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Morphometric Interpretation for Sub-Basin Management Planning and Practices in Hassan District, Karnataka India Using GIS and Remote Sensing

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Abstract

Classification and categorization of water basins is essential in sustainable growth, planning and management. Implementing the modern strategic techniques over a wider area needs huge resources and proper planning. Hence, morphometric analysis can be used as necessary tool for prioritizing sub-watersheds in the present study. The study area encompasses 265 sq. km, which is divided into nine sub-basins, specifically Bannur (W-1), Conimarur (W-2), Hampapura (W-3), Harohalli (W-4), Kaneyar (W-6), Konanuru (W-7), Saraguru (W-8), and Torenuru (W-9) ranging from 8 to 64 km^2. The Survey of Indian toposheets and Digital Terrain Model are utilized to explain the drainage characteristics. The study reveals dendritic stream arrangement of fourth to fifth order. The density of drainage ranged between 1.03 to 1.32 km/km^2, suggesting that the drainage texture was coarse to moderate, but low infiltration and high runoff. The change in stream length ratio over time implies that geomorphological progress is approaching its end. The bifurcation ratios range from 0.5 to 2.58, indicating that the region has good lithological control over the stream system and whole sub-watersheds are classified as "normal". The form factor and circulatory ratio suggest elongated to circular sub-watersheds. Thus, the results of this analysis would be useful for the basin management planning and groundwater development.

Keywords: Morphometry, Aerial Aspects, Linear aspects, Relief aspects, Hassan District

Introduction

Assessing watershed morphometry is the most basic and reasonable tool for explaining quantitative watershed features **(**Deepak, 2015). Due to its complexity and has fluctuating attribute, it is not easy to apply over a larger area. Understanding the present watershed characteristics and potentials are fundamental for the selection and use of various parameters for describing and categorizing sensitive sub-watersheds (Karabulut and Ozdemir, 2019). These studies are important because they provide important information on the drainage network, hydro-geomorphometric features, and natural hazards of the watershed for planning activities for renewable groundwater resources management (Gunjan *et al.,* 2019). A watershed's morphometric feature generally represents the quantitative and physical features of the watershed (Nitheshnirmal *et al.*, 2019). It calculates quantitative landscape aspects including a watershed's linear, aerial, and relief aspects. Drainage provides a basis to understand initial slope,inequalities in rock hardness, structural controls,geological and geomorphological history (Kale and Deshmukh, 2020). The watershed characteristics depend on subsurface structure, geomorphological features, and hydrological properties, these are the properties that are useful for morphometric calculations (Murkute and Solanki, 2019). It is also important because it can be used to explain erosion, flooding, and various geological processes. Quantitative description of a drainage basin helps in understanding the geo-hydrological behaviour, soil susceptibility to land degradation and watershed prioritization (Varade *et al.,* 2018). Watershed characterization is the process of characterizing the watershed and its components. During the last few decades, remote sensing and GIS methods have been familiar for land assessment. Using GIS-based geographic assessment software, SRTM data is a quick, affordable, accurate way to evaluate hydrologic systems. The study of watersheds is essential for sustainable groundwater development activities and implementing the management practices in the watershed. The focus of the research was to fill in some research gaps, such as why and how we evaluate morphometric aspects of watersheds. In terms of improving the research result, Geographical Information System (GIS) and Remote Sensing (RS) approaches were used in this study. Along with the previous studies, this research provides with crucial information on academics, policy-makers, local communities, and others. It gives to watershed research in terms of execution of the works design and implementation, as well as the scaling up of groundwater management techniques (Shrivatra *et al.,* 2021). In addition, it is beneficial to other academics who are working on related research issues in different domains. Thus, the results of this analysis would be useful for the basin management planning and groundwater development in the Arkalgud Taluk of the Hassan District, Karnataka.

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Study Area

The Arkalgud Taluk is situated in the Hassan District, roughly in the southwest corner. The study area is present in semi-malnad and maidan tract and is centered in the southwestern part of Karnataka state between 12° 32′30″ to 12° 45′N latitude, 75° 55′ to 76° 07′ 30″E longitude found a part of river Cauvery (Fig.1). The taluk's total geographical study area is 265 sq Km, and it is canopied by the survey of India toposheet Nos. 57D/2 and 48P/14, with a scale of 1: 50000. The region has semi-arid weather with warmer seasons, low precipitation, and a nice winter monsoon. The average annual temperature is 20.4°C, and the precipitation is 560 mm. Soils in the region have a reddish-brown patterning and vary in thickness (CGWB, 2013).

Geological Setting

The lithology of the research area is quite simple covering 80% of region by the peninsular gneissic complex (PGC) (Ramakrishnan and Vaidyanadhan, 2008). Several dolerite dykes intrude on the gneisses, demarcating some of the watersheds. The presence of amphibolite schistose granulite metamorphic rocks of Archean age, which divide the amphibolite schist and granitic gneissic rocks of Archean age, constitute well-defined narrow ranges that form the western portion of the research. They encroach on earlier rock types as well as provide coarse-grained and coarsely porphyritic contact (Ramakrishnan and Vaidyanadhan, 2008).

