Quantitative Morphometric Analysis of the Adula Watershed, in Ahmednagar Maharashtra Using the ESRI- ArcGIS tool

ABSTRACT

Remote sensing and geographic information system (GIS) are two of the most important tools used to evaluate the morphometric characteristics of watersheds, as morphometric analysis of river basins using conventional methods, is very time to consume, laborious and cumbersome. In this study, the morphometric characteristics of the Adula watershed were calculated using ESRI-ArcGIS. The areal extent of the Adula watershed varies between 19^{0}32’40” N to 19^{0}43’2” N latitude and 74^{0}10’15” E to 74^{0}48’18” E longitude. The topographic sheets obtained from the survey of India on a scale of 1:50000 and the 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), aerial (basin area, basin perimeter, drainage density, form factor, stream frequency, and circulatory ratio), relief (height of outlet of watershed, basin relief, maximum height of watershed, total basin relief, absolute relief, relief ratio, ruggedness number) aspects. bifurcation ratio for varies from 3.0 to 8.33, indicating elongated shape of the watershed. Drainage density factor values were 4.43 km/km^2 indicating high drainage densities and 0.132 indicating an elongated basin with lower peaks respectively. Ruggedness number was 3.78 showing a dendritic and radial pattern with drainage texture. 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.

Introduction

Ahmednagar is 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/year to about 879 mm/ year. Rainfall is minimum in the northern parts of the district around Kopargaon and Sangamner and it gradually increases towards the southeast and reaches the maximum around Jamkhed (CGWB report, 2014). The district is situated in “Rain Shadow” zone of Western Ghats, it often suffers the drought conditions. Almost entire district covering Nagar, Rahuri, Nevasa, Shevgaon, Jamkhed, Karjat, Srigonda, Pathardi and Parner talukas comes under “Drought Area”. Pravara basin up to the Sangamner River gauging station is considered as upper Pravara basin

(Sabale et al., 2015). Adula is the tributary of the Pravara River which joins from the north side before it reaches Sangamner and was considered for the present study. Adula river basin is situated in the north-western part of the Ahmednagar district covers an area of 222.07 km^2. The higher rainfall in the hilly region may be a result of Topography (Oettli et al., 2005). The rainfall intensity is high around 30 mm/hr to 80 mm/hr, which result in high run-off erosion and flash floods (Bannari et al., 2016). The annual rainfall is not satisfactory. Therefore, originally the agricultural cropping pattern of this region is only dependent upon rainfall, and *Kharif* is the major season (Krishna Kumar et al., 2004).

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 (Luca et al., 2018). Assessment of soil and water resources is necessary to estimate the water conservation interventions required in the basin (Mekonnen et al., 2011). 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 (Kang et al., 2009). Deforestation and unsustainable agricultural practices have been recognized as key drivers of watershed degradation (Paudel et al., 2014). Thus, promoting soil and water resource sustainability through 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 the basin scale (de Paul et al., 2013). This tool is universally adopted for different work such as groundwater 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 act as the fundamental units of the fluvial landscape. A great amount of research has focused on its geometric characteristics. This includes the topology of the stream network and quantitative description of drainage texture, shape, pattern, 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, 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 (Abboud and Nofal, 2016). Hence, the information of geomorphology, hydrology, geology, and land use pattern is highly informative for the reliable study of drainage pattern of the watershed (Astras and Soulankellis, 1992).

Proper planning and management of watershed are very 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 Maharashtra state, using GIS and RS.

METHODOLOGY

Study Area

The latitudinal and longitudinal extent of the Adula River basin is 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 the hill which enclose the Samsherpur valley, then falling into the rocky chasm approximately 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 Adula River basin is 222.07 km^2. 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 (Jeelani, et al., 2017).

