

Quantitative Morphometric Analysis of Adula Watershed, Ahmednagar Maharashtra Using Arc-GIS tool

ABSTRACT

(Limit to a maximum of 200 words!) - see Journal Guidelines

Remote sensing and GIS is one of the most important tool ^{s currently} now-a-days to evaluate the morphometric characteristics of watershed, ^{s This is because} as morphometric analysis of river basins using conventional methods is very time consuming, laborious and cumbersome. In ^{this} Present study the morphometric characteristics of Adula watershed ^(India) were calculated by using ArcGIS. The ^a areal extent of Adula watershed ^a varies between $19^{\circ}32'40''$ N to $19^{\circ}43'2''$ N latitude & $74^{\circ}10'15''$ E to $74^{\circ}48'18''$ E longitude. The Topo sheets obtained from ^a survey of India on ^a scale of 1:50000 and ^a SRTM (spectral Radar Topographic Mission) Digital Elevation Model of 30 m resolution were used for watershed delineation ^{and} & deriving the linear (stream order, stream number, bifurcation ratio etc.), ^a Aerial (basin area, basin perimeter, drainage density, form factor, stream frequency, and circulatory ratio etc.), ^a & relief (height of outlet of watershed, ^b Basin relief, maximum height of watershed, total basin relief, absolute relief, relief ratio, ruggedness number etc.) ^{were used} aspects. The results revealed that ^{the} bifurcation ratio ^{for Adula watershed} varies from 3.0 to 8.33, which indicated that the shape of watershed is elongated. The most important parameter is ^a Drainage density ^{and} & form factor whose values were 4.43 km/km² indicating high drainage densities ^{an} & 0.132 indicating ^a elongated basin with lower peaks respectively. An extreme value of ruggedness ^{number} occurs when basin relief and drainage density is maximum and slope is steep ^{the} and for Adula watershed its value was 3.78 showing dendritic and radial pattern with drainage texture. It was found that there is variation in stream length ratio ^{that} it might be due to change in slope and topography. ^{Therefore} This morphometric analysis using geo-processing techniques employed in this study will assist in planning and decision making in the watershed development and management. ^{Future}

Introduction

Ahmednagar is ^a the largest district of Maharashtra state in respect of area and situated in the central part of the state. The normal rainfall over the district varies from 484 ^{mm} to about 879 mm. Rainfall is ^{at its} minimum in the northern parts of the district around Kopergaon and Sangamner and it gradually increases towards ^{the} southeast ^{ing its} and reaches the maximum around Jamkhed. ^{Because} The district ^{is} being situated in ^{the} "Rain Shadow" zone of Western Ghats, it often suffers the drought conditions.

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Grammar needs serious up grading !!

31 Almost ~~the~~ entire district, covering Nagar, Rahuri, Nevasa, Shevgaon, Jamkhed, Karjat, Srigonda,
 32 Pathardi and Parner talukas, ~~comes under~~ "Drought Area". Pravara basin up to the Sangamner
 33 River ~~gauging~~ station is considered as upper Pravara ~~B~~ basin. Adula is the tributary of the Pravara
 34 River which joins from north side before it reaches Sangamner and was considered for the present
 35 study. Adula ~~River~~ ~~Basin~~ is situated in the north-western part of the Ahmednagar district, covers an
 36 area of 222.07 ~~Sq~~ ^{km²}. The higher rainfall in ~~the~~ hilly region may be a result of ~~Topography~~. The
 37 rainfall intensity is high around 30 ~~mm/hr~~ to 80 mm/hr, which result in high run-off erosion and
 38 flash floods. The annual rainfall is not satisfactory. Therefore, originally the agricultural
 39 cropping pattern of this region is only dependent upon rainfall, and ~~Kharif~~ is the major season.

