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Geospatial Assessment of Morphometric and Hypsometric Characteristics of the Karanja River Basin

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Abstract

Morphometric analysis of river basins provides vital quantitative information for understanding watershed characteristics, hydrological behaviour, and geomorphic evolution, which are essential for sustainable water and land resource management. The present study evaluates the morphometric and hypsometric characteristics of the Karanja River Basin, a right-bank tributary of the Godavari River in peninsular India, using remote sensing and GIS techniques. ALOS PALSAR DEM data with 12.5 m spatial resolution were employed to delineate the basin and extract linear, areal, and relief morphometric parameters following standard methods proposed by Horton, Strahler, and Schumm. The basin covers an area of 2953.03 km² and exhibits a well-developed seventh-order drainage network. The mean bifurcation ratio (4.31) indicates minimal structural disturbance, while drainage density (2.05 km/km²) and stream frequency (2.57 km^{-2}) suggest moderate runoff and infiltration capacity. Areal parameters, including circulatory ratio (0.22), elongation ratio (0.49), and form factor (0.19), reveal elongated basin geometry, favourable for reduced peak discharge and enhanced flood regulation. Hypsometric analysis yielded a hypsometric integral value of 0.50, indicating that the basin is in a mature or equilibrium geomorphic stage with moderate erosion and active denudational processes. Overall, the results highlight a moderately dissected and evolving landscape, providing valuable insights for watershed prioritization, erosion control, and sustainable river basin management.

Keywords: Morphometric analysis, Hypsometric curve, Remote Sensing & GIS, Karanja River Basin

1 Introduction

Natural resources, such as water and land, play a crucial role in supporting human development and maintaining ecological balance. However, rapid population growth, unplanned urbanization, and excessive exploitation are increasingly threatening the availability and sustainability of these resources[19]. River basins are fundamental to a region's hydrological and geomorphological systems, shaping water distribution, sediment dynamics, and landscape development[8]. Watershed based approaches has emerged as key strategy for sustainable planning and conservation. Analysing the morphometry of river basins is crucial element of basin management and is essential for ensuring long-term sustainability[7, 13, 18].

The drainage basin represents one of Earth's most prominent land surface features, and its evaluation forms a key branch of morphometric studies. Morphometric analysis offers a quantitative interpretation of the drainage network, playing a vital role in understanding basin characteristics[22]. Such analysis provides measurable insights into the drainage system, contributing significantly to the comprehension of a watershed's hydrologic and geomorphic attributes[5, 22]. Foundational research on drainage basin morphometry was carried out by Horton (1945)[5], Smith (1950)[21], Miller (1953)[11], Strahler (1964)[22], among others.

In last few years, remote sensing and geographic information system (GIS) techniques were used in basin morphometric study. The progression of remote sensing and GIS technology has facilitated morphometry to emerge as a technical field that possesses a powerful analytical toolbox[17]. The remote sensing technique is a convenient method for morphometric analysis as the satellite images provide a synoptic view of a large area and is very useful in the analysis of drainage basin morphometry[7].

The hypsometric curve depicts a basin's overall slope and geomorphic characteristics by showing the proportion of its area above a given elevation[23]. It helps assess erosional stages, slope, and landform development, providing valuable insights for watershed management and rainwater harvesting planning[14]. Based on curve shape, Strahler (1952)[23] categorized basins as youthful (convex), mature (S-shaped), or old/peneplain (concave). The hypsometric integral (HI) further indicates erosion status and aids in watershed prioritization. According to Strahler (1954), HI values classify basins as old or stable (HI < 0.3), mature with moderate erosion (0.3–0.6), or young and highly erosive (HI > 0.6)[16].

The objectives of this current research are to derive morphometric parameters such as linear, relief, and areal or shape parameters of the Karanja River basin, and also, the study aims to find the hypsometric analysis of the Karanja River basin, India.

