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Research Article

Characterizing Morphometric Attributes of the Lower Vellar Watershed Using the Geographic Information System, Tamil Nadu, India

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ABSTRACT

Morphometric analysis provides invaluable insights into watershed behavior and hydrological processes. This study delves into the morphometric characteristics of the Lower Vellar Watershed, a vital watershed of the Vellar basin in Tamil Nadu, India. Employing geospatial techniques, including remote sensing and geographic information systems (GIS), the study meticulously delineated the watershed boundary and computed a range of linear, areal, and relief parameters. The watershed exhibits a dendritic drainage pattern characterized by five stream orders and 598 streams. Key morphometric indices, such as bifurcation ratio (9.69), drainage density (0.20), and elongation ratio (0.427), were calculated to assess their influence on hydrological processes. The high drainage density indicates a propensity for surface runoff, while the circularity and elongation ratios suggest an elongated basin susceptible to delayed peak flows. Relief parameters, including relief ratio (0.00199) and ruggedness number (24.77), reveal moderate relief features that impact sediment transport and deposition. This study underscores the significance of morphometric analysis as a valuable tool for regional planning and natural resource management, particularly in semi-arid regions like Tamil Nadu. The findings contribute to a comprehensive understanding of watershed behavior, providing a solid foundation for future research and sustainable management strategies for the Lower Vellar Watershed and similar hydrological systems.

Keywords: Morphometric quantification, Lower Vellar watershed, GIS, linear, aerial, relief.

INTRODUCTION

Morphometric analysis has emerged as a critical approach for watershed prioritization in recent years, facilitated by advancements in remote sensing (RS) and GIS technologies (Mohammed et al. 2024; Gezahegn & Mengistu, 2025). A quantitative description of drainage systems, crucial for basin characterization, is derived through the analysis of river basin morphology. As a crucial reconnaissance technique, morphometric analysis facilitates identifying river surfaces and studying dimensional transformations in associated landforms. The significance of basin morphometric within morphometric analysis lies in its application by hydrologists and geomorphologists to address significant environmental challenges, including soil erosion, slope instability, flooding, landslides, and excessive surface runoff. One can investigate and elucidate the relationships linking drainage systems, geological formations, and landform dynamics by utilizing geographic information systems.

Numerous research teams have highlighted morphometric analysis's efficacy through remote sensing and GIS technologies (Rahman et al. 2022; Yılmaz et al. 2023). It was established that remote sensing and geographic information systems are key tools for assessing basin morphometry and monitoring continuous changes over time. Comprehensive analyses were conducted on the linear, areal, and relief aspects of the basin's morphometric characteristics using various mathematical equations and techniques. A watershed functions as a hydrological system, channeling surface runoff through a structured stream or channel toward a specific outlet). The plot reveals a lower logarithmic value with minimal deviation from a straight line in the relationship between stream number and stream order, pointing to regional uplift in the study area (Al Kalbani & Rahman, 2021; Roy & Chowdhury, 2024). Satellite imagery and topographical maps examine morphometric characteristics such as drainage pattern, stream order, bifurcation ratio, drainage density, and other linear and area-based metrics (Radwan et al. 2020). In the catchment area, the morphometry of the drainage network affects the patterns of surface runoff, soil erosion, and flood flow. The basin's drainage density values, ranging from 1.55 to 2.16 km/km², suggest a coarse drainage texture. Key information such as slope, stream network, drainage pattern, and drainage location is essential to evaluating the morphometric features of a drainage basin. This information can be accurately extracted from DEM, digital topographical maps, and satellite images with dependable precision. DEM datasets enable the derivation of linear, areal, and relief morphometric parameters through automated GIS techniques, which are faster, less subjective, and offer more reproducible measurements than traditional manual approaches (Arosio et al. 2024).

