decision making in watershed development.

Key Words: Geospatial Tool, DEM, Climate Change, Linear Aspect, Areal Aspect, Relief Aspect

INTRODUCTION

Climate change affects the entire natural hydrological system (Arnold and Allen, 1996) including local and regional water resources. Climate change impacts on water resources are therefore of major concern in current hydrologic research. While climate projections are typically available at large spatial scales with coarse spatial resolution, decisions on soil and water are usually made on significantly smaller spatial scales. Assessment of soil and water resources is necessary to estimate the water conservation interventions required in the basin. It is important to estimate the effect of varying climatic condition on the soil and water resources of the basin and provide suitable adaptation and mitigation strategies. Deforestation and unsustainable agricultural practices have been recognized as key drivers of watershed degradation. Thus, promoting soil and water resource sustainability by the use of technologies and practices that improve crop productivity without causing environmental damage are crucial in our pursuit for a more sustainable and equitable watershed development. The Remote Sensing and GIS have proven better for evaluation and estimation of soil and water resources at basin scale. This tool is universally adopted for different work such as ground water planning, water quality analysis, crop planning, water budgeting and many more applications (Arnold, 2007). Advancement of technology in natural resource planning has brought new hopes for sustainable development. 'Morphometry may be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms' (Clarke, 1966). Drainage basins are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, which include the topology of the stream network and quantitative description of drainage texture, pattern, shape, and relief characteristics (Abrahams, 1984; Huggett and Cheesman, 2002). A quantitative morphometric characterization of a drainage basin is considered to be the most satisfactory method for the proper planning of watershed because it enables us to understand the relationship among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes (Zende and Nagrajan, 2011). Fluvial morphometric study of a drainage basin includes the consideration of linear, areal and relief aspects, where the linear aspect deals with the hierarchical orders of streams, numbers and length of stream segments, etc. The areal aspect includes the analysis of basin parameters, basin shape both geometrical and topological (Stream frequency, Drainage density) and the relief aspect includes, the study of absolute and relative relief ratios, average slope, dissection index (Singh, 1998; Khakhlari and Nandy, 2016). Morphometric parameters mainly depend upon lithology, bed rock and geological structures. Hence, the information of geomorphology, hydrology, geology, and land use pattern is highly informative for reliable study of drainage pattern of the watershed (Astras and Soulankellis, 1992). For quantitative analysis of the watershed involving various components such as stream segments, basin perimeter, basin area, elevation difference, slope and profile of land has been responsible for the natural development of basin (Horton, 1945). In recent decades, the morphometric analysis of the various river basins, have been done by many researchers and scientist (Pareta, 2005; Mesa, 2006; Magesh et al., 2011; Bhagwat et al., 2011; Wilson et al., 2012; Singh et al., 2014; Sujathaet al., 2014; Meshram and Sharma, 2017; Rai et al., 2017). Morphometric parameters are important for watershed prioritization (Gaikwad and Bhagat (2017). Morphometric analysis of river basins using conventional methods is very time consuming, laborious, and cumbersome also. Proper planning and management of watershed is very necessary for sustainable development (Chandniha and Kansal, 2017). In the present study, an attempt is made to understand the morphometric characteristics of Adhala river basin, a tributary of Pravara river flowing through the Maharashtra using GIS and RS.

METHODOLOGY

Study Area

The latitudinal and longitudinal extent of the Adhala River basin are between 19°32'40" N to 19°43'2" N and 74°10'15"E to 74°48'18" E. Adhala River is one of the major Tributaries of Pravara River (Figure 1). Adhala River rises in the north of Akole on the slope of Patta and Mahakali. It flows for fifteen miles in an easterly direction between two ranges of hill which enclose the Samsherpur valley, then falling into the rocky chasm some 150 feet deep. The area as a whole comprises of hill slopes running parallel with the streams on the north and south, pediments extending up to alluvial banks which are deeply dissected to form badlands (Joshi, 2010). The catchment area of Adhala River basin is 216.17 square km. Basaltic rocks and a typical sub rounded weathering products are common in the study area. The soils of this region are covered by thick alluvial soil and black regur soil. The climatic condition of the basin is under the influence of south west monsoon.