2 Study Area

The location of Karanja basin is depicted in [Fig. 1]. Geographically it lies between 17° 30' and 18° 10' N latitude and 76° 45' and 77° 50' E longitude. The Karanja river is a right tributary of the Godavari River and flows in NW-SE direction. It has a total area of 2953.03 Sq. km^{2}s. The river originates in the Sangareddy district of Telangana at an elevation of 648 meters above mean sea level and flows for 124 kilometers before joining the Manjeera River near Nardasangam village in the Bidar district of Karnataka, at an elevation of 548 meters[9]. The Karanja river basin's height ranges from 474 meters above sea level to 621 meters above sea level, according to ALOS PALSAR DEM. The basin has a semi-arid climate characterized by warm summers, with mean monthly temperatures reaching up to 42 °C. The region receives an average annual rainfall of about 1075.23 mm, with the maximum precipitation typically occurring in July or early August. The mean rainfall in the study area is 827 mm[9].

Physiographically, the area can be divided into two regions. They are northern lowlands and southern highlands. The southern highlands are popularly known as the Bidar plateau, which is made up of laterite[3, 9]. Geologically, the study area is associated with the Deccan Plateau which consists of basalt and laterite[2].

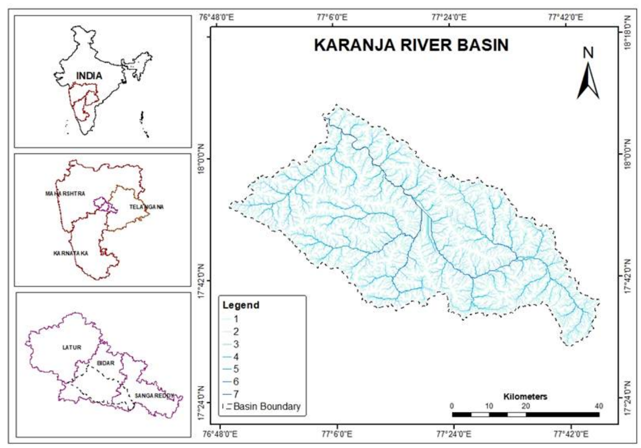

Fig. 1: Location of Karanja River Basin in India

3 Methodology

In the present research, quantitative morphometric features have been calculated for the catchment by using RS and GIS approaches. ALOS PALSAR DEM data with a resolution of 12.5 meters has been utilised to delineate the Karanja river basin [Table. 1]. The dataset was sourced from the Alaska Satellite Facility (ASF) DAAC, which provides open and free access. [Fig. 2] shows the processing of DEM, after acquiring the data, it is projected to WGS 1984 UTM zone 43 North datum using ArcGIS 10.8.2 software. Later several GIS-based processing and spatial analyses were conducted using the spatial analyst tools available in the software. Three types of morphometric parameters such as linear, areal, and relief have been calculated and analysed using standard numerical formulas. [Table. 2], [Table. 5] and [Table. 7] include many empirical approaches for evaluating these three aspects.

Table 1: Information of data used for this current study

Satellite	Sensor	Spatial Resolution
ALOS (Advanced Land Observing Satellite)	PALSAR (Phased Array L-Band Synthetic Aperture Radar)	12. 5 meters

The hypsometric analysis for the Karanja river basin area is examined by utilising RS and GIS approaches as shown in [Fig. 2]. The topography of the Karanja River Basin is categorized into distinct elevation zones, and a Classified Elevation Map [Fig. 7] has been prepared. The catchment's hypsometric curve was plotted using attribute feature classes that contained these values. In this investigation, the HI was determined using the elevation-relief ratio approach, as shown in [Table. 9]. The hypsometric curve and HI, amongst other thing were determined for the watershed.