Hypsometric analysis refers to the study of the horizontal cross-sectional area of a catchment as it relates to elevation (Pande et al. 2021). Kasi et al. (2020) pioneered hypsometric analysis to quantify the relationship between the horizontal distribution of land area and its elevation in a drainage basin. Relative elevation was plotted against the relative area of the land surface to generate the hypsometric curves, using the spatial analyst module of GIS software to process the DEM. The hypsometric curves and integral values of the catchment show the equilibrium stage, erosional processes, and topographical characteristics and provide essential data on the geological stage and catchment development (Yammani & Nagabathula, 2024). In the present study, the quantitative analysis of morphometric parameters is carried out for the lower Vellar sub watershed, Tamil Nadu, India, using SRTM DEM data, SOI toposheet, and other data sources. Using standard mathematical equations, the measurement was performed in linear, areal, and relief aspects. The formulae used to calculate the linear parameters were obtained from the methodology and the relief aspects formulae were derived from techniques.

METHODOLOGY

Study area

The Vellar Basin, one of the major river systems in the Cuddalore district of Tamil Nadu, India, consists of nine sub-basins, including the lower Vellar, upper Vellar, Anaivari, Chinnar, Swethanadhi, Gomukhi, and Manimukthanadhi sub-basins. This study focuses on the lower Vellar sub-basin, which spans approximately 250 sq. km (Figure. 1). The lower Vellar watershed lies between latitudes 11°33'58.249"N and 11°27'48.864"N and longitudes 78°50'31.807"E and 79°22'41.39"E, with a maximum elevation of 61 meters above mean sea level. It falls within the Survey of India (SOI) 1:50,000 toposheets numbered 58M7, 58M3, 58M2, 58I14, and 58I15. The region experiences an average annual temperature of 21°C and receives an average rainfall of 1,249 mm. The study area is north of the Vellar River and includes notable water bodies such as the Wellington Tank. Additionally, the Nanagoor

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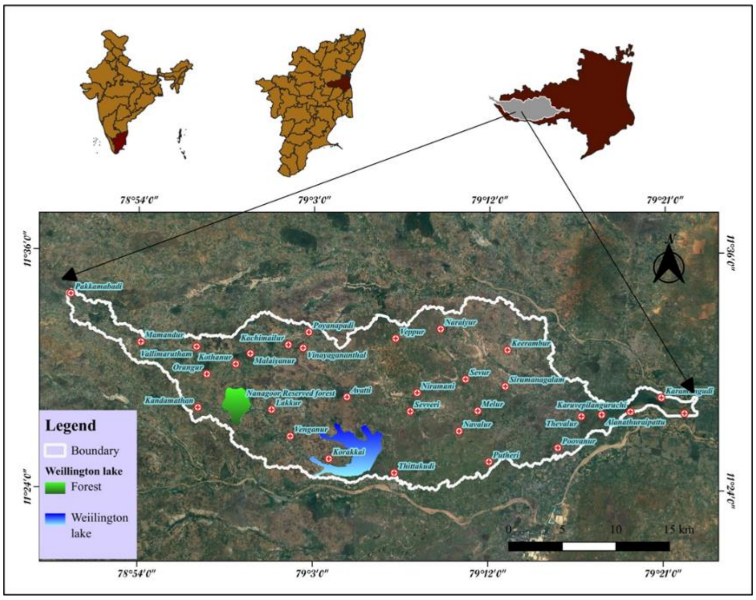

Figure 1. Location map of the Lower Vellar Watershed

Reserved Forest is located within this watershed. The geology of the lower Vellar basin shows distinct variations: the western part is dominated by hard rocks such as charnockites and migmatite gneiss, while the eastern section primarily consists of clay deposits. Geomorphologically, the western area features pediments and pediplains, whereas floodplains characterize the eastern part.

Delineating the Lower Vellar watershed

The process begins with acquiring the SRTM DEM data for the study area to delineate the watershed of the Lower Vellar using SRTM DEM in ArcGIS and ensuring it has adequate resolution and coverage. The DEM is then imported into ArcGIS and pre-processed to fill any sinks or depressions using the "Fill" tool, ensuring a continuous flow direction. Once the DEM is prepared, the "Flow Direction" tool is applied to calculate the direction of water flow for each cell in the raster. The resulting flow direction raster is further processed using the "Flow Accumulation" tool to identify the potential stream network based on accumulated flow. A pour point, representing the outlet of the watershed, is then defined or adjusted based on the study's geographical focus. The watershed boundary is delineated using the "Watershed" tool, which references the flow direction raster and pour point. The final output is a polygon layer representing the watershed of the Lower Vellar, which can be exported for further analysis or visualization.

