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Original Article

Morphometric Analysis for Hydrological and Denudational Characterization of Geo-Structurally Controlled Sub-Basins: A Study from Godavari and Pranahita Basins, India

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Abstract *- Groundwater formation and flow are regulated by the subsurface lithological features at the sub-basin scale. Prospecting over the diverse geological settings within the watershed scale deters the resolution. The established geophysical methods can enhance precision but significant time, energy, and financial aspects. An attempt is made to prospect the groundwater resources over the basalts and sedimentary formations situated across the three adjacent sub-watersheds. We employed several methods to explore the potential groundwater zones, including geological, geomorphological, hydrogeological, and remote sensing techniques. We emphasized large-scale morphometric analysis using a couple of GIS techniques to understand the structurally controlled geological features in the sub-watersheds of Rallavagu (467.26 km^2), Peddavagu (470.78 km^2), Yerravagu (492.78 km^2) in Godavari and Pranahita basins, Southern India. The investigation of these sub-watersheds found that the overall count and length of first-order streams are higher but decrease with increased stream order. The Rb of distinct orders in the stream fluctuates between 2.00 and 4.86, indicating the geo-structurally controlled nature of the sub-basins. The thematic maps of geological features, geomorphology, topographic slope, and drainage density are appraised quantitatively to decide the weightage factor (WF). Further, the WF has been assigned to generate the groundwater prospect map of different categories on a spatial scale. The study concludes, i) potential groundwater resources (high to very high) are limited to the flood plain area of sandstone formations and correlate well with the geomorphic and structural lineaments, ii) moderate category groundwater resources are dominant in the study area, iii) the basalts being situated moderately dissected hills shows very low groundwater resources, iv) geomorphic lineaments were observed with shallow groundwater (unconfined aquifer) while, structural lineaments indicate deeper groundwater (confined aquifer) resources.*

Keywords *- Morphometry, Geo-structural lineaments, Groundwater prospecting, Pranahita-Godavari Basin, Rallavagu.*

1. Introduction

Groundwater has become the primary source of irrigation for agriculture practices in semi-arid climatic conditions [1], especially in India [2]. The unplanned and non-judicial exploitation of aquifer resources has resulted in the groundwater resources being limited to a deeper and discrete pattern [3]. Climatic hot conditions induced the untimely depletion of the surface water bodies resulting in no choice but to elect irrigation with just groundwater [4]. The potential groundwater resources are located in an isolated pattern which poses a challenge to identifying them. Further, the diverse geological settings within a sub-watershed level additionally increase the complexities of understanding the potential groundwater zones. Drilling a borehole for tapping groundwater without adequate knowledge of subsurface lithological set-up may result in wasting time, energy and finances. It necessitates detailed geological and geomorphological knowledge to categorize the rich zones in groundwater resources. We, in this paper, attempt to apply the hydro-geo-morphological information and appraise them using the GIS tools to prospect the groundwater resources in the study area located with three adjacent sub-watersheds belonging to the Godavari and Pranahita basins, southern India.

We emphasize the morphometric assessment, which is a numerical examination of basin geometry. The characteristics of physiographic data are expressed by [5]–[13]. Several researchers have worked on drainage morphometric analysis to sub-watersheds [14]–[16] using traditional research programs, and the morphometric analysis was examined from published maps and ground checks.

Lately, remote sensing and GIS techniques have accomplished autonomous analysis of drainage systems and their features [17], [18]. In southern India, many researchers have developed the morphometric characteristics of drainage basins [19], [20]. However, till now, this study area has not been studied systematically for any hydrogeological aspects using any means of methodology. Hence, the present study delineates the detailed morphometric characteristics of the drainage network using the hydrology tool on the ArcGIS (v. 10.3) platform. We assessed and generated the various thematic maps of geological, geomorphological, topographic, and drainage density and integrate them to generate the groundwater prospect map of various categories in the sub-watersheds of Rallavagu (467.26 km^2), Peddavagu (470.78 km^2), Yerravagu (492.78 km^2) in Godavari and Pranahita basins, Southern India.

