# Quantitative Morphometric Analysis of Adula Watershed, Ahmednagar Maharashtra Using [redacted] tool


## ABSTRACT

Remote sensing and GIS [redacted] of the most important tool [redacted] to evaluate the morphometric characteristics of watershed, as morphometric analysis of river basins using conventional methods is very time consuming, laborious and cumbersome. In [redacted] study the morphometric characteristics of Adula watershed were calculated [redacted] using ArcGIS. The areal extent of Adula watershed varies between 19°32'40" N to 19°43'2" N latitude & 74°10'15" E to 74°48'18" E longitude. The [redacted] sheets obtained from survey of India on scale of 1:50000 and SRTM (Spectral Radar Topographic Mission) Digital Elevation Model of 30 m resolution were used for watershed delineation & deriving the linear (stream order, stream number, bifurcation ratio etc.), aerial (basin area, basin perimeter, drainage density, form factor, stream frequency, and circulatory ratio etc.), & relief (height of outlet of watershed, Basin relief, maximum height of watershed, total basin relief, absolute relief, relief ratio, ruggedness number etc.) aspects. The results revealed that 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 [redacted] Drainage density & form factor whose values were 4.43 km/km$^2$ indicating high drainage densities & 0.132 indicating elongated basin with lower peaks [redacted]. An extreme value of ruggedness number occurs when basin relief and drainage density is maximum and slope is steep 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 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 [redacted] watershed development and management.


## Introduction

Ahmednagar is the largest district of Maharashtra state [redacted] respect [redacted] 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 minimum in the northern parts of the district around Kopargaon and Sangamner and it gradually increases towards southeast and reaches the maximum around Jamkhed. The district being situated in "Rain Shadow" zone of Western Ghats, [redacted] often suffers [redacted] drought conditions.

Almost entire district, covering Nagar, Rahuri, Nevasa, Shevgaon, Jamkhed, Karjat, Srigonda, Pathardi and Parner talukas, [redacted] "Drought Area". Pravara basin up to the Sangamner River gauging station is considered as upper Pravara basin. Adula is the tributary of the Pravara River which joins from north side before it reaches Sangamner and was [redacted] for the present study. Adula river basin is situated in the north western part of the Ahmednagar district covers an area of 222.07 Sq. km. The higher rainfall in hilly region may be a result of topography. The rainfall intensity is high around 30 mm/hr to 80 mm/hr, which result in high run off erosion and flash floods. The annual rainfall is not satisfactory. [redacted] the agricultural crop[redacted] pattern of this region is [redacted] dependent upon rainfall, and *Kharif* is the major season.

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 [redacted] 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 [redacted] the use of technologies and practices that improve crop productivity without causing environmental damage are crucial in our pursuit for more sustainable and equitable watershed development. [redacted] Remote Sensing and GIS have proven [redacted] for evaluation and estimation of soil and water resources at basin scale. This tool [redacted] universally adopted for different [redacted] such as ground water planning, water quality analysis, crop planning, water budgeting and [redacted] 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 [redacted] 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 [redacted] geomorphology, hydrology, geology, and land use pattern is highly informative for reliable stud[redacted] of drainage pattern of [redacted] watershed (Astras and Soulankellis, 1992). [redacted]quantitative analysis of [redacted] watershed involving various components such as stream segments, basin perimeter, basin area, elevation difference, slope and profile of land has been responsible [redacted] 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; Sujatha*et al*., 2014; Meshram and Sharma, 2017; Rai *et al*., 2017). Gaikwad and Bhagat (2017) have analyzed morphometric parameters for watershed prioritization. Morphometric analysis of River basins using conventional methods is very time consuming, laborious, and cumbersome [redacted]. Proper planning and management of watershed is [redacted] necessary for sustainable development (Chandniha and Kansal, 2017). In the present study, an attempt is made to understand the morphometric characteristics of Adula 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 Adula River basin [redacted] between 19°32′40″ N to 19°43′2″ N and 74°10′15″E to 74°48′18″ E. Adula River is one of the major tributaries of Pravara River (Figure 1). Adula 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 fall[redacted] into [redacted] rocky chasm [redacted] 150 feet deep. The area [redacted]

[redacted] comprised of hill slopes running parallel [redacted] the streams [redacted] the north and south pediments extending up to alluvial banks which are deeply dissected [redacted] form badlands (Joshi, 2010). The catchment area of Adula River basin is 222.07 square [redacted]. Basaltic rocks and [redacted] 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.