Extraction of Drainage

The extraction of drainage streams and stream ordering for the Lower Vellar using SRTM DEM in ArcGIS begins with acquiring high-quality SRTM DEM data, ensuring proper resolution for hydrological analysis. The DEM is pre-processed to remove any sinks or anomalies using the "Fill" tool, a critical step to ensure accurate flow modeling. The "Flow Direction" tool is then applied to compute the flow direction for each raster cell based on the steepest downslope path. Using the resulting flow direction raster, the "Flow Accumulation" tool generates a flow accumulation grid, identifying potential drainage paths based on the number of upstream cells contributing to flow. A threshold value is set on the flow accumulation grid to define the drainage network, and this threshold is adjusted to match the specific stream density of the Lower Vellar area. Once the drainage network is delineated, the "Stream Order" tool, based on the Strahler method, is applied to classify the streams into hierarchical orders, with smaller tributaries assigned lower values and major streams receiving higher orders. The final output is a detailed and ordered drainage network, which can be exported and overlaid with other spatial data for hydrological analysis and watershed management. The morphometric analysis of the Lower Vellar watershed was conducted using GIS tools to derive various key parameters that describe the watershed's characteristics. The analysis was categorized into three main aspects: linear parameters, aerial parameters, and relief parameters.

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Linear Parameters

The linear parameters, including stream order, stream number, and stream length, were analyzed to assess the structure and distribution of the stream network. The stream order was determined to reflect the hierarchy of streams in the watershed, while the stream number was calculated to give the total count of streams in each order. The total stream length was computed to understand the spatial extent of the stream network. Additionally, bifurcation ratios and stream length ratios were calculated to examine the branching patterns of the streams and the variation in stream lengths across different orders. These parameters provided a clear view of the stream network's characteristics and behavior.

Aerial Parameters

The aerial parameters focused on the overall size and shape of the watershed. The watershed area and perimeter were derived using GIS tools to define the boundaries and spatial extent of the watershed. Drainage density, stream frequency, and drainage texture were calculated to assess the watershed's hydrological characteristics. Drainage density indicated the total stream length per unit area, while stream frequency referred to the number of streams per unit area. Drainage texture reflected the stream distribution along the watershed's perimeter. These parameters were employed to understand the watershed's potential for runoff, water flow patterns, and overall hydrological behavior.

Relief Parameters

The relief parameters were used to provide insights into the topography and elevation characteristics of the watershed. The minimum and maximum elevations were extracted to understand the vertical range within the watershed. Basin relief was calculated as the maximum and minimum elevation difference, indicating the overall elevation change. The ruggedness number, derived from basin relief and drainage density, was used to assess the roughness of the terrain. Additionally, the relief ratio and hypsometric curve value were calculated to analyze the steepness and elevation distribution across the watershed, providing valuable information about the watershed's topographical features.

Table 1 includes the formula used for each parameter for reference. Together, these analyses offered a comprehensive understanding of the watershed's physical characteristics, hydrology, and suitability for environmental management and conservation.

RESULT AND DISCUSSION

Morphometry of the Lower Vellar watershed: Linear Aspects

The linear aspects of morphometric analysis for the Lower Vellar watershed, including stream order, stream length, stream length ratio, and bifurcation ratio, are discussed below (Table 2).

Stream Order (U) and Stream Number (Nu)

Stream ordering follows the Strahler system, categorizing streams from the smallest tributaries (Order 1) to the highest order (Order 5) (Figure.2). A total of 598 streams were identified in the watershed, with a decreasing number of streams as the order increases (344 first-order streams to 11 fifth-order streams). This inverse relationship between stream order and stream number supports Horton's law of stream numbers, which posits that the number of streams decreases geometrically with increasing order (Figure 3). The dominance of first-order streams indicates the youthfulness of the drainage system, reflecting a high degree of terrain dissection. The analysis of stream numbers in relation to stream order shows that the Lower Vellar watershed predominantly features a dendritic drainage system, suggesting a landscape shaped by homogeneous lithology. However, minor structural influences can be observed in localized areas, affecting the drainage pattern.

