Morphometric Characterization of Netravati River Basin Using Geospatial Tools

L. N. Thakural[1], Manan Bamrara[2], Nitin Mishra[3], Abdul Samad[4], Manjar Alam[5], A. K. Lohani[6], Aradhna Thakur[7]

[1]*Scientist-D, National Institute of Hydrology, Roorkee, INDIA-247667*
[2]*Student, Graphic Era Deemed to be University, Dehradun, INDIA-248002*
[3]*Assistant Professor Graphic Era Deemed to be University, Dehradun, INDIA-248002*
[4]*Researcher, Aligarh Muslim University, INDIA-202002*
[5] *Researcher, Aligarh Muslim University, Aligarh, INDIA-202002*
[6]*Scientist-G, National Institute of Hydrology, Roorkee, INDIA-247667*
[7]*Research Associate, National Institute of Hydrology, Roorkee, INDIA-247667*

Abstract

Assessment of morphometric parameters, which involves the quantification of the geometry of the channel network to predict the behavior of a river basin. In the present study, morphometric analysis for the Netravati River basin has been carried out to evaluate the liner, areal, and relief aspects by using Geospatial tools. Geographically, the Netravati River basin covers an area of 3413 sq. km, falling between 12°29’11” N to 13°11’11” N latitude and 74°49’08” E to 75°47’53’’ E longitude. The ASTER-DEM with a spatial resolution of 30m has been processed to extract the drainage network and compute the morphometric parameters in the GIS environment. Strahler’s method is used for computing the stream orders.

The study mainly focuses on the evaluation of liner, areal, and relief morphometric parameters viz. stream order (Nu), stream length (Lu), bifurcation ratio (Rb), basin relief (Bh), ruggedness number (Rh), drainage density (Dd), stream frequency (fs), texture ratio (T), elongation ratio (Re), circularity ration (Rc), and Form factor (Rf). The morphometric analysis reveals that the basin is mainly a dendritic drainage pattern, which exhibits homogeneity in texture and a lack of structural control. The elongation ratio is found to be 0.155 for the Netravati River basin indicating the elongated shape. Moreover, the form factor is found to be 0.243 also confirms that the basin shape is elongated. The low drainage density (0.699 km/km^2) indicates a very coarse drainage texture in the study area.

Keywords: Morphometric, Linear, Areal, Relief, SRTM, DEM, Netravati River, Geospatial

1. Introduction

Morphometric analysis is the study of physical characteristics of catchment area; such as area, slope, shape, drainage pattern etc. It is a quantitative measurement and mathematical analysis of landforms. It plays a significant role in understanding the geo-hydrological characteristics of a drainage basin in relation to the terrain features and its flow patterns. Morphometry plays an important role in basin-level construction and flood control planning.

2. Materials and Methods

2.1 Study Area and Data Source

2.1.1 Netravati River basin

Netravati River is situated between the latitude 12°29’11” N to 13°11’11” N and longitudes 74°49’08” E to 75°47’53’’ E in the Western Ghats region of Karnataka state. The west-flowing river originates in the Bangrabalige valley in the Chikkamagaluru district at an elevation of 1,000 m above MSL and has a catchment area of about 3416 km^2. Heavy rainfall, high humidity, and harsh weather throughout the hot season characterize the basin's climate. The hot season (March to May) is followed by the South West monsoon (June to September) whereas the receding/retreating monsoon, also known as the post-monsoon season, occurs between October-November. The river basin experiences variation in annual normal rainfall and temperature ranging from 2002mm to 5277mm and 16.0°C (Minimum) to 42.0°C (Maximum) respectively. The wind speed in the region varies from 7.2 to 9.6 km/hr. The upper river basin primarily consists of sandy clay loam (approximately 84%) types of soil whereas the lower part of the basin constitutes clay loam soil (approximately 16%). Clay loam soils befall mostly on the gently rolling topography as a long strip along the coastal region of the basin having higher rainfall.