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40 Climate change affects the entire natural hydrological system (Arnold and Allen, 1996),
 41 including local and regional water resources. Climate change impacts on water resources are
 42 therefore of major concern in current hydrologic research. While climate projections are
 43 typically available at large spatial scales with coarse spatial resolution, decisions on soil and
 44 water are usually made on significantly smaller spatial scales. Assessment of soil and water
 45 resources is necessary to estimate the water conservation interventions required in the basin. It is
 46 important to estimate the effect of varying climatic condition ^S on the soil and water resources of
 47 the basin and provide suitable adaptation and mitigation strategies. Deforestation and
 48 unsustainable agricultural practices have been recognized as key drivers of watershed degradation.
 49 Thus, promoting soil and water resource sustainability by ~~the use of~~ technologies and practices that
 50 improve crop productivity without causing environmental damage are crucial in our pursuit for a
 51 more sustainable and equitable watershed development. ~~The Remote Sensing and GIS have~~
 52 proven better for evaluation and estimation of soil and water resources at basin scale. This tool is
 53 universally adopted for different work, such as ground water planning, water quality analysis,
 54 crop planning, water budgeting ~~and many more applications~~ ^{amongst other} (Arnold, 2007). Advancement of
 55 technology in natural resource planning has brought new hopes for sustainable development.

(English equivalent)

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56 'Morphometry may be defined as the measurement and mathematical analysis of the
 57 configuration of the earth's surface and of the shape and dimensions of its landforms' (Clarke,
 58 1966). Drainage basins are the fundamental units of the fluvial landscape and a great amount of
 59 research has focused on their geometric characteristics, which include the topology of the stream
 60 network and quantitative description of drainage texture, pattern, shape ~~X~~ and relief characteristics
 61 (Abrahams, 1984; Huggett and Cheesman, 2002). A quantitative morphometric characterization

only 2 listed!!

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62 of a drainage basin is considered to be the most satisfactory method for the proper planning of
 63 watershed, because it enables us to understand the relationship among different aspects of the
 64 drainage pattern of the basin, and also to make a comparative evaluation of different drainage
 65 basins developed in various geologic and climatic regimes (Zende and Nagrajan, 2011). Fluvial
 66 morphometric study of a drainage basin includes the consideration of linear, areal and relief
 67 aspects, where the linear aspect deals with the hierarchical orders of streams, numbers and length
 68 of stream segments, etc. The areal aspect includes the analysis of basin parameters, basin shape
 69 both geometrical and topological (Stream frequency, Drainage density) and the relief aspect
 70 includes the study of absolute and relative relief ratios, average slope and dissection index (Singh,
 71 1998; Khakhlari and Nandy, 2016). Morphometric parameters mainly depend upon lithology,
 72 bed rock and geological structures. Hence, the information of geomorphology, hydrology,
 73 geology, and land use pattern is highly informative for reliable study of drainage pattern of the
 74 watershed (Astras and Soulankellis, 1992). For quantitative analysis of the watershed involving
 75 various components such as stream segments, basin perimeter, basin area, elevation difference,
 76 slope and profile of land has been responsible for the natural development of basin (Horton,
 77 1945). In recent decades, the morphometric analysis of the various River basins, have been done
 78 by many researchers and scientist (Pareta, 2005; Mesa, 2006; Magesh *et al.*, 2011; Bhagwat *et*
 79 *al.*, 2011; Wilson *et al.*, 2012; Singh *et al.*, 2014; Sujatha *et al.*, 2014; Meshram and Sharma,
 80 2017; Rai *et al.*, 2017). Gaikwad and Bhagat (2017) have analyzed morphometric parameters for
 81 watershed prioritization. Morphometric analysis of River basins using conventional methods is
 82 very time consuming, laborious, and cumbersome also. Proper planning and management of
 83 watershed is very necessary for sustainable development (Chandniha and Kansal, 2017). In the
 84 present study, an attempt is made to understand the morphometric characteristics of Adula River
 85 Basin, a tributary of Pravara River flowing through the Maharashtra using GIS and RS.