Table 1: Formula and methods used in the morphometric analysis

Parameters	Formula/Method	Unit
Linear Parameter		

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Parameters	**Formula/Method**	**Unit**
Stream Order (U)	Hierarchical rank	Dimensionless
Stream Number (Nu)	(Nu)Nu = Nu1 + Nu2 + ⋯ + Nun	Dimensionless
Stream Length (Lu)	(Lu)Lu = Lu1 + Lu2 + ⋯ + Lun	Kilometer (km)
Bifurcation Ratio (Rb)	Rb = (Nu/Nu+1)	Dimensionless
Stream Length Ratio (Rl)	Rl = (Lu/Lu−1)	Dimensionless
Mean Stream Length (Lsm)	Lsm = Lu / Nu	Kilometer (km)
Mean Bifurcation Ratio (Rbm)	Average of bifurcation ratio of all orders	Dimensionless
Relief Parameter		
Minimum Elevation (h)	GIS software	meter
Maximum Elevation (H)	GIS software	meter
Relative Relief (Rhp)	Rhp = (H × 100/P)	Dimensionless
Basin Relief (Bh)	Bh = (H−h)	meter
Ruggedness Number (Rn)	Rn = (Bh × Dd)	Dimensionless
Relief Ratio (Rh)	Rh = (Bh/Lb)	Dimensionless
Hypsometric curve value (E)	E= (E mean - E min)/ (E max - Emin) where E is the Elevation of the basin	Dimensionless
Linear Parameter		
Area of watershed (A)	GIS Software	(Sq.km)
Perimeter of Watershed (P)	GIS Software	(Km)
Drainage Density (Dd)	Dd = ((ΣLu)/A)	Km/Sq.km
Stream frequency (Fs)	Fs = ((ΣNu)/A)	streams per unit area
Drainage Texture (Dt)	Dt = ((ΣNu)/P)	km-1
Infiltration number (If)	If = Fs × Dd	mm/hour
Constant channel maintenance	Inverse drainage density	(km^2/km)
Length of Overland flow (Lo)	Lo = (1/(2Dd))	m
Basin length (Lb)	Lb = 1.312 × $A^{0.568}$	(Km)
Form Factor (Ff)	Ff = $(A/Lb)^2$	Dimensionless
Circulatory ratio (Rc)	Rc = 4 πA /P^2 (Where, Au= Basin Area (km2), P= Perimeter of the basin (km) Π= 3.14)	Dimensionless
Elongation ratio (Lo)	Lo = (1/(2Dd))	Dimensionless

Table 2: Linear parameters of Lower Vellar Watershed

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Stream Order	Stream Number	Stream length (m)	Stream lg (km)	Stream Length Ratio	Mean Stream length (km)	Bifurcation ratio	Mean Bifurcation ratio
1	344	272265.20	272.27	1.28	0.791	2.49	2.42
2	138	139414.86	139.41	1.52	1.010	1.73	2.40
3	80	122713.14	122.71	0.47	1.534	3.20	5.05
4	25	17855.31	17.86	1.40	0.714	2.27	5.98
5	11	10990.23	10.99		0.999		9.69
	598	**563238.74**	**112.65**	**1.16**		**9.69**	**9.69**

