

## GIS and Remote Sensing Analysis of Morphometric Characteristics in Karanthaimalai Hill, Dindigul District, Tamil Nadu

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**Abstract:** The present study integrates GIS and remote sensing technology to do a morphometric analysis of Karanthaimalai Hill in Tamil Nadu's Dindigul district, India. Morphometric analysis is the measurement and quantitative study of many Earth surface features, including shape, length, height, and slope. Karanthaimalai Hill in the Natham region is mostly composed of granite and gneiss. The primary purpose of this study is to identify a wide range of morphometric parameters, including slope, contour, aspect, curvature, drainage, elevation, flow accumulation, flow direction, drainage density, dissection index, relative relief, roughness, and hill stream order. The data used in this study include Survey of India (SOI) toposheet maps and Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) satellite photos with a resolution of 30 metres. The study found that Karanthaimalai Hill has steep and highly dissected topography, with heights ranging from 300 m to 900 m. Notably, the hill provides large relative relief, particularly at the summit and middle, with moderate relief throughout. The dissection index reveals extensive erosion and stream incision, notably on the hill's southern side. The topography roughness varies greatly across the area, indicating a diverse terrain. The slope aspect is primarily orientated west and east, while the hill's curvature displays steep slopes and dips. Furthermore, the hill's drainage density represents a complex network of streams and drainage patterns. These findings have significant implications for regional land-use planning, conservation, and management strategies. However, additional research is required to understand the fundamental principles that affect the landscape and to promote sustainable land management approaches.

**Keywords:** Morphometric analysis, Land-use planning, Karanthaimalai Hill, Remote sensing and GIS, Sustainable land management

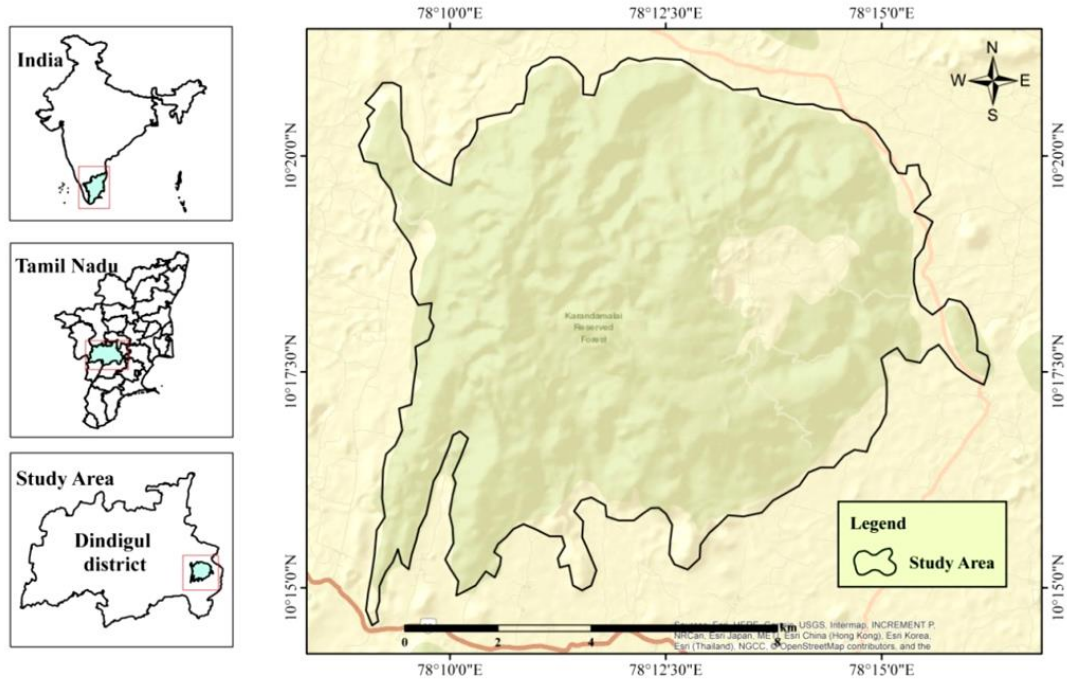
### 1. Introduction

Morphometrics is an important approach in GIS for determining measurement values and doing mathematical analysis of the Earth's surface. It includes shape, length, height, slope, and dimension. Morphometric analysis is used in many different fields, including civil engineering, urban planning, geology, landform surveys, map construction, environmental research, and hydrological studies. The ability of satellite remote sensing to provide a quick overview of a large area is beneficial for morphometric study. A morphometric investigation of drainage basins provides an accurate permeability index as well as useful information about the geological and hydrological features of the host rocks. Morphometric analysis of river basins using remote sensing and GIS has proven to be an effective method for understanding hydrological processes and landform characteristics. Advances in geomorphometry have demonstrated that spatial tools can efficiently extract hills, ranges, and landforms for terrain characterization (Chaudhry and Mackaness, 2008). Similar GIS-supported morphometric techniques have been applied to identify geomorphic features in diverse landscapes such as the Federal District of Brazil (Steinke and Sano, 2011).

Research has extensively focused on watershed prioritization, where morphometric parameters combined with land-use analysis are used to identify erosion-prone and vulnerable sub-watersheds requiring management interventions (Javed et al. 2009; Sahu et al. 2017; Moharir et al. 2020; Verma et al. 2020; Assegide et al. 2025). These approaches have also proved effective in basin-scale studies across tectonically active regions of the Himalaya and Central India to understand drainage behavior and neotectonic controls (Kumar et al. 2018; Barman et al. 2021; Asim et al. 2025).

Morphometric techniques have further supported groundwater and hydrological studies by delineating drainage patterns, slope conditions, and aquifer-favorable zones. Investigations in the Araniar and Panamaram river basins confirmed that quantitative basin parameters effectively contribute to groundwater assessment and watershed development planning (Jasmin and Mallikarjuna, 2013; Joji et al. 2013). Similar applicability has been reported in the alluvial terrain of the Yamuna basin and other parts of Central India (Ansari et al. 2012; Bhatt et al. 2021).