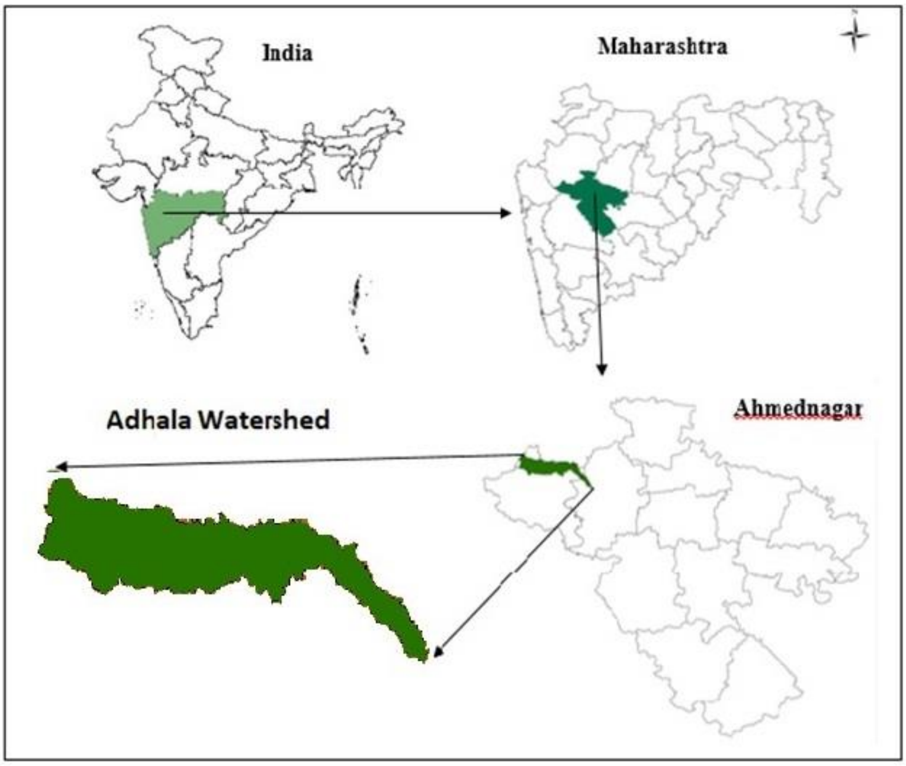

Figure1. Location map of the study area

Data requirement

Survey of India Topo-sheets (E43C2, E43B14) on 1:50,000 and CARTOSAT digital elevation model of Adhala basin of 32 m resolution was used for watershed delineation and stream processing. Survey of India topographic map was georeferenced using WGS 84 datum, Universal Transverse Mercator (UTM) zone 43N projection in ArcGIS desktop 10.3. Digital elevation model in the GeoTiff format to facilitate their ease of use in a variety of image processing and GIS applications.

RESULT AND DISCUSSION

A. Linear Aspect

Stream Order (Su): Stream ordering is the first step of quantitative analysis of the watershed. The stream ordering systems has first demonstrated by Horton (1945), but Strahler (1952) has proposed this ordering system with some modifications. Results of the Stream order are presented in the Table 1 and shown in Figure 2. It is found that stream order of trunk stream is 6th order stream.

Stream Number (Nu): The number of streams of each order stream segments is known as stream number. Horton (1945) stated that the numbers of stream segments of each order form an inverse geometric sequence with order number as presented in Table 1.

Stream Length (Lu): Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The stream length (L_u) has been computed based on Horton's law. In the Adhala watershed length of first order stream is 528.72 km, second order stream is 232.03 km, third order stream is 122.05 km, fourth order stream is 45.75 km, fifth order stream is 14.49 km and Sixth i.e. trunk order stream is 42.17 km. It is presented in Table 1.

