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Geospatial Assessment of Morphometric Characteristics of The Upper Godavari Sub-Basin, Nashik, Maharashtra, India

Gavhane Shubham K.[1*], Pagar Sanjay D.[2]
[1]Department of Geography, MVP Samaj's K. R. T. Arts, B. H. Commerce and A. M. Science (KTHM) College, Nashik, affiliated to Savitribai Phule Pune University, Pune*
[2]Department of Geography, MVP Samaj's Shri Swami Shatkopacharyaji Maharaj Arts, Science and Commerce College, Saikheda, Tal Niphad, Dist Nashik, affiliated to Savitribai Phule Pune University, Pune
[*]Corresponding author: skgavhane.gf@gmail.com

Abstract

Morphometric assessment of watershed provides a numerical framework for understanding geometry, drainage development, relief features of river basin for sustainable watershed management. The current study's objective is to use geospatial tools to evaluate the physical features and characteristics of the Upper Godavari Sub Basin drainage basin in Nashik, Maharashtra. Basin delineation, drainage basin extraction, and stream ordering were done using a DEM based method, and then linear, areal, and relief morphometric characteristics were examined. The findings showed that a 6th order drainage basin had 719 streams totaling 998.17 kilometers in length. The 1st order streams were dominant with 563 streams, while the stream numbers gradually decreased as the stream order increased. The drainage basin has 50.70 km length, 173.95 km in perimeter, and 852.62 km^2 in area. The Drainage density (1.17 km/km^2), stream frequency (0.84 streams/km^2) and drainage texture (0.99) shows moderate drainage basin development. The basin shape is primarily elongated, according to the circularity ratio (0.35), elongation ratio (0.65), and form factor (0.33). The basin has considerable relief of 707 m and a ruggedness number of 0.828, states the variation in topography and geomorphic influence on drainage basin development. The results validate the effectiveness of morphometric studies based on GIS, RS, and DEM for describing drainage and morphological conditions in the Upper Godavari Sub Basin. The study offers a helpful quantitative measure for the study region's sustainable watershed management and planning, soil erosion potential risk assessment, conservation of soil and water resources, and watershed prioritization.

Keywords: morphometric analysis; drainage density; watershed management; dem; basin relief.

1. Introduction

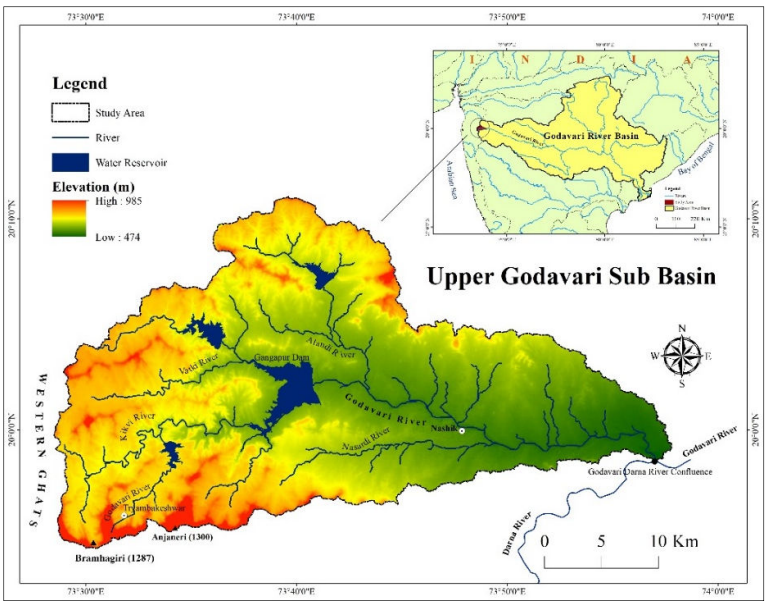
Novel technologies and quantitative techniques changed the nature of geographical studies from descriptive to quantitative. Geomorphology is a subdiscipline of geography that deals with the scientific study of the landforms that shape the Earth's surface, from their origin to current processes and even possible future conditions. In geomorphology, 'Morphometry' is the measurement and mathematical study of the Earth's surface structure, which includes the evaluation of the shape and extent of its landscape (Horton, 1945). River morphometric study is numerical measurement as well as mathematical evaluation of physical structure of a river basin, drainage network, and landscape relief (Mishra et al., 2018; Strahler, 1957). Morphometric analysis is the numerical assessment of the form, dimension, and spatial features of physical and drainage parameters using mathematical, statistical, and geospatial techniques (Krishnan & Arjun .S, 2024). These methods of study allow to study the type and interrelationships of geomorphological features of the drainage basin (Kuhade et al., 2026). In order to get insights from geological data that are normally not achievable with conventional visual observations, morphometric analysis makes use of mathematics, statistics, and GIS technology. By measuring basin characteristics such as linear dimensions, surface area, topography, stream slope, and land slope researchers can quantify the physical properties of a landscape. Horton (1945) established the idea of quantitative drainage basin analysis; the relationships between morphometric parameters of the basin. Horton showed that drainage networks could be described numerically through measurable relationships between stream channel size and basin geometry. Subsequently, Strahler (1957) developed and refined quantitative methods for watershed analysis and established a hierarchical arrangement of streams, which is now widely used in the study of drainage basins. The geomorphic and hydrological features of drainage basins or river catchment areas can be inferred from all morphometric measurements. Ultimately, watershed's unique structure is a direct result of the combined geological and geomorphological changes that occurred throughout the watershed's processes (Rai et al., 2017). Linear, areal and relief aspects are the main classification of river morphometric parameters. The linear parameters are stream order (u), stream number (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), and bifurcation ratio (Rb); the areal parameters are drainage density (Dd), stream frequency (Sf), drainage texture (T), form factor (Ff), elongation ratio (Re), and circularity ratio (Rc); the relief parameters for the morphometric analysis of the drainage basin are basin relief (R), relief ratio (Rr), and ruggedness number (Rn) (Schumm, 1956; Chorley et al., 1984; Nag, 1998; Das & Pardeshi, 2018; Kuhade et al., 2026; Javed et al., 2016). The morphometric analysis has improved significantly over the recent decades due to the use of GIS;RS and DEM techniques (Piccarreta et al., 2026). Previous research used primarily topographic maps and manual measurements, while Geographic Information System (GIS) can extract and measure drainage basin features quickly, visualize them, and analyze them for the drainage basin analysis. Using GIS software, elevation