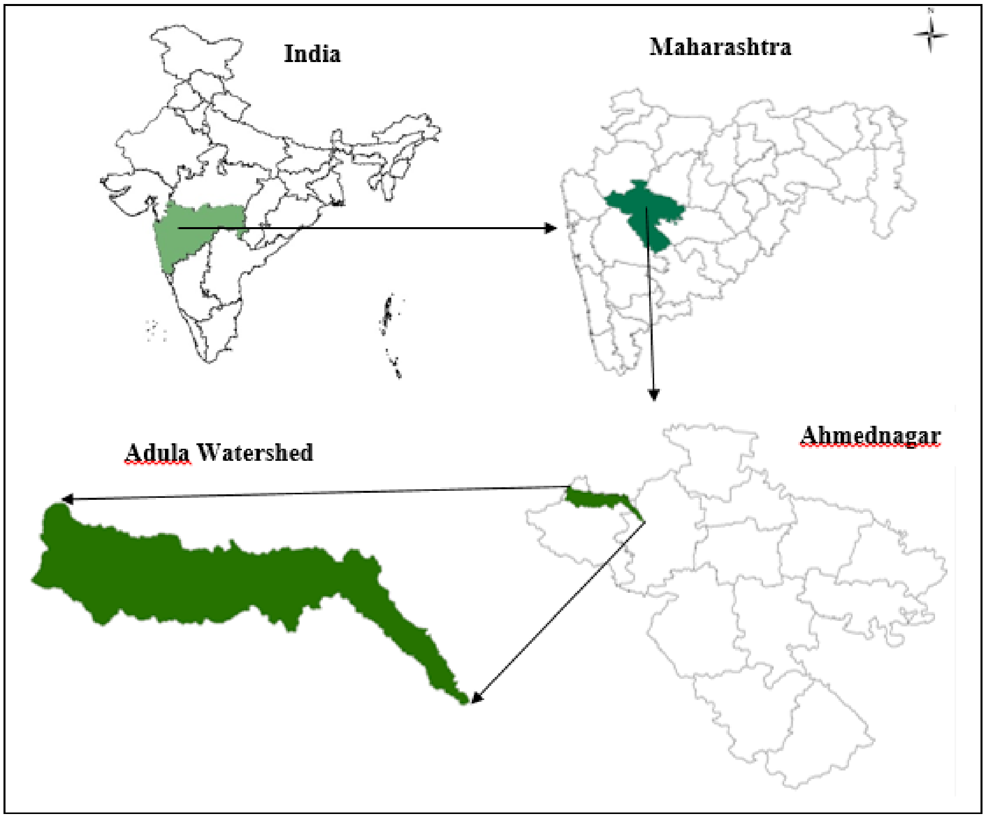

Figure1. Location map of the study area

Data requirement

The survey of India topographic sheets (E43C2, E43B14) on 1:50,000 and SRTM (Spectral Radar Topographic Mission) digital elevation model of Adula basin of 30 m resolution was used for watershed delineation and stream processing. Survey of India topographic map was georeferenced using World Geodeltic system (WGS) 84 datum, Universal Transverse Mercator (UTM) zone 43N projection in ESRI 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 (Al-Fugara, 2015).

RESULT AND DISCUSSION

A. Linear Aspect

Stream Order (Su): The first step of quantitative analysis of the watershed is stream ordering. Results of the Stream order are presented in Table 1 and shown in Figure 2. It was found that stream order of trunk stream was 6th order stream.