METHODOLOGY

Study Area

88 The latitudinal and longitudinal extent of the Adula River basin are between 19°32'40" N
 89 to 19°43'2" N and 74°10'15"E to 74°48'18" E. Adula River is one of the major Tributaries of
 90 Pravara River (Figure 1). Adula River rises in the north of Akole on the slope of Patta and
 91 Mahakali. It flows for fifteen miles in an easterly direction between two ranges of hill which
 92 enclose the Samsherpur valley, then falling into the rocky chasm some 150 feet deep. The area as

What is the problem statement (reason for doing this study) in this specific Basin / watershed ??

Does not indicate Adula River !!

use metric system (km)

use metric system (meters)

Report not on what they did, but what they found

new paragraph

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93 ~~a whole~~ ^{consists} comprises of hill ^y slopes running parallel with the streams on the north and south,
 94 pediments extending up to alluvial banks which are deeply dissected to form badlands (Joshi,
 95 2010). ^{the} The catchment area of Adula River ^{basin} is 222.07 ^{km²} square km. Basaltic rocks and a
 96 typical sub rounded weathering products are common in the study area. The soils of this region
 97 are covered by thick alluvial soil and black regur soil. The climatic condition of the basin is
 98 under the influence of south west monsoon.

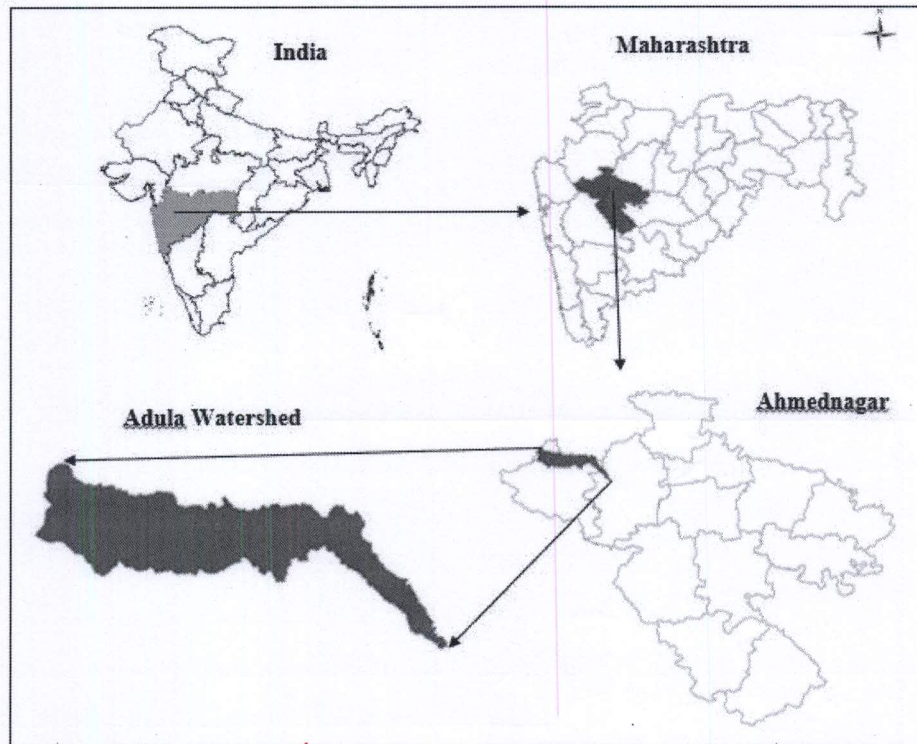


Figure 1. Location map of the study area.

Data requirement

102 Survey of India Topo-sheets (E43C2, E43B14) on 1:50,000 and SRTM (Spectral Radar
 103 Topographic Mission) digital elevation model of Adula basin of 30 m resolution was used for
 104 watershed delineation and stream processing. Survey of India topographic map was
 105 georeferenced using WGS 84 datum, Universal Transverse Mercator (UTM) zone 43N
 106 projection in ArcGIS desktop 10.3. Digital elevation model is available in both ArcInfo ASCII
 107 and GeoTiff format to facilitate their ease of use in a variety of image processing and GIS
 108 applications.

This reviewer stopped attending to grammar issues
 from here onwards!!