Recent developments emphasize the importance of improved spatial databases, high-resolution imagery, and advanced image-processing methods for accurate



**Figure 1: Location Map of the Study Area**

morphometric classification. Digital resources such as the Geomorphometric Atlas of Romania provide valuable datasets for refined topographic analysis (Ioniță et al. 2024). Integrated assessment methods have also been applied in flood-risk and drainage vulnerability mapping in arid and semi-arid regions (Khalifa et al. 2023). Reviews and case studies highlight morphometric analysis as a key component in watershed characterization and sustainable water resource management (Patel et al. 2023; Memon et al. 2024; Mussina et al. 2025). Advancements in remote sensing and terrain modeling have expanded morphometric research beyond terrestrial environments, including the characterization of planetary surfaces such as lunar and Mercurian craters (La Grassa et al. 2025).

The present study offers novelty by incorporating updated morphometric parameters derived from contemporary remote sensing products, improving analytical precision in delineating hydrological behavior and geomorphic controls.

These researchers are several methods used to the river basin geometry and hydrological processes, allowing us to make better decisions about water resource management and environmental planning. The goal of this research is to determine the slope, contour, aspect, curvature, drainage, elevation, flow accumulation, flow direction, drainage density, dissection index, relative relief, roughness, and stream order of Karanthaimalai Hill, which is in the Natham area of Dindigul district in Tamil Nadu.

## 2. Study Area

The hill of Karanthaimalai located in the Dindigul district's Natham area. Karanthaimalai Hill is in  $78^{\circ}12'30.98''\text{E}$  to  $78^{\circ}12'37''\text{E}$  longitude and  $10^{\circ}18'50.27''\text{N}$  to  $10^{\circ}18'15.40''\text{N}$  latitude. It has an area of  $90.54\text{ km}^2$  and has a perimeter of  $49.46\text{ km}$ . The hill is accessible by road and

is approximately 20 kilometres from Dindigul town (Figure 1). Karanthaimalai Hill is mostly made up of granite and gneissic rock formation. The hill is approximately 2,500-3,500 million years old. Geologically, the hill is in the Madurai Block of the Southern Indian Craton, India's oldest region. The hill includes Ayanar Falls, Kuttupatti Falls, Karanthaimalai Aruvi, and Chinna Aruvi. The hill is also a part of the Karanthaimalai Reserve Forest.

## 3. Data and Methodology

The Survey of India (SOI) toposheet maps No. 58J/3, which are 1:50,000 in scale, were used to make (i) a base map and (ii) a study of drainage patterns (Thomas et al. 2010). Morphometric analysis was done utilizing SRTM (Shuttle Radar Topography Mission) DEM satellite images with a resolution of 30 m. All the above data were evaluated using ArcGIS 10.8 software, with the help of the Spatial Analyst tool. Quantitative morphometric analysis was performed for linear, aerial, and relief dimensions (Table 1).

## 4. Result and Discussion

The morphometric analysis of Karanthaimalai Hill has been meticulously explored by employing height and water flow data from Digital Elevation Model (DEM) and GIS technology (Mishra et al. 2023; Mishra and Rai, 2020). The examination comprises perimeter and areal dimensions, relative relief, dissection index, terrain roughness index, slope aspect and gradient (degrees and percentages), curvature, hillshade, contour intervals, stream ordering, stream flow direction, flow accumulation patterns, and drainage density. These metrics provide precise information about the geomorphological evolution, surface runoff potential, and terrain arrangement of the examined area.

**Table 1: Data Preparation in the Morphometric Analysis**

Morphometric Aspects	Parameter	Formula	Symbol Explanation
Linear aspect	Stream Order (U)	Descriptive method	First-order: no tributaries; higher orders form by confluence of equal lower orders.
	Flow Accumulation	Flow accumulation = sum of upstream flow cells	-
	Flow Direction	$\theta = \arctan(dz/dx) + 180^\circ$	$dz$ : elevation change between cells; $dx$ : horizontal distance between cells; $\theta$ : direction of flow in degrees
Areal Aspects	Drainage Density (Dd)	$Dd = Lu / A$	$Lu$ : total stream length (km); $A$ : basin area (km <sup>2</sup> )
	Hill Shape Index (HSI)	$HSI = 1.27 \times A / L^2$	$A$ : basin area (km <sup>2</sup> ); $L$ : maximum basin length (km)
Relief Aspects	Relief (R)	$R = H - h$	$H$ : maximum elevation (m); $h$ : minimum elevation (m); $R$ : total relief
	Relief Ratio (Rr)	$Rr = R / L$	$R$ : total relief (m); $L$ : basin length (m)
	Dissection Index (DI)	$DI = (H - h) / H$	$H$ : maximum elevation (m); $h$ : minimum elevation (m)
	Terrain Ruggedness Index (TRI)	$TRI = (TC \times TF) / (TC + TF)$	$TC$ : terrain complexity; $TF$ : terrain factor (unitless values based on terrain variation, if defined separately)
	Degree of Slope (DS)	$DS = \theta = Rise / Run$	$Rise$ : vertical elevation change; $Run$ : horizontal distance
	Percent of Slope (PS)	$PS = \theta \times 100$	$\theta$ : slope in degrees
	Slope Aspect (SA)	$SA = 57.29578 \times \text{atan2}(dz/dy, dz/dx)$	$dz/dy$ : elevation change in north-south; $dz/dx$ : elevation change in east-west direction
	Curvature (C)	$C = 0.2D + E \times 10$	$D$ : profile curvature; $E$ : plan curvature (as extracted from DEM data layers)

The length and breadth have been measured from north to south and east to west of Karanthai Hill. A tiny pond is found on the eastern side of the Karanthaimalai hill. The hill elevation is 919 m, as per the DEM data, which lies during the Karanthaimalai hill.

#### 4.1 Contour Map and Elevation

A contour map, also known as a topographic map, displays the elevation and shape of the land's surface using contour lines. These lines connect locations of equal elevation so that a continuous line reflects areas with the same elevation. Contour maps are extensively used in geology, geography, and other earth sciences to examine the physical properties of the terrain. The Karanthaimalai Hill formation has a contour value ranging from around 300 to 900 metres (Figure 2). The west of the hill has the greatest contour values, i.e., 900 m, and portion of the east side contains the lowest contour value, i.e., 300 m. The colour shades in the map indicate the elevation profile of the hill.