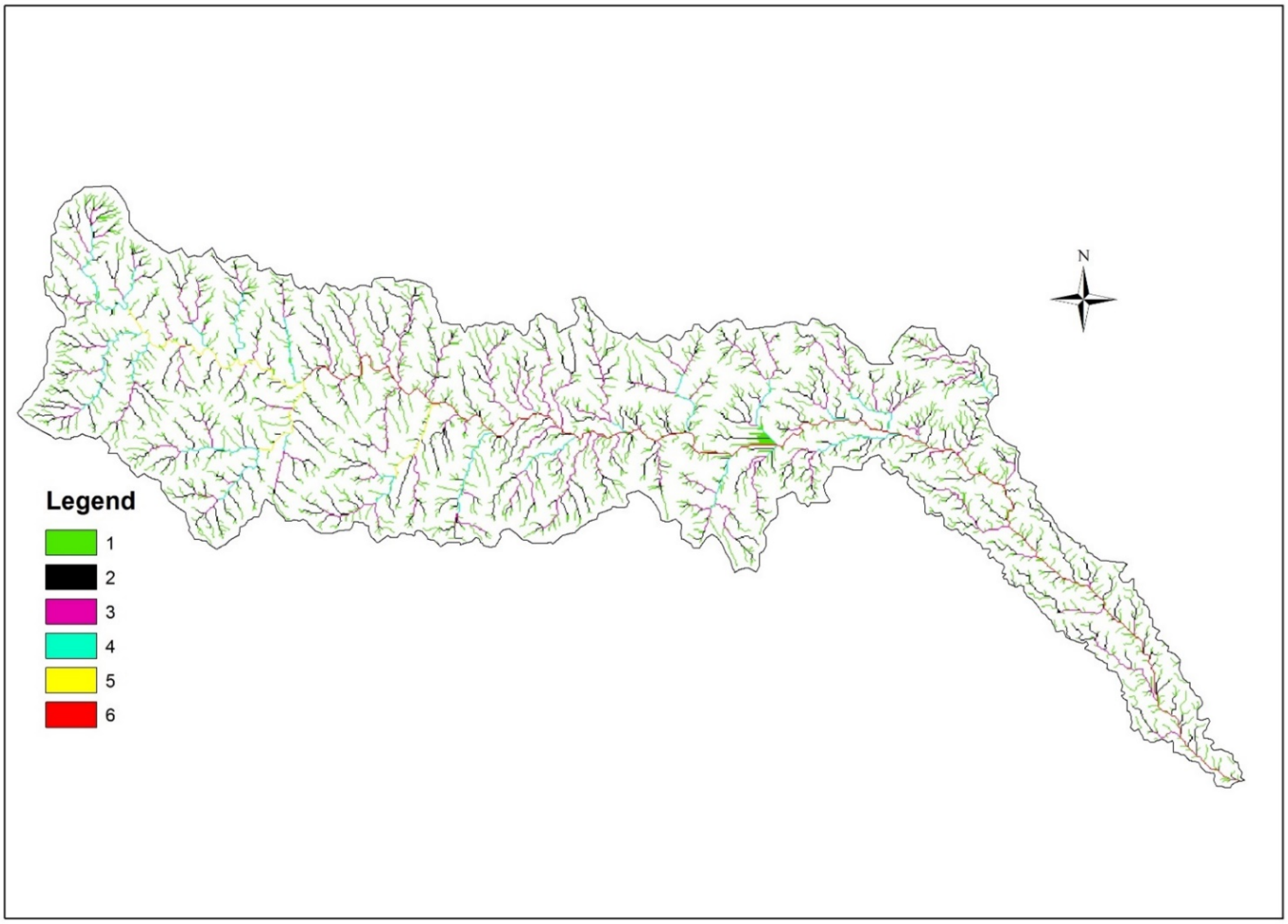

Figure 2 Stream order of the Adula watershed

Stream Number (Nu): The number of streams 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 the order number (Table 1).

Stream Length (Lu): It is one of the important hydrological features of the basin as it reveals surface runoff characteristics (Sukristiyanti et al., 2018). Larger slopes and finer textures are found in the stream of relatively smaller length. Streams with longer lengths are generally indicative of flatter gradient (Asok et al., 2016). In general, the total length of stream segments is higher in the first-order stream and decreases as the stream order increases (Satheesh, 2017). The numbers of streams 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 the 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 (Table 1).

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 character of mean stream length is 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 Km for first, second, third, fourth, fifth and sixth order, respectively. The mean stream length of stream increased with the increase of the order.