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 was found that stream order of trunk stream was 6th order stream.

separate? to Requirement for full paper to see Journal Guidelines

just indicate what you found and discuss it!!

*- meaning? (Discuss!)
Table 1 placed before Figure 2*

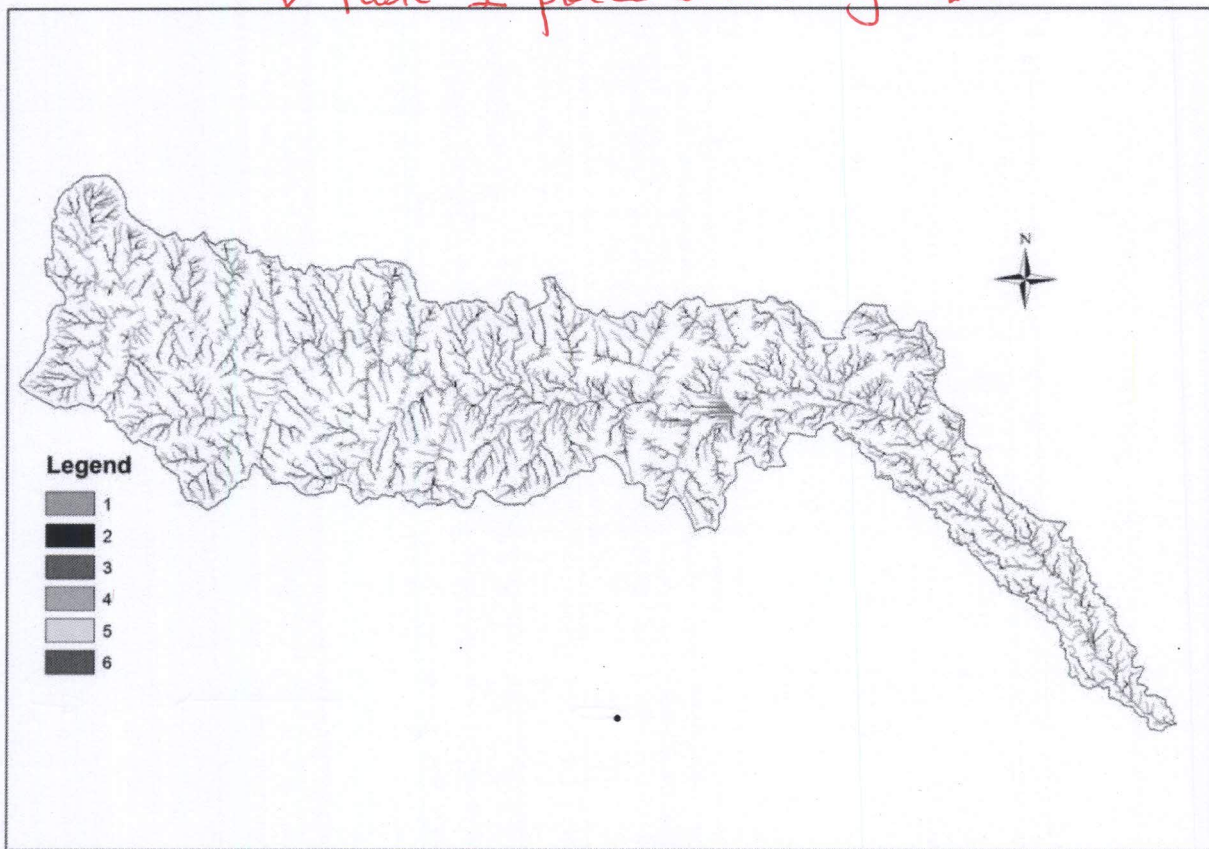


Figure 2 Stream order of the Adula watershed

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

Horton (1945) cited too many times!! in this paper!!