Methodology

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Maps and Toposheet maps of 1:50,000 have been used. Field visits were undertaken to validate the reliability of the ground truth using the GPS tool. There are three types of topographic components: linear, relief, and areal. Based on a comprehensive morphometric investigation of the sub-basin utilizing remote sensing and geographic information system (GIS), the present study was conducted. The CARTOSAT DEM images (1″or ~ 32-m spatial resolution) are utilized for prioritizing the watershed border and draw out the streams and relief aspects with the support of ArcGIS 10.3 program. The digital elevation model (DEM) is a geospatial feature and used for computing morphometric features (Joshi *et al.*, 2013). The CARTOSAT DEM imagery was taken from BHUVAN-ISRO'S website (https://bhuvan-app1.nrsc.gov.in/bhuvan2d/bhuvan/bhuvan2d.php. For calculation and investigation of morphometric features, mathematical methods and formulae have been used (Manjare *et al.*, 2020). The thematic maps of morphometric features have been generated, by using the interpolation technique in the ArcGIS.

Results and Discussion

The study demonstrates usage of satellites to assess various morphometric data for the sub-basin management and planning in the Arkalgud Taluk of the Hassan District. The analysis of the watershed's limits is determined into nine sub-watersheds (Fig. 2).

Categorization of Watersheds

Heavy rainfall rushes to a drain, stream, or river through a watershed, which is a natural hydrological unit. The average watershed area is below 500 km^2 according to AIS and LUS (1990)

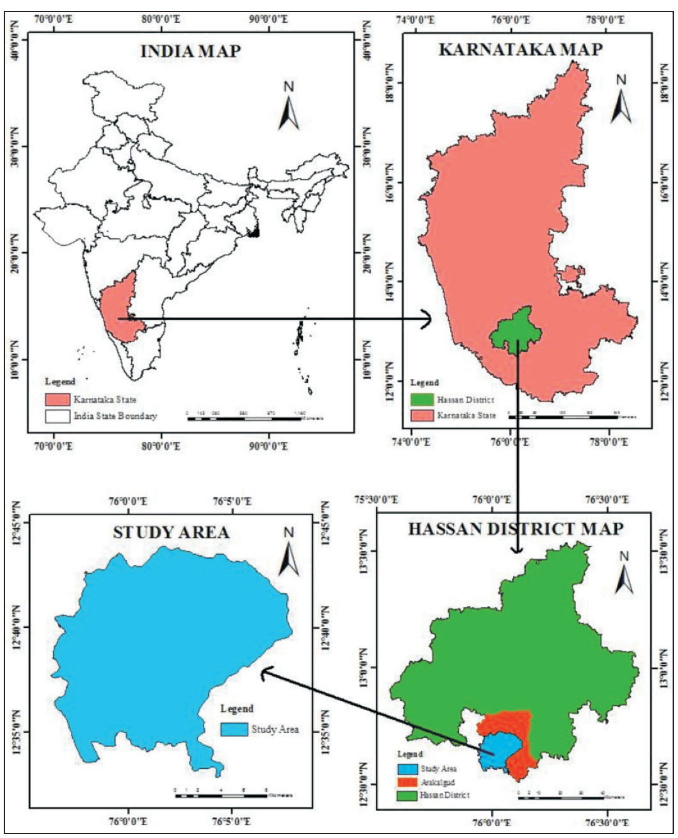

Fig.1. Location map of the study area

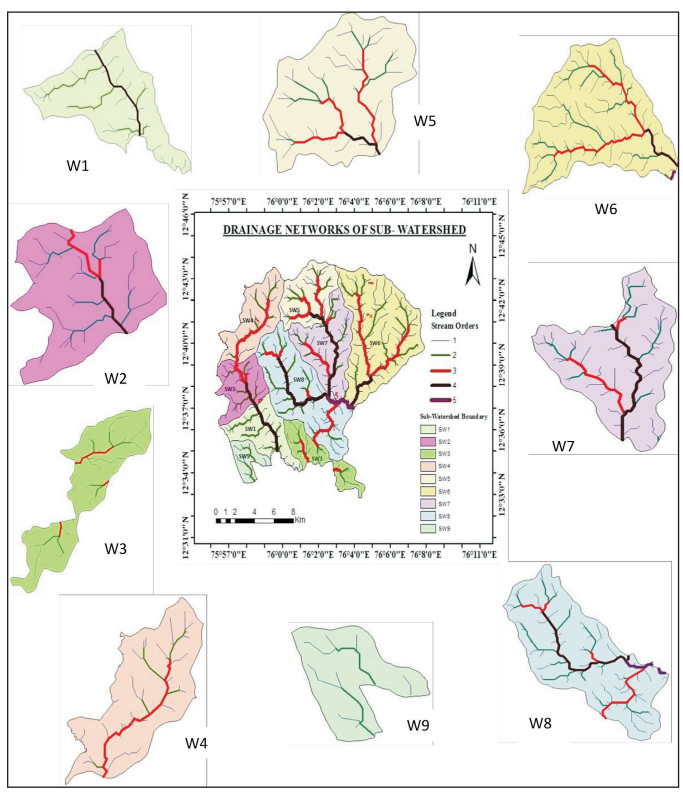

Fig.2. Sub-Basin maps of the study area

guidelines. According to the IMSD Technical Guidelines, watersheds are divided into four types based on area, sub-watersheds (10,000-50,000 ha), mili-watersheds (1,000-10,000 ha), micro watersheds (100-1,000 ha), and mini watershed (10-100 ha). As a result, the whole watershed is categorized into nine sub-basins each varying in size from 8 to 64 sq Km (Table 1).