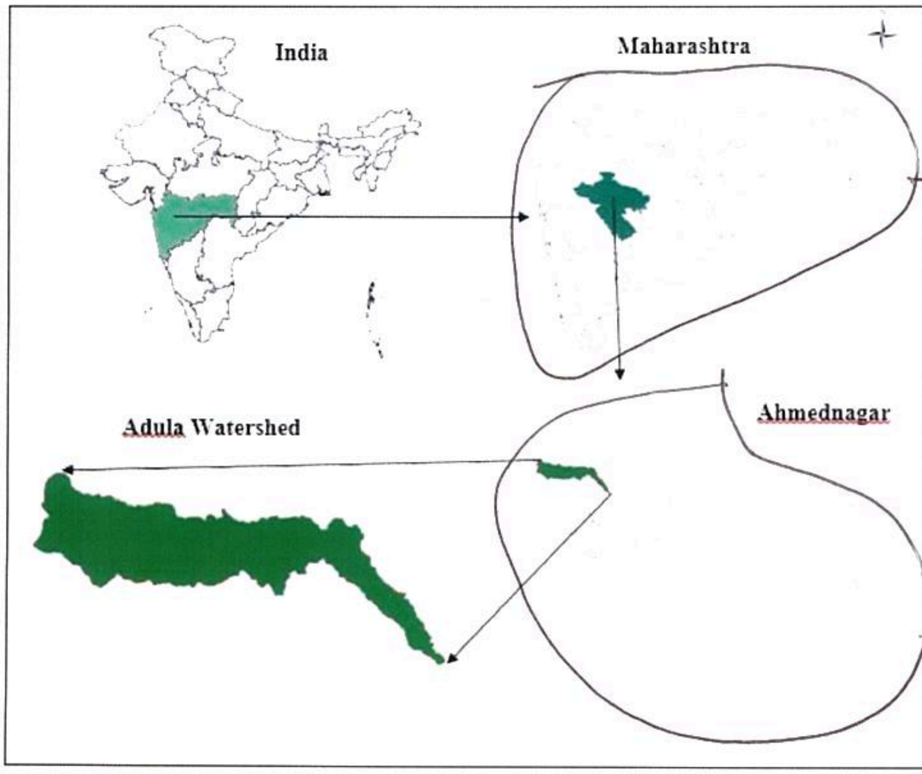


**Figure1. Location map of the study area**

**Data requirement**

Survey of India [redacted]-sheets (E43C2, E43B14) on 1:50,000 and SRTM (Spectral Radar Topographic Mission) Digital elevation Model of Adula basin [redacted] 30 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 is available in both ArcInfo ASCII and 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 [redacted] watershed. The stream ordering system [redacted] first demonstrated by Horton (1945), but Strahler (1952) [redacted] proposed this ordering system with some modifications. Results of the stream order are presented in the Table 1 and shown in Figure 2.It [redacted] found that stream order of trunk stream was 6th order stream.