2.1.2 Data collection

ASTER digital elevation model (DEM) at 30m x 30 m resolution has been used to delineate the drainage network of the Netravati River basin. The DEM has been downloaded and processed thereafter to derive the terrain information. Initially, DEM has been projected to WGS 1984 UTM Zone 43N using appropriate tools in Arc Toolbox. Further, these extracted data have been used for analyzing linear aspects, areal aspects and relief aspects of the Netravati River basin.

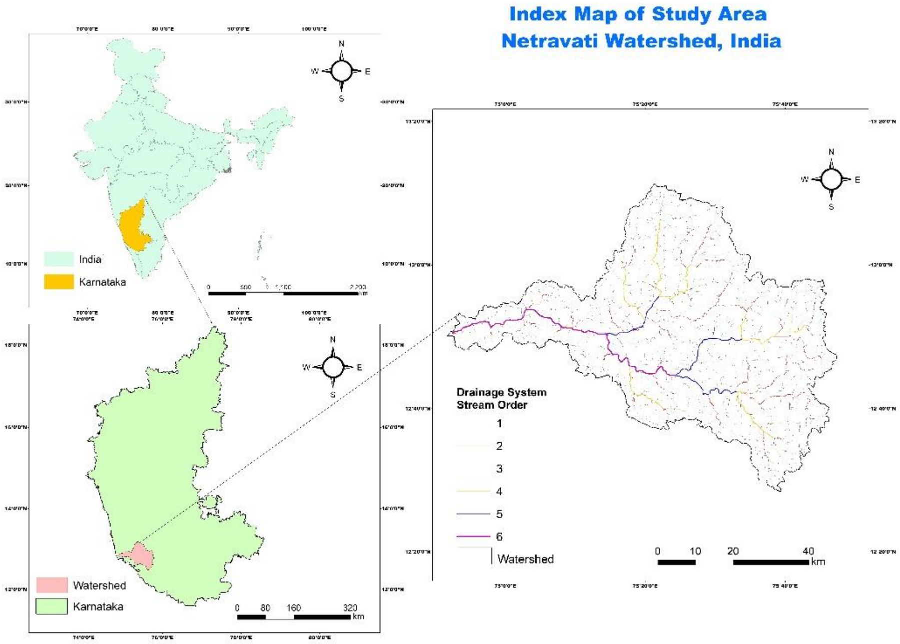

Figure 1 Index map of study area

2.2 Methodology

The methodology used in the present study has been shown in Figure 2. Recent advancements have made remote sensing and GIS-based morphometric analysis much simpler and more accurate than in the past. DEM (30 m resolution) data obtained from http://earthexplorer.usgs.gov has been used to study the present morphometric conditions of the Netravati River Basin. A river basin's morphometric analysis portrays a vivid image of the contemporary geo-hydrological conditions, the kind of rock structure, and the permeability and porosity of the soil. Using ArcGIS environment, stream network, river basin, and morphometric data have been retrieved from the ASTER-DEM. Further computations of morphometric parameters are given in Table 1.