2. Study Area

The north-eastern part of Telangana's Mancherial district is the habitat to the sub-watersheds of the streams Rallavagu, Peddavagu, and Yerravagu. It is centered between the longitude 79^{0}15' E & 79^{0}33' E, latitude 18^{0}54' N & 19^{0}10'N by Survey of India toposheet nos E44B8, E44B12, E44H5, and E44H9. The total geographical areas of the basins are 1430 km^2. The sub-basin boundaries and drainage network was extracted from SRTM-DEM data with the regional projection WGS-1984, Universal Transverse Mercator (UTM) and 43N zone.

The Mancherial district (Figure 1) is limited to the Komarambhem district in the north, Nirmal and Jagitial districts in the west, Peddapalli and Jayashankar Bhupalpally districts in the south and the east by Maharashtra state.

The climatic conditions of this area are semi-arid, with scorching summer months, moderate rainfall, and a mild winter monsoon. The annual mean temperature is 28.30 degrees Celsius, and the mean annual rainfall is 1086 millimeters.

Geologically (Figure 2), the present study area forms a part of the shale, limestone, and sandstone of Penganga formations, overlies granites/gneisses and occurs between Mancherial and Komarambhem districts. The Gondwana formations comprise sandstone, shales, and limestones between Mancherial and Jayashankar Bhupalpally districts.

Geomorphologically (Figure 3), most of the area, i.e., 85.51%, is occupied by the pediment pediplain complex. Steeply dissected hills dominate the west side of the area. Alluvial plains and flood plains occur mainly along the Yerravagu region, and a mining dump is also found. Table 1 illustrates the geomorphology statistics of the region.