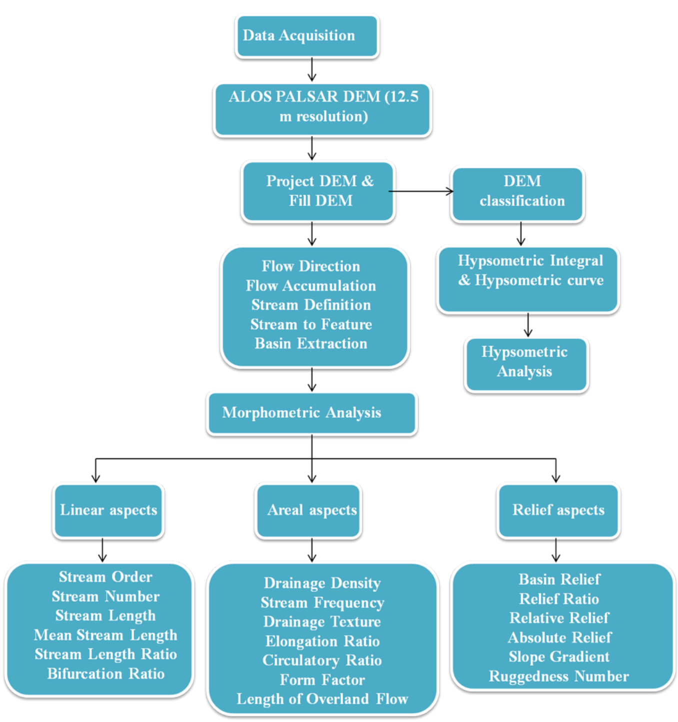

Fig. 2: Methodology flowchart

4 Results

The morphometric parameters of the Karanja River Basin including linear, areal and relief aspects have been determined. Additionally, Hypsometric analysis conducted in the present research is as discussed below.

4.1 Morphometric investigation of Karanja river basin

The morphometric characteristics of the Karanja River Basin provide a quantitative assessment of its geometrical properties, contributing to a better understanding of its geomorphological features, geological structure, and the basin's behaviour during different hydrological cycles.

4.1.1 Linear Aspects:

Stream Order: In the present study the Strahler's[24] stream ordering method has been adapted, which is a simplified version of Horton's[5] classification. According to this method, the smallest unbranched streams are classified as first order. When two streams of the same order converge, they form a stream of the next order. Using this approach, the Karanja River Basin exhibits a maximum stream order of seventh (7th). The stream order distribution within the Karanja catchment is illustrated in [Fig. 3].

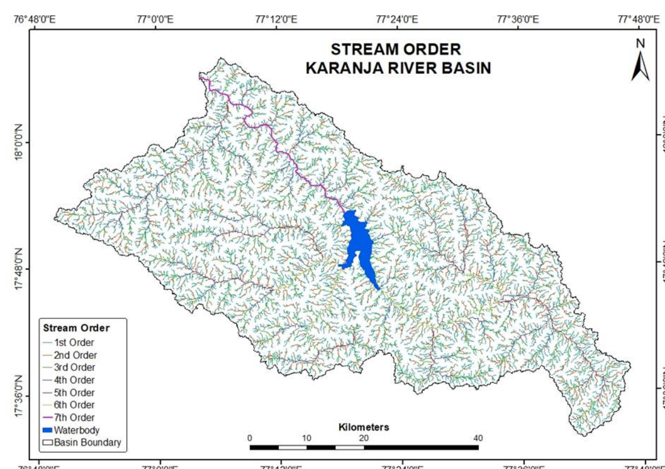

Fig. 3: Order of the stream

Stream number: The stream number refers to the total count of stream segments within each stream order. According to Horton[5]. the number of stream segments typically follows an inverse geometric progression relative to the stream order. The highest order stream segment is known as the trunk stream. In the case of the Karanja River, the drainage network was found to reach up to the 7th order. A total of 7532 stream segments were identified within the basin, comprising 5825 first-order streams, 1361 second-order, 270 third-order, 60 fourth-order, 12 fifth-order, 3 sixth-order and a single seventh order stream.

