

## Determination of morphological parameters of Tidi watershed using remote sensing and geographic information system approaches

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### ABSTRACT

In the current study, an attempt was made to determine the morphological parameters of the Tidi watershed in Udaipur district of Rajasthan, India. Remote sensing and geographic information system (GIS) technique has proved to be an efficient tool in drainage network delineation and update in morphological analysis. For detailed study, ASTER DEM was used for delineation of the watershed boundary, and GIS was used in evaluation of basic, linear, areal and relief aspects of morphometric parameters. The Tidi watershed occupies an area of 114.36 km<sup>2</sup> with a dendritic drainage pattern. The study area is designated as fifth order basin and lower and middle order streams mostly dominate the basin with the drainage density value of 1.74 km/km<sup>2</sup> which exhibits gentle to moderate slope terrain and medium dense vegetation. The mean bifurcation value of the watershed is 3.88 and the value varies from 2 to 4.14 which shows that the drainage network formed on homogeneous rocks when the influences of geologic structures on the stream network were negligible. An elongation ratio of 0.79 implies that the watershed is less elongated in shape. The results from the morphometric analysis of the watershed are very beneficial for developing and designing conservation structures of soil and water and watershed management measures.

**Key words:** dendritic pattern, morphometric evaluation, RS and GIS, Tidi watershed

### HIGHLIGHTS

- Demarcation of Tidi watershed was done using ASTER DEM with spatial resolution of 30 m×30 m.
- Analysis of drainage network characteristics of Tidi watershed using remote sensing and GIS technique.
- Morphological investigation of basic, linear, aerial and relief drainage aspects.

### ABBREVIATIONS

GIS	Geographic information system
km <sup>2</sup>	Square kilometre
RS	Remote sensing
DEM	Digital elevation model
%	Percentage
°C	Degree centigrade
km/h	Kilometre per hour
LULC	Land use land cover
km	Kilometre
Lu	Stream length
Lsm	Mean stream length
R <sub>L</sub>	Stream length ratio
R <sub>b</sub>	Bifurcation ratio
F	Stream frequency
km/km <sup>2</sup>	Kilometre per square kilometre
D <sub>d</sub>	Drainage density
R <sub>c</sub>	Circularity ratio

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Rf	Form factor
Re	Elongation ratio
Sb	Basin shape factor
R <sub>R</sub>	Relative relief
Rr	Relief ratio
Rn	Ruggedness number
A	Area
P	Perimeter
U	Stream order
ASTER	Advanced Spaceborne Thermal Emission and Reflection
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System

## INTRODUCTION

The remote sensing and geographic information system (GIS) used to classify drainage network systems characteristics has been an accurate, time-saving and suitable technology for hydrological analysis over the last decade (Magesh *et al.* 2012). The watershed is characterized here as a region or area bounded circumferentially by a watershed divide and draining ultimately to a specific outlet or watercourse. Horton initiated the quantification of river networks to research the source of river drainage systems (Horton 1932, 1945). The morphometric evaluation of the basin gives a detailed overview of a drainage network system and is a significant feature in watershed characterization (Strahler 1964). The morphometric characteristics, like basin relief and basin shape, affect the existence of hydrographic and hydrological factors. The drainage system contains details about an underlying geological structure and topography. The drainage density differs based on drainage area, relative age, geological difference, etc., making similarities between basins and streams possible (Singh *et al.* 2009; Magesh *et al.* 2012). The perceptible method for substrate classification as well as the method for processing or managing perceptible data have been made very simple by the emerging developments in computer applications, particularly in visualization, the construction of information technology (Rao *et al.* 2010). The ability to create, manipulate, store and use spatial data is much quicker in the Digital Earth concept than traditional methods. The current study utilized similar perceptions at the watershed level and this research article focuses mainly on the portrayal and nature of the wide variation in the physical features of the Tidi watershed drainage network system to define and estimate the morphological parameters. The study utilized DEM (Digital Elevation Model) of a research area; Advanced Spaceborne Thermal Emission and Reflection (ASTER) was downloaded from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov) with a spatial resolution of 30 m×30 m (Magesh *et al.* 2011; Gharde *et al.* 2015; Gavit *et al.* 2016).