Stream Length Ratio (RL): It is the ratio of the mean stream length of a given order to the mean stream length of next lower order. It has an important relationship with the 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 (Farhan et al., 2016). The values of stream length ratio of the Adula watershed are presented in Table 1.

Bifurcation Ratio (Rb): It is the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). It is an index of relief and dissections with a small range of variation for different regions or different environmental conditions, except where the geology dominates (Horton 1945, Strahler 1957). The bifurcation ratio of the watershed is presented in Table 1. 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 the 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 (Najar, 2018).

Length of Main Channel (Cl): This is the length of the channel along the longest watercourse from the outflow point of the watershed to the upper limit to the watershed boundary (Pareta, Pareta, 2011). It was computed by using ESRI- ArcGIS-10.3 software, which was 56.6 Km (Table 1).

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

Rho Coefficient (ρ): Rho coefficient is the ratio between the stream length ratio (RL) and the bifurcation ratio (Rb) (Pareta, Pareta, 2011). The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed. This facilitates the evaluation of storage capacity of drainage network and hence, the ultimate degree of drainage development in a given watershed can be determined (Horton 1945). The geologic, geomorphologic, climatic, biologic, and anthropogenic factors determine the changes in this parameter. Rho value (Table 1), was observed to be 0.69. This was an indication of higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge (Ovando et al., 2016).

Table 1 Linear aspect of the 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)	$RLm = (\sum_{u=2}^{6} RL)/5$	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)	$Rbm = (\sum_{u=1}^{5} Rb)/5$	5.05
9	Length of Main Channel (Cl) (Km)	GIS Software	56.6
10	Areal length of outlet and channel remotest point (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

This deal 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 (Waikar, and Nilawar, 2014).

Basin Area (A): The area of the watershed is an important parameter like the length of the stream drainage. The 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 is presented in Table 2, which was 222.07 Km^2.

Basin Perimeter (P): Basin perimeter is the length of the outer boundary of the watershed which enclosed the 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 is presented in Table 2, which was 127.83 Kms.

Drainage density (Dd): It is the ratio of total channel segment length cumulated for all orders within a basin to the basin area, expressed in Km/Km^2 (Horton, 1932). It indicates the closeness of channel spacing, providing a quantitative measure of the average length of stream channel for the whole basin. It was observed that a low drainage density is more likely to occur and is resistant of highly permeable subsoil material under dense vegetative cover and where relief was low (Waikar, and Nilawar, 2014). High drainage density is the outcome of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density results into coarse drainage texture whereas fine drainage texture is the outcome of high drainage density (Strahaler, 1964). The drainage density (Dd) of the 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 is low permeable subsoil and vegetative cover.

Form Factor (Ff): It 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). For a perfectly circular basin, the value of the form factor should always less than 0.7854 (Tiwari et al., 2016). A smaller value of the form factor results in the more elongated 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 (Najar, 2018). 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 the average.

Stream Frequency (Fs): It is the total number of stream segments of all orders per unit area. It exhibited a 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 Km^2.

Circulatory Ratio (Rc): It is the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, land use/ land cover, geological structures, slope of the basin and climate. 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): It is the ratio of the 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, which 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). One of the most important independent variables is the length of overland flow which affects hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density (Magesh et al., 2013). It is inversely related to the average slope of the channel and is similar to the length of sheet flow to a large degree. The value of the length of overland flow of Adula watershed was 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. Therefore, it increases in magnitude as the scale of the land-form unit increases. The constant of stream maintenance gives information on the number of square Kms of watershed surface required to sustain one linear Km of the stream. The stream maintenance constant of the Adula watershed was 0.225 Km.

Texture Ratio (T): It is the total number of first order stream segments to the perimeter of that area (Horton, 1945). It depends on natural factors such as rainfall, vegetation, climate, soil and rock type, infiltration capacity, relief and stage of development. It was 19.54 Km / Km of the perimeter of the watershed.