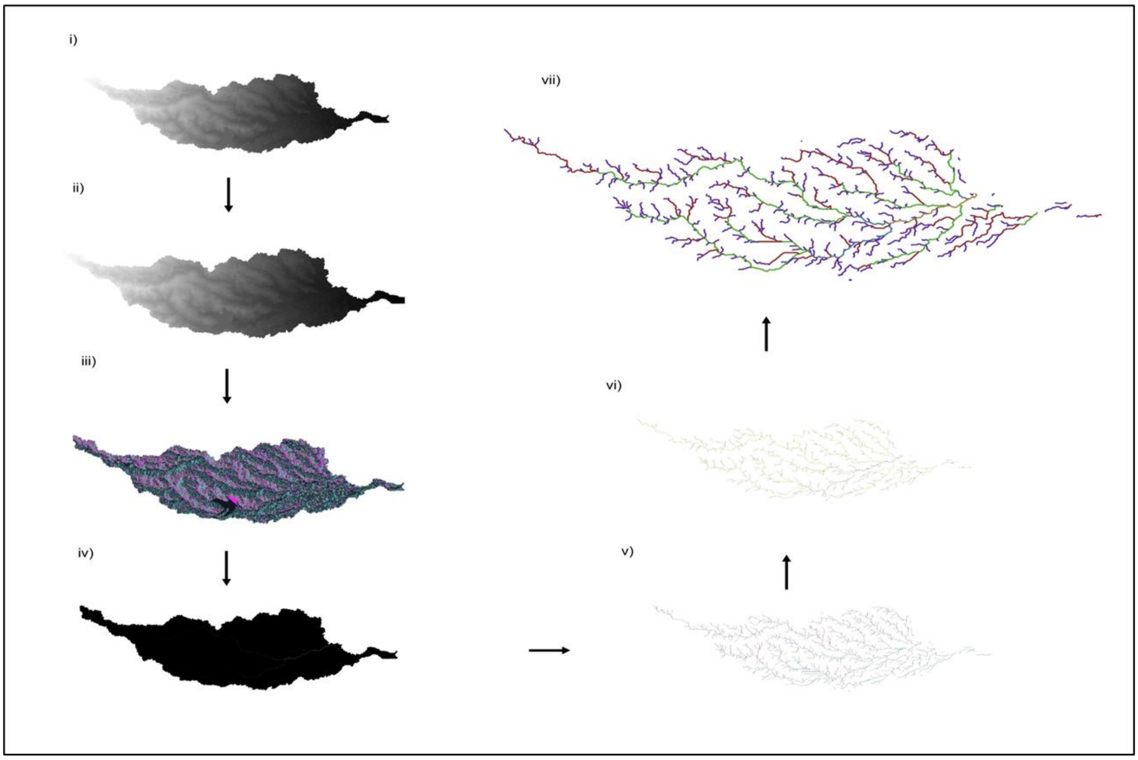

Figure 2. Steps involved in extraction of stream order through SRTM DEM data. i) Raw DEM data downloaded from USGS Earth data. ii) Void and errors were rectified using 'fill' tool iii) Flow direction of fill DEM iv) Flow accumulation v) Stream condition (con>500) threshold vi) stream order in raster vii) Stream feature