Mean Stream Length (L_{sm}): The mean stream length (L_{sm}) has been calculated by dividing the total stream length of each order by the number of streams of respective order. The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). The mean stream length of Adhala watershed is presented in Table 1 which is 0.2, 0.45, 1.08, 1.83, 4.83 and 42.17 km for first, second, third, fourth, fifth and sixth order, respectively. The mean stream length of stream increases with increase of the order.

Stream Length Ratio (R_L): The stream length ratio is defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The different values of stream length ratio of different stream order in the watershed reveal that there is variation in slope and topography. The values of stream length ratio of the Adhala watershed are presented in Table 1.

Bifurcation Ratio (R_b): Bifurcation ratio (R_b) is defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. The bifurcation ratio of the watershed is presented Table 1. It was revealed that bifurcation ratio for the Adhala watersheds varies from 3.0 to 8.33 and mean R_b for entire watershed is 5.05. This higher value of bifurcation ratio indicates that shape of the watershed is elongated which is common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern.

Length of Main Channel (Cl): This is the length of channel along the longest watercourse from the outflow point of watershed to the upper limit to the watershed boundary. It is computed by using ArcGIS-10.3 software, which is 56.6 km and also presented in Table 1.

Channel Index (Ci): The river channel has divided into number of segments as suggested by Mueller (1968) for determination of sinuosity parameter. The measurement of channel length and shortest distance between the remotest point of main channel and outlet of the watershed i.e. air lengths are used for calculation of Channel index which is presented in Table 1.

Rho Coefficient (ρ): Rho coefficient is the ratio between the stream length ratio (R_L) and the bifurcation ratio (R_b). The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton 1945). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho values of the Adhala watershed is presented in Table 1, which is 0.69. This is indication of higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

Table 1 Linear aspect of morphology of Adhala watershed

Sr. No	Morphometric Parameter	Formula	Result
1	Stream Order (S_u)	Hierarchical Rank	1 to 6
2	Stream Number	Hierarchical number	
	Number of 1st order streams (N_1)	Hierarchical number	2498
	Number of 2nd order streams (N_2)	Hierarchical number	506
	Number of 3rd order streams (N_3)	Hierarchical number	112
	Number of 4th order streams (N_4)	Hierarchical number	25
	Number of 5th order streams (N_5)	Hierarchical number	3
	Number of 6th order streams (N_6)	Hierarchical number	1
3	Total number of streams (N_u)	Hierarchical number	3145
4	Stream Length (km)		
	Length of 1st order streams (L_1)	Sum of all 1st order stream length	528.72
	Length of 2nd order streams (L_2)	Sum of all 2nd order stream length	232.03

	Length of 3rd order streams (L_3)	Sum of all 3rd order stream length	122.05
	Length of 4th order streams (L_4)	Sum of all 4th order stream length	45.75
	Length of 5th order streams (L_5)	Sum of all 5th order stream length	14.49
	Length of 6th order streams (L_6)	Sum of all 6th order stream length	42.17
5	Total length of streams (L_u)	$L_u = L_1 + L_2 \ldots\ldots L_n$	985.20
6	Mean Stream Length (km)		
	Length of 1st order streams (L_{sm1})	$L_{sm1} = L_1 / N_1$	0.21
	Length of 2nd order streams (L_{sm2})	$L_{sm2} = L_2 / N_2$	0.45
	Length of 3rd order streams (L_{sm3})	$L_{sm3} = L_3 / N_3$	1.08
	Length of 4th order streams (L_{sm4})	$L_{sm4} = L_4 / N_4$	1.83
	Length of 5th order streams (L_{sm5})	$L_{sm5} = L_5 / N_5$	4.83
	Length of 6th order streams (L_{sm6})	$L_{sm6} = L_6 / N_6$	42.17
	Mean stream length L_{sm}	$L_{sm} = Lu / Nu$	0.313
7	Stream Length Ratio (R_L)	$R_L = L_u / L_{u-1}$	
	2nd order/1st order (R_{L2})	$R_{L2} = L_2 / L_1$	2.14
	3rd order/2nd order (R_{L3})	$R_{L3} = L_3 / L_2$	2.40
	4th order/3rd order (R_{L4})	$R_{L4} = L_4 / L_3$	1.69
	5th order/4th order (R_{L5})	$R_{L5} = L_5 / L_4$	2.63
	6th order/5th order (R_{L6})	$R_{L6} = L_6 / L_5$	8.73
	Mean Stream length ratio (R_{Lm})	$R_{Lm} = (\sum_{u=2}^{6} RL)/5$	3.51
8	Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$	
	1st order/2nd order	$R_{b1} = N_1 / N_2$	4.93
	2nd order/3rd order	$R_{b2} = N_2 / N_3$	4.51
	3rd order/4th order	$R_{b3} = N_3 / N_4$	4.48
	4th order/5th order	$R_{b4} = N_4 / N_5$	8.33
	5th order/6th order	$R_{b5} = N_5 / N_6$	3.00