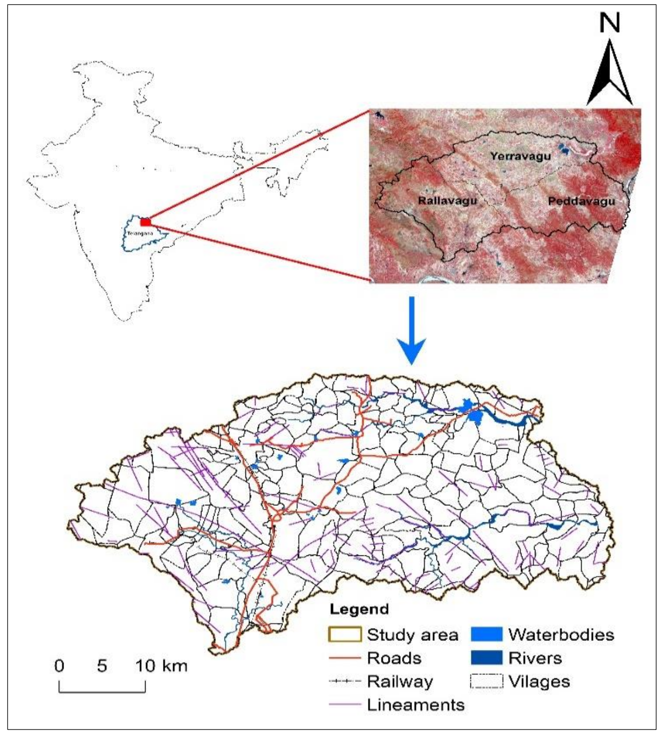

Fig. 1 The study area's location on a map

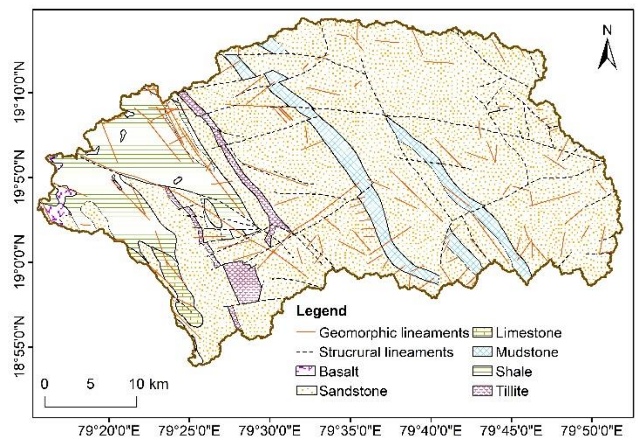

Fig. 2 Geological map

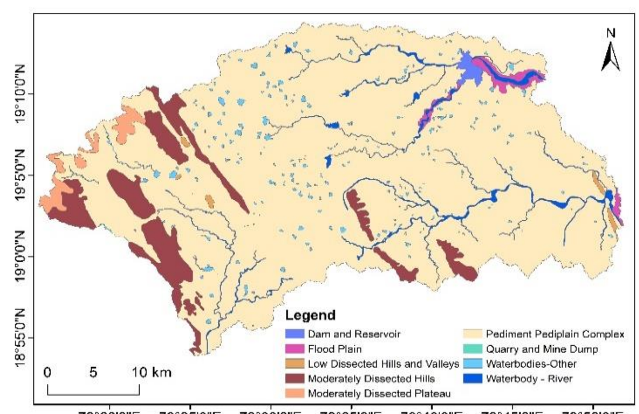

Fig. 3 Geomorphology map

Table 1. Geomorphology statistics

S. No	Landform	Area(sq.km)	% of area
1	Dam and Reservoir	6.15	0.43
2	Flood Plain	12.77	0.89
3	Low Dissected Hills and Valleys (LDHV)	4.36	0.30
4	Moderately Dissected Hills and Valleys (MDHV)	105.43	7.37
5	Moderately Dissected Plateau (MDP)	20.50	1.43
6	Pediment Pediplain Complex (PPC)	1223.55	85.51
7	Quarry and Mine Dump (QMD)	0.22	0.02
8	Waterbodies-Other	20.74	1.45
9	Waterbody - River	37.12	2.59
	Total	**1430.83**	**100.00**

The slope of the ground has a significant role in the area's penetration. The steeper and slope, the lesser the recharge area. The slope map shown in (Figure 4) was divided into five categories: flat (0–2.45), mild (2.45–6.86), moderate (6.86–14.21), steep (14.21–22.78), and extremely steep (22.78–62.48). The Rallavagu sub-watershed, located in the western part of the research area, has very steep slopes, whereas the remainder of the region is flat to mildly hilly. The slope differences in a region have a direct effect on the lithological features of the topography. Remote sensing methods enable the analysis of drainage morphometry by providing a synoptic picture of vast regions.

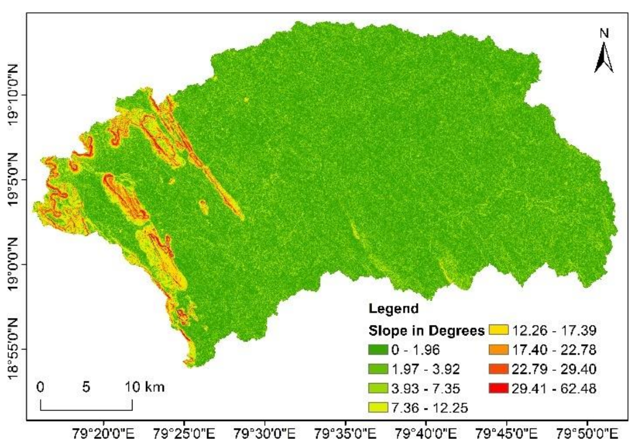

Fig. 4 Slope map

3. Data and Methods

The listed data sets are used to accomplish the objectives: The drainage network was defined using SRTM-DEM data and creating Geological map and Geomorphology maps from the GSI. These three sub-watershed drainage systems range from sub-dendritic to dendritic. The greatest stream order in these sub-watersheds is sixth. The linear, aerial, and relief morphometric characteristics are taken into account. Groundwater potentiality awards a weighted cumulative value based on the reclassification of geology, geomorphology, and lineaments. The assignment of weightage is given in Table 2.

Groundwater prospect zones are identified on the final groundwater prospect map (Figure 8) as being very high, high, moderate, low, and very low.

4. Result and Discussions

Open series topographic maps of Survey of India (SOI) 2011 with no's E44B8, E44B12, E44H5 and E44H9 on a scale of 1:50000 were used for this study. Using ArcGIS 10.3 software, these maps rectifies / geographically aligned and mosaicked to cover the entire research area. The drainage network was extracted from a 1arc (30m) SRTM-DEM using ArcGIS software's assigned projection and radiometric correction. Morphometric parameters are calculated by the adopted various methods given in Table 3. A numerical approach for characterizing and assessing the topography or drainage basin in sizable areas is termed morphometric analysis. Delineating possible groundwater zones within a watershed is helpful. The drainage basin of physiographic characteristics like size, slope and drainage density also correlated with various hydrologic phenomena. Three fundamental features are used to conduct morphometric analysis on a basin.

