The Pharma Innovation Journal 2023; SP-12(7): 705-713

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(7): 705-713

www.thepharmajournal.com
Received: 04-04-2023
Accepted: 09-05-2023

DD More
Ph.D. Scholar, Department of Soil and Water Conservation Engineering, Dr. AS College of Agricultural Engineering & Technology, MPKV, Rahuri, Ahmednagar, Maharashtra, India

Dr. SB Nandgude
Professor and Head, Department of Soil and Water Conservation Engineering, Dr. AS College of Agricultural Engineering & Technology, MPKV, Rahuri, Ahmednagar, Maharashtra, India

SA Gade
Young Professional, School of Atmospheric Stress Management, National Institute of Abiotic Stress Management, ICAR, Baramati, Pune, Maharashtra, India

Corresponding Author:
DD More
Ph.D. Scholar, Department of Soil and Water Conservation Engineering, Dr. AS College of Agricultural Engineering & Technology, MPKV, Rahuri, Ahmednagar, Maharashtra, India

Assessment of geomorphological characteristics of Mula-pravara River basin using geospatial technology

DD More, Dr. SB Nandgude and SA Gade

Abstract
The morphometric characteristics of the river basin are easily evaluated by using the integration of Remote Sensing (RS) and Geographic Information Systems (GIS). The benefits of this integration include saving time and effort as well as improving the accuracy of the analysis. Moreover, this technique is appropriate for describing the river basin and its streams. In this study, a detailed morphometric analysis of the Mula-Pravara River basin has been performed using the Cartosat-1 DEM. The performed morphometric analysis includes linear, areal, and relief aspects. The mean bifurcation ratio (Rb) value of the watershed is 7.615, which shows high overland flow and discharge due to the hilly nature of the terrain. The Mula-Pravara river basin has a drainage density (Dd) value of 0.52 km/km^2 and falls in its lower category which indicates gentle slope terrain, medium-dense vegetation, and less permeability with medium precipitation. The stream frequency (SF) of the Mula-Pravara River basin is 0.39 numbers per km^2, indicating poor runoff. The Mula-Pravara River basin has a length of overland flow (Lo) value of 0.965 indicating the influence of high structural disturbance, low permeability, and gentle slopes and moderate surface runoff. The Mula-Pravara River basin has a circularity ratio (Rc) value of 0.21. A low Rc value implies an elongated basin shape while a high Rc value indicates near circular. The elongation ratio (Re) of the Mula-Pravara River basin is 0.331. The Re values indicate an elongated basin shape with high relief and a gentle to steep slope. The Mula-Pravara River basin has a shape index value of 5.55. A higher shape index shows basin elongation and a weak flood discharge period.

Keywords: Remote sensing (RS), geographic information systems (GIS), morphometric analysis, DEM

Introduction

There is not enough water available in the form of major and minor projects for irrigation to be provided to nearly more than 40% of cultivable land in India, according to a 1971 report by the National Commission for Agricultural (Dabral, and Dabriyal, 2004) [5]. The remaining 60% of farmable land can rely only on the monsoon rainfall. (Schumn, 1956) [18] Recent research has shown that crop productivity can be significantly boosted by delivering one or two irrigations to crops during dry spells using surplus water harvested as runoff during monsoon seasons. This necessitates the creation of water harvesting methods that can be used in a micro-watershed. If appropriate soil and water conservation measures are implemented and new packages of practices are followed, this watershed area should have a high output potential (Assefa *et al*., 2020) [1].

The source of water is precipitation, which when falls on the surface of the earth, is disposed of in various phases, called runoff (Patel and Thakur, 2000) [15]. The runoff is greatly influenced by runoff characteristics like type of precipitation, rainfall intensity, duration of rainfall, rainfall distribution and watershed characteristics like size of the watershed, shape, slope, stream length, stream frequency, soil type, drainage density and time of concentration of watershed (Rai *et al*., 2014) [16]. All these parameters are important for watershed management as they provide a thorough knowledge of the watershed geometry.

The science of remote sensing has emerged as one of the most fascinating subjects over the past three decades. Deriving information about geophysical parameters from the satellite-observed field with appropriate modelling has been a matter of great scientific importance (Ali and Ikbal., 2015) [2]. Geospatial tools such as the Geographical Information System (GIS), advanced image processing techniques, the Global Positioning System (GPS), as well as powerful computing systems, have pushed earth observation research to the forefront of scientific endeavour (Arpita and Kumar, 2009) [3]. The use of the Digital Elevation Model (DEM) is important to derive landscape attributes.

Integration of ground truth data within a GIS database can reduce cost, and time and increase the detailed information gathered for soil surveys (Ballukrayaand, Kalimuthu., 2010) [4].

Geomorphologic studies play an important role in understanding the hydrological behaviour of watersheds (Dabral PP and MK Dabriyal, 2004) [5]. The morphometric analysis of a drainage basin and its stream system can be better achieved through the measurement of linear and shape aspects of the drainage network and contributing ground slopes (Javed, *et al*., 2009) [6] Morphometric analysis could be used for prioritization of sub-watersheds by computing linear and shape parameters. In the absence of huge hydrological data, morphometric parameters of the watershed are helpful in characterizing a watershed (Jenson and Domingue, 1988) [7].