	Mean Bifurcation Ratio (R_{bm})	$R_{bm} = (\sum_{u=1}^{5} Rb)/5$	5.05
9	Length of Main Channel (Cl) (km)	GIS Software	56.6
10	Areal length of outlet and channel remotest point (A_l) (km)	GIS Software	40.01
11	Channel Index (C_i)	$C_i = C_l / A_l$	1.41
12	Rho Coefficient (ρ)	$\rho = R_{Lm} / R_{bm}$	0.69

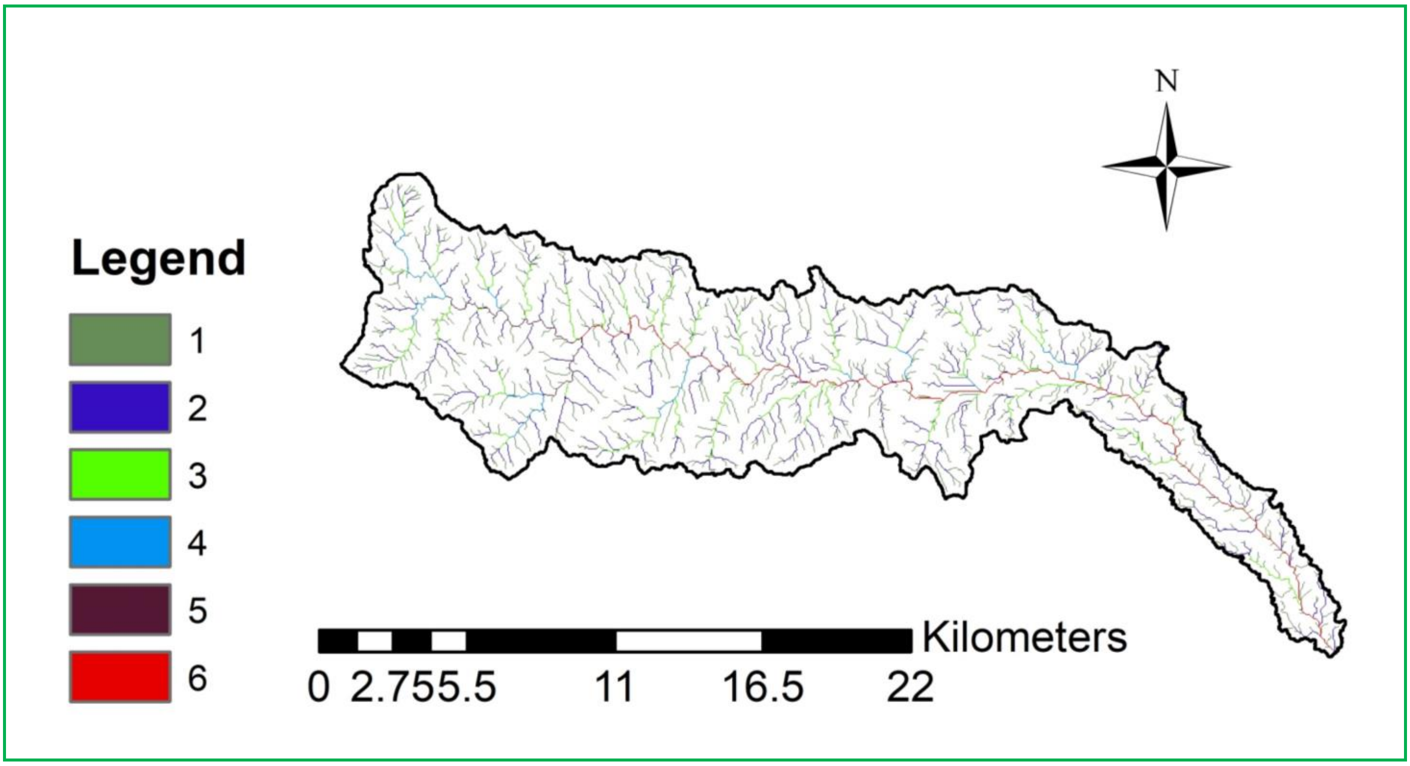

Figure 4.1: Stream order of the Adhala basin

B Aerial Aspects

It deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order.

Basin Area (A): The area of the watershed is an important parameter like the length of the stream drainage. Relationship between the total watershed areas and the total stream lengths, which is supported by the contributing areas, is given by Schumm (1956). Area of the Adhala watershed is computed by using ArcGIS-10.3 software and presented in Table 2, which is 216.17 km^2.

Basin Perimeter (P): Basin perimeter is the length of outer boundary of the watershed which enclosed area. It is measured along the drainage divide between watersheds and may be used as an indicator of watershed size and shape. The perimeter of the watershed was computed by using ArcGIS-10.3 software and presented in Table 2, which is 127.83 km.

Drainage density (D_d): It is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of km/km^2 (Horton, 1932). The drainage density, indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region and highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964). The drainage density (D_d) of study area is presented in Table 2 which is 4.55 km/km^2 indicating high drainage densities. The high drainage density indicates the basin is low permeable subsoil and vegetative cover.

Form Factor (F_f): Form factor (F_f) is the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a basin of a defined area (Horton, 1945). The form factor value should be always less than 0.7854 (the value corresponding to a perfectly circular basin). The smaller the value of the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated watersheds with low form factors experience lower peak flows of longer duration. The value of form factor of Adhala watershed is presented in Table 2, which is 0.132 indicating elongated basin with lower peak flows of longer duration than the average.