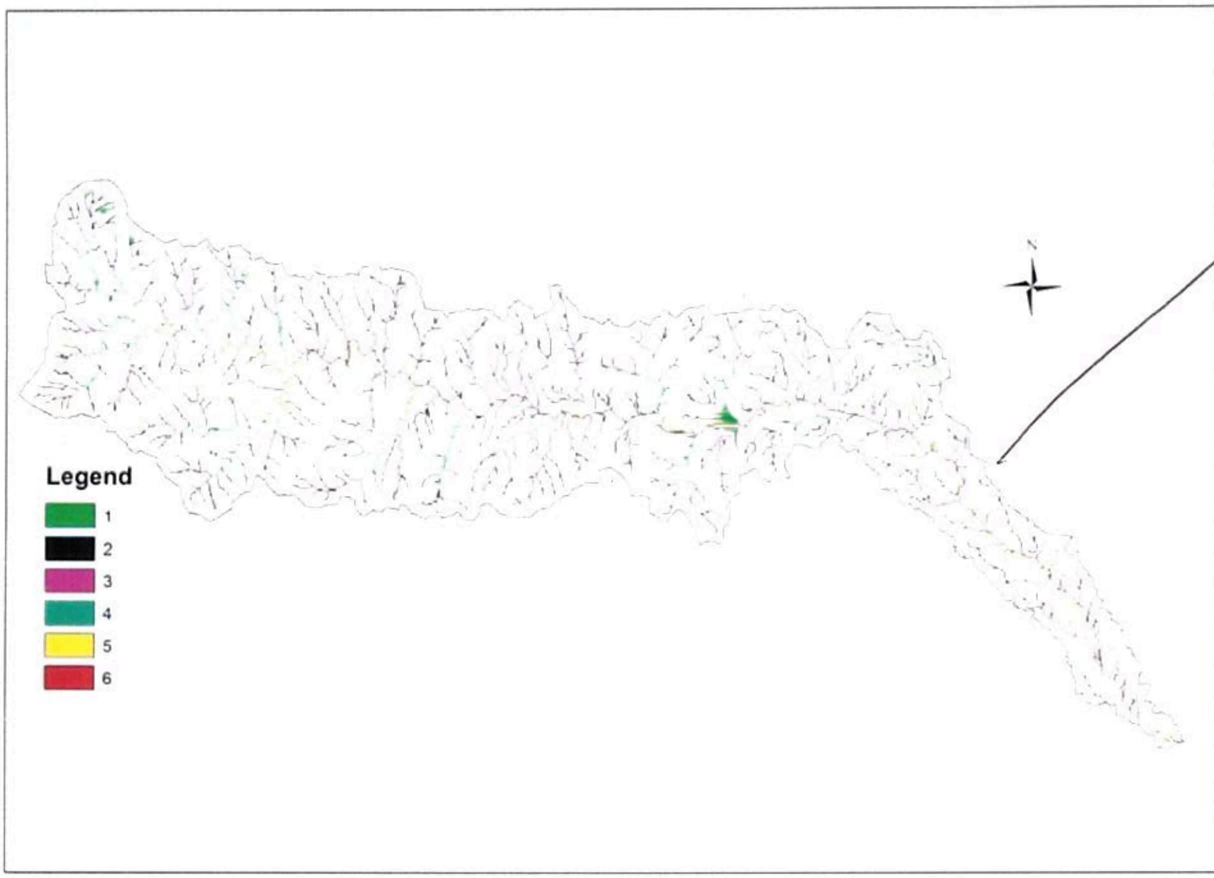


**Figure 2 Stream order of the Adula watershed**

**Stream Number (Nu):** The number of streams [redacted] each order [redacted] segment[redacted] 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. [redacted] stream of relatively small[redacted] length is characteristic[redacted] 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 [redacted] of various orders in [redacted] 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 [redacted], second order stream 232.03 [redacted], third order stream 122.05 [redacted], fourth order stream 45.75 [redacted], fifth order stream 14.49 [redacted] and Sixth (i.e. trunk) order stream was 42.17 [redacted]. [redacted] is presented in Table 1.

**Mean Stream Length (Lsm):** The mean stream length (Lsm) was calculated by dividing the total stream length [redacted] 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 was found to be 0.2, 0.45, 1.08, 1.83, 4.83 and 42.17 [redacted] 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 bifurcation ratio for the Adula watershed[redacted] 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.

**Length of Main Channel ([redacted]):** 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 was computed by using ArcGIS 10.3 software, [redacted] was 56.6 [redacted] and also presented in Table 1.

**Channel Index (Ci):** The river channel was 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 were 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 (RL) and the bifurcation ratio (Rb). 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 value of the Adula watershed is presented in Table 1, which was observed to be 0.69. This was indication of higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

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 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 (Nu) | 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 (Lu) | $Lu = L_1 + L_2 \ldots\ldots Ln$ | 985.20 |
| 6 | Mean Stream Length (Km) | | |

| | | | |
|---|---|---|---|
| | Length of 1st order streams ($Lsm_1$) | $Lsm_1 = L_1 / N_1$ | 0.21 |
| | Length of 2nd order streams ($Lsm_2$) | $Lsm_2 = L_2 / N_2$ | 0.45 |
| | Length of 3rd order streams ($Lsm_3$) | $Lsm_3 = L_3 / N_3$ | 1.08 |
| | Length of 4th order streams ($Lsm_4$) | $Lsm_4 = L_4 / N_4$ | 1.83 |
| | Length of 5th order streams ($Lsm_5$) | $Lsm_5 = L_5 / N_5$ | 4.83 |
| | Length of 6th order streams ($Lsm_6$) | $Lsm_6 = L_6 / N_6$ | 42.17 |
| | mean stream length Lsm | Lsm = Lu / Nu | |
| 7 | Stream Length Ratio (RL) | $RL = L_u / L_{u-1}$ | |
| | 2nd order/1st order ($RL_2$) | $RL_2 = L_2 / L_1$ | 2.14 |
| | 3rd order/2nd order ($RL_3$) | $RL_3 = L_3 / L_2$ | 2.40 |
| | 4th order/3rd order ($RL_4$) | $RL_4 = L_4 / L_3$ | 1.69 |
| | 5th order/4th order ($RL_5$) | $RL_5 = L_5 / L_4$ | 2.63 |
| | 6th order/5th order ($RL_6$) | $RL_6 = L_6 / L_5$ | 8.73 |
| | Mean Stream length ratio (RLm) | RLm = (∑ [illegible] | 3.51 |
| 8 | Bifurcation Ratio (Rb) | $Rb = N_u / N_{u+1}$ | |
| | 1st order/2nd order | $Rb_1 = N_1 / N_2$ | 4.93 |
| | 2nd order/3rd order | $Rb_2 = N_2 / N_3$ | 4.51 |
| | 3rd order/4th order | $Rb_3 = N_3 / N_4$ | 4.48 |
| | 4th order/5th order | $Rb_4 = N_4 / N_5$ | 8.33 |
| | 5th order/6th order | $Rb_5 = N_5 / N_6$ | 3.00 |
| | Mean Bifurcation Ratio (Rbm) | Rbm = (∑ [illegible] | 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) | ρ = RLm / Rbm | 0.69 |