The morphological characteristic of a basin represents its attributes, which may be employed in synthesizing hydrological response (Jenson and Domingue., 1988) [7]. Basin characteristics when measured and expressed in morphometric parameters can be studied for the influence on runoff. Hence, linking the morphologic parameters with the hydrological characteristics of the basin can lead to a simple and useful procedure to simulate the hydrologic behaviour of various basins (Patel and Thakur, 2000) [15]. Interpretation and quantitative analysis of various drainage parameters enable qualitative evaluation of surface runoff, infiltration and susceptibility to erosion within the basin (Kumar *et al*., 2017) [10].

In the aforementioned context morphometric study of the Mula-Pravara River basin is undertaken with the following objective:

1. To determine the geomorphological characteristics of Mula-Pravara River basin using geospatial technologies.

Materials and methods

Location of the study area

The basin under study extends in latitude from 19°2'24" North to 19°34'12" North and in longitude from 73°37'37" East to 74°59'24" East. Both these rivers originate in the Ahmednagar district. Mula River originates from Harishchandragad while the Pravara River originates from Ratangad. Both these rivers flow parallel to each other and meet at Tilapur. The Mula River passes from Shevgaon, Parner and Sanganer tehsils. THE Pravara River is the tributary of the Godavari River, while Mula is the tributary of the Pravara River. The area of the watershed is 5563.55 sq. km. (The area of the Mula watershed is 2919.55 sq. km and that of the Pravara watershed is 2644.00 sq.km.) The watershed shows an elevation ranging from 403 m to 1423 m MSL.

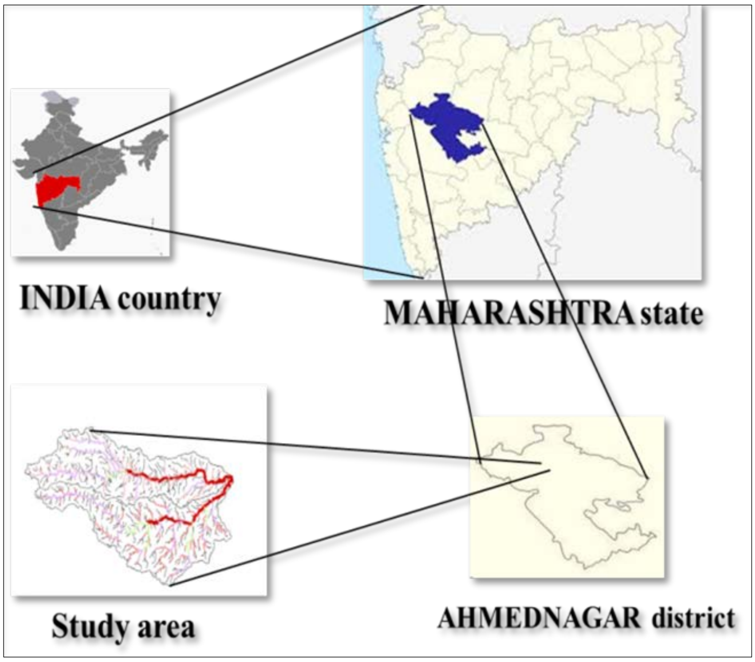

Fig 1: Location map of the study area.

Basic Data

The basic data used in the present study was taken from the free domain. The Digital Elevation Model (DEM) was used for the base map preparation. The DEM was downloaded from http://bhuvan.nrsc.gov.in. the DEM file was downloaded from Cartosat-1 Satellite, Uncompressed Size- 98.92 MB, Number of Bands-1, Source Type- Generic, Pixel Type- Signed Integer, Pixel Depth- 32 Bit, XY Coordinate System- GCS_WGS_1984, Angular Unit- Degree.

Table 1: Basic Data used for the study

Sr. No	Data	Source of Data	Purpose
1	Cartosat-1 Digital Elevation Model (DEM)	http://bhuvan.nrsc.gov.in.	To prepare slope map, flow direction map, flow accumulation map, preparation of thematic layer and delineation of watershed its characteristics study of the area.
2	G-Map	Google Earth Pro	To locate the basin outlet point.
3	Working platform	ArcGIS 10.5	To carry out the operations on the DEM files to obtain the spatial parameters.