Stream Frequency (F_s): Stream frequency (F_s), is the total number of stream segments of all orders per unit area. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density (Horton, 1932). Stream frequency of the watershed is presented in Table 2, which is 14.16 per km^2.

Circulatory Ratio (R_c): Circularity ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The value of circularity ratio of the Adhala watershed is 0.171 and it indicating the basin is characterized by moderate to high relief.

Elongation Ratio (R_e): Elongation ratio is the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). Value of elongation ratio of the Adhala watershed is presented in Table 2, which is 0.21 indicating highly elongated and high relief as well as steep slope.

Length of overland flow (L_g): The length of overland flow (L_g) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). Length of overland flow is one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. The value of the length of overland flow of Adhala watershed is 0.112 km.

Constant channel maintenance (C): The inverse of drainage density as a property termed constant of stream maintenance (Schumm, 1956). This constant, in units of square km per Km, has the dimension of length and therefore increases in magnitude as the scale of the land-form unit increases. Specifically, the constant of stream maintenance provides information of the number of square km of watershed surface required to sustain one linear km of stream. The value of constant of stream maintenance of the Adhala watershed is 0.22 km.

Texture Ratio (T): Drainage texture ratio is the total number of first order stream segments to the perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. It is 19.54 km per km of the perimeter of the watershed.

Infiltration Number (I_f): Infiltration number is the product of drainage density and stream frequency, which helps to understand the infiltration characteristics of the basin. It provides a significant idea about the infiltration characteristics of basin area. It is inversely proportional to the infiltration capacity of the basin. The higher the infiltration number, the lower will be the infiltration and the higher run-off (Rai et al., 2017). The infiltration number of Adhala River basin is 66.15, which indicating that the infiltration capacity is very low resulting in very high runoff.