information in Digital Elevation Models (DEMs) can be used to calculate flow direction, flow accumulation, drainage networks, watershed boundaries, slope, and relief. For quantitative drainage basin analysis and watershed characterization, GIS and remote sensing are therefore helpful tools (Mesa, 2006). The hydrological response and behaviour of a watershed can be studied after using GIS software based watershade morphometric analysis (Adewoyin et al., 2026). Rai et al. demonstrated the use of GIS derived morphometric linear, areal, and relief parameters to assess drainage characteristics of the Kanhar River catchment in 2017. Such analyses provide valuable information for understanding changes in runoff, inflow, and drainage basin development. The importance of morphometric analysis is most evident where the variation in topography, lithology, and geological structure. Disparities in slope, rock resistance, permeability, and structural controls result in local variations in drainage density, stream frequency, and basin geometry. In India, geospatial technologies are increasingly being used to assess watershed, groundwater studies, and conservation planning (Nag, 1998). (Sreedevi et al., 2005) demonstrated that the geomorphological analysis of river basins can identify groundwater zones in structurally controlled terrains. They verified that geomorphological analysis of river basins, which includes drainage density, stream frequency, and the bifurcation ratio, effectively identifies groundwater potential areas in physically controlled topography. This study showed that the geometry and geological structure of the basin have a direct impact on groundwater movement and storage. (Rai et al., 2017) used geospatial techniques to evaluate morphological features of the Narmada basin, and also demonstrated the utility of quantitative drainage analysis at basin scale. (Soni, 2017) used geospatial techniques to assess the morphological features of the Chakar watershed, Madhya Pradesh and stressed the significance of morphological parameters for prioritization of watersheds. In Maharashtra, the interaction of the Western Ghats, the Deccan basaltic region, seasonal monsoon rainfall, and dissected plateau terrain produces significant local disparities in drainage and landform characteristics. Pande & Moharir in 2015 conducted a numerical morphometric study of the Shanur River basin using GIS and remote sensing; drainage networks were drawn to assess the geomorphological parameters of the catchment area. These studies demonstrate the importance of GIS based morphological analysis in understanding the hydrogeographic conditions of drainage basins supporting sustainable watershed and water resources management. This study's goal is to quantify the Upper Godavari Sub Basin's geomorphological characteristics and drainage structure. The study area is delineated, the drainage network is extracted, and its linear, areal, and relief features are quantified using GIS and DEM-based approaches. Stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, drainage density, stream frequency, drainage texture, form factor, elongation ratio, circularity ratio, basin relief, and relief ratio of the study area are among the morphometric parameters that have been measured and examined in this study.

2. Study area

The Upper Godavari Sub Basin, Nashik deceits in the Deccan Plateau region of Indian subcontinent is selected for this study. The Latitudinal Extent of study area is 19º 52’

54'' North to 20º 08'40'' North and longitudinal Extent is 73º 28'40'' East to 73 º 57'02'' East (Fig. 1). The study area has 853 sq.km. area and 174 km basin perimeter. The Upper Godavari Basin is characterized by a variety of terrain, elevation changes, steep slopes, diversity in drainage density and complex landforms. Situated at a crucial point in this system, the Nashik region has a distinctive structural mix of highlands, flat plateaus and deep valleys. The heavy monsoon rainfall generates heavy monsoon runoff, hence understanding the functioning of the drainage network in this region is of utmost importance for actual administration of the basin responses. The Upper Godavari region is important from the approach of agriculture, urban development, water, and watershed management. Agriculture expands; cities spread; land use changes affect surface runoff generation, infiltration and soil erosion.