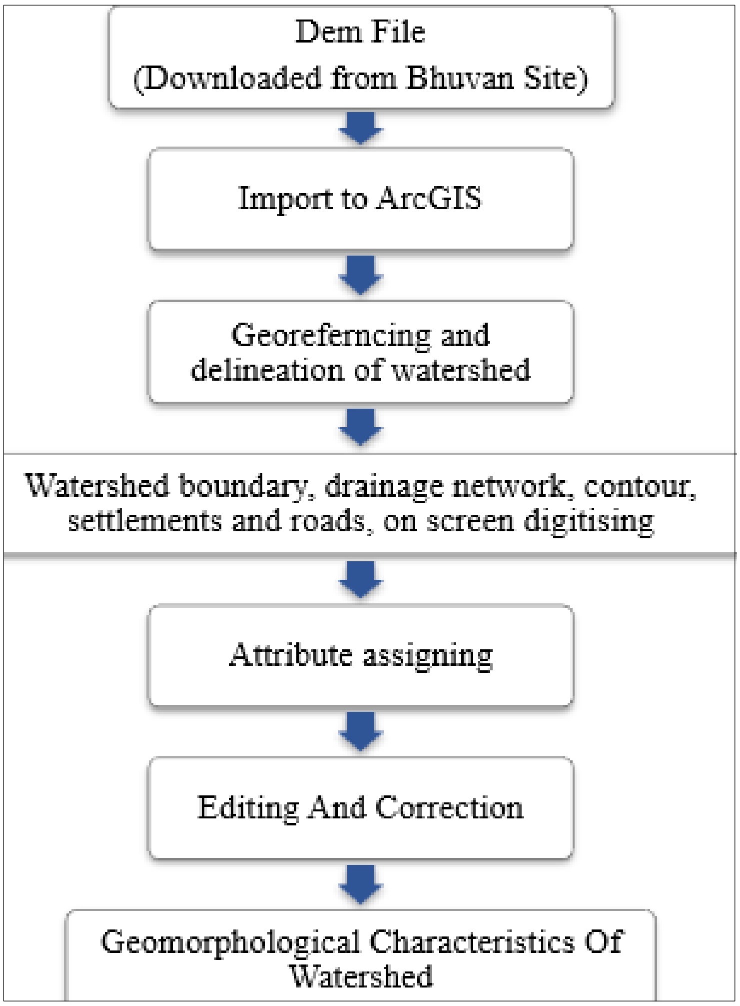

Fig 2: Flow chart showing the procedure of the GIS technique for obtaining geomorphological characteristics of the watershed

Morphological characteristics of watershed under study

Morphological analysis is the systematic description of the watershed's geometry and its stream system to measure the linear aspects of the drainage network, areal aspects of the watershed and relief aspects of the stream network. The morphological parameters directly or indirectly reflect the entire watershed. The morphological information pertaining to each of the watersheds was obtained with reference to its size, shape, slope, relief, stream density, vegetation, land use and stream network system. These parameters can be used to compare runoff-producing potential, such comparisons of watershed is useful in prioritizing watershed development work and selecting priority watersheds for applying various treatments to reduce runoff and soil loss through suitable conservation measures.

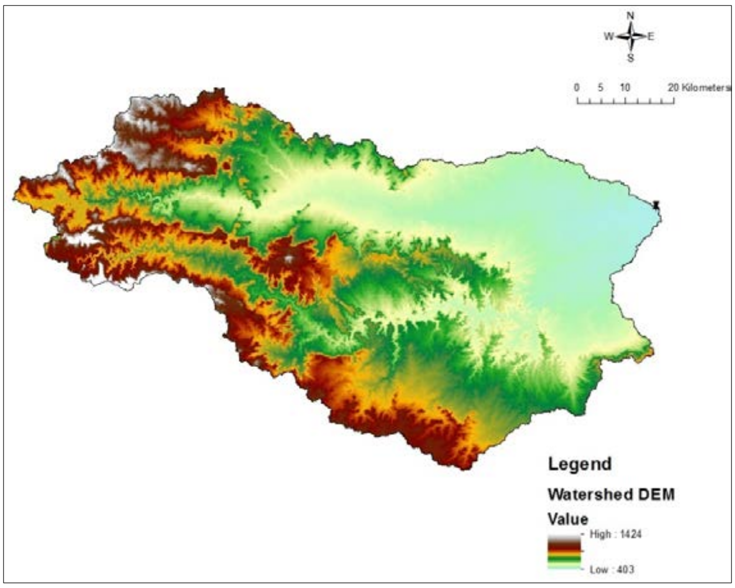

Fig 2: Digital Elevation Model (DEM) of the study area

Table 2: Formulae for computation of morphometric parameters

Parameter	Formula	Reference
Steam Order	Hierarchical rank	Strahler (1964) [22]
Mean Steam Length (Lsm)	Lsm = Lu/Nu	Horton (1945) [9]
Stream Length Ratio (RL)	RL = Lu/Lu-l	
Length of Overland Flow (Lg)	Lg = 1/ Dd*2	
Bifurcation Ratio (Rb)	Rb = Nu/Nu+l	Schumn (1956) [18]
Relief Ratio (Rh)	Rh = H/Lb	
Elongation Ratio (Re)	$Re=(2/Lb)^* (A/Pi)^{0.5}$	
Mean Bifurcation Ratio (Rbm)	Rbm = Average Rb of all orders	Strahler (1957) [24]
Drainage Density (Dd)	D = Lu/A	Horton (1932) [8]
Stream Frequency (Fs)	Fs = Nu/A	
Form Factor (Rf)	$Rf = A/Lb^2$	
Circulatory Ratio (Rc)	$Rc = 4^*Pi^*A/P^2$	Miller (1953) [11]
Textural Ratio (T)	T = N1/P	Nookaratnam *et al.* (2005) [13]