#### 4.2 Hill Profile

The map shows the profile of Karanthaimalai hill; the A and B parts of the line represent the hill's east-west flow

direction, while C and D illustrate the hill's north-south profile direction. Graphs based on the profile illustrate the dissecting profile of the Karanthaimalai Hill from east to west and north to south (Figure 3).

#### 4.3 Drainage Density Map

Drainage refers to the natural movement of water, such as surface water or groundwater, through the landscape and towards a central location, such as a river or lake. A drainage map displays the patterns of this movement by illustrating the locations of streams, rivers, lakes, and other water bodies, the direction of flow and the drainage basin boundaries. Drainage density estimates how much stream length per unit area is in a drainage basin. It is commonly computed by dividing the total length of streams in a drainage basin by the size of the basin. Drainage density can be used as an indicator of the qualities of the landscape, such as the permeability of the soil or the amount of precipitation that falls in the area. The drainage density map provides drainage density values in length per unit area. Specifically, the map is organised into five classes or ranges of values:

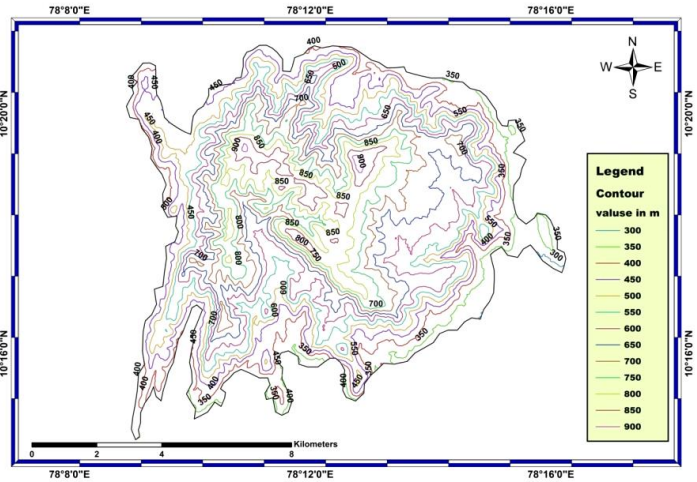


Figure 2: Contour Map of the Study Area

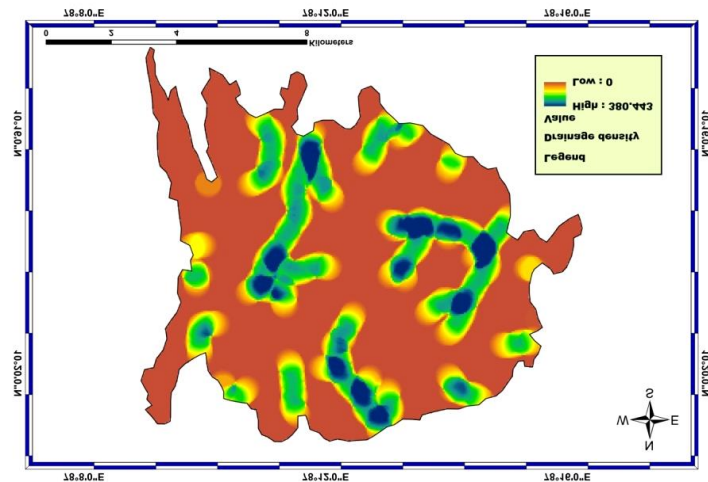


Figure 4: Drainage Density Map of the Study Area

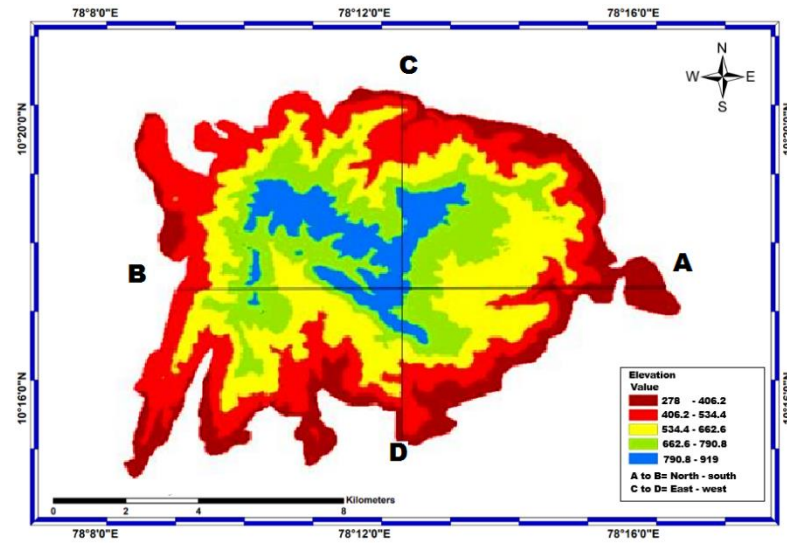
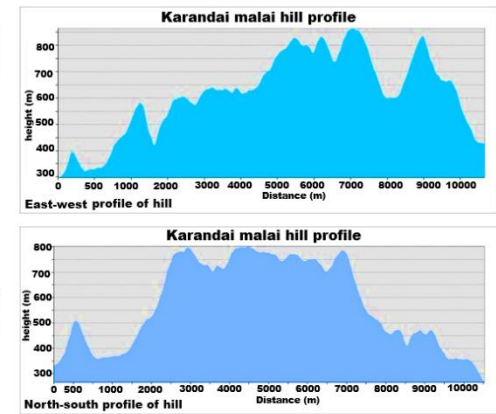


Figure 3: Hill Profile of the Study Area



0 to 350 length per unit area  
 350 to 650 length per unit area  
 650 to 1000 length per unit area  
 1000 to 1300 length per unit area  
 1300 to 1600 length per unit area

Each range of values is often represented by a different colour or shading in the map legend, making it easier to observe the distribution of drainage density values over the area (Figure 4). The map can help identify locations with high or low drainage density, enabling decision-making on land use, water management, and infrastructure planning.

#### 4.4 Hill Shade

The hill shade tool provides a shaded relief depiction of a terrain model, graphically displaying the terrain's surface using light and shadow. In the hill shade of the Karanthaimalai Hill area, the values range from 0 to 180, signifying distinct hues of grey (Figure 5). The hill shade of the area shows the topographic qualities and relief of the ground. It is depicted by shades of grey, where lighter hues imply higher altitudes and slopes facing the light source, while darker shades represent lower elevations and slopes according to shadow.