Linear Features

The linear features of morphometric interpretation of the watershed were determined. The outcomes of the morphometric study are discussed in the table 2.

Order of Streams (U) - We observe four distinct ordering schemes for streams. In-stream analysis, the first determinant of streams is the stream order defined by a hierarchy of factors. The ranking of streams using Strahler's proposed process (Strahler, 1964). Table 2 displays the order of the geographic units as well as the sub-basins. Torenuru is in a 2^{nd} order sub-basin, Bannur, Conimarur, Hampapura, Harohalli, are 3^{rd} order sub-basin, Jogihosahalli, and Konanuru is 4^{th} order sub-basin while remaining sub-basins are in the 5^{th} order. Table 2 exhibits that the 1^{st} order streams have the largest number. The research discovered that as the stream order rises, stream frequency falls. Stream runoff patterns show a dendritic pattern,

Table 1: Formulae and methods adopted to compute watershed morphometric parameters

SN	Morphometric Parameters	Methodology	Reference
1	Stream Order (u)	Hierarchical order	Smith (1950)
2	Stream Length (Lu)	Length of the stream	Imran *et al.* (2011)
3	Mean Stream Length (Lsm)	Lsm = Lu / Nu; Where, Lu=Mean stream length of a given order, Nu= Number of stream segments	Smith (1950)
4	Stream Length Ratio (Rl)	Rl =Lu/Lu-1; Lu =Total stream length of order "u"; Lu-1 = Total stream length of its next lower order	Imran *et al.* (2011)
5	Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu=Number of stream segments present in the given order; Nu+1= Number of segments of the next higher order	Schumm (1956)
6	Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders)	Smith (1950)
7	Length of the basin (Lb)	The straight-line distance from a basin's mouth to the point on the water divide intersected by the projection of the direction of the line through the source of the mainstream.	Horton (1945)
8	Perimeter (P)	Horizontal projection of its water divide	Zavoianu (1978)
9	Area of the basin (Ba)	The entire area drained by a stream or system of streams	_
10	The density of drainage (Dd)	D = Lu /Ba ;Lu=Total Stream length of all orders (km); Ba = Area of the Basin (km^2)	Imran *et al.* (2011)
11	Drainage Texture(Dt)	Dt = Nu/P; Nu = Total no. of streams of all orders; P=Perimeter (km)	Scheidegger (1970)
12	Drainage intensity(Di)	Di = Fs/Dd; Where, Fs = Stream frequency; Dd = Drainage density	Gardiner (1975)
13	Stream Frequency (Fs)	Fs = Nu /Ba; Nu=Total number of streams of all orders Ba = Area of the basin (km^2)	Horton (1945)
14	Length of OverLand Flow (Lg)	Lg = 1/ D × 2; D = Drainage density (km/km^2)	Imran *et al.* (2011)
15	Form Factor (Rf)	Rf = Ba / Lb^2 ;Ba =Area of the Basin (km^2); Lb^2 = Square of basin length (km)	Imran *et al.* (2011)
16	Circularity Ratio (Rc)	$Rc = 4 \times \pi \times Ba / P^2$; Ba = Basin Area (km^2); P= Perimeter of the basin (km), $\pi = 3.14$	Miller (1953)
17	Elongation Ratio (Re)	$Re = \sqrt{(Ba/\pi)} / Lb$; Ba= Area of the Basin (km^2) ; Lb = Basin length (km), $\pi = 3.14$	Schumm (1956)
18	Shape Index (Si)	$Si = Lb^2/Ba$; Lb^2 = Square of basin length (km); Ba = Basin Area (km^2)	Gardiner (1975)
19	Texture Ratio (Rt)	Rt = N1 / P; N1 =Number of stream 1st order, P = perimeter.	Schumm and Hadley (1961)
20	Constant Channel Maintenance (C)	C = 1/Dd, where Dd = Drainage density	--
21	Compactness coefficient (Cc)	Cc = 0.2841 * (P/Ba 0.5), P = Perimeter (km), Ba = Area of the basin (km^2)	Manjare *et al.* (2020)
22	Infiltration Number (If)	If = Fs × Dd ; Fs = Stream Frequency; Dd = Drainage Density	Gardiner (1975)
23	Maximum height of the basin (H_{max}) m	GIS analysis/DEM	--
24	Height of basin mouth (H_{min}) m	GIS analysis/DEM	--
25	Total Basin Relief (R)	$R = H_{max} - H_{min}$	Smith (1950)
26	Relief Ratio (Rr)	Rr = H/Lb ; H = Total relief (Relative relief) of the basin in meter ; Lb = Basin length	Schumm, S. A. (1956)
27	Relative Relief Ratio (Rhp)	Rhp = R×100/P ; R = Maximum basin relief, P = Perimeter of the basin (km)	Murkute and Solanki (2019)
28	Watershed Slope (Sw)	Sw = R/Lb ; R= Maximum basin relief, Lb = Basin length	--
29	Ruggedness Number (Rn)	Rn = Dd ×(R/1000); R= Maximum basin relief, Dd= Drainage density	Patton and Baker (1976)
30	Slope analysis (Sa)	GIS analysis/DEM	--