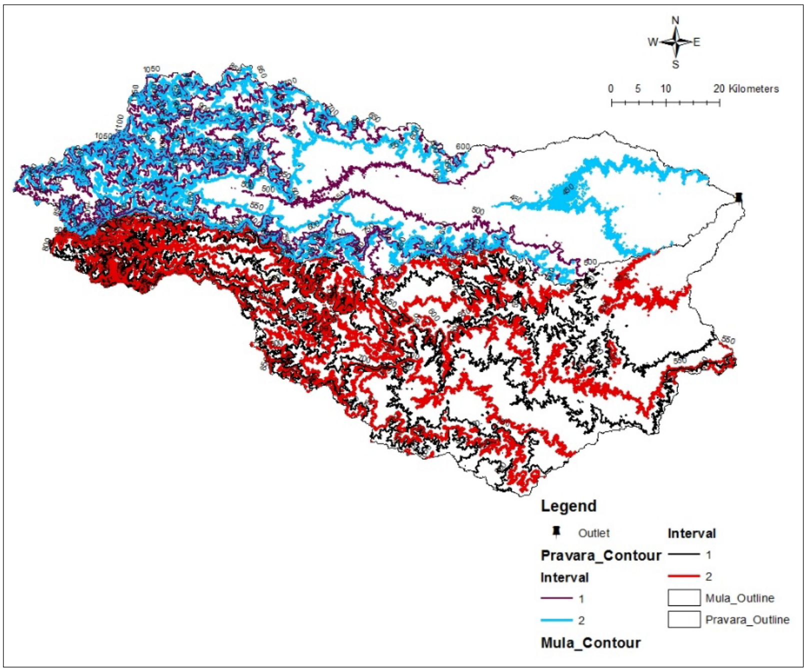

Fig 3: Contour Map

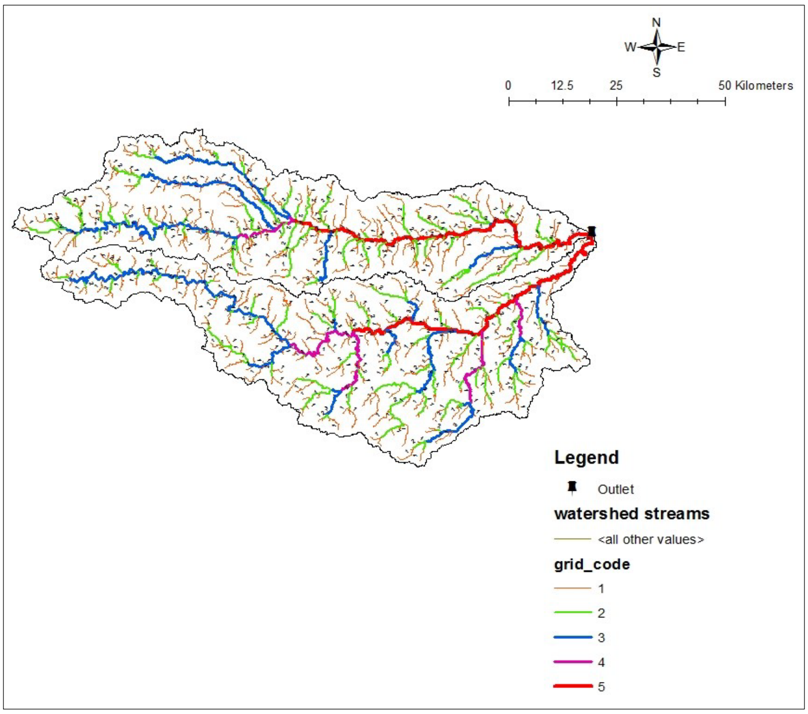

Fig 4: Streams Network

Work and operations

The work carried out in this study was performed using Arc GIS software. The ArcGIS 10.5 was available to the students and was used for various GIS operations. It contains Arc Toolbox, a collection of tools and functions for operation in Arc Catalogue. ArcGIS improves quality, adds important new capabilities and includes documentation improvement.

Result and Discussion

The geomorphological characteristics of the watershed were extracted in a GIS environment from the Digital Elevation Model of the survey area. The DEM file was downloaded from ISRO's website Bhuvan. The computations of all the geomorphologic characteristics of the Mula-Pravara River basin are given in respective tables.

Geomorphological Characteristics of Mula-Pravara River Basin Watershed

The Mula-Pravara River basin was delineated using the Digital Elevation Model. The area of the Mula River basin is 2919.55 km^2 and that of the Pravara River basin is 2644.00 km^2 and the total area of the Mula-Pravara River basin is 5563.55 km^2. The perimeter of the watershed is 465.45 km.

Linear Aspect

Linear aspects of the watershed include perimeter, basin length, stream order, stream number (Nu), stream length (Lu), bifurcation ratio (Rb), and stream length ratio (Rl). The perimeter of the Mula River basin is 427.52 km and that of the Pravara River basin is 380.522 km. The basin length of the Mula River is 126.451 km and that of Pravara River is 121.125 km.

Stream order

The term 'stream orders' is the primary step of morphometric analysis, which is based on the delineated streams and their branching proposed by Strahler, 1964 [22]. The first-order streams have no tributaries. The second-order streams have only first-order streams as tributaries. Similarly, third-order streams have first and second-order streams as tributaries, and so on (Rai, 2014) [16]. The number of stream segments decreases as the stream order increases following the Horton's law of stream ordering. It reveals about size of the stream, runoff, and drainage area and its extent is directly proportional to the size. The ordering of streams in the watershed is tabulated in Table 3. It has been found that the Mula River basin is a V order study area having 1148 streams over 2919.55 sq. km. area and the Pravara River basin is also a V order basin having 1037 streams sprawled over 2644.00 sq. km area. The whole watershed under study has 2185 streams over an area of 5563.55 sq. km.

Stream number (Nu)

The number of streams of each order in a given watershed is known as stream number. The stream number is inversely proportional to stream order. Figure 4.2 suggests the same. The law of stream order (Horton 1945) [9] describes that the number of streams of each order forms an inverse geometric sequence against stream order. The variation in stream order and size of the tributary basin is largely dependent on the physiographical, geomorphological and geological condition of the region (Ozdemer and Bird, 2009) [14]. The number of streams and their stream order, the total length of the stream and the average length of the stream are given in Table 3.