[Fig. 1 Location map of the study area]

Previous research has already demonstrated the applicability of geomorphometric analysis in the Nashik part of the Godavari watershed. In the Nashik area of the Godavari River basin Kumar et al., 2020; Wilson et al., 2012, employed geospatial tools for morphometric analysis and subbasin ranking. It demonstrates the relevance of geospatial geomorphometric techniques for watershed assessment and also emphasized on morphometric study of catchment areas for watershed management. Although previous morphological studies exist, they are limited in that they focus only on isolated, individual catchments. Studies at the micro-catchment level help to better understand the soil erosion potential and hydrological response of basin (Jana, 2026). Therefore, a comprehensive, micro level assessment is needed to reveal how the drainage network of entire basin is connected to the topography, slope, and geometry. It is now feasible to conduct extremely thorough and repeatable analyses of this complicated terrain because to the use of cutting-edge GIS technology and

contemporary, high-resolution DEMs. Therefore, the integration of morphometric analysis, GIS, remote sensing and DEM based terrain analysis provides an effective framework for studying the spatial structure and developmental characteristics of the Upper Godavari Sub Basin drainage system. The research works therefore efforts on the geospatial evaluation of morphometric characteristics and drainage basin development of the Upper Godavari Sub-Basin, Nashik, Maharashtra.

3. Data

The study integrates geospatial techniques, topographic and supplementary datasets for the morphometric assessment of the study area. The study area illustrated on SOI topographic maps numbered: 47E/5, 47E/9, 47E/13, 46H/8, 46H/12 and 46H/16; downloaded from the Survey of India's Online maps portal of the scale 1:50,000. The digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM) was obtained from the USGS website (https://earthexplorer.usgs.gov/) has a spatial resolution of 30 meters. The basin selected for the study was demarcated by combining topographic maps and Digital Elevation Model (DEM) data. In the study area, DEM is the main dataset utilized for drainage network derivation and basin demarcation. The Upper Godavari sub-basin's morphological characteristics were extracted and measured using the drainage network and DEM. ESRI ArcGIS 10.7.1 software was used to processed and analyzed the entire spatial data. Satellite images and SOI topographic maps are used as subsidiary datasets for visual interpretation and validation for the morphometric analysis of Upper Godavari Sub Basin.

4. Methodology

The hydrological analysis tools of ARC GIS software were used to demarcate the study region. The streams were demarcated based on DEM analysis to obtain several morphological features of the watershed (Choudhari et al., 2018; Das & Pardeshi, 2018; Krishnan & Arjun .S, 2024; G. Kumar et al., 2025; Pande & Moharir, 2015). Stream order (u), stream number (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb), drainage density (Dd), surface flow length (Lo), flow frequency (Sf), and drainage texture (T) are examples of linear parameters; aerial parameters include circularity ratio (Rc), length ratio (Re), shape factor (Ff), shape factor (Fs), and stream channel maintenance constant (C); and relief parameters include basin relief (R), relief ratio (Rr), and roughness number (Rn) (Das & Pardeshi, 2018; Krishnan & Arjun .S, 2024; G. Kumar et al., 2020). The streams that were delineated on the basis of DEM analysis to derive numerous morphometric parameters of the drainage basin. The linear, aerial and relief morphometric parameters of the study area were measure on the formulas listed in the Table 1. The computation and visualization analysis were done by using ArcGIS software.

[Table 1 Formulas to calculate the drainage basin's morphometric parameters (Das & Pardeshi, 2018; Krishnan & Arjun .S, 2024; G. Kumar et al., 2020)]