Infiltration Number (If): It is the product of drainage density and stream frequency, which helps to understand the infiltration characteristics of the basin. 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 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 which is depending on the underlying lithology, relief aspect and infiltration capacity of the terrain (Schumm, 1965). It is expressed as the ratio between a total number of first-order streams and perimeter of the basin ($Rt = N_l / P$). 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 the 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 westernmost part of the basin, in the uppermost part of the catchment area. The absolute relief gradually decreases towards the outlet of the watershed.

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

Relative Relief (Rr): The relative relief represents the 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 extremely high value of ruggedness number occurs when both variables are large and the slope is steep (Strahler, 1956). The value of ruggedness number for the Adula watershed was 3.78.

Table 3 Relief aspect of the morphology of Adula watershed

Sr. No	**Morphometric Parameter**	**Formula**	Result
1	The height of Outlet of the watershed (z) (m)	GIS Software Analysis	552
2	Max. the 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

The present study has demonstrated abilities of GIS tool for analysis of various morphometric parameters 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 shows a positive correlation with increasing stream population with respect to increasing drainage density. The value of form factor and circulatory ration suggested that Adula watershed is highly elongated.

Ethical approval and consent are not applicable.

REFERENCE

Abrahams, A. D., 1984. Channel Networks: A Geomorphological Perspective. *Water Resources Research*, 20(2), 161-188.

Arnold, J. G. 2007. Soil and water assessment tool user's manual-version 2005, soil and water research laboratory, Agriculture Research Services, 808 East Blackland, road Temple, Texas.

Arnold, J. G. and P. M. Allen. 1996. Estimating hydrological budget for three Illinois watersheds. *Journal of Hydrology*. 176: 57-77.

Astras, T., and Soulankellis, N., 1992. Contribution of digital image analysis techniques on Landsat-5 TM imageries for drainage delineation. A case study from the Olympus mountain, west Macedonia, Greece. In Proc. 18th Annual Conf. Remote Sensing Soc., Univ of Dundee, 163-172.

Bera, A., Bhabani, P. M. and Das, D., 2018. Morphometric analysis of Adula river basin in Maharashtra, India using GIS and remote sensing techniques; geospatial data in Natural Resources, 13-35.

Bhagwat, T. N., Shetty, A., and Hegde, V. S., 2011. Spati +al variation in drainage characteristics and geomorphic instantaneous unit hydrograph (GIUH); implications for watershed management-A case study of the Varada River basin, Northern Karnataka. Catena, 87(1), 52-59.

Bhunia, G. S., Samanta, S. and Pal, B., 2012. Quantitative analysis of relief characteristics using space technology. *International Journal of Physical and Social Sciences*, 2(8), 350-365.

Chandniha, S. K., and Kansal, M. L., 2017. Prioritization of sub-watersheds based on morphometric analysis using geospatial technique in Piperiya watershed, India. *Applied Water Science*, 7(1), 329-338.

Clarke, J. I., 1966. Morphometry from Maps, Essays in geomorphology. *Elsevier* Publ. Co., New York, 235-274.

Gaikwad, R. and Bhagat, V., 2017. Multi-Criteria Watershed Prioritization of Kas Basin in Maharashtra India: AHP and Influence Approaches. *Hydrospatial Analysis*, 1(1), 41-61.

Horton, R.E (1932), "Drainage Basin Characteristics", Transactions, American Geophysical Union, 13, pp 350-61.

Horton, R.E (1945), "Erosional Development of Streams and their Drainage Basins", Bulletin of the Geological Society of America, 56, pp-275-370.

Huggett, R. J. and Cheesman, J., 2002. Topography and the Environment. Prentice Hall, Pearson Education, Upper Saddle River, NJ, 274.

Khakhlari, M. and Nandy, A., 2016. Morphometric Analysis of Barapani River Basin in Karbi Anglong District, Assam. *International Journal of Scientific and Research Publications*, 6(10), 238-249.