Table 3: Number of stream and stream order

Sub-basin		Mula basin	Pravara basin	Total
Area in km^2		2919.55	2644.00	5563.55
I order	No.	846	764	1610
	Length in km	770.41	743.9	1514.34
II order	No.	284	254	538
	Length in km	356.59	336.83	693.4
III order	No.	13	16	29
	Length in km	200.25	186.10	386.35
IV order	No.	4	2	6
	Length in km	80.35	176.37	256.72
V order	No.	1	1	2
	Length in km	84.12	90.43	174.55
Total	No.	1148	1037	2185
	Length in km	1491.71	1374.93	2866.64

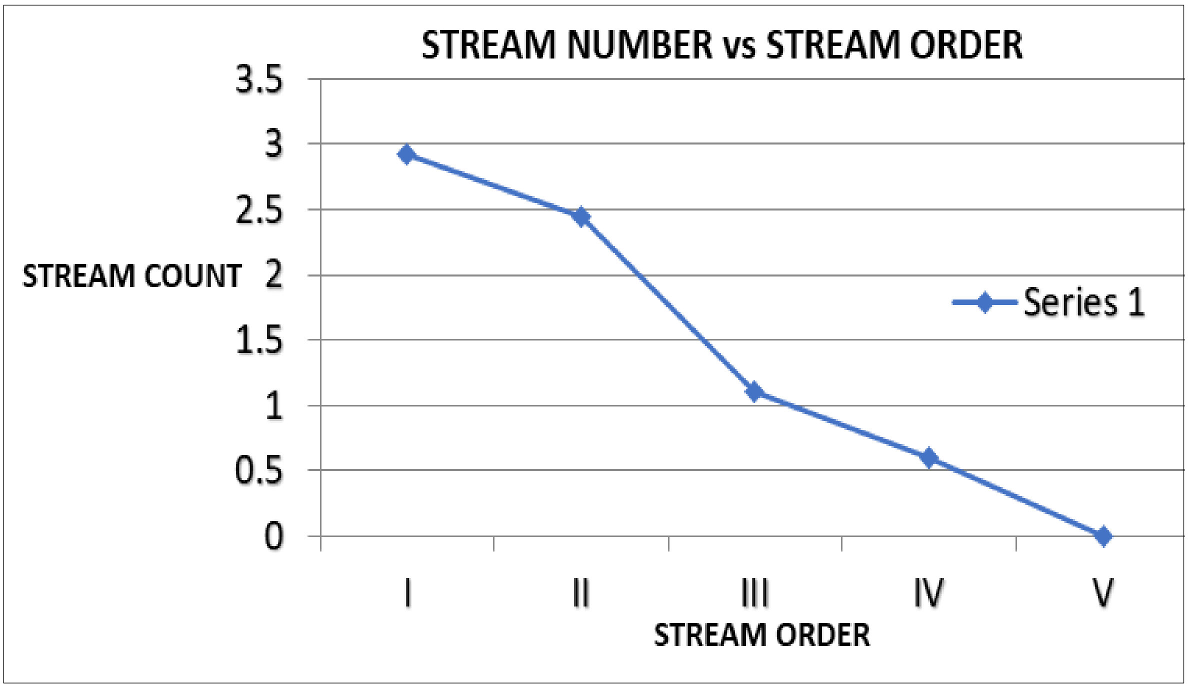

Fig 5: Plot of number stream vs stream order for Mula river basin.

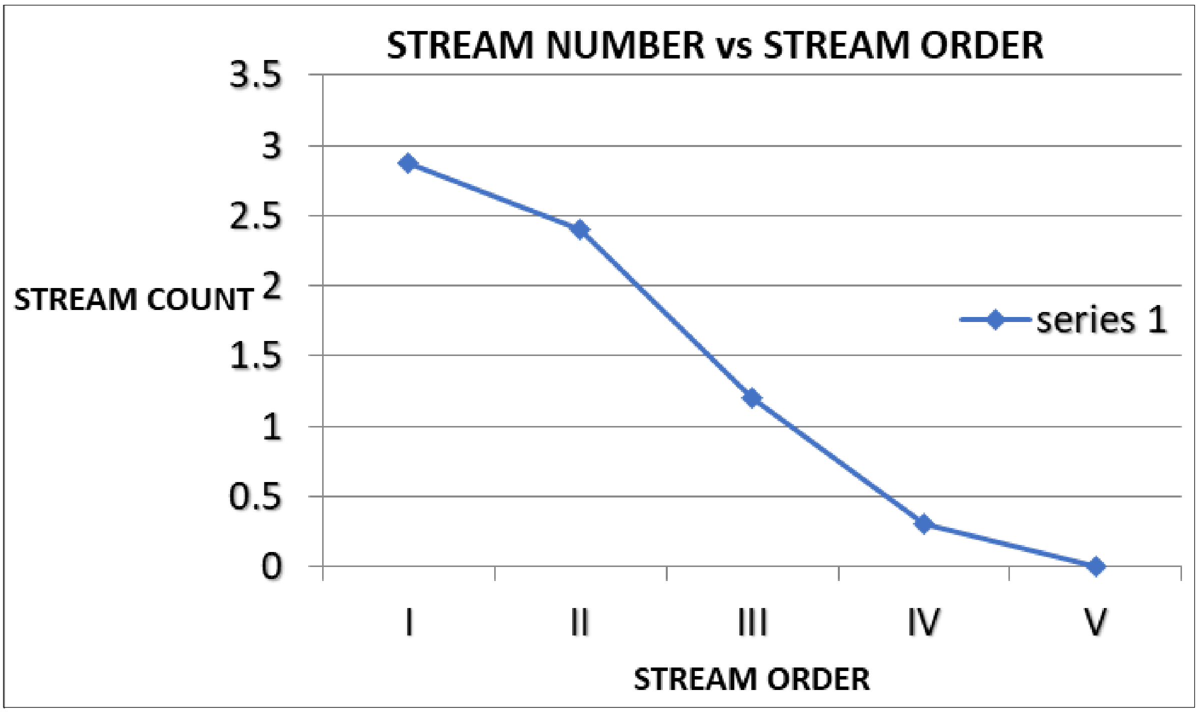

Fig 6: Plot of stream number vs stream order for the Pravara River basin.