Sr. No		Morphometric parameters	Formula & Definition	References
1	Linear	Stream order (u)	Hierarchical rank	(Strahler, 1964)
2		Stream number (Nu)	Number of streams in each order	(Horton, 1945)
3		Stream length (Lu)	Total Length of the stream segments of a particular order	(Horton, 1945)
4		Mean stream length (Lsm)	Lsm = Lu/Nu	(Strahler, 1964)
5		Stream length ratio (RL)	RL = Lsm/Lsm - 1	(Horton, 1945)
6		Bifurcation ratio (Rb)	Rb = Nu/Nu+ 1	(Schumm, 1956)
7		Drainage density (Dd)	Dd = Σ Lu / A	(Horton, 1932)
8		Length of overland flow (Lo)	Lo = 1/(2Dd)	(Horton, 1945)
9		Stream frequency (Sf)	Sf = Σ Nu / A	(Horton, 1945)
10		Drainage texture (T)	T = Dd × Sf	(Horton, 1945)
11	Areal	Circularity ratio (Rc)	Rc = 4πA/P²	(Miller, 1953; Strahler, 1964)
12		Elongation ratio (Re)	Re = D/L = 1.128 √A / L	(Schumm, 1956)
13		Form Factor (Ff)	Ff = A/L²	(Horton, 1932, 1945)
14		Shape Factor (Fs)	Fs = L² / A	(Horton, 1932)
15		Constant of channel maintenance (C)	C = 1/Dd	(Schumm, 1956)
16	Relief	Basin relief (R)	R = H - h	Hadley and Schumm (1961)
17		Relief ratio (Rr)	Rr = R/L	(Schumm, 1956)
18		Ruggedness number (Rn)	Rn = R × Dd	(Schumm, 1956)

5. Results and discussions

Geospatial analysis of study area generated a detailed drainage system used for the morphometric assessment. The stream-ordering technique (Strahler, 1957) was used to build the network, revealing a distinct hierarchical pattern. This stream flows

continuously from the lowest ordered streams the highest ordered streams main streams in the watershed. The drainage network mainly shows dendritic pattern; however, local variations are found in areas influenced by the lithology, geological structure, slope and topographic conditions of the region. While any small deviations show particular structural variations, the dendritic drainage system shows that the original topography has a uniform resistance to erosion. In study area, the drainage network and range of streams within it demonstrate that the landscape here has been shaped by the dynamic interaction of its basaltic geological foundation, regional uplift, slope, erosion and seasonal monsoon runoff.

5.1. Linear parameters estimation

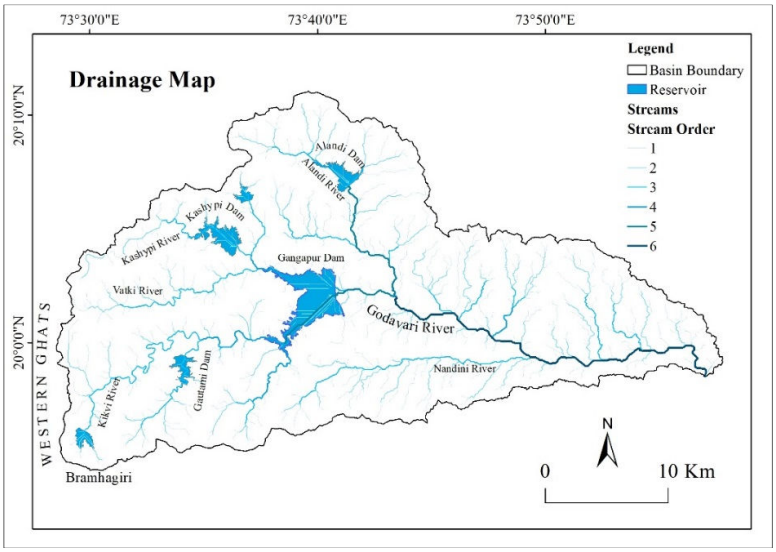
The research area's drainage network's extension and hierarchical setting are revealed by the linear morphometric characteristics. The measured results for stream order, number, length, mean length, stream length ratio, and bifurcation ratio are shown in Table 2.

[Table 2 The Upper Godavari Sub Basin's drainage network characteristics]

Stream order (u)	Stream number (Nu)	Stream length (Lu) (km)	Mean stream length (Lsm) (km)	Stream length ratio (RL)	Bifurcation ratio (Rb)
1	563	528.1858	0.9382	-	4.5403
2	124	247.3985	1.9951	0.4684	5.3913
3	23	134.4366	5.8451	0.5434	3.8333
4	6	33.0643	5.5107	0.2459	3.0000
5	2	23.5281	11.7641	0.7116	2.0000
6	1	31.5586	31.5586	1.3413	-

Stream order (u) and Stream number (Nu)

Stream order describes how streams are arranged in a drainage basin. In this study, Strahler, 1957 stream order method was implemented for categorizing the drainage network. The result shows 6^{th} stream order as the highest stream order of the basin. The stream order is inversely proportionate to numbers of stream. The 1^{st} order streams show highest drainage density among all stream orders. Stream number is the total stream count of the specific stream order. First, second, third, fourth, fifth, and sixth order stream numbers were 563, 124, 23, 6, 2, and 1 respectively; shown in (Fig. 2).



[Fig. 2 Drainage Map of the Upper Godavari Sub Basin Here…..]