indicating texture uniformity and the absence of structural influence.

Length of the Stream (Lu) - calculation was used to measure the stream extent. Since it exposes surface runoff conditions. Streams with a shorter length are found in areas with steeper slopes as well as a finer texture. The longer a water body is the flatter the slope. The total length of the stream is usually greatest in the 1st order of stream and gradually reduces as the order rises. However, in the frame of Kaneyar, Konanuru, and Saraguru sub-basins the stream segments display several stream configurations (Table 2). The change is due to high-altitude stream flow, lithological heterogeneity, and the presence of medium steep slopes. Horton's rule of stream number is verified by the observation of stream order; a geometric progression is formed by analyzing the pattern of stream sections of each order.

The Average Stream Length (Lsm) **-** By dividing an order's total stream length by the number of streams in the order, the average stream length is a key feature associated with the drainage system and its related surfaces. Table 2 provides Lsm values from 0.2 to 0.8 and it can be seen that in any given order, the Lsm values were higher than that of the lowest order which is lower than the next higher-order. Vary in gradient and geomorphology may have caused the separate sub-basins.

The Ratio of Stream Length (RL) - Flow length of one order divided by the next lower order's length is called the ratio of stream length. As reported by Horton's rule, stream length segments in each of a basin's consecutive orders indicate a geometrical succession of stream length rising in the direction of a higher order of streams. There is a difference in stream length in each sub-watershed, according to the ratio of stream length among streams of different order in the study region (Table 2). The transition may be due to variations in the gradient and geography. The length ratio in Bannur, Conimaruru, Hampapura, Harohalli, and Konanuru sub-basins increases through lower to upper order, indicating that they are in the moderate geomorphologic stage, while in the leftover sub-basins, there is a transition through one order after another, suggesting that they are in their youth geomorphological stage.

Bifurcation Ratio (Rb) - The number of divisions in one order divided by several divisions in the next higher-order is known as the bifurcation ratio. The bifurcation ratio was used by Horton as a compute of relief and breakdowns. The ratio of bifurcation displays a smaller level for various territories. Table 2 indicates that the Rb in one sequence isn't similar to that in the next order. The geological and petrological conditions of the local terrain control the morphological characteristics (Strahler, 1964). Lower Rb values are associated with sub-watersheds that have experienced few structural disruptions and drainage arrangements that have not been affected. A higher Rb rate suggests a positive structural effect on drainage arrangement.

The Basin's Length (Lb) - It is the distance between a basin mouth as well as a spot upon the perimeter that is equidistant from the basin mouth in any direction all over the perimeter (Gardiner, 1975). The sub watershed's basin length ranges from 2.99 km to 11.55 km.

The Average Bifurcation Ratio (Rbm) - The sum of all orders bifurcation ratios is called the average bifurcation ratio. The average bifurcation in the research area varies from 0.50 to 2.58 (Table 2), and all sub-basins are classified as natural basins (Strahler, 1964).

Area of the Basin (Ba) - The watershed's area is the length of the stream's drainage, which is a significant parameter to evaluate. Total basin area and whole stream length have a strong relationship, according to Schumn (1956), which is confirmed by providing area relationships. The area, which is 265 km^2, has been measured using ArcGIS-10.1.3 software.

The Perimeter of the Basin (P) - The external border of the basin which includes its area is known as the basin perimeter. It is calculated on the stream divides and can be used to determine the size and morphology of a watershed (Zavoianu, 1978). The basin perimeter of a sub-watershed was determined, which ranges from 14.53km to 37.49 Km.

Aerial Features

It describes the whole area calculated on a horizontal plane that provides overland flow to a given order's channel segment, which contains all smaller tributaries. All the aerial parameters are described in table 3.

Drainage Density (Dd) - Density of drainage was first used by (Horton, 1932) to show the compactness of channel spacing (Table 1). The value is determined by the cumulative channel length of all orders inside a basin. Climatic conditions, precipitationn, rock type, relief, absorption capacity, natural vegetation, surface roughness, and run-off management all impact drainage density. The extent of precipitation and the form of precipitants decide the amount and quality of surface runoff. The quantity of vegetation and soil moisture affects the intensity of surface runoff which in turn influences the drainage texture of a region. Drainage with a low density contributes to coarse texture, while drainage with a high density contributes to fine texture. Table 3 shows that the Dd of the research area is between 1.03 and 1.32 km/km2, suggesting low drainage density. In this illustration, we may assume that the low drainage density exists because of high permeability and dense vegetation (Nag, 1998).