The relationship between logarithms of a number of streams against stream order shows a straight line with a deviation. This indicates that the number of streams decreases as stream order increases and describes homogeneous subsurface material subjected to weathering and the latter basin is characterized by lithological and topographic variation (Nag and Lahiri, 2011) [25]. The graph (Fig. 5 and 6) validates Horton's law of stream number. To know the relationship between the number of streams and stream order, the graph is plotted as stream order on the X-axis and number of streams on Y-axis. The graph is shown in Fig. 5 for the Mula River basin and Fig. 6 for the Pravara River basin.

Bifurcation ratio (R_b)

The bifurcation ratio reflects the geological as well as tectonic characteristics of the watershed. The Rb value ranges from 3 to 6 in almost all watersheds. A high bifurcation ratio value denotes high overland flow and early hydrograph peak, with a high potential of susceptibility to flash flooding during intense rainfall storms. The Rb value also reflects the shape of the basin. Elongated basins have low Rb values while circular basins have high Rb values (Mesa, 2006) [26]. The mean Rb value of watershed is 7.615 which shows high overland flow and discharge due to the hilly nature of the terrain. Also, the high value suggests that the structural disturbance is severe in the basin. Horton, 1945 [9] considered R_b as an index of relief and dissections. The bifurcation ratios and their representation value are tabulated in Table 4.

Table 4: Bifurcation ratio and its respective value

Bifurcation Ratio	Value for sub-basins		Mean value for whole watershed
	Mula basin	Pravara basin	
R_b (1-2)	2.97	3.00	2.985
R_b (2-3)	21.84	15.87	18.85
R_b (3-4)	3.25	8	5.625
R_b (4-5)	4	2	3
Mean value	8.015	7.217	7.615

Stream length (L_u)

The mean and total stream length of each order are measured using the GIS technique and tabulated in Table 5. It shows the development of the stream segments and surface runoff characteristics. Streams having relatively smaller lengths indicate that the area is with high slopes. The mean stream length of a given order is less than the next higher order. In contrast, the total stream length is maximum in the first order and decreases as the stream order increases.

Table 5: Mean stream length

Stream order	Sub basins		For Whole watershed
	Mula basin	Pravara basin	
I	0.910	0.973	0.942
II	1.255	1.326	1.290
III	15.403	11.631	13.517
IV	20.078	8.818	14.448
V	84.129	90.433	87.28
Mean of the averages	24.355	22.636	23.495

Stream length ratio (R_L)

The mean R_l of the Mula-Pravara River basin is 5.03, which also shows that there is a variation in stream length ratio between streams of different order due to differences between slope and topography. The high degree of variation in the stream length ratio was due to slope and topographic variability in the watershed. It shows that the watershed is still in the geomorphic stages of development. This means that the region is prone to rapid and continual change in the future.

Table 6: Stream length ratio and their respective values

Stream Length Ratio	Value for sub-basin		Mula-Pravara basin
	Mula basin	Pravara basin	
R_{l2-1}	1.37	1.36	1.365
R_{l3-2}	12.26	8.78	10.52
R_{l4-3}	1.30	0.75	1.025
R_{l5-4}	4.19	10.25	7.22
Mean value	4.78	5.28	5.03

Areal aspects

The shape of watershed is dependent on the size of the basin and the length of the master stream (trunk order) of the basin and basin perimeter. The areal aspects of the watershed consist of drainage density (D_d), stream frequency (S_f), length of overland flow (L_o), constant channel maintenance (C), form factor, constant of channel maintenance, compactness ratio, elongation ratio, etc. The total area of the Mula-Pravara river basin is 5563.55 km^2. Out of which, Mula River has 2919.55 km^2 and Pravara River has 2644.55 km^2.

Table 7 shows the tabular information of the areal aspects which are calculated, as per the given procedure in Chapter 3. Values for parameters are calculated for Mula and Pravara sub-basins separately. The values for the Mula-Pravara River basin have been calculated by taking averages of the obtained values. For accuracy testing, the mean value has been cross-checked with the values obtained for the Mula-Pravara river basin as a whole.

Table 7: Areal aspects of the Mula-Pravara River basin.

Sr. No	Areal aspects	Sub basins		Mula-Pravara River basin
		Mula basin	Pravara basin	
	Drainage density (km/km^2)	0.52	0.52	0.52
	Stream frequency (km^{-2})	0.39	0.39	0.39
	Length of overland flow (L_o)	0.97	0.96	0.965
	Constant channel maintenance (C)	1.95	1.92	1.935
	Form factor (F_f) 3.	0.18	0.18	0.347
	Compactness ratio (C_c)	2.23	2.08	2.155
	Circularity ratio (R_c)	0.20	0.22	0.21
	Elongation ratio (R_e)	0.482	0.18	0.331
	Shape index (S_w)	5.55	5.55	2.81

Drainage density (D_d)

The drainage density indicates the groundwater potential of an area, due to its relation with surface runoff and permeability. The Mula-Pravara River basin has a D_d value of 0.52 km/km^2 and falls in its lower category which indicates gentle slope terrain, medium-dense vegetation and less permeability with medium precipitation. The low drainage density is also indicative of a relatively long overland flow of surface water. By considering its influence of drainage density on soil erosion, the weights are assigned to each subbasin.