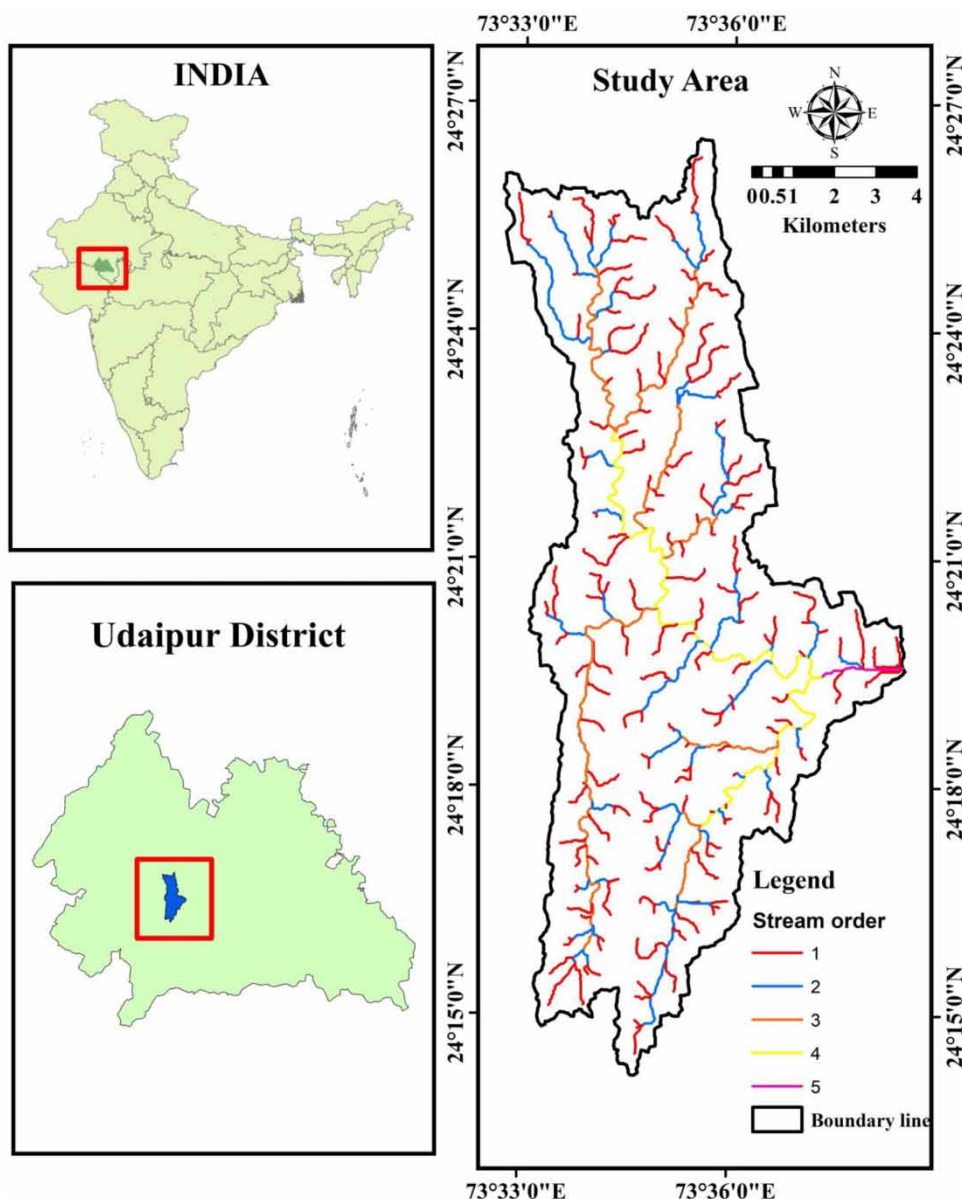
In the recent past, many researchers have found that remote sensing and GIS are vital techniques for analysis of drainage network parameters from different data sources (Singh *et al.* 2013). Most researchers classified morphological parameters as linear, areal and relief aspects (Aravinda & Balakrishna 2013; Rahaman *et al.* 2015; Panda 2016). Some scholars categorized morphological parameters as drainage network, drainage texture and relief (Dubey *et al.* 2015; Tribhuvan & Sonar 2016). The foremost advantage of the remote sensing and GIS method for drainage network analysis over conventional methods of analysis lie primarily in the fact that remote sensing and GIS is capable of managing and processing spatial information in large amounts, efficiently and accurately (Singh *et al.* 2013). In the present study an integrated application of remote sensing and GIS was utilized for the analysis of drainage network parameters of the Tidi watershed of Udaipur district, Rajasthan, India. The determined values were plotted and evaluated by utilizing GIS and statistical approaches to recognize the drainage basin and stream network systems.

The main objective of this paper was the demarcation of the Tidi catchment and determination of morphological characteristics using remote sensing and GIS technique. Specifically, we focused on drainage network analysis to provide knowledge to further appreciate the hydrological features of a study area and conceptual foundations and illustrate how spatial mapping approaches can be used to produce morphological information related to basin, flow directions, flow accumulation, upstream and downstream, stream link, stream network, stream order, and DEM.

## MATERIALS AND METHODS

### Elucidation of the research area

The Tidi watershed is located in Udaipur district of Rajasthan. The coordinates of the research area are 24.1415° to 24.2631° N latitude and 73.3250° to 73.3829° E longitude and the total area of the watershed is 114.36 km<sup>2</sup> (Figure 1). The research area