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 higher in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a watershed were counted and their lengths from mouth to drainage divide were measured with the help of GIS software. The stream length (Lu) was computed based on Horton's law. In the Adula watershed length of first order stream was 528.72 Km, second order stream 232.03 Km, third order stream 122.05 Km, fourth order stream 45.75 Km, fifth order stream 14.49 Km and Sixth i.e trunk order stream was 42.17 Km. ~~It is presented in Table 1.~~

belongs in methodology

Mean Stream Length (Lsm): The mean stream length (Lsm) was 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 Adula watershed ~~is presented in Table 1~~ ~~which~~ ~~found to be~~ 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 increased with increase of the order.

Stream Length Ratio (RL): 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 revealed that there was variation in slope and topography. The values of stream length ratio of the Adula watershed are presented in Table 1.

Bifurcation Ratio (Rb): Bifurcation ratio (Rb) 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 in Table 1. ~~It was revealed that~~ ~~The~~ bifurcation ratio for the Adula watersheds varies from 3.0 to 8.33 and mean Rb for entire watershed was 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.

Definitions of concepts / terminology is NOT
Discussion of RESULTS

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

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

160 **Rho Coefficient (p):** Rho coefficient is the ratio between the stream length ratio (RL) and the
161 bifurcation ratio (Rb). The Rho coefficient is an important parameter relating drainage density to
162 physiographic development of a watershed which facilitate evaluation of storage capacity of
163 drainage network and hence, a determinant of ultimate degree of drainage development in a
164 given watershed (Horton, 1945). The climatic, geologic, biologic, geomorphologic, and
165 anthropogenic factors determine the changes in this parameter. Rho value of the Adula watershed
166 is presented in Table 1, which was observed to be 0.69. This was indication of higher hydrologic
167 storage during floods and attenuation of effects of erosion during elevated discharge.

168 Table 1. Linear aspect of morphology of Adula watershed.

Sr. No	Morphometric Parameter	Formula	Result
1	Stream Order (Su)	Hierarchical Rank	1 to 6
2	Stream Number	Hierarchical number	
	Number of 1 st order streams (N ₁)	Hierarchical number	2498
	Number of 2 nd order streams (N ₂)	Hierarchical number	506
	Number of 3 rd order streams (N ₃)	Hierarchical number	112
	Number of 4 th order streams (N ₄)	Hierarchical number	25
	Number of 5 th order streams (N ₅)	Hierarchical number	3
	Number of 6 th order streams (N ₆)	Hierarchical number	1
3	Total number of streams (Nu)	Hierarchical number	3145
4	Stream Length (Km)		
	Length of 1 st order streams (L ₁)	Sum of all 1 st order stream length	528.72
	Length of 2 nd order streams (L ₂)	Sum of all 2 nd order stream length	232.03
	Length of 3 rd order streams (L ₃)	Sum of all 3 rd order stream length	122.05
	Length of 4 th order streams (L ₄)	Sum of all 4 th order stream length	45.75
	Length of 5 th order streams (L ₅)	Sum of all 5 th order stream length	14.49
	Length of 6 th order streams (L ₆)	Sum of all 6 th order stream length	42.17
5	Total length of streams (Lu)	Lu = L ₁ + L ₂ L _n	985.20
6	Mean Stream Length (Km)		