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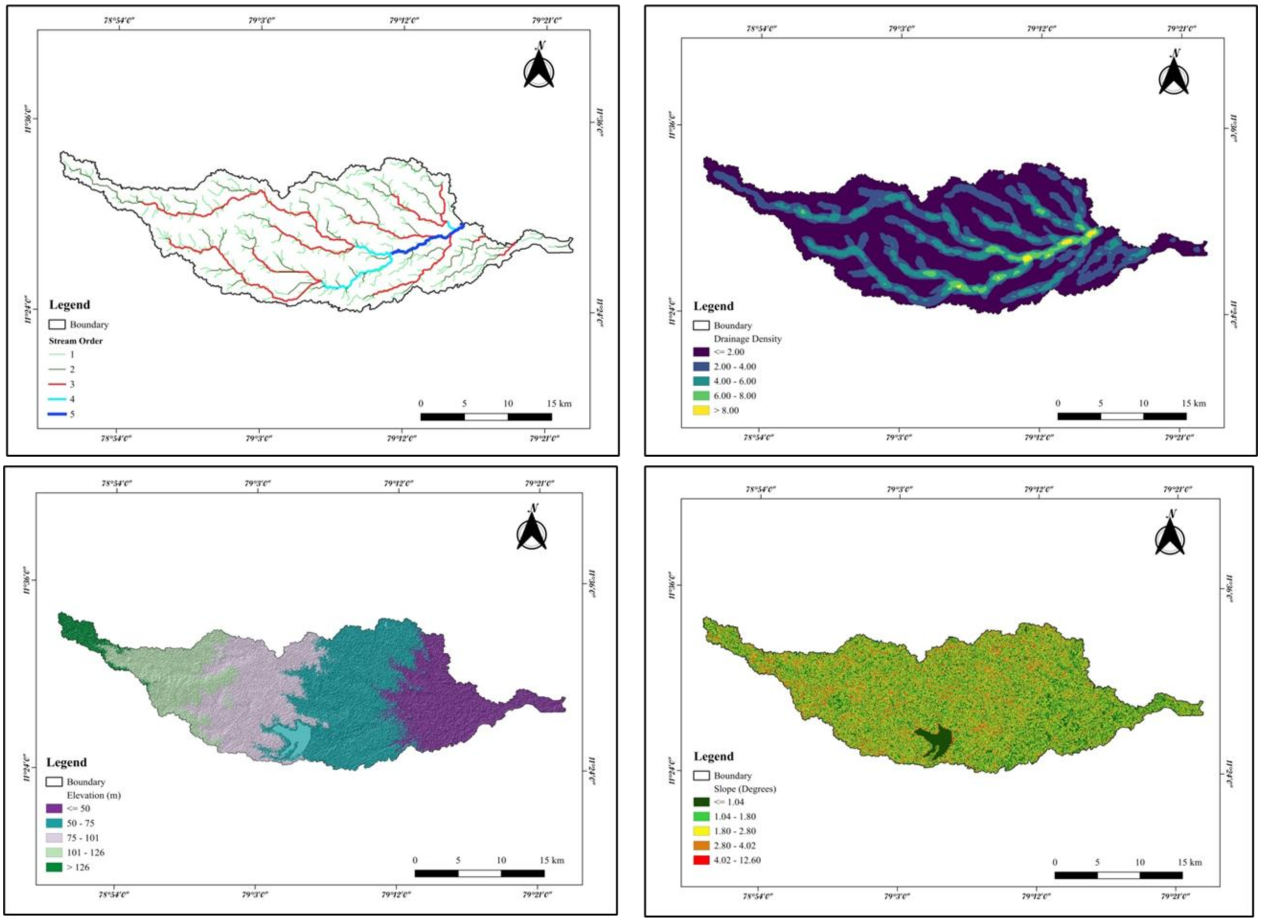

Figure 3. Map representing the Lower Vellar Watershed

Stream Length (Lu) and Length Ratios (Rl)

The total stream length for all orders in the watershed was calculated as 563,238.74 m (563.24 km). First-order streams contributed significantly to this total, with 272,265.20 m (272.27 km), while fifth-order streams contributed only 10.99 km. This pattern reflects the tendency for smaller-order streams to dominate the drainage network, as they are more numerous and have shorter lengths compared to higher-order streams.

The Stream Length Ratio (SLR), which is the ratio of the mean length of streams in one order to the mean length of streams in the next lower order, shows irregular variation across orders. The SLR between orders 1 and 2 is 1.28, while between orders 3 and 4, it is 1.40. These variations in SLR can be attributed to lithological heterogeneities and structural controls in the watershed. Areas with more resistant geological formations exhibit lower stream lengths due to limited erosion potential, as observed in regions with similar geomorphic and structural characteristics. The relationship between stream length and stream order in the Lower Vellar Watershed underscores the hierarchical nature of the drainage system, where lithology and structure significantly influence channel morphology.

Mean Stream Length (Lsm)

The Mean Stream Length ((Lsm)) increases with stream order, ranging from 0.791 km for first-order streams to 9.69 km for fifth-order streams. This trend aligns with the natural expectation that higher-order streams traverse longer distances as they integrate flow from lower-order tributaries. The higher MSL values for third- and fifth-order streams reflect enhanced flow integration and increased water and sediment transport capacity in these larger channels.