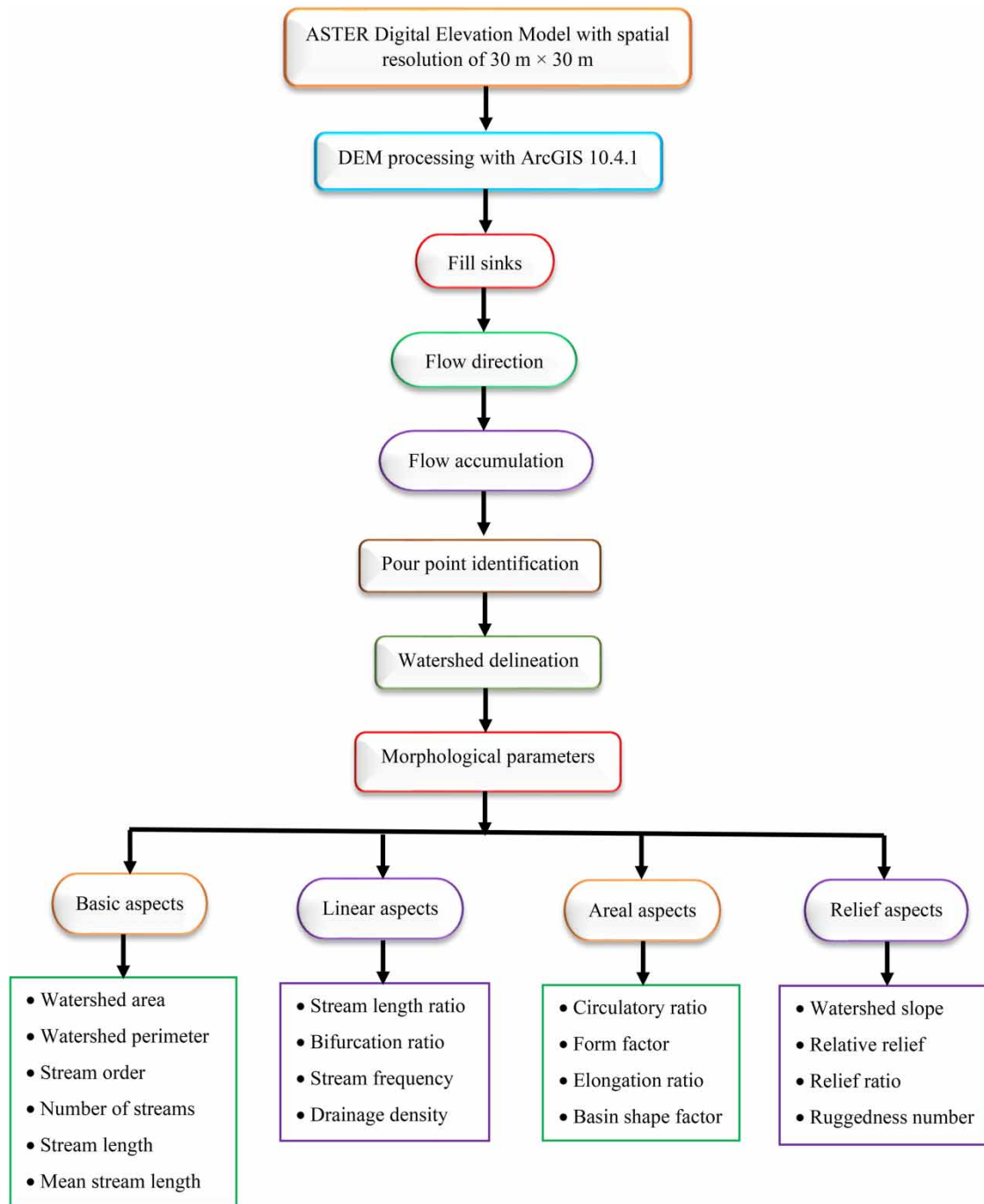
**Figure 1** | Location of the study area with stream segments.

is precipitous slopes and has high relief. The drainage pattern was dendritic, known by the uneven splitting of a tributary stream entering the trunk channel in several directions. A subtropical climate was observed in the Tidi watershed. It is characterized by a hot and dry summer and a mild winter extending from April to June and November to February, respectively. The Tidi watershed area is predominantly under the influence of southwest monsoons with 90% of the rainfall falling from June to September, August being the wettest month. The study area's average annual rainfall is 635 mm. The annual evaporation rate is 1,747 mm. The mean minimum and maximum temperature observed are 4.6 °C in January and 41.5 °C in May respectively. The humidity varies between 27 and 90% and is maximum during August. The wind speed varies from 12.3 to 44 km/h and is maximum during June.

### Methodology

The different indicators of drainage network parameters provide information about the rock formation and hydrological characteristics of the watershed (Singh *et al.* 2013). Topographic maps were obtained and used as the foundation for the creation of many GIS data maps to establish an effective information platform to systematically proceed with

the determination of morphometric parameters. ASTER DEM was downloaded from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov) with a spatial resolution of  $30\text{ m} \times 30\text{ m}$ . The base charts of the Tidi watershed were prepared based on Advanced Spatial Thermal Emission and Reflection (ASTER). The drainage networks from the DEM were mapped and digitized. To delineate the area of research and to export the data to DEM format ArcGIS 10.4.1 software was used. ASTER DEM data was then incorporated into ArcGIS 10.4.1 and, as a result, important geomorphological parameters like drainage network, slope gradient and contour were computed. The watershed drainage networks were digitized by using ASTER DEM in ArcGIS 10.4.1 environment. The complete procedure of morphological investigation is illustrated in Figure 2.



**Figure 2** | Flowchart of methodology used for morphological investigation.

### Extraction of Tidi watershed

The Tidi watershed was automatically extracted from the ASTER DEM with spatial resolution of  $30\text{ m} \times 30\text{ m}$ , through the pour point identification with the various geoprocessing tools of ArcGIS 10.4.1. The pour point is the user defined cell of highest flow accumulation within DEM (Mahala 2020).

### Calculation of drainage morphometry

The various drainage morphological parameters (basic, linear, areal and relief) were extracted and calculated with a combination of geoprocessing tools available in ArcGIS 10.4.1 (Mahala 2020). The basin stream network was evaluated according to Horton's laws. Streams without tributaries are described in the grouping as their first-order; the two first order streams are added to generate the second stream order. To create a stream of a higher order, typically the same order two streams are merged. The different morphological parameters (basic, linear, areal and relief) like perimeter, watershed area, basin-length, total stream orders, drainage density, stream frequency, form factor, bifurcation ratios, stream length ratios, drainage factor, basin shape factor, relative relief, relief ratio, ruggedness number, circulatory ratio and elongation ratio were calculated through the standard formula given in Table 1 (Tufa & Feyissa 2018). The slope characteristics were also derived through the spatial analysis tool in ArcGIS 10.4.1.