Table 2. Assignment of weightage to distinctive capabilities for potential groundwater zone

Geology	Geomorphology	Lineaments	Weightage
Sandstone	River & Active Flood Plain	-	1 (Very High)
Limestone	Waterbodies & Dam and Reservoir	-	2 (High)
Mudstone	PPC	-	3 (Moderate)
Tillite	Active Quarry & MDP	Geomorphic	4 (Low)
Shale & basalt	MDHV & LDHV	Structural	5 (Very Low)

4.1. Linear Aspects

4.1.1. Stream Order (OS)

According to [11], "the connection of two same-order rivers generates a higher-order stream," which is shown in (Figure 5). The highest order in these three subbasins is the sixth order. The semi-logarithmic plot (Figure 6) depicts the number of streams in each subbasin versus their order. The best-fitting model explains the exponential trendline.

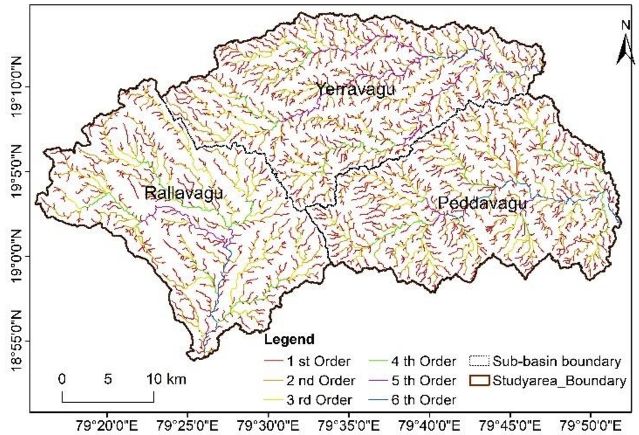

Fig. 5 Drainage network map

4.1.2. Stream Number (NS)

The stream count denotes the total number of streams included in each sequence. We found that when stream order rises, the NS reduces in these subbasins. The number of first to sixth-order streams included in the basins is 1927, 484, 93, 25, 8, and 3, respectively. Table 4 represents the stream numbers for each order.

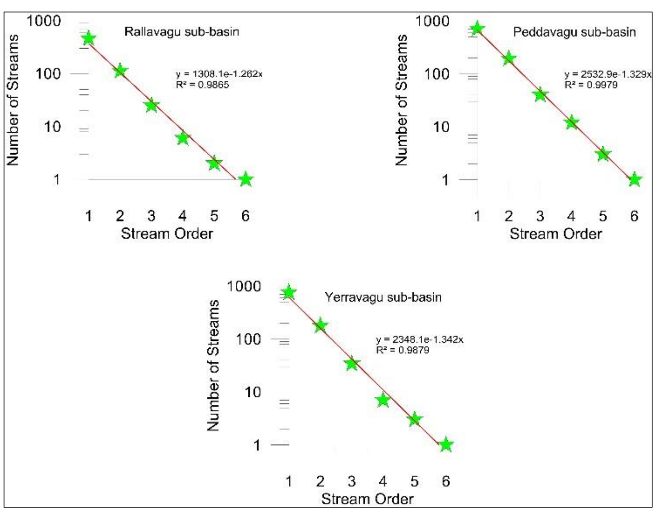

Fig. 6 Semi-logarithmic plot of the number of streams against stream order for the study area

4.1.3 Stream Length (LS)

The sum of the lengths of all stream sectors in each order equals the order's stream span. [13] discovered that a direct geometric ratio is often approximated by the average length of streams of different orders within a drainage basin. As the stream's order grows, the stream's length decreases exponentially. The lengths of first to sixth-order streams are 1204.09km, 626.07km, 289.48km, 137.93km, 78.94km, and 62.26km, respectively. Table 3 contains specific information on the lengths of each stream.