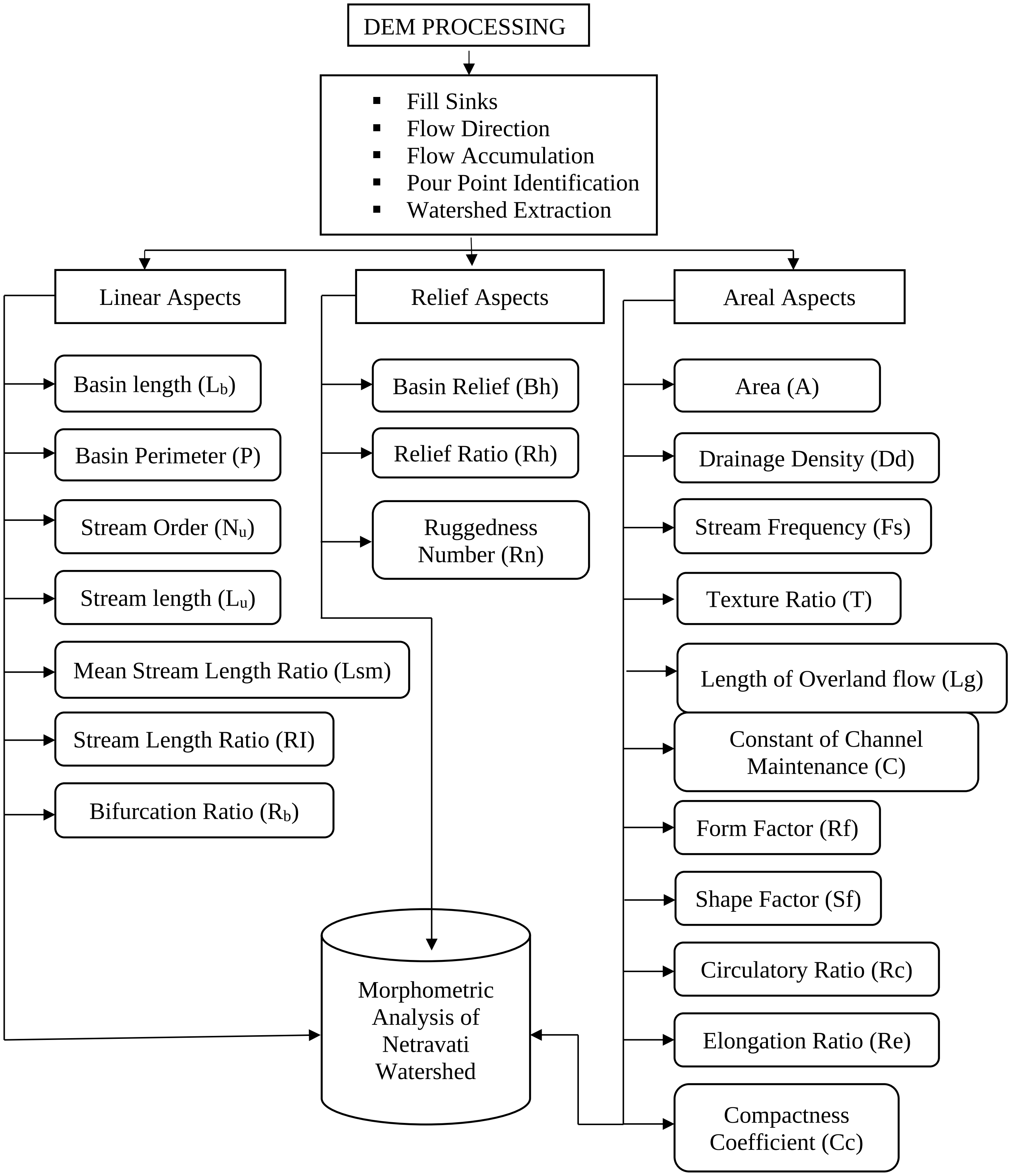

Figure 2 Flow diagram of methodology

Table 1 Computations of morphometric parameters

S. No	Morphometric Parameters	Formula/Definition	References
1	Basin length (L_b)	Maximum length of the basin measured parallel to the main drainage line	Strahler
2	Basin Perimeter (P)	Length of the drainage basin boundary	-
3	Stream Order (N_u)	Hierarchal rank	Strahler
4	Stream length (L_u)	Length of the Major stream	Horton
5	Mean Stream Length Ratio (Lsm)	Lsm = Lu / Nu, Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	Strahler
6	Stream Length Ratio (RI)	Rl = Lu / Lu – 1, Lu = The total stream length of the order 'u' Lu – 1 = The total stream length of its next lower order	Horton
7	Bifurcation Ratio (R_b)	Rb = Nu / Nu + 1, Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumm
8	Basin Relief (Bh)	R = H− h, H is maximum elevation and h is minimum elevation within the basin.	Schumm
9	Relief Ratio (Rh)	Rr = R/Lb	Schumm
10	Ruggedness Number (Rn)	Rn = Dd× H/1000 R is the basin relief and Dd is the drainage density	Strahler
11	Area (A)	Total area of river basin	-
12	Drainage Density (Dd)	Dd = ∑Lu / A	Horton
13	Stream Frequency (Fs)	Fs = ∑Nu / A	Horton
14	Texture Ratio (T)	Drainage texture ratio is the total number of streams segments of all orders (Lu) per perimeter of that area (A)	Smith
15	Length of Overland flow (Lg)	Lg = 1/2Dd	Horton
16	Constant of Channel Maintenance (C)	It is the inverse of drainage density	Strahler
17	Form Factor (Rf)	$Rf = A / Lb^2$	Horton
18	Shape Factor (Sf)	It is the ratio of square of basin length to the basin area. This factor is inversely proportional to form factor (Rf)	
19	Circulatory Ratio (Rc)	$Rc = 4 A / P^2$	Miller
20	Elongation Ratio (Re)	$Re = 1.128\sqrt{A} / Lb$	Schumm
21	Compactness Coefficient (Cc)	The ratio of perimeter (P) of watershed to circumference of circle whose area is equal to area of watershed (A)	Gravelius