Stream frequency (S_f)

Low stream frequency indicates high permeable geology and low relief. The Sf of Mula-Pravara River basin in 0.39 numbers per km2 indicates poor runoff. This also indicates poor runoff potential. The minimum stream frequency indicates the less number of streams availability. It is mainly dependent on the lithology of the basin. Thus, reflects the texture of the drainage network. Channel frequency density serves as a tool in establishing the erosional process operating over an area, to be more specific, the same in relation to the stream orders and their characteristics provides data which can throw light even on the sequences of relief developments and the degree of ruggedness in the area (Sharma, *et al*., 2014) [19].

Length of overland flow (L_o)

The length of overland flow relates inversely to the important independent parameter affecting both hydrologic and hydrologic watershed development. The values in 0.6-0.8 are generally associated with strong relief and steep ground slopes. The value nearing 1, indicates the region of low relief. The Mula-Pravara River basin watershed has L_0 value of 0.965, indicates the influence of high structural disturbance, low permeability, and steep to very steep slopes and high surface runoff. The Mula-Pravara River basin watershed shows a well-developed stream network and mature geomorphic stage.

Constant of channel maintenance (C)

Basin configuration floods are formed and move depending on basin shape. It is known that floods are formed and travel more rapidly in a round basin than in an elongated one and moreover that floods in basins of the former type are stronger and have a higher velocity and thus greater erosion and transport capacities. An elongated shape favours a diminution of floods because tributaries flow into the mainstream at greater intervals of time and space. Table 4.5 shows that the constant of channel maintenance is 1.935. It tells the number of sq. feet of watersheds surface area required to sustain one linear feet of channel. Thus, Mula-Pravara River basin requires a 1.935 sq. feet area, to sustain 1 feet of the channel.

Form factor (F_f)

The form factor is a dimensionless ratio of the area (A) of a drainage basin to the square of its maximum length (L_b) (Horton, 1932) [8]. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Sharma, *et al*., 2014) [19]. The form factor is an indicator for flood formation and movement, degree of erosion and transport capacities of sediment load in a watershed. The F_f of Mula-Pravara River basin is 0.18. The value of F_f varies from 0 (Highly elongated shape) to unity i.e.; 1 (perfect circular shape).

Compactness coefficient (Cc)

If the Cc value is 1.28 the basin is a more square shape, while the basin is a very elongated one, if the Cc is greater >3.0. The compactness coefficient of the Mula-Pravara River basin is found to be 2.155. While the selected basin is elongated in shape the Cc value is near to 2.0, it indicates the low peak flows for a longer duration. Flood flow of watershed is easier to manage.

Circularity ratio (Rc)

The value of the ratio is equal to unity when the basin shape is a perfect circle and is in the range of 0.4-0.5 when the basin shape is strongly elongated and highly permeable homogeneous geologic materials. The circularity ratio is influenced by the slope, relief geologic structure of the basin and land use land cover. The Mula-Pravara river basin has an Rc value of 0.21. A low Rc value implies an elongated basin shape while a high Rc value indicates near circular.

Elongation ratio (Re)

It is an important index for the analysis of basin shape. Analysis of the elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin. Strahler (1964) [22] classified elongation ratio as follows: circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (< 0.5). The Re of the Mula-Pravara River basin is 0.331. The Re values indicate elongated basin shape with high relief and gentle slope.

Shape index (Sw)

The shape index is a dimensionless entity and is a reciprocal of the form factor. The Mula-Pravara River basin has a value of 5.55. Higher the shape index more is the basin elongation and weak the flood discharge.

Relief aspects

Relief aspects watershed consists of Relief (H), Relief ratio (RH), Ruggedness Number (RN), Slope (Sg), and Geometric Number. These features relate to the three-dimensional features involving area of the basin, volume and altitude of the vertical dimension of landforms wherein different morphometric methods are used to analyze terrain characteristics. The values of Relief aspects are described below as well as compiled in Table 8.

Relief (H)

The relief between the most distant point and the watershed outlet is found to be 1020 m.

Relief ratio (RH)

It measures the overall steepness of a drainage basin by considering the extreme elevation difference and is an indicator of the intensity of the erosion processes operating on the slopes of the basin. The ratio of relief (H) to the horizontal distance on which relief was measured is the relief ratio. Relief ratio value for Mula-Pravara River basin is 0.0162, which shows a moderate relief basin with a moderate slope. It normally increases with a decrease in drainage area and size of the given drainage basin.

Ruggedness Number (Rn)

The ruggedness number for Mula-Pravara River basin was found to be 0.5304. Rn shows the structural complexity of the terrain in association with relief and drainage density. This provides an idea of the overall roughness of the water.

Channel slope (Sg)

The Mula-Pravara River basin’s channel slope value is 2.325%. Though the topography of the sub-basin in the region of stream origin is hilly, the majority of the watershed has flat topography.