4.1.4. Mean Stream Length (MLS)

The MLS scores differ from 0.68 to 15.46 kilometres for Rallavagu, 0.62 to 29.25 kilometres for Peddavagu, 0.58 to 17.55 kilometres for Yerravagu sub-basins. The MLS value of any given NS is larger than the lowest order in the basin and less than that of the next level of higher order.

4.1.5. Stream Length Ratio (LRS)

The LRS of streams of various order in the study area demonstrates a modest fluctuation due to variances in slope and terrain.

4.1.6 Bifurcation Ratio (BR)

A drainage basin's geological and lithological evolution results in abnormalities in the BR from one order to the following [11]. The BRs in the Rallavagu sub-basin range from 2.00 to 4.48, the Peddavagu sub-basin from 3.00 to 4.85, and the Yerravagu sub-basin from 3.00 to 5.24. The presence of greater BR values indicates that the studied region is under structural control. The mean bifurcation ratios of the three sub-basins (3.55, 3.76, and 3.93) are within the regular basin group [27].

4.2. Aerial Aspects

The various parameters of the aerial aspects of the study area are as follows:

4.2.1 Drainage Density (DD)

It is designated as the quantity of the length of all streams in a catchment area. Weather, rock form, relief, the capability of infiltration, plant cover, the roughness of the material, and the strength of run-off affect the density factor. Precipitation amount and kind have a direct effect on the surface run-off amount. Sem semi-arid regions' lithology and geological formations have a finer drainage density pattern than tropical weather. The DD (Table 4) ranges from 1.43 to 1.83 km / km^2, showing a low DD (Figure 7). This low Dd proposes reflecting a highly permeable subsurface and thick plant cover in the area.

4.2.2. Stream Frequency (SF)

It is theoretically feasible for basins with the same river frequency to have different drainage densities and vice versa. The SF (Table 4) ranges between 1.30 and 2.04. It denotes a rise in stream population as a consequence of rising in drainage density.

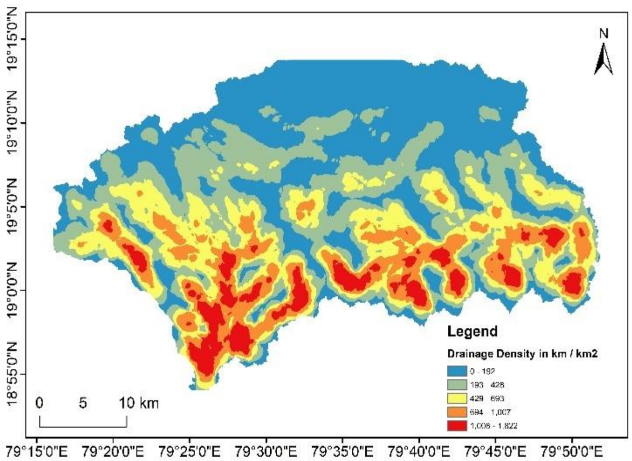

Fig. 7 Drainage Density map

4.2.3. Drainage Texture (TD)

One of the most significant notions in geomorphology is drainage texture [22], which is the virtual distance of drainage lines. The Dt of Rallavagu is a fine texture, whereas the Dt of Peddavagu and Yerravagu is a wonderful texture. The details of Dt are given in Table 3. The current investigation demonstrates an extremely coarse drainage density.

4.2.4. Form Factor (FF)

The observed FF values vary from 0.28 (Yerravagu sub-watershed) to 0.56 (Rallavagu sub-watershed), showing that all sub-watersheds in the study site are elongated in shape with low form factor values.

4.2.5. Circularity Ratio (CR)

It is impacted by stream length and frequency [23], weather, LULC, geological structures, basin relief, and slope. The CR (Table 4) varies between 0.44 and 0.69. The presence of CR values greater than 0.50 in the Rallavagu, and Peddavagu sub-watersheds indicates that they are less circular, have a high to moderate relief, and have a structurally regulated drainage system. The remaining sub-watershed (0.44) of yerravagu is elongated.