#### 4.5 Stream Order

Stream order is a means of classifying streams based on their position within a drainage network. The order of a stream is determined by the number of tributaries that flow into it, with higher-order streams having more tributaries and so carrying more water. Stream order is a crucial tool for understanding the hydrology of a landscape and can be used to forecast the flow rates and other features of streams. It is commonly utilised in environmental evaluations, watershed management, and stream restoration projects. In a Strahler stream order system, a stream segment is allocated a number based on the order of its tributaries. Most tiny streams that have no tributaries are accorded a first order. When two first-order streams meet, they form a second-order stream. When two second-order streams collide, they form a third-order stream and others. Figure 6 illustrates the stream network of the Karanthaimalai Hill region up to the third order. First-order streams are the smallest, while third-order streams are the largest, according to the current classification. The stream order hierarchy is defined by the number of tributaries in a stream segment, with higher-order streams conveying more water.

#### 4.6 Flow Accumulation and Flow Direction

Flow accumulation is a hydrological process of water flow accumulation in a drainage basin. It estimates the total upstream area that contributes to a certain location on a stream or river. In other words, it indicates the entire volume of water that flows through a certain point in a stream network, including water from all the upstream places that drain into that point. Flow accumulation is commonly calculated using digital elevation models (DEM) and GIS software. The DEM is used to detect the direction of water flow at each location in the terrain, and this information is utilised to design a stream network. Flow direction is a fundamental notion in hydrology that refers to the direction of water flow in a landscape. It is often depicted as a map or model that illustrates the

direction of water flow at each point in a digital elevation model (DEM) or other topographic dataset. Flow direction maps are commonly used in hydrological modelling and analysis to simulate water movement through the landscape, predict flood risk, identify areas of high or low runoff potential, and make decisions regarding land use and water management. In Karanthaimalai Hill, exhibits range from 1 to 129 directions (Figure 7 a and b).

#### 4.7 Relative Relief

The ratio between the highest and lowest contours is known as relative relief. It is sometimes referred to as 'available relief' and 'local relief'. The Karanthaimalai Hill has considerable relative relief, rising from 469m to 547m at the top and centre. Most of the hill's elevation ranges from 360 to 415 meters. At the same time, the east and southwest regions have relative relief ranging from 285 to 359 meters. Karanthaimalai has the lowest relative relief on the top corner of the hill's south-west slope, ranging from 173m to 284m (Figure 8).

#### 4.8 Dissection Index

The dissection index indicates the nature and extent of terrain dissection. The dissection of the Karanthai hill was analysed using the DOVNIR (1957) approach. The west to southwest portion of Karanthai hill has a low dissection index, ranging from 0.39 to 0.63. The highest level of dissection is found in the southeast of the hill, with a dissection index ranging from 1.24 to 1.74. The average dissection index is 1.06, indicating that the erosion cyclone has reached maturity (Figure 9).

#### 4.9 Terrain Ruggedness

The roughness of the earth's surface is another name for terrain ruggedness. By multiplying the total number of contours by the total number of contour fluctuations and combining the total number of contours and fluctuation, the Terrain Ruggedness Index (TRI) is determined.

$$TC \times TF / TC + TF = TRI$$

Karanthaimalai Hill's average terrain roughness is 0.50, with a range of 0.11 to 0.89 (Figure 10). The maximum percentage of the Karanthai hill's high-rough sides falls between 0.53 and 0.89 on the roughness index.

#### 4.10 Slope Aspect

The slope is the gradient's magnitude or size, and the aspect of the slope is the direction in which this magnitude reaches its highest. Understanding the four cardinal and four sub-cardinal directions' downslope directions is beneficial. Karanthaimalai Hill's northern portion is north, northeast, west, and north-west. East, Southeast, South, and Southwest on the Eastern side. There is south, southwest, east, and southeast in the southern portion of the hill. Additionally, there are west, northwest, and southwest in the western section. There are east and west ways along the entire downslope (Figure 11).