	Length of 1 st order streams (Lsm ₁)	$L_{sm1} = L_1 / N_1$	0.21
	Length of 2 nd order streams (Lsm ₂)	$L_{sm2} = L_2 / N_2$	0.45
	Length of 3 rd order streams (Lsm ₃)	$L_{sm3} = L_3 / N_3$	1.08
	Length of 4 th order streams (Lsm ₄)	$L_{sm4} = L_4 / N_4$	1.83
	Length of 5 th order streams (Lsm ₅)	$L_{sm5} = L_5 / N_5$	4.83
	Length of 6 th order streams (Lsm ₆)	$L_{sm6} = L_6 / N_6$	42.17
	mean stream length Lsm	$L_{sm} = L_u / N_u$	
7	Stream Length Ratio (RL)	$RL = L_u / L_{u-1}$	
	2 nd order/1 st order (RL ₂)	$RL_2 = L_2 / L_1$	2.14
	3 rd order/2 nd order (RL ₃)	$RL_3 = L_3 / L_2$	2.40
	4 th order/3 rd order (RL ₄)	$RL_4 = L_4 / L_3$	1.69
	5 th order/4 th order (RL ₅)	$RL_5 = L_5 / L_4$	2.63
	6 th order/5 th order (RL ₆)	$RL_6 = L_6 / L_5$	8.73
	Mean Stream length ratio (RLm)	$RLm = (\sum_{i=2}^6 RL_i) / 5$	3.51
8	Bifurcation Ratio (Rb)	$Rb = N_u / N_{u+1}$	
	1 st order/2 nd order	$Rb_1 = N_1 / N_2$	4.93
	2 nd order/3 rd order	$Rb_2 = N_2 / N_3$	4.51
	3 rd order/4 th order	$Rb_3 = N_3 / N_4$	4.48
	4 th order/5 th order	$Rb_4 = N_4 / N_5$	8.33
	5 th order/6 th order	$Rb_5 = N_5 / N_6$	3.00
	Mean Bifurcation Ratio (Rbm)	$Rbm = (\sum_{i=1}^5 Rb_i) / 5$	5.05
9	Length of Main Channel (Cl) (Km)	GIS Software	56.6
10	Areal length of outlet and channel remotest point (Al) (Km)	GIS Software	40.01
11	Channel Index (Ci)	$Ci = Cl / Al$	1.41
12	Rho Coefficient (ρ)	$\rho = RLm / Rbm$	0.69

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, was given by Schumm (1956) Area of the Adula watershed was computed by using ArcGIS-10.3 software and presented in Table 2, which was 222.07 km².

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 was 127.83 Kms.

belongs in methodology - kms

181 **Drainage density (Dd):** It is the ratio of total channel segment length cumulated for all order
 182 within a basin to the basin area, which is expressed in terms of Km/Km^2 (Horton, 1932). The
 183 drainage density indicates the closeness of spacing of channels, thus providing a quantitative
 184 measure of the average length of stream channel for the whole basin. It was observed from
 185 drainage density measurement made over a wide range of geologic and climatic type that a low
 186 drainage density is more likely to occur in region and highly resistant of highly permeable
 187 subsoil material under dense vegetative cover and where relief was low. High drainage density is
 188 the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous
 189 relief. Low drainage density leads to coarse drainage texture while high drainage density leads to
 190 fine drainage texture (Strahler, 1964). The drainage density (Dd) of study area ~~is presented in~~
 191 ~~(Table 2 which~~ was 4.43 Km/Km^2 indicating high drainage densities. The high drainage density
 192 indicated that the basin is low permeable subsoil and vegetative cover.

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

201 **Stream Frequency (Fs):** Stream frequency (Fs), is the total number of stream segments of all
 202 orders per unit area. It exhibited positive correlation with drainage density in the watershed
 203 indicating an increase in stream population with respect to increase in drainage density (Horton,
 204 1932). Stream frequency of the watershed ~~is presented in~~ (Table 2) ~~which~~ was found 14.16 per
 205 Km^2 . *meaning? indicating??*

206 **Circulatory Ratio (Rc):** Circularity ratio is the ratio of the area of a basin to the area of circle
 207 having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by
 208 the length and frequency of streams, geological structures, land use/ land cover, climate and
 209 slope of the basin. The value of circularity ratio of the Adula watershed was 0.171. ~~and it~~ *This*
 210 indicated that ~~the~~ basin was characterized by moderate to high relief.

the

211 **Elongation Ratio (Re):** Elongation ratio is the ratio of diameter of a circle of the same area as
 212 the drainage basin and the maximum length of the basin (Schumm, 1956). Value of elongation
 213 ratio of the Adula watershed is presented in Table 2, which was found to be 0.205 indicating
 214 highly elongated and high relief as well as steep slope.

215 **Length of overland flow (Lg):** The length of overland flow (Lg) is the length of water over the
 216 ground surface before it gets concentrated into definite stream channel (Horton, 1945). Length of
 217 overland flow is one of the most important independent variables affecting hydrologic and
 218 physiographic development of drainage basins. The length of overland flow is approximately
 219 equal to the half of the reciprocal of drainage density. This factor is related inversely to the
 220 average slope of the channel and is quite synonymous with the length of sheet flow to a large
 221 degree. The value of the length of overland flow of Adula watershed was 0.112 Km.