## RESULTS AND DISCUSSION

Morphology is the quantification and statistical study of surface, shape and structure measurements of the earth (Strahler 1957; Magesh *et al.* 2012). This research stressed the utilization of remote sensing and GIS towards morphological assessment and the outcomes are addressed below.

The DEM was acquired with a pixel scale of 30 m, as shown in Figure 3. The DEM was also used for the calculation of slope, type of soil, contour bund, drainage map and land use land cover (LULC) map. The dendritic drainage pattern was found in the Tidi catchment area. The Tidi watershed is categorized as a fifth stream order watershed based on Horton's order to deduce the geomorphologic parameters mentioned in Table 1 (Horton 1932, 1945; Miller 1953; Schumm 1956; Strahler 1957, 1964; Clarke 1966; Rai *et al.* 2017).

### BASIC ASPECTS

#### Watershed area

Drainage area is a calculation of an average watershed of a stream on every order. It increases with increasing stream order (Umrikar 2016). In the current research, the watershed area of Tidi is  $114.36\text{ km}^2$  as shown in Table 2.

#### Watershed perimeter

An outer border of a watershed that encloses the area is known as the watershed perimeter. This is measured along the divided watershed and can be used as a monitor for the size and shape of the watershed (Arabameri *et al.* 2020). The perimeter of the Tidi watershed is 74 km (Table 2).

#### Stream order

Stream order is a vital feature for drainage basin assessment. This is described as a measurement of the location of the streams in the stream hierarchy (Soni 2016). The Tidi watershed streams were graded as per Strahler's grouping technique. In the grouping, streams formed with zero tributaries are called the first-order stream. The two first-order streams are joined to generate the second stream order. Universally, a similar order of two streams is joined together to create a stream of one higher order (Strahler 1964). The main channel through which most of water discharged is marked as the highest order stream of any particular drainage basin. Table 2 shows the order length of the stream and the total stream numbers of the Tidi watershed. The variability in the watershed area and the stream order are mainly because of the structural and physiographic circumstances of the region. The Tidi watershed forms a fifth-order following Strahler's ordering technique as shown in Figure 1.

#### Stream number

With the assistance of the ArcGIS 10.4.1 environment, the numbers of the streams under different orders as well as the overall number of stream orders in the Tidi watershed were determined separately. It is indeed evident that the overall number of

**Table 1** | Basic, linear, areal and relief morphological parameters and equations

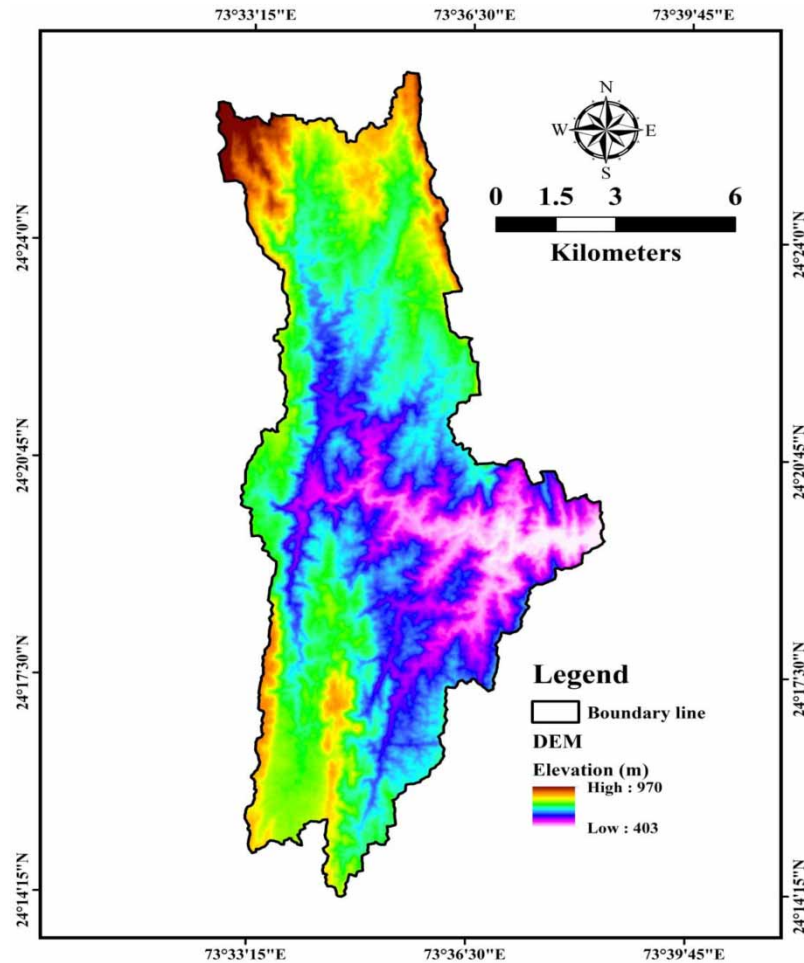
Sr. No.	Aspects	Parameters	Equation	Reference
1	Basic aspects	Watershed area (A)	The surface area of the watershed from ArcGIS	Rai <i>et al.</i> (2017)
2		Watershed perimeter (P)	Length of the boundary of the watershed	Rai <i>et al.</i> (2017)
3		Stream order (U)	Hierarchical rank (Strahler Scheme)	Strahler (1952)
4		Stream length (Lu)	Length of the stream (Spatial analysis tool)	Horton (1945)
5	Linear aspects	Mean stream length (Lsm)	$Lsm = Lu/Nu$ Where, $Lsm$ = Mean stream length; $Lu$ = Total stream length of order 'u'; $Nu$ = Total no. of stream segments of order 'u'	Strahler (1964)
6		Bifurcation ratio (Rb)	$Rb = Nu/Nu + 1$ Where, $Rb$ = Bifurcation ratio; $Nu$ = Total no. of stream segments of order 'u'; $Nu + 1$ = Number of segments of the next higher order	Schumm (1956)
7		Stream length ratio ( $R_L$ )	$R_L = Lu/(Lu-1)$ Where, $R_L$ = Stream length ratio; $Lu$ = The total stream length of order 'u'; $Lu - 1$ = The total stream length of its next lower order	Horton (1945)
8		Stream frequency (F)	$F = N/A$ Where, $F$ = Stream frequency; $N$ = Total no. of streams of all orders; $A$ = Area of the basin ( $\text{km}^2$ )	Horton (1945)
9	Areal aspects	Drainage density (Dd)	$Dd = L/A$ Where, $Dd$ = Drainage density; $L$ = Total stream length of all orders; $A$ = Area of the basin ( $\text{km}^2$ )	Horton (1945)
10		Circularity ratio (Rc)	$Rc = 4A\mu/P^2$ Where, $Rc$ = Circularity ratio; $\pi = 3.14$ ; $A$ = Area of the basin ( $\text{km}^2$ ); $P$ = Perimeter (km)	Miller (1953)
11		Form factor (Rf)	$Rf = A/L^2$ Where, $Rf$ = Form factor; $A$ = Area of the basin ( $\text{km}^2$ ); $L^2$ = Square of the basin length	Horton (1932)
12		Elongation ratio (Re)	$Re = L/B = (2/Lb)\sqrt{A/\mu}$ Where, $Re$ = Elongation ratio; $A$ = Area of the basin ( $\text{km}^2$ ); $\pi = 3.14$ ; $Lb$ = Basin length	Strahler (1964)
13	Relief aspects	Basin shape factor (Sb)	$Sb = Lb^2/A$ Where, $Sb$ = Basin shape factor; $Lb$ = Basin length; $A$ = Area of the basin ( $\text{km}^2$ )	Horton (1932)
14		Slope (%)	ArcGIS analysis (Spatial analysis tool)	Rai <i>et al.</i> (2017)
15		Relative relief ( $R_R$ )	$R_R = 100(H/Lp)$ Where, $R_R$ = Relative relief; $H$ = Total relief of the basin; $Lp$ = Length of perimeter	Schumm (1956)
16		Relief ratio (Rr)	$Rr = H/Lb$ Where, $Rr$ = Relief ratio; $H$ = Total relief (Relative relief) of the basin in km; $Lb$ = Basin length	Schumm (1956)
17		Ruggedness number (Rn)	$Rn = H \times Dd$ Where, $Rn$ = Ruggedness number; $H$ = Total relief of the basin in kilometre; $Dd$ = Drainage density	Strahler (1964)