Table 2: Methods or formulae for linear aspects

Linear aspects	Formulae or methods	Units
Stream Order (U)	Hierarchical rank	Dimensionless
Stream Number (N_u)	$Nu = N_{u1} + N_{u2} + \dots + N_{un}$	Dimensionless
Stream length (L_u)	$L_u = L_{u1} + L_{u2} + L_{u3} + \dots + L_{un}$	Kilometers (km)
Bifurcation Ratio (R_b)	$R_b = (Nu/Nu + 1)$	Dimensionless
Stream length ratio (R_l)	$R_l = (Lu/Lu - 1)$	Dimensionless
Mean bifurcation ratio (R_{bm})	Average of bifurcation ratio of all orders	Dimensionless
Mean Stream Length Ratio (R_{lm})	Average of the stream length ratio of all orders	Dimensionless
Drainage Texture (D_t)	$D_t = ((\Sigma N_u)/P)$	Km^{-1}
Drainage Density (D_d)	$D_d = ((\Sigma L_u)/A)$	Km/km^2
Stream Frequency (F_s)	$F_s = ((\Sigma N_u)/A)$	Km^{-2}
Length of Overland Flow (L_o)	$L_o = (1/(2D_d))$	Kilometers (km)

Stream length: Stream length was calculated based on Horton's[5] law. Among hydrological parameters, stream length is one of the most significant, as it reflects both surface runoff behaviour and the geomorphological structure of the basin. Typically, shorter stream segments are found in areas with steep gradients and finer textures, while longer segments are associated with gentler slopes. The distance between stream segments is generally greatest in first order stream and decreases progressively with higher stream orders. Using GIS tools, the number and lengths of streams for each order within the catchment were recorded by measuring the distance from the outlet to the drainage divide. The first order streams extends for 3372.57 km, second order stream for 1446.72 km, third order stream for 635.19 km, fourth order stream for 321.56 km, fifth order stream for 146.75 km, sixth order stream for 88.46 km, seventh order stream for 56.76 km. The detailed calculations of the linear parameters are presented in [Table. 4].

Table 3: Karanja catchment linear aspect

Stream order (U)	Stream Number (N_u)	Stream Length (L_u)	Mean Stream Length	Stream Length ratio (Rl)	Bifurcation ration (Rb)
1st Order	5863	3372.57	0.57	-	-
2nd Order	1368	1446.72	1.06	0.429	4.286
3rd Order	273	635.19	2.33	0.439	5.011
4th Order	60	321.56	5.36	0.506	4.550
5th Order	12	146.75	12.23	0.456	5.000
6th Order	3	88.46	29.49	0.603	4.000
7th Order	1	56.76	56.76	1.558	3.000
Total	**7580**	**6068.01**	**107.79**	**3.992**	**25.847**

Table 4: Linear aspects results of Karanja River Basin

Sl. No	Linear Aspects	Results
1.	Stream Order	7th
2.	Stream Number	7580
3.	Stream length	6068.01
4.	Bifurcation Ratio	25.85
5.	Stream length ratio	3.99
6.	Mean bifurcation ratio	4.31
7.	Mean Stream Length Ratio	0.67
8.	Length of Overland Flow	0.24
9.	Drainage Texture	18.35
10.	Drainage Density	2.05
11.	Stream Frequency	2.57

Mean stream length: The mean stream length is a key characteristic of a catchment network and its associated surfaces. It is calculated by dividing the total stream length of a given order by the number of streams within that order[5].

Stream length ratio: According to Horton (1945)[5], the length ratio (R_l) represents the ratio of the average stream length of a given order to that of the next lower order. This parameter plays an important role in influencing surface flow and runoff.

Bifurcation ratio: The bifurcation ratio (R_β) is defined as the ratio of the number of streams of a given order to those of the next higher order, according to Schumm, S. A., 1956[15].