4.2.6. Elongation Ratio (ER)

A ER close to one indicates extremely low relief, while 0.6 to 0.8 indicates a moderately severe ground gradient [11]. The ER values can be classified as greater than 0.9 (round), 0.9 to 0.8 (ovel), and less than equal to 0.7 (elongated). The ER of the three sub-basins ranges between 0.39 to 0.53, indicating that it is elongated in the lower entity.

4.3. Relief Aspects

4.3.1. Basin Relief (BR)

Specifically, it is employed to comprehend the landform features and geomorphic progressions of the river basin under consideration [24]. The influence of BR is the most noticeable peak run-off rates and sediment delivery in the study area. The current area relief is 519 m, indicating that erosion pressures and mean denudational rates are relatively modest compared to the surrounding terrain.

4.3.2. Relief Ratio (RR)

It rises with a declining drainage zone and the overall size of the drainage network. The maximum number of the RR implies a steep slope with significant relief, while the lowermost value of the Rh suggests a gentle slope with little relief. The RR of the study region is 0.017939; the basin has a lower degree of slope than the surrounding area.

5. Groundwater Potential Zone

Groundwater is an invaluable resource that humans have used. It may well be found in practically all geological formations. However, there are majorly aquifers like gravels, unstratified tills in a sophisticated structure, limestones, and sandstones. The potential and quality of it each place are determined by geological, geomorphological, biogeographical, and socioeconomic variables [25]. In combination with geological, lithological, pedological, and topographical contexts, quantitative morphometric analysis is particularly useful in analyzing an area's geo-hydrological condition and finding and detecting ground water-rich zones [26].

5.1. Zone with High to Extremely High Potential

The area of these zones is about 100 to 170 m altitude occupied by the flood plain formed by sand. This region of the basin is driven by 5th and 6th-order streams, and it has the lowest drainage density, a very coarse texture, a flat and gentler slope, and substantial infiltration. This region contains fertile agricultural fields, flat topography, and efficient surface and groundwater available.

5.2. Moderate Potential Zone

This zone occupies more than 60 per cent of the area. The area is about 170 to 250m altitude occupied by sand and mudstone, which are moderately permeable water. As a result, this zone has comparatively moderately rich groundwater, with local lenses occurring in sandstone and some parts of shale deposits. It may be due to the region's dominance of second, third, and fourth-order streams and its comparatively high drainage network, moderate gradient, medium drainage pattern, and medium infiltration number.

5.3. Low and Very Low Potential Zone

This is an area of more than 250m altitudes by deciduous forest. It is formed geologically of shale, granite, and tillite rocks. This section also has a subsequently deposited alluvium stretch. Because of its solid geological structure, steep slopes, poor drainage texture, high drainage density, and infiltration number, this part of the basin has the least groundwater potential and availability.

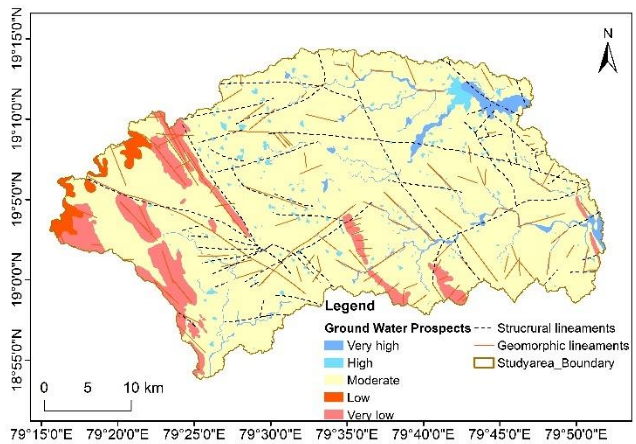

Fig. 8 Groundwater perspective map of the study area

6. Conclusion

The current work intends to outline the morphometric parameters of portions of the Pranahita and the Godavari River basins, as well as three sixth-order sub-watersheds, for a better understanding of the hydrological and denudational aspects of the present sub-watersheds; Rallavagu, Yerravagu, Peddavagu and their tributaries. The morphometric examination of drainage patterns in three sub-watersheds reveals the presence of a dendritic to sub-dendritic drainage pattern, with the difference in RL perhaps attributable to variations in slope and terrain in each sub-watershed. Significant differences exist in the BR values across the three sub-watersheds, indicating that the study region is under structural control. The average values of the BR in the study area fall into a normal basin category. The low DD and coarse TD indicate that the studied area has a highly permeable subsurface and thick vegetation. The Fs in each of the three sub-watersheds positively correlates with each other. According to the results, the ERs, CRs, and FFs of the three sub-watersheds all indicate that an elongated pattern characterizes the research region. The Ground Water Potentiality Zone Map has also clearly shown that the potentiality of groundwater diminishes as it moves from the plain region to the plateau region of the basin.