streams is steadily decreasing while the order of the stream rises (Magesh *et al.* 2011). Table 2 shows the number of streams and stream orders of the Tidi watershed.

### Stream length

The length of the stream is indicated by the contributive area of the watershed of the specified stream order. The length of the stream (Lu) was computed according to Horton's legislation. The number of streams of different orders within the Tidi watershed was calculated based on topo maps using ArcGIS 10.4.1 software (Table 2) and their distance from the head to the drainage division was determined within the same framework. The cumulative length of the stream orders was maximal in first-order streams, which decreases as the stream order increases (Kumar *et al.* 2015). The stream length for different orders of the Tidi watershed was first (95.65 km), second (45.04 km), third (35.38 km), fourth (21.25 km) and fifth order (2.15 km). The low length of streams in upper reaches and consistency of stream length throughout the basin is indicative of mature to old geological formation and sufficient morphological adjustment throughout the basin (Mahala 2020).





**Figure 3** | ASTER DEM map of Tidi watershed.

**Table 2** | Basic morphometric aspects of Tidi watershed

Sr. No.	Basic aspects	Stream order				
		I	II	III	IV	V
1	Stream number (total)	178	43	8	2	1
2	Stream length (Lu) (km)	95.65	45.04	35.38	21.25	2.15
3	Mean stream length (Lsm) (km)	0.53	1.04	4.42	10.62	2.15
4	Area (km <sup>2</sup> )	114.32				
5	Perimeter (P) (km)	74				
6	Basin length (Lb) (km)	14.82				

### Mean stream length

The mean stream length (Lsm) is calculated by deducting the overall stream length of order ‘*u*’ by the number of streams for its order ‘*u*’. It is descriptive of the size and surfaces of the drainage network components (Strahler 1964). In general, the ratio of the Lsm increases with increasing order of streams (Shrestha *et al.* 2010). Most research indicates lower mean stream length value in mountain environments than in plains morphology (Rai *et al.* 2017). The mean Lsm ratio of the Tidi watershed was first (0.53 km), second (1.04 km), third (4.42 km), fourth (10.62 km) and fifth order (2.15 km) (Table 2).