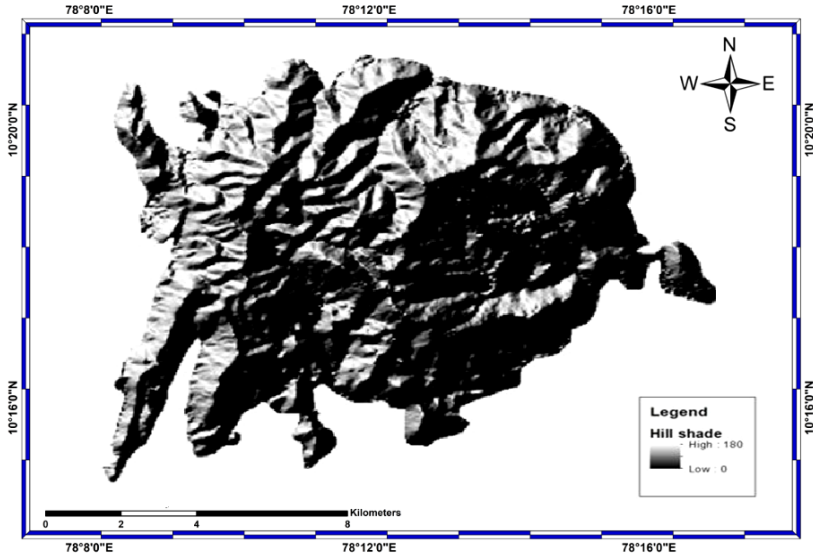


Figure 5: Hill Shade Map of the Study Area

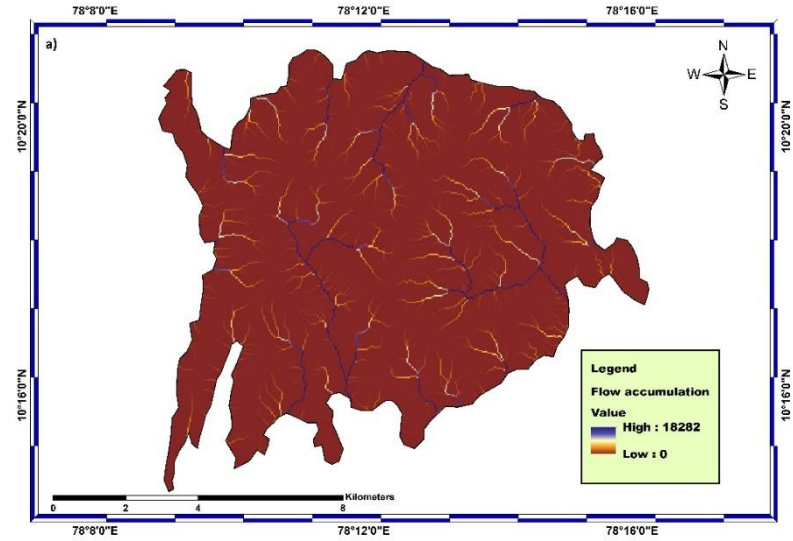


Figure 7: a) Flow Accumulation

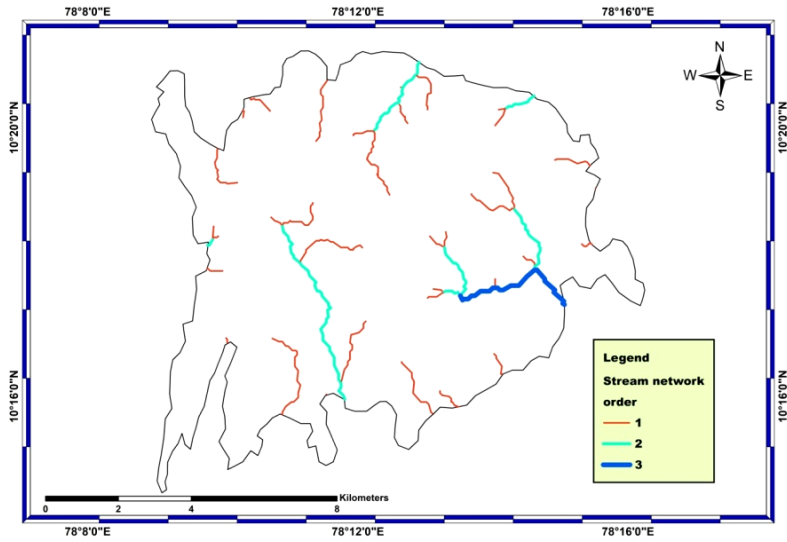


Figure 6: Stream Order Map of the Study Area

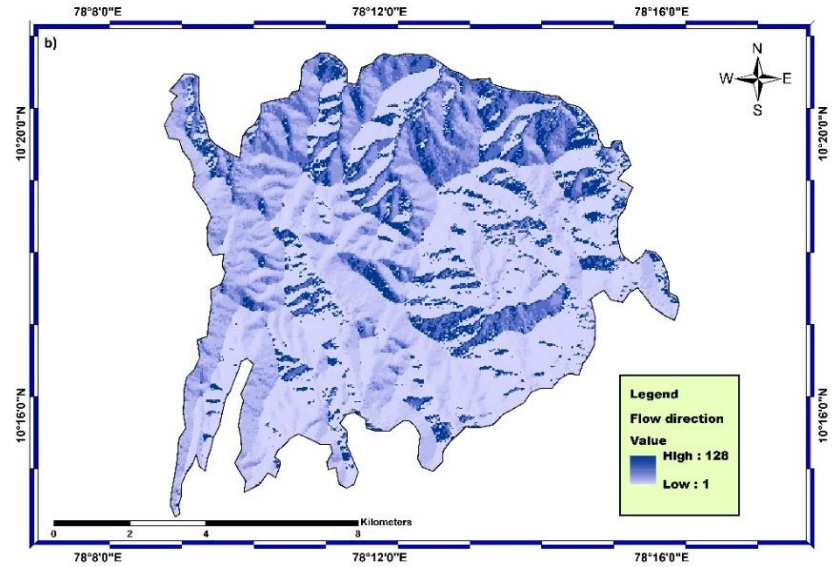


Figure 7: b) Flow Direction Map of the Study Area

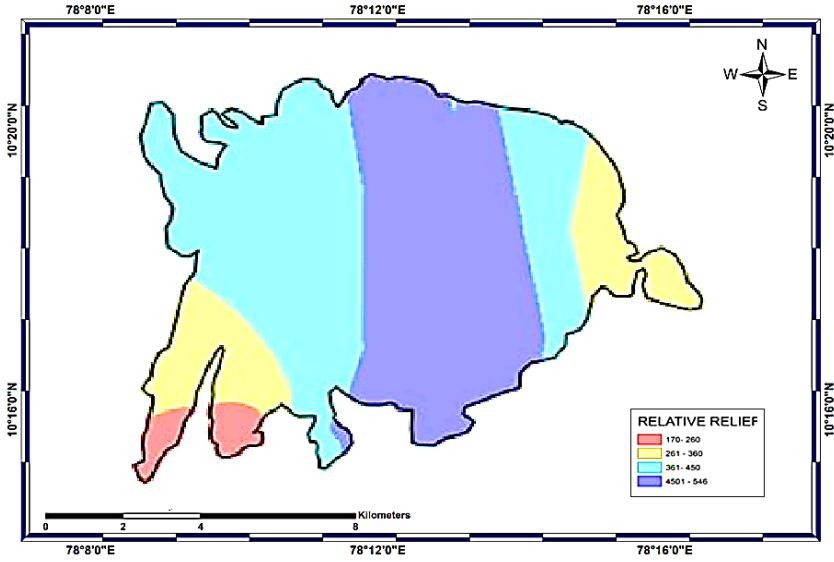


Figure 8: Relative Relief Map of the Study Area

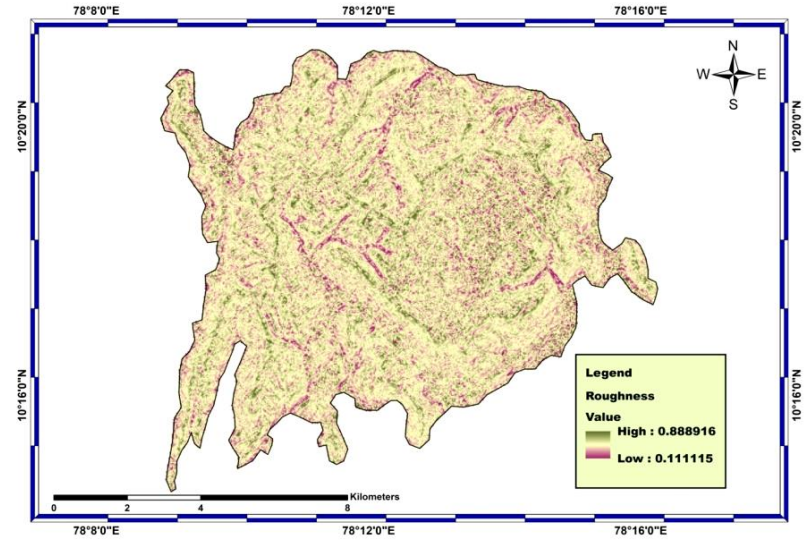


Figure 10: Terrain Ruggedness Map of the Study Area

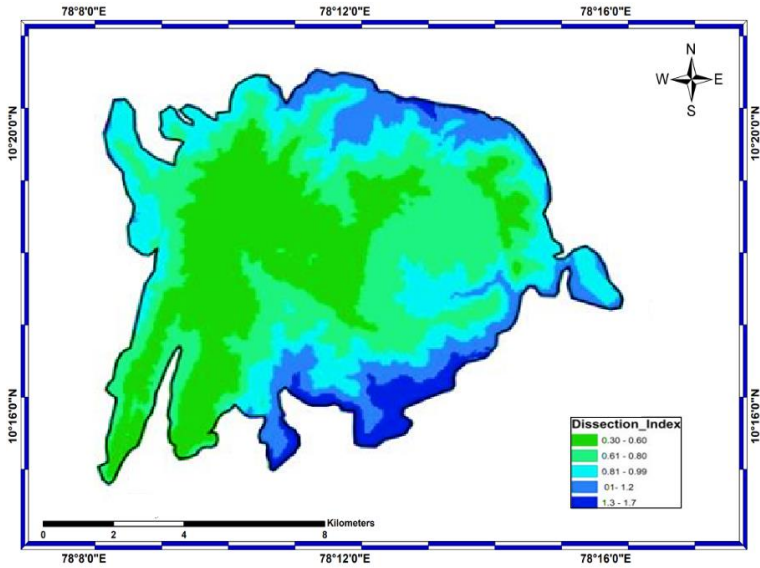


Figure 9: Dissection Index Map of the Study Area

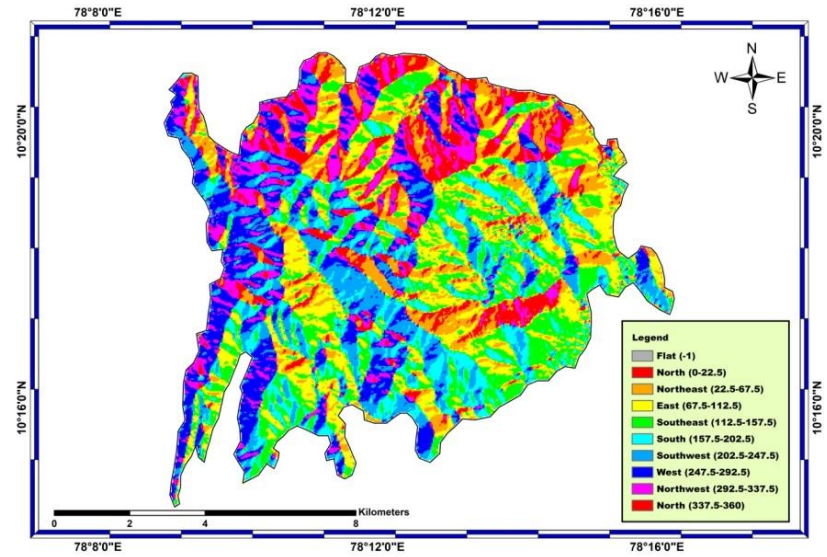


Figure 11: Slope Aspect Map of the Study Area

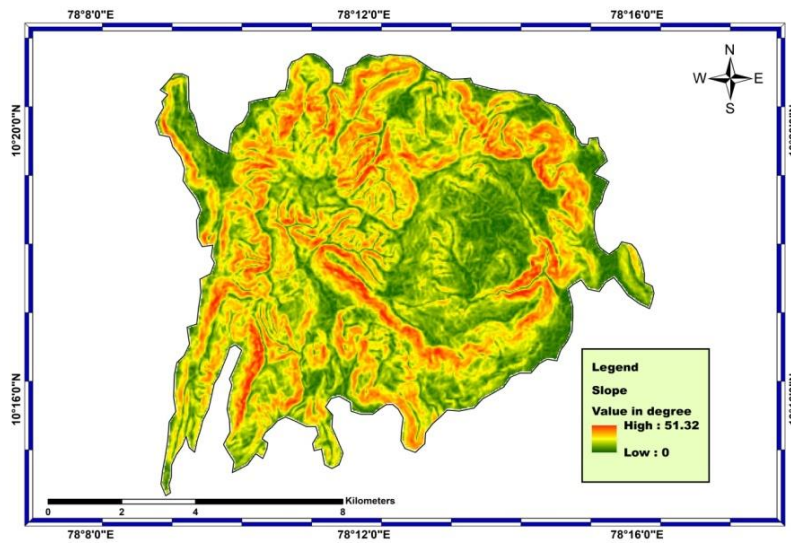


Figure 12: Slope Map of the Study Area

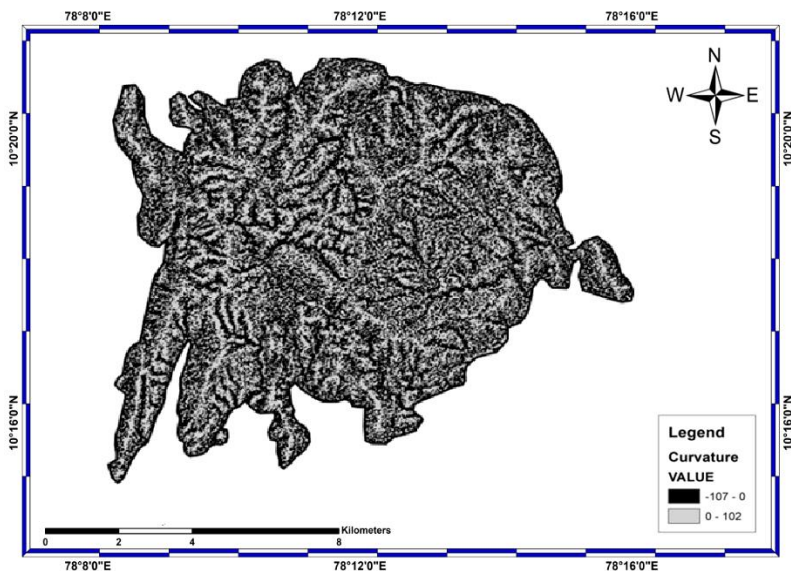


Figure 13: Curvature Map of the Study Area

**4.11 Slope Analysis in Degree**

The slope, which may be examined in two ways, is the rate at which the z-value changes the most.

- Degree of Slope
- The percentage's slope

The slope's inclination is measured in degrees, while its rise is measured in percentages. The south side of Karanthaimalai hill gradually rises in slope. The hill's western and northern regions feature a steep slope that ranges from 30 to 50 degrees. The slope in the middle of the hill is low, ranging from 0 to 5 degrees. The Karanthaimalai hill's slope, expressed as a percentage, can reach 15,000,000. Between 0 and 1,600,000 is the smallest percentage of slopes, while between 6,200,000 and 15,000,000 is the greatest. 3,100,000 is the average slope percentage. These classes can visually distinguish the slope steepness inside Hill's research area by looking at

the slope percentage, which displays distinct colours for each class (Figure 12).

**4.12 Curvature**

The Curvature reveals the contour or curvature of the slope, positive curvature implies the surface is upwardly convex, and a negative curvature indicates the surface is upwardly concave. The positive curvature denotes Grey colour, and the negative curvature shows Black on the map.