**B Aerial Aspects**

[redacted] deal[redacted] with the total area projected [redacted] 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, [redacted] 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, [redacted] was 222.07 $Km^2$.

**Basin Perimeter (P):** Basin perimeter is the length of outer boundary of the watershed which enclose[redacted] 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 [redacted] using ArcGIS 10.3 software and presented in Table 2, [redacted] was 127.83 [redacted]

**Drainage density (Dd)**: It is the ratio of total channel segment length [redacted] for all orders within a basin to the basin area, which is expressed in terms of [redacted] (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 was 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 [redacted] highly resistant [redacted] highly permeable subsoil [redacted] under dense vegetative cover [redacted] where relief was low. High drainage density is the result[redacted] 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 (Strahaler, 1964). The drainage density (Dd) of study area is presented in Table 2 which was 4.43 $Km/Km^2$ indicating high drainage densities. The high drainage density indicated that the basin [redacted] low permeable subsoil and vegetative cover.

**Form Factor (Ff):** Form factor (Ff) 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, [redacted] elongated watersheds with low form factors experience lower peak flows of longer duration. The value of form factor of Adula watershed is presented in Table 2, which was 0.132 indicating elongated basin with lower peak flows of longer duration than [redacted] average.

**Stream Frequency (Fs):** Stream frequency (Fs), is the total number of stream segments of all orders per unit area. It exhibit[redacted] 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 was found 14.16 per [redacted]

**Circulatory Ratio (Rc):** 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 Adula watershed was 0.171 and it indicated that basin was characterized by moderate to high relief.

**Elongation Ratio (Re):** 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 Adula watershed is presented in Table 2, [redacted] was found to be 0.205 indicating highly elongated and high relief as well as steep slope.

**Length of overland flow (Lg):** The length of overland flow (Lg) 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 [redacted] synonymous with the length of sheet flow to a large degree. The value of the length of overland flow of Adula watershed was 0.112 [redacted]

**Constant of [redacted] maintenance (C):** The inverse of drainage density [redacted] a property termed constant of stream maintenance (Schumm, 1956). This constant, in units of square kms per [redacted], 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 [redacted] the number of square [redacted] of watershed surface required to sustain one linear [redacted] of stream. The value of constant of stream maintenance of the Adula watershed was 0.225 [redacted]

**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 was 19.54 [redacted] per [redacted] of [redacted] perimeter of the watershed.

**Infiltration Number (If):** 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 [redacted] the infiltration and the higher run-off (Rai et al., 2017). The infiltration number of Adula River basin was 62.81, which indicated that the infiltration capacity is very low resulting in very high runoff.

**Texture Ratio (Rt)**: It is an important factor in the drainage morphometric analysis, [redacted] [redacted] 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) | $Dd = Lu / A$ | 4.43 |
| 4 | Form Factor (Ff) | $Ff = A / Lb^2$ | 0.13 |
| 5 | Stream Frequency (Fs) (per Sq. Km) | $Fs = Nu / A$ | 14.16 |
| 6 | Circulatory Ratio (Rc) | $Rc = 4 \pi A / P^2$ | 0.17 |
| 7 | Elongation Ratio (Re) | $Re = (A / \pi)^{0.5} / Lb$ | 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 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: Rr = (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 was 0.66 for Adula watershed.

**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) | Rhl = H / Lb | 0.02 |
| 6 | Relative Relief (Rr) (per cent) | Rr = (H / P) * 100 | 0.66 |
| 7 | Ruggedness number (Rn) | Rn = Dd * (H / 1000) | 3.7 |

## CONCLUSION

[redacted] study [redacted] 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 [redacted] 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 suggest[redacted] that it has low permeable sub-soil, and fine drainage texture. The value of stream frequency indicated that the watershed show positive correlation [redacted] increasing stream population [redacted]

[redacted] increasing drainage density. The value of form factor and circulatory ratio suggested that Adula watershed is highly elongated.

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