### Relation of stream order with log stream number and log stream length

The plot of the logarithm of cumulative stream number along the ordinate and stream order along the abscissa for the Tidi watershed is a straight-line fit as shown in Figure 4(a). The straight-line fit indicates that the ratio between cumulative stream number is constant throughout the successive order of a watershed and suggests that geometrical similarity is preserved in the watershed of increasing order (Kumar *et al.* 2007). The correlation coefficient of the relation of stream order with log stream number for the current study was found to be 0.87. Nearly similar results were also reported by Gupta (2003). A similar geometric relationship was found to exist between the stream order and logarithmic stream length for the Tidi watershed under consideration, which further indicates the area has uniform underlying lithology, and geologically, there has been no probable uplift (Said *et al.* 2018). The correlation coefficient relation of stream order with log stream length for the current study was 0.97 as shown in Figure 4(b). Gharde *et al.* (2015) studied the relation of stream order with log stream length for the Gandhari basin and also found similar outcomes (0.96).

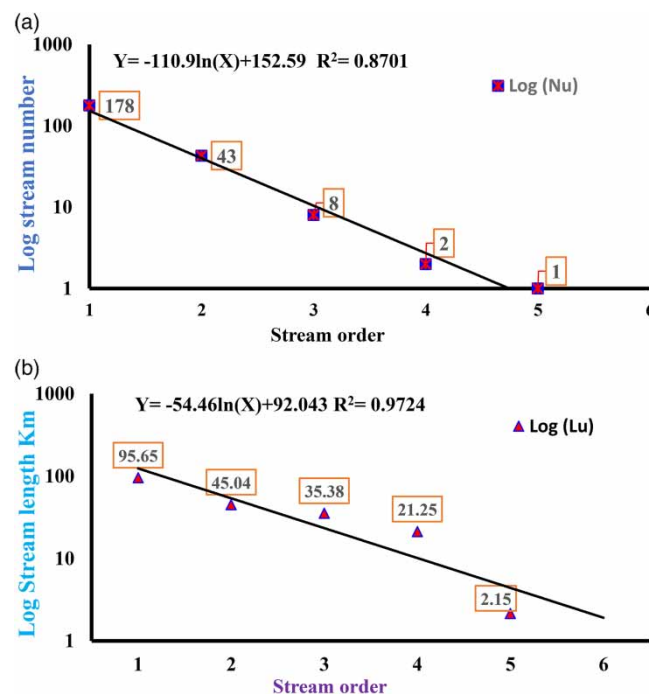
### Linear aspects

#### Stream length ratio

The stream length ratio ( $R_L$ ) is defined by the proportion of the average one-order length towards the next lesser stream segments (Horton 1945). Mean stream length segment of each successive order of the basin tends to direct geometric series with stream length increasing towards higher order according to Horton. The stream length ratio of Tidi watershed starts with 1.95 for first to second order, 4.22 for second to third order, 2.40 for third to fourth order and 0.20 for fourth to fifth order of streams (Table 3). There was a difference in  $R_L$  values among various order streams in the Tidi watershed. This deviation could be related to topography and slope, which is also the late youth stage of geomorphic development.

#### Bifurcation ratio

A bifurcation ratio ( $R_b$ ) was computed as the sum of a stream of a certain order as well as the sum of a following higher order segment (Miller 1953). Strahler has also demonstrated that bifurcation proportion shows a tiny number of differences with various areas or environmental influences instead of where geological influence is predominant. Besides, the  $R_b$  is a demonstrative instrument for basin shape. Lengthened basins have lower bifurcation ratio values, whereas circular basins have higher bifurcation ratio values (Aravinda & Balakrishna 2013). As shown in Table 3 from one order to the next,  $R_b$  is not



**Figure 4** | Plot of stream order with: (a) log of stream number (b) log of stream length.



**Table 3** | Linear morphometric aspects of Tidi watershed

Sr. No.	Linear aspects	Stream order				
		I	II	III	IV	V
1	Bifurcation ratio (Rb)		I/II 4.14	II/III 5.38	III/IV 4	IV/V 2
2	Mean bifurcation ratio (Rbm)	3.88				
3	Stream length ratio ( $R_L$ )		II/I 1.95	III/II 4.22	IV/III 2.40	V/IV 0.20
4	Stream frequency (F)	2.03				
5	Drainage density (Dd) (km/km <sup>2</sup> )	1.74				

the same. The average bifurcation ratio of the Tidi watershed was 3.88, which implies that this watershed does not have a major impact on the drainage pattern. [Rai et al. \(2017\)](#) studied a morphometric evaluation of the Son basin, using geospatial techniques and reported similar results.

### Stream frequency

Horton developed the stream frequency (F), which is the proportion of the total stream segments of all orders in the watershed to an entire basin area. It may also be defined as the ratio between the total number of stream segments cumulative of all orders and the basin area. It may be possible to have different stream frequency, though the basin has the same drainage density. Stream frequency is related to permeability, infiltration capacity and relief of the basin. It provides drainage basin response to runoff processes. Stream frequency depends on the rainfall, relief, initial resistivity of rocks as well as drainage density of the basin ([Thomas et al. 2010](#)). High slope and greater rainfall increase stream frequency in mountain areas, whereas low permeability and less available surface flow decrease the Sf value in plateau environments. The stream frequency of the Tidi watershed is 2.03 km/km<sup>2</sup>, shown in [Table 3](#). The stream frequency depends on the precipitation, lithology, and temperature of the basin and represents a drainage network texture.