Table 8: Relief aspects of the Mula-Pravara River basin

Sr. No.	Relief aspect	Subbasin in meters		Mula-Pravara river basin in meters
		Mula basin	Pravara basin	
1.	Relief (H)	1020	1020	1020
2.	Relief ratio (RH)	0.0080	0.0084	0.00825
3.	Ruggedness Number (RN)	0.520	0.530	0.525
4.	Channel slope (S_g)	2.56%	2.09%	2.325%
5.	Geometric Number	0.2071	0.2537	0.2305

Conclusions

The Mula-Pravara River basin is characterized by its poor drainage, which is due to low permeability. This low permeability leads to a high creation of overland flow and runoff when there is precipitation. Additionally, the basin has a large area but fewer streams to drain the water, resulting in increased discharge during the monsoon season. As a result of these factors, the flood occurrence in the basin is high, and the area is classified as an erosion-prone watershed. The shape of the Mula-Pravara river basin resembles that of a fern, which contributes to a slow and continuous discharge at the outlet following precipitation events. Moreover, the upper side of the basin features a hilly terrain with closely spaced contour lines, further influencing the hydrological processes within the watershed.

References

1. Assefa F, Elias E, Soromessa T, Ayele GT. Effect of changes in land-use management practices on soil physicochemical properties in Kabe watershed, Ethiopia. Air, Soil and Water Research. 2020;13:11-58.
2. Ali S, Ikbal J. Prioritization based on geomorphic characteristics of Ahar watershed, Udaipur district Rajasthan, India using Remote Sensing and GIS. Journal of Environmental Research and Development. 2015;10(1):187-200.
3. Arpita P, Kumar P. GIS-based morphometric analysis of five major sub-watersheds of Song River, Dehradun district, Uttarakhand with special reference to landslide incidences. Journal of the Indian Society of Remote Sensing. 2009;37:157-166.
4. Ballukraya PN, Kalimuthu R. Quantitative hydrogeological and geomorphological analyses for groundwater potential assessment in hard rock terrains. Current Science. 2010;98(2):253-259.
5. Dabral PP, Dabriyal MK. Morphological investigation and priority fixation in a hilly catchment. Indian Journal of Soil Conservation. 2004;32(1):61-65.
6. Javed A, Khanday MY, Ahmed R. Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS Techniques. Journal of Indian Society of Remote Sensing. 2009;37(2):261-274.
7. Jenson SK, Domingue JO. Extracting topographic structure from digital elevation data for geographic information system analysis. Photogrammetric engineering and remote sensing. 1988;54(11):1593-1600.
8. Horton RE. Drainage basin characteristics. Am. Geophys. Union, Trans. 1932;13:348-352.
9. Horton RE. Erosional development of drainages and their drainage basins. Bull Geol. Soc. Am. 1945;56:275-370.
10. Kumar A, Bhardwaj A, Kumar P, Padaliya H. Delineation of micro-watershed using geospatial techniques. Inter. J. of Environment, Science and Technology. 2017;3(2):14-34.
11. Miller VC. A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee of. Nav. Res. Proj. NR 389-042, Tech. Rep. 3, Ph.D. Dissertation). Columbia University; c1953.
12. Nag SK. Morphometric analysis using remote sensing Technique in the Chaka sub watershed, Purulia district, West Bengal. J Indian Society of Remote Sensing. 1998;26(1&2):69-76.
13. Nookaratnam K, Srivastav YK, Murthy KSR, Amminedu E, Venkateswara Rao V. Check dam positioning by prioritization micro watersheds using SYI model and morphometric analysis: Remote Sensing and GIS perspective. Journal of the Indian Society of Remote Sensing, 2005, 33(I).
14. Ozdemir H, Bird D. Evaluation of morphometric

parameters of drainage networks derived from topographic maps and DEM in point of floods. Environ Geol. 2009;56:1405-1415.
15. Patel RC, Thakur SC. Hydro-geomorphological studies of the Markanda basin Haryana (India). Journal of Applied Hydrology. 2000;13(3&4):20-29.
16. Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VN. A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Appl. Water Sci. 2014;7:217-232.
17. Rao LAK, Ansari ZR, Yusuf A. Morphometric analysis of drainage basin using remote sensing and GIS techniques: A case study of Etmadpur Tehsil, Agra District UP. International Journal of Research in Chemistry and Environment. 2011;1(2):36-45.
18. Schumn SA. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull; c1956. p. 597-646.
19. Sharma SK, Gajbhiye S, Tignath S. Application of principal component analysis in grouping geomorphic parameters of a watershed for hydrological modelling. Appl. Water Sci. 2014;5:89-96.
20. Singh RV. Watershed planning and management. Yash Publishing House, Bikaner, Rajasthan, India; c1994.
21. Strahler AN. The dimensional analysis applied to fluvially eroded landforms. Geological Society American Bulletin. 1958;69:279-300.
22. Strahler AN. Quantitative geomorphology of the drainage basin and channel network. In Handbook of Applied Hydrology (Ed. VT Chow), McGraw Hill, New York; c1964. p. 39-76.
23. Vladimir K, Talhofer V. General procedure of thematic map production using GIS technology, international conference on military technologies, faculty of military technology, University of defence in BRNO; c2013.
24. Strahler AN. Quantitative analysis of watershed geomorphology. Eos, Transactions American Geophysical Union. 1957 Dec;38(6):913-20.
25. Nag SK, Lahiri A. An integrated approach using Remote Sensing and GIS techniques for delineating groundwater potential zones in Dwarakeswar watershed, Bankura District, West Bengal. International Journal of Geomatics and Geosciences. 2011;2(2):430-42.
26. Mesa LM. Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). Environmental Geology. 2006 Sep;50(8):1235-42.