Magesh, N. S., Chandrasekar, N., and Soundranayagam, J. P., 2011. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environmental Earth Sciences*, 64(2), 373-381.

Mesa, L. M., 2006. Morphometric analysis of a subtropical Andean basin (Tucumán, Argentina). *Environmental Geology*, 50(8), 1235-1242.

Meshram, S. G. and Sharma, S. K., 2017. Prioritization of watershed through morphometric parameters: a PCA-based approach. *Applied Water Science*, 7(3), 1505-1519.

Mueller, J. E., 1968. An introduction to the hydraulic and topographic sinuosity indexes. *Annals of the Association of American Geographers*, 58(2), 371-385.

Pareta, K (2005), "Rainfall-Runoff Modelling, Soil Erosion Modelling, Water Balance Calculation, and Morphometric Analysis of Molali Watershed, Sagar, Madhya Pradesh using GIS and Remote Sensing Techniques", Proceeding in 25th International Cartographic Congress, INCA.

Rai, P. K., Mishra, V. N. and Mohan, K., 2017. A study of morphometric evaluation of the Son basin, India using geospatial approach. *Remote Sensing Applications: Society and Environment*, 7, 9-20.

Schumm, S.A (1956), "Evolution of Drainage Systems and Slopes in Badlands at Perth Anboy, New Jersey", Bulletin of the Geological Society of America, 67, pp 597-646.

Singh, P., Gupta, A., and Singh, M., 2014. Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science*, 17(2), 111-121.

Singh, S., 1998. Geomorphology. Allahabad: Prayag Pustak Bhavan. 353

Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union, 38(6), 913-920.

Strahler, A.N (1952), "Hypsometric Analysis of Erosional Topography", Bulletin of the Geological Society of America, 63, pp 1117-42.

Strahler, A.N (1956), "Quantitative Slope Analysis", Bulletin of the Geological Society of America, 67, pp 571-596.

Strahler, A.N (1964), "Quantitative Geomorphology of Drainage Basin and Channel Network", Handbook of Applied Hydrology, pp 39-76.

Sujatha, E. R., Selvakumar, R. and Rajasimman, B., 2014. Watershed prioritization of Palar sub-watershed based on the morphometric and land use analysis. *Journal of Mountain Science*, 11(4), 906-916.

Wilson, J. S., Chandrasekar, N. and Magesh, N.S., 2012. Morphometric analysis of major subwatersheds in Aiyar and Karai Pottanar Basin, central Tamil Nadu, India using remote sensing and GIS techniques. *Bonfring International Journal of Industrial Engineering and Management Science*, 2 (1), 8–15.

Zende, A. N. and Nagrajan, R., 2011. Drainage Morphology Approach for Water Resources Development of Sub–Watershed in Krishna Basin. *International Journal of Computer and Communication Technology*, 2(8), 13-21.

Tiwari, Jagriti and Patil, Rupesh and Sharma, Shailesh. (2016). Gour River Sub-watersheds Prioritization using Morphometric Parameters: A Remote Sensing and GIS Based Approach. International Journal of Science, Engineering and Technology Research (IJSETR). 5. 3041-3046.

Waikar and Nilawar. (2014). Morphometric analysis of a drainage basin using geographical information system: a case study. Int J Multidiscip Curr Res. 2. 179-184.

Najar, Gh. (2018). Drainage Morphometric Analysis of Watershed Basin of River Beas at Harike Pattan, Punjab-Using Remote Sensing and GIS Approach.

Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., and Jini, K. V. (2013). Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. *Applied Water Science*, *3*(2), 467-477.

Govt of India Ministry Of Water Resources Central Ground Water Board- Ground Water Information- Ahmadnagar District Maharashtra. 2014.

Sabale, P., DESHMUKH, J., KSHIRSAGAR, S., POKHARKAR, D., SARWADE, K., KAMBLE, P., & RAO, N. (2015). Preliminary report on quaternary geoarchaeological excavation at math pimpri, district Ahmednagar. *Bulletin of the Deccan College Research Institute*, *75*, 25-36.