Karanthaimalai Hill sits on a rugged hill, therefore extreme high relief based on curvature ranges spanning from -110 to 100. The concavity and convexity range from 0 to -110 curvature index and 0 to 100 curvature indices. So, concavity is more than convexity in the present research of hills (Figure 13).

## 5. Conclusions

Based on the results of this study, it can be inferred that Karanthaimalai Hill is a rugged and severely dissected terrain with an elevation range of 300 m to 900 m. The hill has considerable relative relief, extending from 469 m to 547 m, covering the top and centre parts of the peak. Most areas of the slope have a moderate relative relief of 360 m to 415 m. The dissection index is highest in the southern part of the slope, with a range of 1.24 to 1.74, indicating extensive erosion and stream incision. The terrain roughness ranges from 0.11 to 0.89, indicating a very diverse topography. The slope aspect is dominated by the west and east directions, indicating that most down-slope movement happens in those directions. The curvature of the hill is quite high, ranging from -110 to 100, suggesting considerable fluctuations in the topography and the presence of steep slopes and valleys. The drainage density of the hill ranges from 0 to 1600, reflecting a very diverse distribution of streams and drainage patterns. The flow direction ranges from 1 to 128, reflecting a complicated network of stream channels and flow paths. The stream order runs from 1 to 4, with higher-order streams having more tributaries and transporting more water. Overall, the morphometric research of Karanthaimalai Hill has revealed a complex and dynamic landscape with substantial variations in terrain, drainage, and erosion patterns. The conclusions of this study can influence land-use planning, conservation, and management in the region. Further research is needed to explore the underlying processes that form the landscape and better comprehend the significance of these results for sustainable land management.

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### Data Availability

Data will be available on request.