Mean bifurcation ratio: According to Strahler AN 1964[22], the weighted mean bifurcation ratio ($R_{\beta m}$) is obtained by combining the bifurcation ratios (R_β) for each successive pair of stream orders, weighted by the total number of streams involved in each ratio. The average of these weighted values provides a more representative measure of the bifurcation ratio for the basin. In this study, the $R_{\beta m}$ value for the basin is 4.31.

Stream frequency: The stream frequency (F_s) represents the total number of stream segments of all orders per unit area. For the basin, the F_s value is 2.57, as shown in [Table. 4].

Drainage density: Drainage density (D_d), according to Schumm, S. A., 1956[15] is the ratio of the total length of all stream segments to the catchment area. It provides a quantitative measure of how closely the channels are spaced, representing the mean distance between streams within the catchment. A low drainage density generally occurs in regions with highly porous subsurface materials, dense vegetation cover, and gentle relief. In contrast, areas characterized by impermeable underlying materials, sparse vegetation, and rugged topography tend to exhibit high drainage density. Consequently, low drainage density results in a coarse drainage texture, whereas high drainage density produces a finer texture. For the basin, the D_d value is 2.05.

Drainage texture: According to R.E. Horton, 1945[5], drainage texture (D_t) is defined as the total number of stream segments of all orders divided by the perimeter of the basin. For this basin, the D_t value is 18.35.

Length of overland flow: According to Horton[5], the overland flow length (L_o) is the distance water travels over the ground surface before reaching a stream channel. It can be calculated as half of the reciprocal of the drainage density. For the basin, the L_o value is 0.24.

4.1.2 Relief aspects:

The relief characteristics of the basin, which describe its morphological features, are explained below.

Table 5: Methods or formulae for relief aspects

Relief Aspects	Formulae or Methods	Units
Minimum Elevation (h)	GIS software	Meter
Maximum Elevation (H)	GIS software	Meter
Relative Relief (R_{hp})	R_{hp} = (H×100/P)	Dimensionless
Relief (B_h)	B_h = (H-h)	Kilometer (km)
Ruggedness Number (R_n)	$R_n = B_h \times D_d$	Dimensionless
Relief Ratio (R_h)	$R_h = (B_h/L_b)$	Dimensionless

Relief: Relief refers to the difference in elevation between the highest and lowest points of a catchment. It is denoted by B_h, and the basin's B_h value is 147.

Relief ratio: According to Schumm[15], the relief ratio (R_h) is defined as the ratio of the maximum basin relief to the shortest horizontal distance along the basin's main flow direction. For the basin, the R_h value is 0.00119.

Relative relief: Relative relief is calculated using the basin's perimeter and area[10]. It is denoted by R_{hp}, and the value for the catchment is 0.15.

Ruggedness number: According to Strahler[25], the ruggedness number (R_n) is calculated as the product of the catchment relief and drainage density using the same units. A higher R_n indicates a more rugged topography, while a lower value suggests gentler terrain. For the basin, the R_n value is 0.30, as shown in [Table. 6].

Table 6: Relief aspects of Karanja River Basin

Sl. No	Relief Aspects	Results
1.	Maximum Elevation	621
2.	Minimum Elevation	474
3.	Relief	147
4.	Relief Ratio	0.00119
5.	Relative Relief	0.15
6.	Ruggedness Number	0.30

4.1.3 Areal aspects:

It refers to the total catchment area, projected onto a horizontal plane, that contributes surface flow to a channel of a given order, including all tributaries of the lowest order. Circulatory ratios, elongation ratio, and so on are all part of it.

Table 7: Methods or formulae for areal aspects

Sl. No	Relief Aspects	Formulae or Methods
1.	Area of the watershed (A)	GIS software
2.	Perimeter of the watershed (P)	GIS software
3.	Basin Length (L_b)	$L_b=1.312*A^{0.568}$
4.	Circulatory Ratio (R_c)	$R_c = (4\pi A/P^2)$
5.	Elongation Ratio (R_e)	$R_e=((2*(A/\pi)^{0.5})/(L_b)$; where $\pi=3.14$
6.	Form Factor (F_f)	$F_f=(A/L_b^2)$

Circulatory ratio: The relation of a catchment's to the region of a circle with a similar diameter as the catchment's perimeter, according to Miller[11] it is represented by the symbol R_c. The basin's R_c value is 0.22.