Stream length (Lu)

A stream's length is the total of all of its segments. The overall length of all stream segments connected to a particular stream is represented by this total sum; establishes the stream length (Kanhaiya et al., 2019). Over 91% of the basin's 998.17 km total stream length is made up of lower order streams. 528.19 km (52.9%) are covered by first order streams, 247.40 km (24.8%) by second order streams, and 134.44 km (13.5%) by third order streams. The remaining contribution of higher order streams is negligible, with fourth-, fifth-, and sixth-order streams covering 33.06 km, 23.53 km, and 31.56 km, respectively. Due to the abundance of small headwaters, first-order streams have the largest overall extent, and as the number of stream segments increases from first to fourth order, the overall stream length typically declines. However, this systematic pattern breaks down in the higher orders, where 6^{th} order streams are longer than 5^{th} order streams (31.56 km versus 23.53 km). This structural discrepancy is produced because of the local variations in the spatial arrangement of the main streams, the geometry and topography of the basin, and the lithology and geological structures (Subba Rao, 2009).

Mean Stream Length (Lsm)

The mean stream length of a given stream order is defined as the average length of each individual stream inside that stream order (Ansari et al., 2012). The average stream length of a given stream order is calculated by dividing its total length by the number of streams in that order (Kumar et al., 2015). The mean stream length, which ranges from 0.94 km (1st Order) to 31.56 km (6th Order), is directly correlated with the stream order. This confirms the graded drainage development according to the principles of (Horton, 1945; Strahler, 1957). The main stream is of the 6^{th} order. A minor structural deviation occurs between the 3^{rd} and 4^{th} order (length decreases from 5.85 km to 5.51 km), caused by local differences in the slope of the catchment area, lithology, topography, and stream geometry (Kumar et al., 2015).

Stream length ratio (RL)

The average stream length of a specific stream order divided by the average stream length of the previous lower stream order is known as the stream length ratio (RL). A consistent trend in this ratio, considered by (Horton, 1945) as a key parameter for assessing the morphometric development of a drainage basin, is indicative of a homogeneous basin, while highly variable values indicate the influence of topography, slope, lithology, and geological structure. The stream length ratio fluctuates significantly (0.2459 to 1.3413), which proves that the progress of the drainage network has not been uniform. The lowest ratio is found between the third and fourth orders due to a slight decrease in the average stream length, while the highest stream length ratio is between the fifth and sixth order stream, highlighting a dominant main stream.

Bifurcation ratio (Rb)

The link between the number of streams of one order and the number of streams of the next higher order is displayed by the bifurcation ratio (Jahan et al., 2018; Schumm, 1956; Singh et al., 2019). The Upper Godavari Sub Basin's bifurcation ratio (Rb) falls between 2.00 to 5.39, highest between the 1st and 2nd orders suggests the geological control over the drainage basin whereas less bifurcation ratios states a relatively gentle slope of the basin favorable for infiltration of water to increase the level of groundwater with soft bedrock. The bifurcation ratio of the basin reveals a well-organized hierarchical drainage system. Ultimately, these fluctuating ratios reflect well structural control of the geology over Upper Godavari Sub Basin.

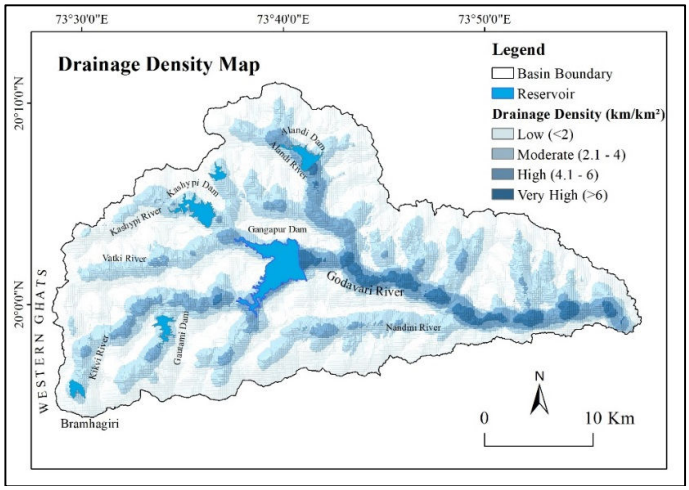
Table 3 Morphological parameters.

Sr. No.	Basin Morphological Parameter	Value
1.	Basin area (A)(km²)	852.62
2.	Basin perimeter (P)(km)	173.95
3.	Basin length (L)(km)	50.70
4.	Drainage density (Dd)(km/km²)	1.17
5.	Length of overland flow (Lo)	0.43
6.	Stream frequency (Sf)	0.84
7.	Drainage texture (T)	0.99
8.	Circularity ratio (Rc)	0.35
9.	Elongation ratio (Re)	0.65

10.	Form factor (Ff)	0.33
11.	Shape factor (Fs)	3.01
12.	Constant of channel maintenance (C)	0.85
13.	Basin relief (R) (m)	707
14.	Relief ratio (Rr)	13.94
15.	Ruggedness number (Rn)	0.828