Texture Ratio (R_t): It is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain (Schumm, 1965). The texture ratio is expressed as the ratio between total number of first order streams and perimeter of the basin ($R_t = N_l / P$). In the present study, the texture ratio of the watershed is 19.54 and categorized as high in nature (Table 2).

Table 2 Areal aspect of morphology of Adhala watershed

Sr. No	Morphometric Parameter	Formula	Result
1	Basin Area (A) (Sq. km)	GIS Software Analysis	216.17
2	Basin Perimeter (P) (km)	GIS Software Analysis	127.83
3	Drainage density (D_d) (km/sq. km)	$D_d = L_u / A$	4.55
4	Form Factor (F_f)	$F_f = A / L_b^2$	0.13

5	Stream Frequency (F_s) (per Sq. km)	$Fs = N_u / A$	14.54
6	Circulatory Ratio (R_c)	$R_c = 4 \pi A / P^2$	0.17
7	Elongation Ratio (R_e)	$R_e = (A / \pi)^{0.5} / L_b$	0.21
8	Constant channel maintenance (C)	$C = 1/ Dd$	0.22
9	Infiltration Number (I_f)	$I_f = F_s * D_d$	66.15
10	Texture Ratio (R_t)	$R_t = N_1 / P$	19.54

C Relief Aspects

Absolute relief: Absolute relief is the difference in elevation between given location and sea level. Absolute relief of Adhala watershed is 552 m. High absolute relief was found in the western most part of the basin, in the upper most part of the catchment area. The absolute relief is gradually decreases towards the outlet of the watershed.

Relief Ratio (R_h): The relief ratio is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The Rh normally increases with decreasing drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The value of relief ratio of the Adhala watershed is 0.02 indicating overall low relief due to highly elongated watershed.

Relative Relief (R_r): The relative relief represents actual variation of altitude in a unit area with respect to its local base level. The relative relief does not take into account the dynamic potential of the terrain but as it is closely associated with slopes and it is more expressive and also useful in understanding the morphogenesis of this region (Bhunia et al., 2012). The relative relief was calculated using the formula: $R_r = (H*100) / P$, where H is the basin relief and P is perimeter in meters Melton (1957). Value of relative relief of the study watershed is 0.66 for Adhala watershed.

Ruggedness number (R_n): It is the product of maximum basin relief (H) and drainage density (D_d), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Strahler, 1956). The value of ruggedness number for the Adhala watershed is 3.78.

Table 3 Relief aspect of morphology of Adhala watershed

Sr. No	**Morphometric Parameter**	**Formula**	Result
1	Height of Outlet of the watershed (z) (m)	GIS Software Analysis	552
2	Max. height of the watershed (Z) (m)	GIS Software Analysis	1406
3	Total Basin Relief (H) (m)	$H = Z – z$	854
4	Absolute relief (R_a)	GIS Software Analysis	552
5	Relief Ratio (R_h) (m)	$R_h = H / L_b$	0.02
6	Relative Relief (R_r) (per cent)	$R_r = (H / P) * 100$	0.66
7	Ruggedness number (R_n)	$R_n = D_d * (H / 1000)$	3.7

CONCLUSION

The present study has demonstrated abilities of GIS tool for analysis of various morphometric parameters of the watershed. The geo-processing techniques employed in this study will assist in planning and decision making in the watershed development and management. The morphometric analyses were carried out through measurement of linear, areal and relief aspects of the watershed. The morphometric analysis of the drainage network of the watershed show dendritic and radial patterns with high drainage texture. The variation in stream length ratio might be due to change in slope and topography. The bifurcation ratio in the watershed indicates watershed is elongated and the presence of high drainage density suggesting that it has low permeable sub-soil, and fine drainage texture. The value of stream frequency indicate that the watershed show positive correlation with increasing stream population with respect to increasing drainage density. The value of form factor and circulator ration suggests that Adhala watershed is highly elongated.

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