### Declarations

**Funding** - No funding.

**Conflict of Interest** - The authors declare that they have no conflicts of interest.

**Ethical standards** - No applicable

The authors declare that no AI-assisted tools were used for data analysis, interpretation, or preparation of scientific content. Minor editorial assistance for grammar correction was applied without affecting originality.

### References

Ansari, Z. R., L. A. K. Rao, and A. Yusuf. 2012. "GIS Based Morphometric Analysis of Yamuna Drainage Network in Parts of Fatehabad Area of Agra District, Uttar Pradesh." *Journal of the Geological Society of India* 79(5):505–514. <https://doi.org/10.1007/s12594-012-0075-2>

Asim, M., J. Singh, S. Singh, and P. Tiwari. 2025. "Watershed Prioritization of the Upper Ravi Basin, Himachal Himalaya Using Morphometric and Hypsometric Analysis." Pp. 103–135 in *Land and Water Nexus in South Asia: Exploring the Interplay of Resources*. Cham: Springer Nature Switzerland. [https://doi.org/10.1007/978-3-031-87429-1\\_4](https://doi.org/10.1007/978-3-031-87429-1_4)

Assegide, E., T. Alamirew, C. L. Walsh, and G. Zeleke. 2025. "Prioritizing Watersheds for Intervention Design Using GIS and Remote Sensing." *Journal of Environmental & Earth Sciences* 7(1). <https://doi.org/10.30564/jees.v7i1.6887>

Barman, B. K., C. U. B. Rao, K. S. Rao, A. Patel, K. Kushwaha, and S. K. Singh. 2021. "Geomorphic Analysis, Morphometric-Based Prioritization and Tectonic Implications in Chite Lui River, Northeast India." *Journal of the Geological Society of India* 97(4):385–395. <https://doi.org/10.1007/s12594-021-1696-0>

Bhatt, S. C., R. Singh, M. Taiyab, and S. Bhatt. 2021. "Quantitative Morphometric Analysis of Watershed of Upper Pahuj Basin, Bundelkhand Region, Central India." Pp. 293–304 in *Geological and Geo-Environmental Processes on Earth*. Singapore: Springer. [https://doi.org/10.1007/978-981-16-4122-0\\_19](https://doi.org/10.1007/978-981-16-4122-0_19)

Chaudhry, O. Z., and W. A. Mackaness. 2008. "Creating Mountains out of Mole Hills: Automatic Identification of Hills and Ranges Using Morphometric Analysis." *Transactions in GIS* 12(5):567–589. <https://doi.org/10.1111/j.1467-9671.2008.01116.x>