Stream Frequency (Fs) - Horton (1932) defined stream frequency as the whole number of stream orders per square meter of all orders (Table 1). However, a similar drainage density can exist in similar frequency streams and different drainage densities can occur in similar stream frequency basins (Horton, 1932). Table 3 shows that Fs are the same for all sub-basins. The sampling rate (Fs) ranges between 1.62 and 2.31. The Fs also have a close relationship because of the drainage density rate of the sub-basins, implying that a rise in the drainage density of the sub-watershed leads to a rise in the stream number.

Drainage Texture (Dt) - Drainage texture, as well as the spacing of streams that drain water, is among the most essential concepts of geomorphology. The factor depends on the underlying lithology, rainfall, climate, infiltration capacity, relief aspect of the terrain and stage of development (Kamble *et al.*, 2019). Dt is the whole number of stream orders in a system across all orders including the area (Table1). Smith (1950) classified it into the five different textures. The density of drainage under 2 suggests extremely coarse, around 2 and 4 suggest coarse, between 4 and 6 suggest medium, around 6 and 8 suggest fine, and more than 8 suggest extreme fine drainage texture. The density of drainage in this study is characterized as coarse texture.

Form Factor (Ff) - it is measured as the proportion of basin area to basin length squared (Table 1). This element explains how quickly flowing water travels through a region (Horton, 1945). The Ff total must be greater than or equal to 0.7854 (the meaning that

Table 2: Linear feature calculation of the study area

	Sub-basins	W- 1	W - 2	W - 3	W - 4	W - 5	W - 6	W - 7	W - 8	W - 9
Parameters	Stream order	3rd	3rd	3rd	3rd	4th	5th	4th	5th	2nd
Stream Orders	1st	27	19	16	24	29	60	36	50	8
	2nd	11	10	8	9	13	26	14	19	4
	3rd	12	8	2	10	12	26	8	22	0
	4th	0	0	0	0	2	5	12	4	0
	5th	0	0	0	0	0	4	0	3	0
	ΣNu	50	37	26	43	56	121	70	98	12
Length of the Stream (KM)	1st	16.69	13.63	12.88	14.81	15.95	44.18	23.28	37.26	5.75
	2nd	5.8	5.19	4.13	5.88	8.7	18.36	7.12	11.58	3.6
	3rd	4.88	4.51	0.78	6.67	7.74	14.74	4.46	11.88	0
	4th	0	0	0	0	0.41	3.92	7.24	1.88	0
	5th	0	0	0	0	0	1.31	0	2.3	0
	ΣLu	27.37	23.33	17.78	27.35	32.8	82.51	42.11	64.9	9.35
Average stream length (km)	1st	0.61	0.71	0.8	0.61	0.55	0.73	0.64	0.74	0.71
	2nd	0.52	0.51	0.51	0.65	0.66	0.7	0.5	0.6	0.9
	3rd	0.4	0.56	0.39	0.66	0.64	0.56	0.55	0.54	0.3
	4th	0	0	0	0	0.2	0.78	0.6	0.47	0
	5th	0	0	0	0	0	0.32	0	0.76	0
Ratio Stream length	2/1	0.35	0.38	0.32	0.39	0.54	0.41	0.3	0.3	0.62
	3/2	0.84	0.86	1.88	1.33	0.88	0.8	0.62	1.02	0
	3/4	0	0	0	0	0.05	0.26	1.62	0.15	0
	4/5	0	0	0	0	0	0.33	0	1.22	0
Bifurcation ratio (Rb)	I/II	2.45	1.9	2	2.66	2.2	2.6	2.57	2.63	2
	II/III	0.91	1.25	4	0.9	1.08	1	1.75	0.86	0
	IV/V	0	0	0	0	6	5.2	0.66	5.5	0
	IV/V	0	0	0	0	0	1.25	0	1.33	0
Average bifurcation ratios (Rbm)		1.68	1.58	3	1.78	3.09	2.51	1.74	2.58	2
Area of the basin (Ba)in Sq. Km		21.78	19.22	15.94	26.66	24.78	64.35	32.28	51.72	8.22
Length of the basin (Lb) in Km		7.11	5.03	3.84	9.02	5.46	11.55	8.98	11.26	2.99
Perimeter (P) of the sub-watersheds		25.99	21.58	27.76	28.1	21.6	37.49	28.54	36.18	14.53

would be associated with an excellently circular basin). The basin would be more elongated as the form factor rate decreases. The surplus flow of a shorter period occurs in basins with high form factor, while lack of flow in a longer period occurs throughout elongated watersheds. The Ff rate for the study region ranges from 0.32 and 1.07, with a smaller peak flow and extended period than average.