3. Results and Discussions

*3.1 **Linear Aspects***

The drainage network in the watershed was analyzed to calculate various linear parameters such as stream order, stream number, stream length, and bifurcation ratio, among others, for the drainage network depicted. Table 2 shows the results of the watershed morphometric analysis. The Netravati watershed was subjected to quantitative morphometric analysis using GIS techniques to determine the Drainage Network, Drainage Texture Analysis, Shape, and Relief Characterization, which are discussed in the following sections.

3.1.1 Basin length (L_b)

The basin length (L_b) is calculated as the longest dimension parallel to the main drainage line (usually the highest stream order). The shape of the river basin is determined by Lb. The longest length of the basin indicates that it is elongated. The basin's length was calculated to be 118.589 km.

3.1.2 Basin Perimeter (P)

The outer boundary of the watershed that encloses its area is called the basin perimeter. It is used to estimate the size and shape of the river basin. In this study, the basin perimeter has been calculated by using ArcGIS 10.4.1 software, and it came out to be 459 km.

3.1.3 Stream order (N_u)

Horton introduced the concept of stream order. The Netravati basin is classified as a sixth-order basin. Stream order is an important indicator of stream size, discharge, and drainage area. The stream order of the Netravati basin area was calculated on the basis of Strahler.

3.1.4 Stream length (L_u)

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristic of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. The total length of stream segments is generally greatest in first order streams and decreases as stream order increases. It can be measured by using length-measuring instruments. For this, the watershed map showing the drainage system is required. Stream length (L_u) is actually the total length of individual stream segments of each order. It represents the size of different lines of drainage systems and their contributing areas. Stream length measures the average (or mean) length of a stream in each order and is calculated by dividing the total length of all streams in a particular order by the number of streams in that order. The stream length in each order increases exponentially with increasing stream order.

3.1.5 Mean stream length (Lsm)

The Netravati watershed mean stream length and the majority of stream lengths (1st and 2nd orders) in the current study are relatively short. Short length streams, on the other hand, are representative of steep slope areas, whereas low gradients represent longer lengths (Chitra.et.al,). Horton's (1945) law was used to calculate the stream length and mean stream length.

3.1.6 Stream length ratio (RI)

Stream length ratio has a significant relationship with surface flow discharge and basin erosion stage. The mean stream length ratio of Netravati watershed is 0.63 Km.

3.1.7 Bifurcation ratio (Rb)

The Netravati watershed mean bifurcation ratio is 4.165. In general, the Bifurcation ratio (Rb) is a dimensionless parameter that expresses the effect of the drainage network and tells the geometric similarity of the basin (Strahler).

3.2 Relief Aspects

The highest point of a basin or a high relief value, in general, indicates high gravity of water flow, high runoff, and low permeable conditions (Kadam et al.,). Relief is defined as the difference in elevation between the highest and lowest points on any valley floor of a basin (Magesh et al.,). The relief aspect includes studies on basin relief (Bh), relief ratio (Rh), and ruggedness number (Rn), as shown in Table 1 and their observed values in Tale 2.