Elongation ratio: According to Schumm[15], it is the ratio of the diameter of a circle covering the same region as the river basin to the minimum length of the watershed. R_e is the symbol for it. The basin's R_e value is 0.49.

Table 8: Aerial aspects results of Karanja River Basin

Sl. No	Relief Aspects	Results
1.	Watershed Area	2953.03
2.	Watershed Perimeter	412.99
3.	Basin Length	122.75
4.	Circulatory Ratio	0.22
5.	Elongation Ratio	0.49
6.	Form Factor	0.19

Form factor: According to Horton, R. E. (1932) [4]**,** it is the ratio of catchment region to the square of catchment length. The catchment will be more extended as the form factor value decreases. F_f is the symbol for it. The basin's F_f value is 0.19, as shown in [Table. 8].

4.2 Slope

Slope is a key parameter in the morphometric analysis of any drainage basin, representing the topographic inclination relative to a level plain. In the Karanja river basin, slope values range from 0 to 39.35°. The slope gradient of the catchment was generated using the Spatial Analyst tool in ArcGIS 10.8.2. With ALOS PALSAR data. Variations in slope influence flow direction, velocity, erosion and deposition processes, as well as the formation of depositional features within the catchment. The distribution of slope values is illustrated in [Fig. 5].

4.3 Aspect

Aspect refers to the horizontal direction toward which a slope faces. Aspect maps are important for assessing the influence of sunlight on local climate, as temperature variations depend not only on elevation but also on slope orientation. Differences in aspect can lead to temperature variations within a catchment. For instance, variations between western and eastern slopes affect the amount of solar radiation received throughout the day, from sunrise to sunset, resulting in corresponding temperature differences. The aspect of the Karanja catchment was generated using the Spatial Analyst tool in ArcGIS 10.8.2. The resulting raster map displays slope directions ranging from 0° to 360°, with 0° representing north and, 90 east, and so on. [Fig. 6] illustrates the aspect map.