Circularity Ratio (Rc) – It is the proportion of the basin's total area of a circle with a similar diameter as the basin's perimeter (Miller, 1953). Variables such as flow length and stream number, regional geological systems, land use/land cover, atmospheric conditions, relief, and basin gradient affect the circularity ratio (Rc). Rc has a range of 0.25 to 0.66 (Table 3). The high Rc 0.66 in Joghihosahalli and 0.57 in Kaneyar sub-basins suggests that they are almost circular, characterized by extreme to medium relief, and the drainage mechanism is structurally regulated. Sub watersheds with an Rc of below 0.50 are said to be elongated.

Elongation Ratio (Re) - it is the proportion between the circumference of a circle with the uniform area as drainage basin and the basin's largest length (Table 1). In terms of runoff release, a round basin is more active than an elongated basin (Schumm, 1956). Over a broad variety of climates and geological forms, Re values typically range from 0.6 to 1.0. Regions with very low relief have values similar to 1.0, while the values in the 0.6-0.8 range are typically linked to high relief and a steep surface gradient (Strahler, 1964). These measurements are divided into three classes, as follows: (i) round (>0.9), (ii) elliptical (0.9 to 0.8), (iii) less elongated (<0.7). The study area's Re ranges from 1.70 to 3.52. (Table 3). The minimum Re (1.70) in the Torenuru sub-basin indicates a steep gradient with high relief, while the maximum Re (3.52) in the Kaneyar sub-basin suggests comparatively flat terrain.

Infiltration Amount (If) - which is determined by the density of drainage and stream frequency, is used to evaluate infiltration occurred in a landscape. It is inversely proportional to the basin's ability to absorb water. Surface penetration will be lower and runoff will be higher as the 'If' value rises (Table 3). Sub-basins "If" rate varies from 1.66 to 2.98, which denotes a low penetration capacity that increases water flow in monsoon.

Length of Overland Flow (Lg) - It is the distance that water travels before splitting up and flowing into specific stream channels. With the Lg, the drainage basin is affected in hydrologic and physiographic growth. Table 3 shows that the Lg is smaller in the Joghihosahalli and Konanuru sub-basins because drainage density is higher in both these sub-basins than in the others. For all sub-basins, the calculated rate of Lg ranges from 0.37 to 0.48.

Constant of Channel Maintenance (C) - It specifies regarding drainage area is needed to sustain a given channel length. In this analysis, C varies between 0.75 for SB5 and SB7, and 1.0 for SB4 as shown in Table 3. Small amounts of C in the SB5 and SB7 suggest that two sub-basins are linked to the minimum or extremely minimum resistance soils, little foliage, and mountainous terrain, while the remaining sub-basins are linked to the maximum resistance soils, vegetation, and relatively flat terrain.

Compactness Coefficient (Cc) - It measures how compact a container is concerning a circular basin of equal area. A round basin produces the shortest cycle of absorption before the basin reaches its surplus flow. When Cc = 1, the basin is functioning only as a round basin. The circular presence of the basin indicates more divergence if Cc > 1. Table 3 shows that the Cc amounts for all sub-basins vary between 0.09 for SB8 to 0.25 for SB9. As a result, SB8 has the greatest deviation from the round nature, and as a result, it will have the longest period of absorption before surplus flow in the basin.

Shape Index (Si) - The relief, length, and shape of the drainage basin influence the water yield rate (Faniran, 1968). Basin shape indices of streams in the research area range from 0.93 in SB3 to 3.15 in SB4, Table 3 shows the results. SB3 and SB4 have the longest and shortest basin lags, respectively.

Texture Ratio (T) - which is based on the lithology penetration ability and the texture ratio, is the relief function of the terrain. Based on Table 3, T is 0.55 for SB9 and 1.60 for SB6. Hydrologically, it may be said that SB9 during the monsoon periods would have the longest basin lag times, while SB6 during the monsoon season would have the shortest basin lag times.

Table 3: Aerial feature calculation of the study area

Sub- watershed	W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9
(Fs)	2.31	1.94	1.64	1.62	2.26	1.89	2.17	1.89	1.49
(Dd)	1.26	1.22	1.12	1.03	1.32	1.28	1.3	1.25	1.16
(Di)	1.83	1.6	1.46	1.57	1.71	1.47	1.66	1.51	1.28
(Dt)	1.92	1.71	0.93	1.53	2.59	3.22	2.45	2.7	0.82
(Rf)	0.43	0.75	1.08	0.32	0.83	0.48	0.4	0.41	0.91
(Re)	0.74	0.98	1.17	0.64	1.02	0.78	0.72	0.72	1.08
(Rc)	0.4	0.51	0.25	0.42	0.66	0.57	0.49	0.49	0.47
(If)	2.96	2.34	1.83	1.66	2.98	2.41	2.82	2.36	1.72
Compactness coefficient (Cc)	0.16	0.15	0.24	0.14	0.12	0.08	0.12	0.09	0.25
Constant of channel maintenance (C)	0.79	0.82	0.89	0.97	0.75	0.78	0.76	0.8	0.86
Length of over land flow (Lg)	0.4	0.44	0.44	0.48	0.37	0.39	0.38	0.4	0.43
Shape index (Si)	2.32	1.32	0.93	3.15	1.2	2.07	2.49	2.45	1.08
Texture ratio (T)	1.03	0.88	0.73	0.85	1.34	1.6	1.26	1.38	0.55

Relief Aspect

The watershed's most important relief features are evaluated and calculated, including the altitude of the maximum and minimum points, drainage relief, relief ratio, ruggedness number, and slope. Table 4 summarizes the results.