3.2.1 Basin Relief (Bh)

The morphometric analysis determined the maximum relief value of the Netravati watershed to be 1560 m, and the height of the mouth to be 1100 m above sea level. Furthermore, the catchment relief varies between 460 m, indicating gravity of water flow, low infiltration, and moderate runoff conditions. As a result, the watershed relief for Netravati appears to be moderately high in areas with moderate erosional forces.

3.2.2 Relief ratio (Rh)

In the current study, the relief ratio for the entire basin is 13.154. This high Rh value indicates a steep slope and a high basin relief (1560 m). Lower values, on the other hand, indicate the presence of basement rocks, which are exposed in the form of small ridges and mounds with a lower degree of slope, as reported by Chitra and Alaguraja.

3.2.3 Ruggedness Number (Rn)

The relationship between relief and drainage density is measured by the ruggedness number. The ruggedness number (Rn) was defined by Strahler as the product of basin relief and drainage density. The value of the Netravati Watershed is 1091.807, which indicates a high drainage density and relief.

3.3 Areal Aspects

3.3.1 Drainage density (Dd)

Horton identified drainage density as an important morphometric parameter. It is defined as the sum of all stream lengths per unit area. Drainage density is an important feature of a drainage basin because it influences the texture of a drainage system and is affected by several factors such as lithology, topography, and vegetation. Smith classified drainage density into five ranges. A coarse drainage texture is produced by low drainage density, whereas a fine drainage texture is produced by high drainage density. The study area has a drainage density of 0.699. According to Horton's classification, the low drainage density value of the Netravati River basin in the study area reveals very coarse drainage texture, dense vegetation, and a permeable subsurface.

3.3.2 Stream Frequency (Fs)

Horton (1945) developed it to study basin morphology, and it is directly related to the basin's lithological characteristics. The number of stream segments per square kilometre (number of streams/sq.km) is referred to as "stream frequency," "channel frequency," or "drainage frequency." It is written as follows:

$Fs = \Sigma Nu/A$ = 1437 / 3416.318 km2=0.421 km-2

Where,

Fs = stream frequency,
Nu = total number of stream segments of all orders, and
A = basin area.

3.3.3 Texture Ratio (T)

The texture ratio (T) is calculated as the product of stream frequency and drainage density (Horton 1945). Horton identifies filtration capacity as the single most important factor influencing texture ratio. It is also an important fluvial parameter which denotes the relative spacing of drainage network of any basin. Texture Ratio is affected by a variety of natural factors such as rainfall, vegetation density, soil types, infiltration capacity, stages of geomorphic development, and relief (Smith 1950). Netravati basin has a texture ratio of 3.13, indicating coarse drainage texture. The values indicate a low infiltration capacity, low rock permeability, high relief, and sparse vegetation.

3.3.4 Length of Overland flow (Lg)

The longer the overland flow, the slower the runoff process, and the shorter the overland flow, the faster the runoff process (Horton). The length of overland flow in the Netravati watershed is 0.714, indicating that surface runoff is low in the study area. Furthermore, with lower overland flow values, rain water will enter the stream relatively quickly (Prabhakaran, A. and N.J. Raj). Furthermore, the shorter the length of overland flow, the faster surface runoff enters the stream.

3.3.5 Constant of Channel Maintenance (C)

The channel maintenance constant (C) is defined as the reciprocal of drainage density as a property used to define overland flow (Schumm 1956). The lower the value of (C), the greater the food potentiality and the younger the geomorphological adjustment. Mountain environments have low (C) values due to lower bare soil infiltration and high overland fow. In comparison to the plateau-plain environment, the plateau-plain environment has a higher (C) value due to low drainage density and high infiltration. The Netravati watershed has a (C) value of 1.42. (Table 2). It indicates that there are fewer channels available to drain excess water and that the soil has a low infiltration capacity.