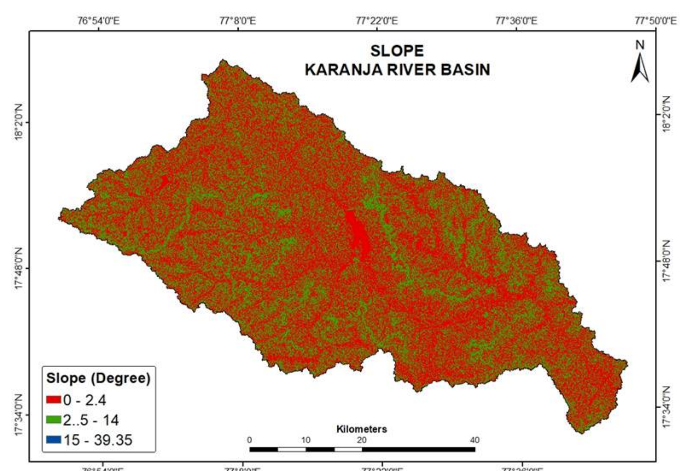

Fig. 5: Slope of Karanja River Basin

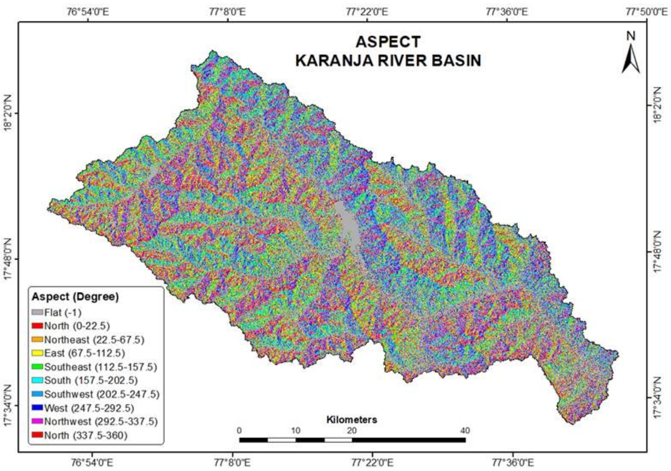

Fig. 6: Aspect of Karanja River Basin

4.4 Hypsometric analysis

The shape of the river system and its catchment significantly influences hypsometry. In particular, the catchment's width-to-length ratio, or aspect ratio, affects the hypsometric curve[27]. Hypsometric curves are typically plotted using relative elevation (h/H) and relative area (a/A)[26]. Hypsometric curve morphology reflects the geomorphic stage of a basin. A convex upward hypsometric curve indicates a young basin, an S-shaped curve corresponds to a mature basin, and a concave curve reflects an old or highly eroded basin. In the case of the Karanja River basin, the hypsometric curves exhibit a combination of convex, concave, and S-shaped forms, which could be attributed to soil erosion from washout and stream incision.

Table 9: Hypsometric curve calculations

Sl. No.	Minimum (Min)	Maximum (Max)	Mean	(Mean-Min)	(Max-Min)	Area	a	h	Relative Area (a/A)	Relative Height (h/H)	Hypsometric Integral (H.I.)	Geological Stage
1.	474	498	486	12	24	102	2953	24	1.00	0.16	0.5	Mature Stage
2.	498	511	504.5	6.5	13	236.5	2851	37	0.97	0.25		
3.	511	522	516.5	5.5	11	295.5	2716.4	48	0.92	0.33		
4.	522	534	528	6	12	444.8	2657.5	60	0.90	0.41		
5.	534	545	539.5	5.5	11	436.4	2508.3	71	0.85	0.48		
6.	545	555	550	5	10	432.2	2516.6	81	0.85	0.55		
7.	555	566	560.5	5.5	11	408.8	2520.8	92	0.85	0.63		
8.	566	577	571.5	5.5	11	306.5	2544.2	103	0.86	0.70		
9.	577	589	583	6	12	212.6	2646.5	115	0.90	0.78		
10.	589	621	605	16	32	77.6	2740.4	147	0.93	1.00		