Oettli, Pascal & Camberlin, Pierre. (2005). Influence of topography on monthly rainfall distribution over East Africa. Climate Research - CLIMATE RES. 28. 199-212. 10.3354/cr028199.

Bannari, A. , Kadhem, G. , El-Battay, A. , Hameid, N. and Rouai, M. (2016) Assessment of Land Erosion and Sediment Accumulation Caused by Runoff after a Flash-Flooding Storm Using Topographic Profiles and Spectral Indices. *Advances in Remote Sensing*, **5**, 315-354.

Krishna Kumar, K., Rupa Kumar, K., Ashrit, R. G., Deshpande, N. R., & Hansen, J. W. (2004). Climate impacts on Indian agriculture. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *24*(11), 1375-1393.

Lucà, Federica & Buttafuoco, Gabriele & Terranova, O. (2018). GIS and Soil. Reference Module in Earth Systems and Environmental Sciences. 37-50. 10.1016/B978-0-12-409548-9.09634-2.

Mekonnen, Kirubel & Tesfahunegn, Gebryesus. (2011). Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. Maejo International Journal of Science and Technology. 5. 312-330.

Kang, Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security–A review. *Progress in Natural Science*, *19*(12), 1665-1674.

Paudel, Naya & Khatri, Dil & Karki, Rahul & Paudel, Govinda. (2014). Understanding drivers and causes of deforestation and forest degradation in Nepal: potential policies and measures for REDD+. 10.13140/RG.2.2.22416.00001.

de Paul Obade, Vincent & Lal, Rattan & Chen, Jiquan. (2013). Remote Sensing of Soil and Water Quality in Agroecosystems. Water, Air, & Soil Pollution. 224. 10.1007/s11270-013-1658-2.

Abboud, Iyad & Nofal, Ramadan. (2016). Morphometric analysis of wadi Khumal basin, western coast of Saudi Arabia, using remote sensing and GIS techniques. Journal of African Earth Sciences. 126.

Joshi, V., Tambe, D., & Dhawade, G. (2009). Geomorphometry and fractal dimension of a riverine badland in Maharashtra. *Journal of the Geological Society of India*, *73*(3), 355-370.

Jeelani, Ghulam & Deshpande, Rajendrakumar & Shah, Rouf & Hassan, Wasim. (2017). Influence of southwest monsoons in the Kashmir Valley, western Himalayas. Isotopes in Environmental and Health Studies. 53.

Al-Fugara, A. (2015) Comparison and Validation of the Recent Freely Available DEMs over Parts of the Earth's Lowest Elevation Area: Dead Sea, Jordan. *International Journal of Geosciences*, **6**, 1221-1232.

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Asok, Smitha & Sobha, V. (2016). Implications of linear morphometric parameters on the geo-environment of Shendurney River Basin, South Kerala, India - A GIS based analysis. 22. S13-S19

Farhan, Y. , Anaba, O. and Salim, A. (2016) Morphometric Analysis and Flash Floods Assessment for Drainage Basins of the Ras En Naqb Area, South Jordan Using GIS. *Journal of Geoscience and Environment Protection*, **4**, 9-33.

Satheesh, B. 2017. Gis Based On Morphometric Analysis of Part of Manair River Basin In Karimnagar District, Telangana State. IOSR Journal of Applied Geology and Geophysics . 5(5): 1-7.

Pareta, Kuldeep & Pareta, Upasana. (2011). Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. International Journal of Geomatics and Geosciences. 2.

Ovando, A., Tomasella, J., Rodriguez, D. A., Martinez, J. M., Siqueira-Junior, J. L., Pinto, G. L. N., … von Randow, C. (2016). Extreme flood events in the Bolivian Amazon wetlands. Journal of Hydrology: Regional Studies, 5, 293–308. doi:10.1016/j.ejrh.2015.11.004