Drainage density (Dd)

The total length of all streams per unit area of a drainage basin is measured by drainage density (Dd), work as an important parameter for evaluating surface dissection and drainage basin development (Ahmed et al., 2017; Horton, 1932). Steep slopes, closely spaced channels, impermeable surface materials, and high surface runoff potential are often associated with higher drainage density values. whereas, a low value of drainage density is commonly linked with gentle slopes, extremely porous bedrock, compact vegetation cover, and a higher capacity for water infiltration (Ganie et al., 2024). As per Choudhari et al., 2018, the drainage density (Dd) is classified as low (< 2), moderate (2− 4), high (4− 6), and very high (> 6) four classes. The research area's drainage density is depicted in Fig. 3. The Upper Godavari Sub Basin's drainage density (Dd) of 1.17 km/km² indicates less surface drainage development with widely dispersed streams. This value of drainage density indicates a stable, reasonable equilibrium within surface runoff and water infiltration.



[Fig. 3 Drainage Density Map of Upper Godavari Sub Basin]

Length of overland flow (Lo)

The average distance surface water travels before entering a designated stream channel is known as the length of overland flow (Lo), and it is often calculated as half the inverse of the discharge density (Dd) (Horton, 1945). The lower values of overland flow (Lo) indicates closer flow paths and faster flow concentration, while a longer length indicates greater spacing between flow paths and longer flow paths (Farhan et al., 2015). The length of overland flow of the basin is 0.43 km, representing the surface paths are relatively short before the flow reaches a main stream. The short paths allow rainfall-generated runoff to be rapidly concentrated in streambeds, especially during severe storms.

Stream frequency (Sf)

Stream frequency (Sf), a crucial indicator of the degree of drainage fragmentation and stream growth, counts all streams per unit area of a drainage basin (Horton, 1932; Rai et al., 2017). The Stream frequency (Sf) value of the drainage basin is 0.84 streams/km^2; shows a moderate degree of drainage dissection and has a moderately developed stream network (Withanage et al., 2015). Therefore, Stream frequency (Sf) suggests the moderate and intermediate surface drainage development across the Upper Godavari Sub Basin.

Drainage texture (T)

Drainage texture (T), which quantifies the relative spacing and fragmentation of a basin's drainage network, is calculated utilizing the relationship between drainage density and stream frequency (Smith, 1950). The fine drainage texture shows closely spaced streams and intense fragmentation, while coarse texture shows wider spacing in the streams of the drainage basin (Javed et al., 2009). The calculated drainage texture value of 0.99 shows that the basin's drainage texture is rather coarse. The moderate drainage texture of the Upper Godavari Sub Basin generally indicates comparatively wider spacing between drainage channels than fine drainage texture and may be associated with permeable lithology, higher infiltration capacity, resistant rock formations, vegetation cover or relatively gentle terrain.

5.2. Estimation of aerial parameters

The areal morphometric parameters describe the two-dimensional (2D) geometry and shape characteristics of the drainage basin. These parameters are important for evaluating basin compactness, elongation, runoff concentration and hydrological response. The circularity ratio, elongation ratio, shape factor, form factor, and constant of channel maintenance were the aerial morphometric parameters that were measured for this investigation.

Circularity ratio (Rc)

On the basis of basin’s area and perimeter, the circularity ratio calculates how closely a drainage basin resembles a perfect circle (Miller, 1953). A Circularity ratio value near 1 indicates a circular basin whereas near 0 shows more complex and elongated shape of the study area (Strahler, 1964). The circularity ratio of 0.35 demonstrates that the upper Godavari sub-basins are very elongated and deviate significantly from a circular shape. The elongated shape of the basin causes the hydrological response of the basin is spread out over time, meaning that flows from different parts do not reach

the mouth at the same time, resulting in a later and lower peak surface water flow level than in a circular basin.

Elongation ratio (Re)

The elongation ratio (Re), which is also described as the ratio between the diameter of a circle with the same basin area and the maximum basin length, indicates how elongated or circular is a drainage basin (Schumm, 1956). The Elongation ratio (Re) close to 1 indicate elongated basins, while lower numbers indicate increase in circular shape (Jalem et al., 2025; Malik et al., 2011). Depending on the local landscape and slope features, this morphometric parameter is important for understanding the basin geometry and how it directly affects flow density and peak discharge timings. The Upper Godavari Sub Basin has a moderately to significantly elongated shape with comparatively higher relief and steeper slopes, as shown by the basin's elongation ratio (Re) of 0.65. This basin's morphology can affect the hydrological response by lengthening the runoff's journey from highlands to the main river.