222 **Constant of channel maintenance (C):** The inverse of drainage density as a property termed
 223 constant of stream maintenance (Schumm, 1956). This constant, in units of square kms per Km,
 224 has the dimension of length and therefore increases in magnitude as the scale of the land-form
 225 unit increases. Specifically, the constant of stream maintenance provides information of the
 226 number of square Kms of watershed surface required to sustain one linear Km of stream. The
 227 value of constant of stream maintenance of the Adula watershed was 0.225 Km.

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

232 **Infiltration Number (If):** Infiltration number is the product of drainage density and stream
 233 frequency, which helps to understand the infiltration characteristics of the basin. It provides a
 234 significant idea about the infiltration characteristics of basin area. It is inversely proportional to
 235 the infiltration capacity of the basin. The higher the infiltration number, the lower will be the
 236 infiltration and the higher run-off (Rai et al., 2017). The infiltration number of Adula River basin
 237 was 62.81, which indicated that the infiltration capacity is very low resulting in very high runoff.

238 **Texture Ratio (Rt):** It is an important factor in the drainage morphometric analysis which is
 239 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 ($R_t = N_1 / P$). In the present study, the texture ratio of the watershed was found to be 19.54 and categorized as high in nature (Table 2).

Table 2 Areal aspect of morphology of Adula watershed

Sr. No	Morphometric Parameter	Formula	Result
1	Basin Area (A) (Sq. Km)	GIS Software Analysis	222.07
2	Basin Perimeter (P) (Km)	GIS Software Analysis	127.83
3	Drainage density (Dd) (Km/sq. Km)	$Dd = L_u / A$	4.43
4	Form Factor (Ff)	$Ff = A / L_b^2$	0.13
5	Stream Frequency (Fs) (per Sq. Km)	$Fs = N_u / A$	14.16
6	Circulatory Ratio (Rc)	$Rc = 4 \pi A / P^2$	0.17
7	Elongation Ratio (Re)	$Re = (A / \pi)^{0.5} / L_b$	0.205
8	Constant channel maintenance (C)	$C = 1 / Dd$	0.225
9	Infiltration Number (If)	$If = Fs * Dd$	62.81
10	Texture Ratio (Rt)	$Rt = N_1 / P$	19.54

C Relief Aspects

Absolute relief: Absolute relief is the difference in elevation between given location and sea level. Absolute relief of Adula watershed was 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 gradually decreases towards the outlet of the watershed.

Relief Ratio (Rh): 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 Adula watershed was 0.02 indicating overall low relief due to highly elongated watershed.

Relative Relief (Rr): 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

"Discussion" focusses on what these values mean in general, but not in terms of Adula watershed!!
 - Discussion should be refocussed on Adula watershed!!

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: $R_r = (H \times 100) / P$, where H is the basin relief and P is perimeter in meters, Melton (1957). Value of relative relief of the study watershed was 0.66 for Adula watershed.

belongs in methodology

Ruggedness number (Rn): It is the product of maximum basin relief (H) and drainage density (Dd), 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 Adula watershed was 3.78.

Table 3: Relief aspect of morphology of Adula 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 (Ra)	GIS Software Analysis	552
5	Relief Ratio (Rh) (m)	$R_h = H / L_b$	0.02
6	Relative Relief (Rr) (per cent)	$R_r = (H / P) \times 100$	0.66
7	Ruggedness number (Rn)	$R_n = D_d \times (H / 1000)$	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 showed 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 indicated 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 indicated that the watershed show positive correlation with increasing stream population with

This looks like discussion

What does all this mean in terms of planning and management of this area for sustainable development (as indicated on lines 82/83 of Introduction)?

279 respect to increasing drainage density. The value of form factor and circulatory ration suggested
280 that Adula watershed is highly elongated.

281 **REFERENCE**

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