Bifurcation Ratio (Rb)

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The Bifurcation Ratio (Rb), which reflects the branching pattern and structural influence, ranges from 1.73 between second- and third-order streams to 9.69 between fourth- and fifth-order streams. The mean bifurcation ratio across the Watershed is 2.42 for lower-order streams. Higher values in the upper orders indicate that structural factors, such as faults or fractures, exert control over drainage patterns. Lower Rb values in the lower orders suggest a dendritic drainage pattern, which is typically associated with homogeneous lithology. However, higher Rb values in higher-order streams suggest the influence of geological structures in controlling stream distribution, a phenomenon frequently observed in tectonically active regions.

Hydrological Implications of Linear Parameters

The dominance of first-order streams (344 streams) indicates rapid runoff generation and low infiltration capacity. This suggests a potential for flash flooding during heavy rainfall events, especially in the upper reaches of the Watershed. The transition to fewer, higher-order streams indicates the integration of smaller tributaries into larger channels, which enhances the capacity for sediment transport and the development of floodplains in lower-order regions. The irregularities observed in bifurcation ratios suggest localized tectonic influences or lithological variations, which may affect the distribution and connectivity of drainage networks within the Watershed.

Morphometric of the Lower Vellar Watershed: Aerial Aspects

The aerial morphometric analysis of the Lower Vellar Watershed provides important insights into the shape, hydrological response, and geomorphological characteristics of the study area. The following parameters were considered in the analysis (Table 3).

Area (A) and Perimeter (P)

The total area of the watershed is 573 km², with a perimeter of 245.86 km. These values suggest a moderately large basin with an elongated shape, which influences the hydrological behavior of the watershed. Larger basins typically generate significant runoff volumes, and the perimeter impacts factors such as time of concentration and sediment deposition along the watershed boundary. The shape of the basin also dictates the flow dynamics, including water transport and storage, with elongated basins generally exhibiting longer times for water to reach the basin outlet.

Drainage Density (Dd)

The drainage density (Dd) for the Lower Vellar Watershed is calculated as 0.20 km/km², which is considered low. This value indicates a relatively permeable surface, often due to a porous substrate that facilitates infiltration over surface runoff. Low drainage density suggests a less dissected terrain, where stream networks are sparse. Such values are typical of regions with high vegetation cover, low relief, and substantial groundwater recharge potential. The low drainage density further implies that surface runoff is limited, and subsurface flow is more dominant in the hydrological regime.

Stream Frequency (Fs)

The stream frequency (Fs), representing the number of streams per unit area, is 1.04 streams/km². This low value supports the interpretation of limited surface drainage density, in line with the Watershed's permeable lithology and low relief. A low stream frequency indicates reduced surface runoff, as the terrain allows for greater infiltration, suggesting that flooding risks are lower during high-intensity rainfall events.

Drainage Texture

The drainage texture, calculated as the ratio of stream number to watershed perimeter, is 2.43. According to values between 2 and 4 indicate a moderate drainage texture. This reflects a balanced interaction between the lithological resistance and the structural controls of the terrain. The moderate drainage texture suggests that the watershed is influenced by both fluvial processes and variations in the underlying lithology, which may include areas with differing levels of resistance to erosion.

Infiltration Number

The infiltration number, calculated as the product of drainage density and stream frequency, is 0.21. This low value further confirms the watershed's high infiltration capacity, reinforcing the dominance of subsurface flow over surface runoff. Such conditions make the watershed less prone to flash flooding and indicate significant potential for groundwater recharge, aligning with the region's permeable lithology and low relief.

Table 3: Aerial parameters of Lower Vellar Watershed

S.no	Parameters	Values
1	Area of watershed (Sq.km)	573
2	Perimeter of Watershed (Km)	245.86
3	Drainage Density	0.20
4	Stream frequency	1.04
5	Drainage Texture	2.43
6	Infiltration number	0.21
7	Constant of channel maintenance	5.087
8	Length of Overland flow	2.54
9	Basin length (Km)	63.19
10	Form Factor	0.144
11	Circulatory ratio (Rc)	0.119
12	Elongation ratio	0.427

Constant of Channel Maintenance (C) and Length of Overland Flow

The constant of channel maintenance (C), which measures the land area required to sustain a unit length of a channel, is 5.087 km^2/km. This relatively high value reflects a low degree of channel development, suggesting that a substantial area is needed to support the drainage network. This is likely due to the high infiltration rates and low surface runoff in the Watershed, which limits channel development. The length of overland flow, inversely related to drainage density, is 2.54 km. This high value implies that water travels a longer distance over the surface before entering a stream channel. This characteristic is indicative of a permeable substrate and a reduced slope gradient, both of which facilitate infiltration and subsurface flow. The extended overland flow suggests that the watershed's surface runoff potential is relatively low, further promoting groundwater recharge.