Relief of the Basin (R) - It measures the altitude differences that are between the maximum and minimum points of a basin (Fig.3). The maximum (1015 m) and minimum (807 m) altitude is located in the northwest portion and lowermost southeastern portion, respectively. The sub-basins vary in altitude from 40 m in the SB 9 (Torenuru sub-basin) to 1026 m in the SB4 (Harohalli sub-basin). The hard mountain region is described by high relief; low to medium relief is observed in the mountainous and plain land. Rising R causes increased surface runoff and low penetration, resulting in increased sediments load and erosion.

Relief Ratio (Rr) - It is calculated as the proportion of basin relief to the basin's longest dimension parallel to the mainstream channel. Relief ratios for all the sub-watershed vary between 5.19

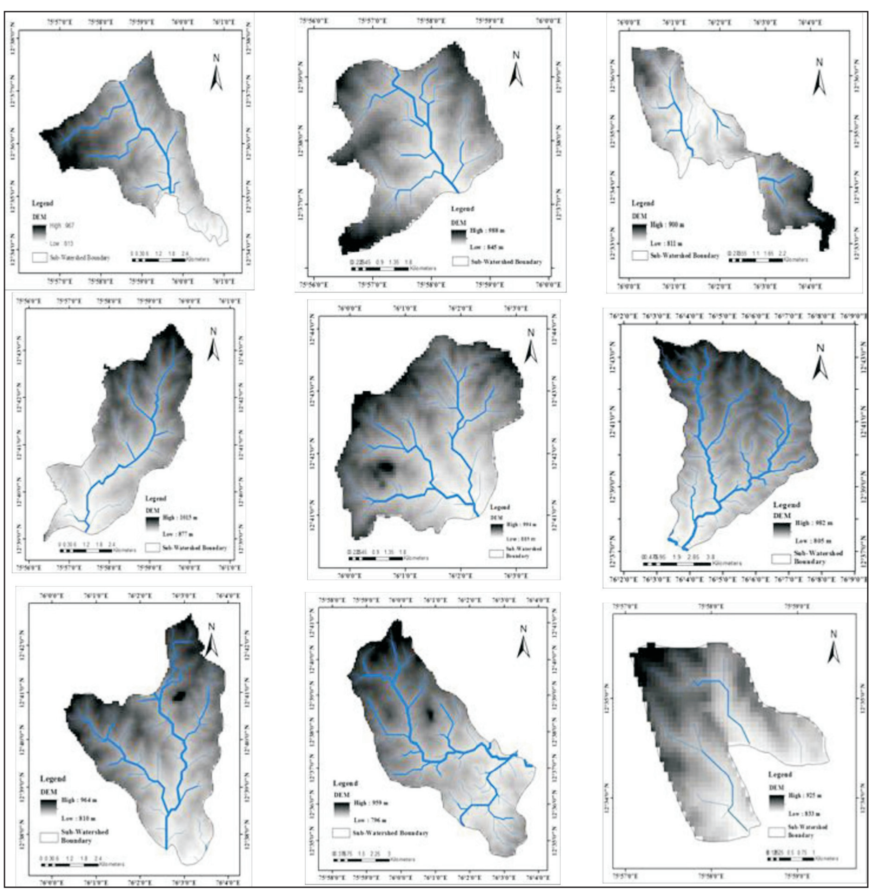

Fig.3. The DEM of the sub-basins of the study area (W1 to W9)

Table 4: Relief aspect of the study area

S. No.	Sub-basins	Minimum altitude (m)	Maximum altitude (m)	Basin relief (R)	Relief ratio (Rr)	Relative relief (Rhp)	Ruggedness number (Rn)	Watershed slope (Sw)
1	W - 1	813	967	69	9.70	265	0.087	9.7
2	W - 2	845	988	63	12.52	291	0.077	12.52
3	W - 3	811	900	55	14.32	198	0.061	14.32
4	W - 4	877	1015	124	13.74	441	0.013	13.74
5	W - 5	861	996	95	17.39	440	0.012	17.39
6	W - 6	805	982	60	5.19	160	0.077	5.19
7	W - 7	810	964	137	15.25	480	0.018	15.25
8	W - 8	796	959	136	12.07	375	0.017	12.07
9	W - 9	833	925	40	13.37	275	0.046	13.37

(SB6 Kaneyar) to 17.34 (SB5 Joghihosahalli). There is a variety of structural elements, geomorphological units, and lithology throughout the study region due to the wide range of relief. The relief ratio values indicate the strength of channel gradient, thereby showing the extent of sediments load and rate of erosion. Approximate maximum runoff and maximum discharge can be measured using such values.