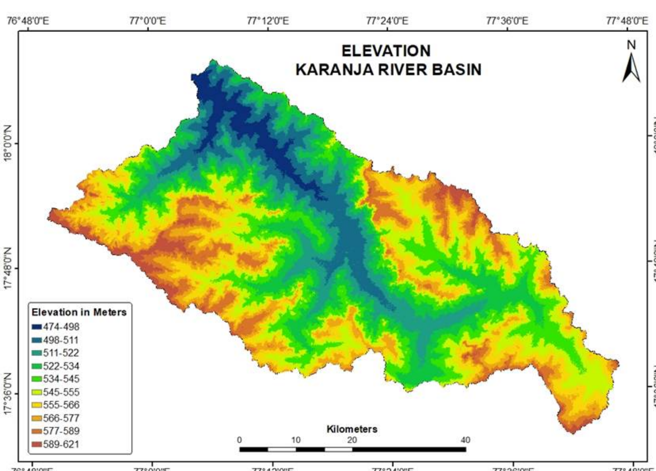

Fig. 7: Elevation of Karanja River Basin

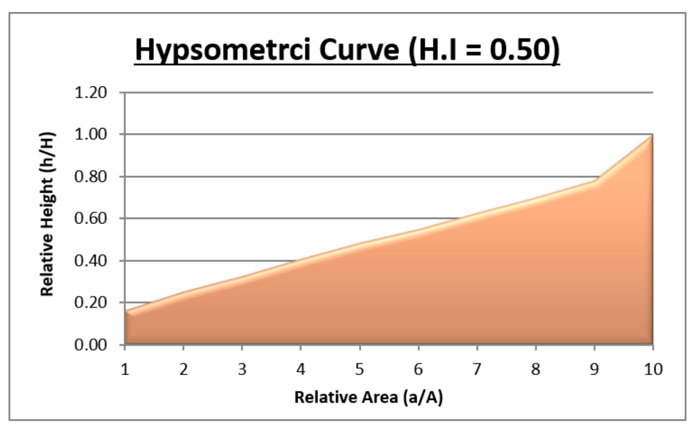

Fig. 8: Hypsometric Curve of Karanja River Basin

[Table. 9] represents the key parameters required to plot the hypsometric curve and calculate the Hypsometric Integral (H.I). The method developed by Pike, R. J., & Wilson, S. E. (1971)[12]. Involves computing the ratio of elevation to relief, was applied to determine the HI values for the study area. Using this approach the hypsometric integral for the Karanja river basin was found to be 0.50, indicating that the soil is in a mature or equilibrium state. An elevation map of the Karanja river basin is shown in [Fig. 7].

5 Discussion

A lower drainage density produces a coarser catchment texture, whereas a higher catchment density produces a finer catchment texture. The texture is quite coarse if the drainage density is less than 1.24. The texture is coarse if it is 1.24 - 2.49 and moderate if it is 2.49 - 3.73. The texture is fine if the value is 3.73 - 4.97 and very fine if the value is less than 4.97. The Karanja River drainage density is 2.05 km/km2, indicating coarse texture and high infiltration. The Karanja River Basin's stream frequency is 2.57/km^2 indicating moderate to high frequency. Furthermore, if the elongated ratio is 0.9, then it is round and oval if the *R e* is 0.8–0.9. If the *R e* is 0.7–0.8, it is less elongated; if the *R e* is 0.5–0.7, it is more elongated; if the *R e* is less than 0.5, it is more elongated. The Karanja River's elongation ratio is 0.49, indicating that it has a nearly more elongated structure. The form factor ranges from zero to one, with zero indicating a highly elongated structure and one indicating a circular structure. The Karanja river catchment has an F_f of 0.19, indicating that it has an elongated structure. The bifurcation ratio is a dimensional feature that is greater than 5 for catchments where the drainage pattern is distorted by geologic structures. In this study, the lower value is 4.31, indicating that the Karanja River catchment is not affected by structural disturbances. The catchment texture indicates the coarse texture of the Karanja catchment.

The hypsometric curve (HC), which explains the allocation of heights across a large region of land, has been used to assess the evolutionary status of landforms. The hypsometric integral value was determined to be 0.50, suggesting that the soil was mature or in equilibrium.

6 Conclusion

The morphometric and hypsometric characteristics of the Karanja River Basin derived from RS and GIS analysis provide valuable insights into its hydrological behaviour and geomorphic evolution and are broadly consistent with findings from similar semi-arid basins in peninsular India. The morphometric and hypsometric analyses of the Karanja River Basin reveal a well developed seventh order drainage network. The mean bifurcation ratio (4.31), drainage density (2.05 km/km^2), and stream frequency (2.57 km^{-2}) indicate moderate runoff and infiltration capacity. Areal parameters such as the circulatory ratio (0.22), elongation ratio (0.49), and form factor (0.19) show that the basin is elongated, which helps reduce peak discharge and enhance flood regulation.

The hypsometric integral (0.50) indicates that the Karanja Basin is in a mature stage. This reflects moderate erosion and active geomorphic processes, where both denudation and deposition are ongoing while the terrain retains notable relief and structural influence. Overall, the basin represents a moderately dissected, evolving landscape, providing important insights for erosion control, watershed management and sustainable resource planning.

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