Form factor (Ff)

The drainage basin's shape and compactness are measured by the form factor (Ff), which is calculated by dividing its area by the square of its length (Chowdhury, 2024; Horton, 1945). A lower count denotes an elongated shape basin with a longer time of runoff concentration and comparatively modest peak discharges, whereas high numbers imply a compact, circular basin that concentrates stream water quickly and produces strong peak discharges. The Upper Godavari Sub Basin's form factor of 0.33 illustrates the connection between basin size and basin length squared. The count of form factor approaching 1 indicates a relatively compact and circular shape basin, whereas a lower value shows an elongated shape basin (Kanhaiya et al., 2019).

Shape factor (Fs)

A further indicator of a basin's elongated shape is the shape factor, which is the reciprocal of the form factor and is computed by dividing the square of the basin's length by its area (Horton, 1945). Due to they share an inverse relationship, higher shape factors indicate elongated basins, while lower values represent compact basins. This morphometric parameter helps to assess geometry and hydrologic response, and works alongside circularity and elongation ratios to provide a comprehensive image of basin shape (Yadav et al., 2014). The Upper Godavari Sub Basin's form factor of 3.01 suggests that runoff produced throughout the basin will probably be dispersed along a somewhat lengthy flow path before arriving at the main river.

Constant of channel maintenance (C)

The surface area needed to maintain a unit length of drainage channel is known as the constant of channel maintenance, and it is computed as the reciprocal of drainage density (Schumm, 1956). A high value of channel maintenance indicates widely spaced channels, high ground infiltration, and low drainage density, while a low value reflects closely spaced channels, low permeability, and high surface runoff. The basin's constant of channel maintenance is 0.85 km^2/km. The value is consistent with the drainage density of 1.17 km/km^2 because the reciprocal of 1.17 is 0.85. The value obtained for the Upper Godavari Sub Basin therefore indicates moderate channel development and suggests that infiltration and surface runoff both contribute to the drainage basin development.

5.3. Estimation of relief aspects

Relief parameters describe the vertical dimensions, elevation changes, and topographic structures of a drainage basin. Relief has a key impact on runoff velocity, erosion, sediment transport, channel deepening, and drainage basin development. The basin relief, slope, relief ratio, and basin ruggedness number have all been measured in this study.

Basin relief (R)

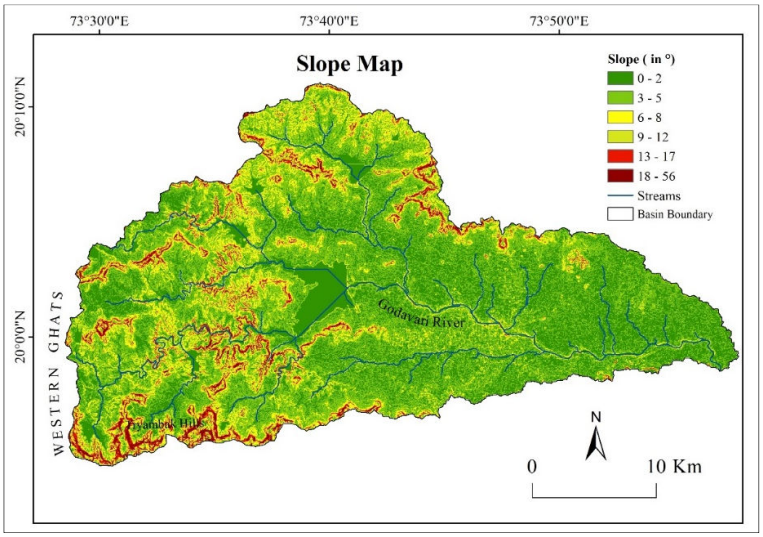
The difference between a drainage basin's highest and lowest elevations is known as its relief, and it provides an important indicator of the basin's vertical expansion and topographic diversity (Kanhaiya et al., 2019). High basin relief shows considerable elevation differences and generally corresponds to steep terrain, high runoff velocity and greater soil erosional potential. The topography with low relief is comparatively mild, and there is less chance of rapid surface runoff and channel incision. The 707 m basin relief of the Upper Godavari Sub Basin results in a notable vertical topography variation, ranging from the region's low plains to its high altitudes. This sharp drop in elevation creates variations in slope and potential energy across the land, which act as a major triggering factor for the runoff through the drainage basin. As a result, this topography controls runoff velocity, soil erosion, sediment transport and bed depth, and ultimately shapes the morphometric diversity and structural development of the study area (Choudhari et al., 2018).

Relief ratio (Rr)

Relief ratio (Rr), a measure of a drainage basin's overall slope, is the ratio of the basin's entire relief to its maximum length (Schumm, 1956). High relief ratios denote rough terrain with rapid surface water flow, severe valley erosion, and high soil erosion due to elevation decreases over short flat distances. Whereas, low values of relief ratios indicate gentle topographic gradients that result in a slower, more prolonged runoff response. The relief ratio of the study area is 13.94, shows a significant relationship between the vertical slope and the longitudinal extension of the basin. Also increases the velocity of runoff on its steep slopes, causes severe channel erosion, and increases soil erosion. Although this average ratio indicates that elevation is a major geomorphic controller in the entire drainage system, local topography variations necessitate the consideration of specific GIS definitions and measurement units in the analysis of sub-basins.