Ruggedness Number (Rn) - Shows the degree of steepness and overall roughness in the landscape (Patton and Baker, 1976). The region is vulnerable to soil erosion. The minimum value is SB5 (Rn = 0.012) and the maximum is SB1 (Rn = 0.087). The finding describes that SB5 is least prone to erosion and the SW1 has the highest sensitivity.

Watershed Slope (Sw) - The rate of change in attitude concerning the distance along the mainstream channel is reflected in the gradient of a basin. Flood magnitudes represent the time conduct of fluid discharge. The gradient has a major impact on the momentum. The sub-basins have a spectrum of slope from 5.19 to 17.39.

Slope analysis (Sa) - Due to tectonic, erosional, and depositional processes, it is required to analyze the angular properties of the earth's surface, which has to gain the attention of geomorphologists towards the slope analysis in region and the determination of landform features based on angular properties (Choudhary, 2002). Wentworth's method for calculating the average slope of the watershed has been used (Wentworth, 1930). The slopes vary widely from nearly level (<1) to steep sloping (35–50) in the main basin (Table 5). The majority of the slope is relatively level and gently sloping (Fig. 4).

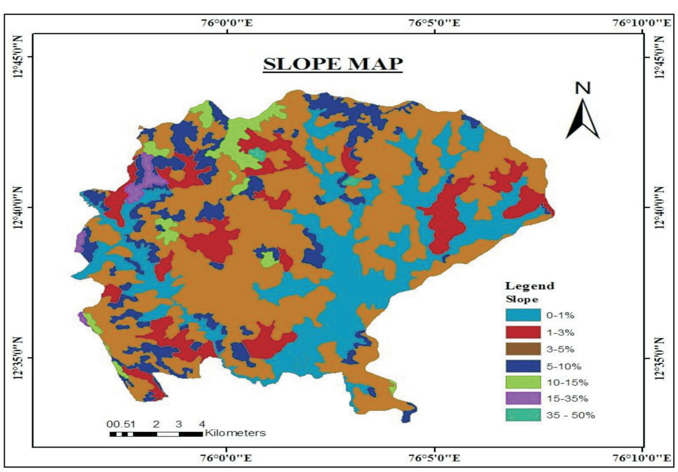

Fig.4. The gradient map of the study area

Table 5: IMSD (Integrated Mission for Sustainable Development) classification of slope classes in the sub-basins

S. No.	Slope classes	Slope (%)	Slope (in degree)	Area (Km^2)	Area (%)
1	Nearly level	0 - 1	0 - 0.9	68.72	25.66
2	Extreme gently slope	1 - 3	0.9 - 2.7	36.34	13.71
3	Gently slope	3 - 5	2.7 - 4.5	105.26	39.72
4	Medium slope	5 - 10	4.5 - 9	36.70	13.84
5	Strong slope	10 - 15	9 - 13.5	10.46	3.94
6	Medium steep slope	15 - 35	13.5 - 31.5	4.43	1.6
7	Steep slope	35 - 50	31.5 - 45	0.77	0.29
8	Extreme steep slope	50 - 75	45 - 67.5	0.00	0.00
9	Escarpment	75 - 89.30	67.5 - 80.37	0.00	0.00

Conclusions

The study comprises the morphometric analysis using GIS and Remote Sensing, its an effective tools for drainage delineation and modification, and revised drainage was used for morphometric interpretation. The morphometric interpretation of the streams in all 9 sub-watersheds reveals a sub-dendritic to dendritic stream arrangement, with fluctuations in stream length ratio probably due to the gradient and topographic variations. The study also found that streams in the Konanuru, Bannur, Hampapura, and Joghihosahalli sub-basins are mature, while the left-over sub-watersheds are in the youth stage of streams. The average bifurcation ratio reveals that geological formations have almost no impact on the drainage arrangement. The basin's drainage density and drainage texture suggest that the effect of subsurface strata varies between sufficiently permeable to impermeable. Drainage density is extreme coarse to coarse texture, varies from 0.82 to 3.22. The elongation ratio illustrates that the Conimarur, Hampapura, Joghihosahalli, and Torenuru sub-watershed have a circular form, while the others have an elongated form, low surface runoff, and low relief of the landscape. Stream segments up to the third order are observed to pass through sections of high elevational areas with effective relief, which are distinguished by hill cliffs, whereas the fourth and fifth-order stream divisions occur in relatively medium relief areas, where runoff penetration is highest. Hence, the study provides a necessary tool to identify regions for planning the groundwater management, soil erosion control and soil conservation measures.

Authors' Contributions

Venuprasad A: Investigation, Data Analysis, Writing-Original Draft, Methodology, Software. **D. Nagaraju**: Supervision, Reviewing and Editing. **Pramoda G.:** Conceptualization, Formatting, Writing- Reviewing. **Manjunath K.:** Software and Editing.

Conflict of Interest

The authors declare no conflict of interest.

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