Table 3. Morphometric Parameters of the Drainage basin

	Morphometric Units	Formula	References
LINEAR	Stream order (OS)	Hierarchical order	[11]
	Stream Length (LS)	Length of the stream	[13]
	Mean stream length (MLS)	MLS = LS/OS; Where, LS=Stream length of a given order(km), Nu=Number of stream segments.	[13]
	Stream length ratio (LRS)	LRS = Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1= The whole length of the stream in its lowermost order.	[13]
	Bifurcation Ratio (BR)	R_b = Nu / Nu+1 Where Nu= How many stream segments are present in the specified order Nu+1= Number of segments of the next higher order	[24]
AERIAL	Drainage density (DD)	D_d=L/A Where, L=Total length of the stream, A= Area of the basin.	[13]
	Stream frequency (SF)	SF=N/A Where, L=Total number of streams, A=Area of the basin	[13]
	Drainage Texture (TD)	TD=DD*SF Where, Dd = Drainage density, Fs= Stream frequency	[22]
	Form factor (FF)	FF=A/(Lb) Where, A=Area of the basin, Lb=Basin length	[13]
	Circulatory ratio (CR)	Rc=4πA/P Where A= Area of basin, π=3.14, P= Perimeter of basin	[23]
	Elongation ratio (ER)	R_e=√(Au/π)/ Lb Where, A=Area of the basin, π=3.14, Lb=Basin length	[24]
RELIEF	Basin relief (BR)	The vertical distance between the lowest and highest points of the basin.	[24]
	Relief Ratio (RR)	RR = BR / Lb Where, Bh=Basin relief, Lb=Basin length	[24]

Table 4. Result of Morphometric Analysis

Linear Parameters

Sub water shed Name	Stream order (SO)	No. of Streams	Stream length (km)	Mean stream length (MLS)	Stream length ratio (LRS)	Bifurcation ratio (BR)
Rallavagu	I	461	312.44	0.68	2.29	4.12
	II	112	174.12	1.55	2.56	4.48
	III	25	99.52	3.98	2.02	4.17
	IV	6	48.21	8.04	1.02	3.00
	V	2	16.39	8.20	1.89	2.00
	VI	1	15.46	15.46		
Peddavagu	I	709	445.56	0.63	1.87	3.65
	II	194	227.88	1.17	2.12	4.85
	III	40	99.54	2.49	1.69	3.33
	IV	12	50.56	4.21	0.61	4.00
	V	3	7.69	2.56	11.41	3.00
	VI	1	29.26	29.26		
Yerravagu	I	757	446.09	0.59	2.14	4.25
	II	178	224.08	1.26	2.11	5.24
	III	34	90.44	2.66	2.10	4.86
	IV	7	39.17	5.60	3.27	2.33
	V	3	54.87	18.29	0.96	3.00
	VI	1	17.55	17.55		

Areal Parameters

	Rallavagu	**Peddavagu**	**Yerravagu**
Basin area (sq. km)	467.00	470.78	492.79
Perimeter (km)	92.35	102.04	118.50
Basin length (km)	28.93	33.99	41.82
Drainage density (DD)	1.43	1.83	1.77
Stream frequency (SF)	1.30	2.04	1.99
Drainage Texture (TD)	6.57	9.40	8.27
Form factor (FF)	0.56	0.41	0.28
Circularity Ratio (CR)	0.69	0.57	0.44
Elongation ratio (ER)	0.39	0.45	0.53
Length of overflow (Lg)	0.35	0.27	0.28

Relief Parameters

	Total relief (m)	**Relief ratio (Rh)**
Rallavagu	519	0.018
Peddavagu	155	0.005
Yerravagu	421	0.010

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