3.3.6 Form Factor (Rf)

In order to predict the flow intensity of a basin in a defined area, Horton proposed this parameter, which is the dimensionless ratio of basin area to the square of basin length. The form factor value ranges from 0 (for basins with a highly elongated shape) to 1. (For a basin with perfect circular shape). The basin will be longer if the form factor value is lower. The watershed's form factor is 0.243, indicating that the basin has an elongated shape.

3.3.7 Shape Factor (Sf)

The sediment- and runoff-production rates, drainage length, and roughness are influenced by Shape factor. The Sf of Netravati watershed is 4.116. Therefore, the highest erodibility is observed.

3.3.8 Circulatory Ratio (Rc)

The circulatory ratio of the Netravati watershed is 0.203, indicating an elongated watershed with a herringbone drainage pattern, indicating low runoff discharge and high subsoil permeability.

3.3.9 Elongation Ratio (Re)

It is a critical indicator for shape basin analysis, as it helps to provide information about the hydrological character of a drainage basin. Values near 1.0 are typical of regions with very low relief, high infiltration capacity, and low runoff, whereas values near zero are associated with high relief and steep ground slope, which are characterized by high vulnerability to erosion and sediment load. As a result, the basin's shape will be more elongated as the elongation ratio decreases, and vice versa. The elongation ratio for the Netravati watershed is 0.155, indicating a more elongated shape that is vulnerable to erosion and sediment loading.

3.3.10 Compactness Coefficient (Cc)

The compactness coefficient of a basin was calculated as the ratio of the basin perimeter to the circular perimeter of the same area of river basin (Horton, 1945), and it was directly related to the basin's erosion risk assessment factor. A higher Cc value indicates that the soil is more prone to erosion.

Table 1 Linear, areal and relief aspects calculated for morphometric analysis

Aspects	S. No.	Morphometric Parameters	Observed Values
Linear Aspect	1	Basin length (L_b)	118.589 km
	2	Basin Perimeter (P) km	459 km
	3	Stream order (N_u)	2391 km
		1	1123
		2	249
		3	51
		4	10
		5	03
		6	01
	4	Stream length (L_u) km	2391 km
		1	1125
		2	621
		3	361
		4	133
		5	72
		6	79
	5	Mean stream length {$Lsm=L_u/N_u$}	
		1	1.001
		2	2.49
		3	7.078
		4	13.3
		5	24
		6	79
	6	Stream length ratio {RI}	
		6/5	1.097

		5/4	0.541
		4/3	0.368
		3/2	0.581
		2/1	0.552
	7	Bifurcation ratio (Rb)	
		1/2	4.51
		2/3	4.882
		3/4	5.1
		4/5	3.33
		5/6	3
		Mean	4.165
Relief Aspect	1	Basin Relief (Bh)	1560 m
	2	Relief ratio/Slope (Rh)	13.154
	3	Ruggedness Number (Rn)	1091.807
Aerial Aspect	1	Area (A)	3416.318 km
	2	Drainage density (Dd)	0.699
	3	Stream Frequency (Fs)	0.421
	4	Texture Ratio (T)	3.13
	5	Length of over land flow (Lg)	0.714
	6	Constant of channel maintenance (C)	1.42
	7	Form factor (Rf)	0.243
	8	Shape factor (Sf)	4.116
	9	Compactness Coefficient (Cc)	2.215
	10	Circulatory Ratio (Rc)	0.203
	11	Elongation Ratio (Re)	0.155

4. Conclusions

The following conclusions are derived from the foregoing study:

(i) The study of morphometric analysis using GIS helps to analysis the drainage basin easily & accurately with have various watershed problems like drought area, soil erosion, change of land use land cover, watershed evaluation, flooding, groundwater potential zones & its Scarcity.

(ii) In this study, morphometric parameters for Netravati basin have been carried out for addressing linear, areal and relief aspects by using remote sensing and GIS environment.

(iii) GIS based analysis with morphometric parameter gives a relationship between hydrological aspect, geological, topographical, pedological which is useful for planning & management of watershed construction & watershed structure (check dam, recharge shaft, percolation tank).

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