Ioniță, A., M. Lungu, M. Balet, and A. Todor. 2024. "The Geomorphometric Atlas of Romania: An Open-Access Database on Landform Classifications and Morphometric Variables." *Journal of Maps* 20(1):2354712. <https://doi.org/10.1080/17445647.2024.2354712>

Jasmin, I., and P. Mallikarjuna. 2013. "Morphometric Analysis of Araniar River Basin Using Remote Sensing and Geographical Information System in the Assessment of Groundwater Potential." *Arabian Journal of Geosciences* 6(10):3683–3692. <https://doi.org/10.1007/s12517-012-0627-1>

Javed, A., M. Y. Khanday, and R. Ahmed. 2009. "Prioritization of Sub-Watersheds Based on Morphometric and Land Use Analysis Using Remote Sensing and GIS Techniques." *Journal of the Indian Society of Remote Sensing* 37(2):261–274. <https://doi.org/10.1007/s12524-009-0016-8>

Joji, V. S., A. S. K. Nair, and K. V. Baiju. 2013. "Drainage Basin Delineation and Quantitative Analysis of Panamaram Watershed of Kabani River Basin, Kerala Using Remote Sensing and GIS." *Journal of the Geological Society of India* 82(4):368–378. <https://doi.org/10.1007/s12594-013-0164-x>

Khalifa, A., B. Bashir, A. Alsalman, S. P. Naik, and R. Nappi. 2023. "Remotely Sensed Data, Morphometric Analysis, and Integrated Method Approach for Flood Risk Assessment: Case Study of Wadi Al-Arish Landscape, Sinai, Egypt." *Water* 15(9):1797. <https://doi.org/10.3390/w15091797>

- Kumar, D., D. S. Singh, S. K. Prajapati, I. Khan, P. K. Gautam, and B. Vishwakarma. 2018. "Morphometric Parameters and Neotectonics of Kalyani River Basin, Ganga Plain: A Remote Sensing and GIS Approach." *Journal of the Geological Society of India* 91(6):679–686. <https://doi.org/10.1007/s12594-018-0923-9>
- La Grassa, R., C. Re, E. Martellato, A. Tullo, S. Bertoli, G. Cremonese, et al. 2025. "From the Moon to Mercury: Release of Global Crater Catalogs Using Multimodal Deep Learning for Crater Detection and Morphometric Analysis." *Remote Sensing* 17(19):3287. <https://doi.org/10.3390/rs17193287>
- Memon, A. V., Y. S. Patel, and T. Parangi. 2024. "Exploring Watershed Dynamics: A Comprehensive Review on Morphometric Analysis and Geospatial Techniques." *ISH Journal of Hydraulic Engineering* 30(5):744–757. <https://doi.org/10.1080/09715010.2024.2383184>
- Mishra, A. K., A. Upadhyay, P. K. Mishra, A. Srivastava, and S. C. Rai. 2023. "Evaluating Geo-Hydrological Environs through Morphometric Aspects Using Geospatial Techniques: A Case Study of Kashang Khad Watershed in the Middle Himalayas, India." *Quaternary Science Advances* 11:100096. <https://doi.org/10.1016/j.qsa.2023.100096>
- Mishra, A. K., and S. C. Rai. 2020. "Geo-Hydrological Inferences through Morphometric Aspects of the Himalayan Glacial-Fed River: A Case Study of the Madhyamaheshwar River Basin." *Arabian Journal of Geosciences* 13(13):533. <https://doi.org/10.1007/s12517-020-05571-9>
- Moharir, K., C. Pande, R. S. Patode, M. B. Nagdeve, and A. M. Varade. 2020. "Prioritization of Sub-Watersheds Based on Morphometric Parameter Analysis Using Geospatial Technology." Pp. 19–33 in *Water Management and Water Governance: Hydrological Modeling*. Cham: Springer. [https://doi.org/10.1007/978-3-030-58051-3\\_2](https://doi.org/10.1007/978-3-030-58051-3_2)
- Mussina, A., A. Abdullayeva, Z. Zhanabayeva, M. Rakhimova, M. Akhmetova, U. Kozhakhmetova, T. Liu, and T. Omirzhan. 2025. "GIS and RS Data-Based Morphometric Analysis of the Talas River Watershed Characteristics." *Hydrology Research* 56(7):572–592. <https://doi.org/10.2166/nh.2025.161>
- Patel, A., K. Ajaykumar, A. Dhaloiya, K. R. Rao, Y. Rajwade, and C. K. Saxena. 2023. "Application of Remote Sensing and GIS for Morphometric Analysis: A Case Study of Burhanpur Watershed." Pp. 21–37 in *Surface and Groundwater Resources Development and Management in Semi-Arid Region*. Cham: Springer. [https://doi.org/10.1007/978-3-031-29394-8\\_2](https://doi.org/10.1007/978-3-031-29394-8_2)
- Sahu, N., G. O. Reddy, N. Kumar, M. S. S. Nagaraju, R. Srivastava, and S. K. Singh. 2017. "Morphometric Analysis Using GIS Techniques: A Case Study from the Basaltic Terrain of Central India." Pp. 301–326 in *Sustainable Management of Land Resources*. Apple Academic Press. <https://doi.org/10.1201/9781315365565>
- Steinke, V. A., and E. E. Sano. 2011. "Semi-Automatic Identification, GIS-Based Morphometry of Geomorphic Features of Federal District of Brazil." *Revista Brasileira de Geomorfologia* 12(1). <https://doi.org/10.20502/rbg.v12i1.213>
- Thomas, J., S. Joseph, and K. P. Thirvikramaji. 2010. "Morphometric Aspects of a Small Tropical Mountain River System, the Southern Western Ghats, India." *International Journal of Digital Earth* 3(2):135–156. <https://doi.org/10.1080/17538940903464370>
- Verma, S., D. Khalkho, and L. K. Gupta. 2020. "Morphometric Analysis of a Drainage Basin Using Remote Sensing and Geographical Information System (GIS)." *International Journal of Current Microbiology and Applied Sciences* 9(4):1950–1959. <https://doi.org/10.20546/ijcmas.2020.904.232>