### Drainage density

The drainage density (Dd) suggests the proximity from its channel spacing ([Horton 1932](#)). The drainage density is the cumulative length of the total stream order per drainage area. Based on Strahler's classification, a lower value of drainage density appears where the basin relief was low, whereas a higher Dd is preferred wherever the basin relief was high. The weather, relief, infiltrate capacity, runoff intensity, vegetation cover and type of rocks are correlated with the density factor ([Joji et al. 2013](#)). Slope steepness and relative relief are the key morphometric features influencing drainage density. In the Tidi watershed, the drainage density value was 1.74 km/km<sup>2</sup> ([Table 3](#)). This value in the research area indicates that the structure of sub-surface strata is porous, and it is the prominent aspect of coarse drainage because Dd values would be less than 5.0. A similar result was also reported by [Mahala \(2020\)](#). Quantification of drainage density gives the quantitative assessment of runoff ability and landscape dissection.

### Areal aspects

#### Circularity ratio

The circulatory ratio (Rc) is the proportion of the watershed area to the area of a circle of the same perimeter of the watershed ([Smith 1950](#)). The Rc proportion is mostly concerned with its length and land use/land cover, geological formations, stream frequency weather, slope and basin relief. Value of Rc varies from '0' (minimum circularity) to '1' (maximum circularity). The circulatory ratio values depend upon stream frequency, drainage density, climate, geological structure, slope, relief, and so on of any basin. The higher circular basin will affect peak discharge in high rainfall season. It is an indicative value determined by the geomorphological stages of development of any basin. The high, medium and low value of Rc is indicative of old, mature and young stages of geomorphological adjustment of any basin. The Rc value of the Tidi watershed is less than 0.5, which means that it is elongated ([Magesh et al. 2012](#)). The value of the circulatory ratio in the Tidi watershed is 0.26 ([Table 4](#)), suggesting that the study area has achieved maturity in topographical condition.

**Table 4** | Areal morphometric aspects of Tidi watershed

Sr. No.	Areal aspects	Tidi watershed
1	Circularity ratio ( $R_c$ )	0.26
2	Form factor ( $R_f$ )	0.52
3	Elongation ratio ( $R_e$ )	0.79
4	Basin shape factor ( $S_b$ )	1.92

### Form factor

The form factor ( $R_f$ ) is described as the proportion of the area of the basin to the square length of the basin. The value of the form factor may never exceed 0.7853 (this value conforming to an impeccably circular basin). The basin would be elongated with long-term low peak discharge if the value of a form factor was tiny (Magesh *et al.* 2012). The circular basins have a medium form factor that is similar to 1. A basin with a higher-value form factor encounters high peak flow with a shorter duration period, whereas an enlarged basin with a lower form factor encounters tiny peak flows for a lengthier time. The  $R_f$  chart proposes an alternative relation to an axial length of the square and the significant connection to the peak discharge. The form factor value of the Tidi watershed is 0.52 (Table 4), therefore the Tidi watershed consists of an enlarged watershed with a lower peak discharge of a lengthier period than average. Altaf *et al.* (2013) studied morphometric analysis of the Liddar watershed, India and reported comparable outcomes.

### Elongation ratio

The elongation ratio ( $R_e$ ) is the proportion of circumference of the circle with a comparable area to the basin to a maximal distance of the basin (Miller 1953). Elongation ratio values typically vary from 0.6 to 1.0 across a broad variety of climatic and geographical environments. These values could be integrated in to the four groups: enlarged (<0.7), less enlarged (0.7–0.8), oval (0.8–0.9), circular (>0.9) (Sukristiyanti *et al.* 2017). In the current study, the  $R_e$  value was 0.79 (Table 4), which suggests that the study area is less enlarged and has precipitous slopes and high relief.

### Basin shape factor

The form of the watershed does have a significant impact on both the sediment transportation phenomenon and the runoff. The index of shape, basin shape factor as defined by Horton, is the ratio here between squares of a full length of the watershed as well as the watershed area. The basin shape factor ( $S_b$ ) value for the Tidi watershed is 1.92 (Table 4).