Slope

The rate at which elevation changes over a horizontal distance is known as slope, and it plays a significant role in regulating basin growth and activities. The slope map provides significant information for analyzing regional changes in runoff, erosion, drainage density, and stream development. The Upper Godavari Sub Basin's slope ranges from 0º to 56º (Fig. 2). A substantial difference in slope shows the rapid surface runoff and augmented exposure to soil erosion in region.



[Fig. 4 Slope Map of the Upper Godavari Sub Basin]

Ruggedness number (Rn)

The Ruggedness Number (Rn) is a composite morphometric parameter that provides a single assessment of the region's topography's vertical and horizontal discontinuities by combining the drainage density and a basin's steepness (Schumm, 1956; Strahler, 1952). High Rn values indicate steeply sloping, mountainous, highly dissected, and erosion-prone landforms, which are characterized by steep, highly dissected and erosion-prone terrain. The Rn low values indicate gentle slopes and lower drainage density, making this parameter very useful for assessing the overall roughness of a topography and its potential for soil erosion. The ruggedness number of the Upper Godavari Sub Basin is 0.828, which combines its relatively high vertical elevation of 707 m with a horizontal drainage density of 1.17 km/km². This ruggedness number value indicates a significant interaction between basin's relief and its drainage development show relatively high runoff and soil erosion potential, particularly where steep slopes coincide with dense stream frequency.

6. Limitations and Future Scope

Although this study provides a foundational geomorphological assessment of the Upper Godavari Sub Basin using a GIS framework, several limitations highlight critical pathways for future research. Minor and seasonal channels were left out because drainage network extraction mostly depended on the spatial resolution of the used DEM. Consequently, further studies should leverage high resolution datasets to capture finer drainage features. Also, while basin geomorphology is heavily driven by lithology, soil characteristics, vegetation, and surface runoff dynamics, these factors were not quantitatively analyzed here. Future investigations should integrate these physical environmental parameters alongside field validated measurements of stream discharge, soil infiltration, and sediment load. Studies at micro basin levels will help to identify priority areas for targeted soil and water resource conservation practices. In addition, the use of GIS-based multi criteria decision analysis and RUSLE modelling

can improve the estimation of sedimentation rates and soil erosion status of the drainage basin. Finally, incorporating groundwater analysis and field measurements of runoff and discharge will validate these GIS based findings, providing a sustainable framework for watershed management planning in the Upper Godavari Sub Basin.

7. Conclusions

This work uses remote sensing, digital elevation model (DEM) data, and GIS techniques to show the morphological and drainage characteristics of the Upper Godavari Sub Basin in Nashik, Maharashtra. A genuine 6th order drainage basin with 719 streams totalling 998.17 km in length is shown by the analysis. The basin is dominated by headwaters, with 563 streams of 1st order streams. The Stream orders are inversely proportional to stream numbers, indicating a highly systematic structural hierarchy of the basin. From 0.9382 km in the first order stream to 31.5586 km for the sole main channel in the sixth order stream, the average stream length generally exhibits an increasing tendency. The stream length ratio differs widely between 0.2459 and 1.3413, indicating rough development of the stream. Also, the bifurcation ratio (Br) ranges from 2.00 to 5.39, directly reflecting distinct spatial disparities in geological structures, drainage patterns, and active geomorphic controls over the basin. An area of the drainage basin is 852.62 km², with 173.95 km of perimeter and a maximum basin length of 50.7 km. A moderate development of surface drainage is indicated by its areal and textural parameters, which include a drainage density of 1.17 km/km², a stream frequency of 0.84 streams/km², and a drainage texture of 0.99. This is further supported by the constant of channel maintenance of 0.85 km²/km and the relatively short length of the overland flow (0.43 km), which suggests rapid concentration paths for surface water flow. The circularity ratio of 0.35, the elongation ratio of 0.65, and the form factor of 0.33 all indicate that the basin's geometry is primarily elongated. Topographically, this area has a important relief of 707 meters and a ruggedness number of 0.828, which shows the important terrain variation and the strong geomorphic influences controlling the overall evolution of the drainage basin. The Upper Godavari Sub Basin is mostly an elongated, fairly dissected, sixth-order basin with notable vertical gradients. These morphological results provide a crucial quantitative metric for comprehending the drainage basin's particular structure. The region's thorough structural profile provides local planning authorities with a crucial foundation that directly supports drainage management, soil and water conservation, soil erosion risk assessment, watershed prioritization, and sustainable watershed planning.

Conflicts of interest

The authors confirm that they have no conflicts of interest in this study.

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