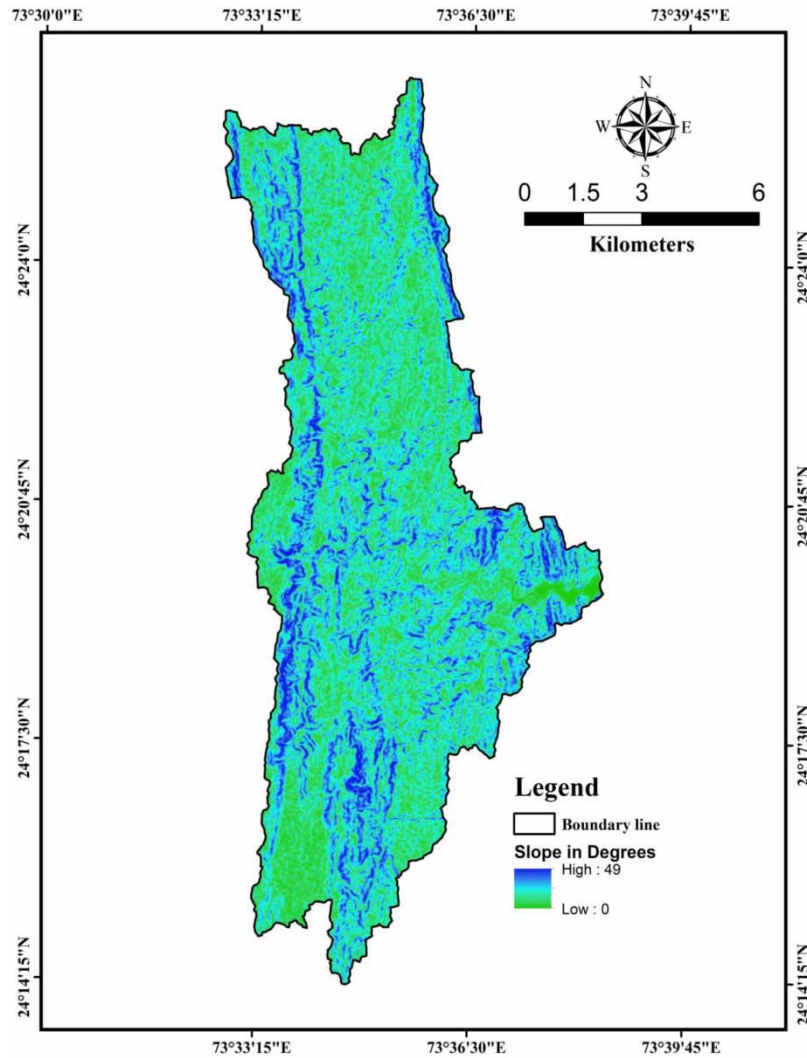
### Relief aspects

#### Watershed slope

'The slope is an important morphometric parameter controlled by morpho-climatic processes of any area underlain by varying resistance of rock surface. As slope determines the infiltration vs runoff relation, it is important to understand the nature of slope in any region' (Mahala 2020). The research area's slope map was developed with the help of ASTER DEM data using ArcGIS 10.4.1 software. The slope diagram of the Tidi watershed is shown in Figure 5. The slope of the Tidi watershed ranges from 0° to 49° (Table 5). High-grade slopes lead to rapid runoff as well as enlarged erosion with meagre potential for ground-water recharge.

#### Relative relief

Relative relief ( $R_R$ ) is defined as total watershed relief and its perimeter. It is an indication of the regular elevation of the basin from peak to the outlet point. Relief is the vertical maximum difference between the lowest and highest points of the basin. Basin relief is a crucial parameter to consider the denudatory properties of the basin (Rai *et al.* 2014). It serves a crucial part in the growth and development of landforms, the runoff, subsurface and surface water transport, perviousness and the degradation of the land. The overall relief for the Tidi watershed varies from 403 to 970 m and is shown in Figure 3. A high relative relief value shows the flow of water under gravity, less penetration and runoff circumstances are high.



**Figure 5** | Slope map of Tidi watershed.

**Table 5** | Relief morphometric aspects of Tidi watershed

Sr. No.	Relief aspects	Tidi watershed
1	Watershed slope ( $^{\circ}$ )	0° to 49°
2	Relative relief ( $R_R$ )	0.77
3	Relief ratio ( $R_r$ )	0.04
4	Ruggedness number ( $R_n$ )	0.99

### Relief ratio

The relief ratio ( $R_r$ ) is determined as the parallel distance measured across the long axis of the drainage perpendicular to the trunk stream segment (Miller 1953). The  $R_r$  shows the basin's average steepness and is a measure of the rate of erosion. The  $R_r$  value depends upon different factors of areal and relief characteristics of basin. A high basin relief, circular basin shape, and small basin area increase the  $R_r$  value of any basin. It indicates the overall steepness of the drainage basin and related degradation processes. It was also observed in the current analysis that the Tidi watershed relief ratio was 0.04 (Table 5), corresponding to steep slopes and moderate relief. Sharma & Sharma (2013) carried out drainage analysis of Brahmaputra valley and reported similar results.

### Ruggedness number

The ruggedness number (Rn) is defined as the cross-product of the drainage density and watershed relief and generally incorporates length with its steep slope (Kumar *et al.* 2015). High ruggedness number values were found in the study area due to steep slope and high peak discharge in the Tidi watershed. The ruggedness number of the Tidi watershed was 0.99 (Table 5).

The current research is important for rainwater harvesting, development and design of soil water conservation measures and management of ecology. First- and second-order streams are not appropriate to construct check dams; thus, rainwater harvesting structures cannot be used in this study area due to rapid runoff and high gradient. In addition, ecosystem management for the well-being of human relationships with the natural environment should be diligently carried out.

### CONCLUSION

Remote sensing and GIS techniques have proved to be a more accurate and efficient tool in drainage network delineation and watershed management than conventional methods. The present paper described morphometric analysis of the Tidi watershed based on several drainage parameters, by which the watershed has been classified as a fifth order basin. The mean stream length ratio (2.19) of Tidi watershed fluctuates according to local changes in topography and slope. The drainage density ( $1.74 \text{ km/km}^2$ ) of the Tidi watershed has a value below 5 revealing that the subsurface stratum is pervious, a characteristic feature of coarse drainage. The mean bifurcation ratio (3.88) suggests that the watershed area does not exercise a dominant influence on drainage pattern. The elongation ratio (0.79) shows that the Tidi watershed has steep slopes, high relief and is less enlarged than the average, mainly because of the guiding effect of impulsion and forcing. The tools (remote sensing and GIS) utilized in this study provided detailed morphological analysis, which can be used by other researchers in watershed drainage analysis to understanding the drainage network features of a river or basin environment.

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### AUTHORSHIP CONTRIBUTION STATEMENT

L.S.V. (PhD scholar) carried out the research and determined morphological parameters and wrote the first draft. P.K.S. (Professor) guided the PhD scholar, wrote and revised the manuscript. P.R.P. (SRF Fellow) encouraged and helped in initial draft preparation. A.J. (M. Tech student) assisted with review collection.

### DECLARATION OF COMPETING INTEREST

The authors declare that there is no conflict of interest.

### DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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