Form Factor (Ff) and Circulatory Ratio (Rc)

The form factor of the watershed is 0.144, indicating an elongated basin shape. Basins with low form factor values typically have longer times of concentration, which can help reduce peak discharges during storm events. An elongated shape implies that the watershed is likely to experience more gradual runoff, mitigating the risk of flash floods by providing more time for water to infiltrate and flow downstream. The circulatory ratio (Rc) is 0.119, further supporting the elongated nature of the basin. Lower circulatory ratio values indicate that the basin is not circular, and its elongated shape contributes to delayed runoff concentration. This elongated shape further enhances the watershed's ability to store and manage water, reducing the likelihood of rapid runoff and flooding during heavy rainfall.

Elongation Ratio (Er)

The elongation ratio (Er) is 0.427, indicative of an elongated watershed with lower relief. This value suggests that the Lower Vellar Watershed has undergone less erosion and is in a relatively early stage of geomorphic development. The elongated shape and low relief also imply that the watershed's topography is conducive to infiltration, further decreasing the likelihood of flooding and surface runoff.

Hydrological Implications of Aerial Parameters

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The combination of low drainage density, stream frequency, and infiltration number indicates that the Lower Vellar Watershed is dominated by infiltration processes rather than surface runoff. These characteristics suggest that the watershed is less prone to flash floods and more conducive to groundwater recharge, as subsurface flow plays a dominant role. Additionally, the elongated shape of the basin, as reflected in the form factor, circulatory ratio, and elongation ratio, implies a prolonged time of concentration, which further mitigates the likelihood of rapid runoff. The conditions described are ideal for implementing groundwater recharge structures and soil conservation practices to enhance water retention and reduce erosion risks.

Morphometry of the Lower Vellar Watershed: Relief Aspects

The relief morphometric analysis of the Lower Vellar Watershed offers valuable insights into the watershed's topography, erosional processes, and hydrological characteristics. The major relief parameters of the Lower Vellar Watershed are discussed below (Table 4).

Table 4: Relief parameters of Lower Vellar Watershed

S.no	Parameters	Values
1	Maximum height of basin (m)	152
2	Minimum height at basin mouth (m)	26
3	Basin relief	126
4	Relative Relief	0.0512
5	Relief Ratio	0.00199
6	Ruggedness number	24.77
7	Hypsometric curve	0.50

Basin Relief

The basin relief, calculated as the difference between the maximum height of the basin (152 m) and the minimum height at the basin mouth (26 m), is 126 m. Basin relief represents the total elevation difference within the watershed and serves as a key indicator of erosional energy and slope gradient. The moderate basin relief of the Lower Vellar Watershed suggests that the terrain is neither extremely rugged nor completely flat, indicating a landscape in a transitional geomorphic stage. The moderate relief also implies a moderate potential for surface runoff and sediment transport, which plays a role in shaping the watershed's hydrological behavior.

Relative Relief

The relative relief, defined as the ratio of basin relief to the perimeter of the watershed, is 0.0512. This relatively low value indicates that the Watershed has relatively subdued topography with gentle slopes. Low relative relief values are typical of watersheds that are less dissected and experience lower erosion rates. This characteristic aligns with the observed moderate drainage density and high infiltration potential, which further reduces the likelihood of severe surface runoff and erosion. The subdued topography suggests a landscape that is less susceptible to rapid changes due to erosion or landslides.

Relief Ratio (Rr)

The relief ratio (Rr), calculated as the ratio of basin relief to basin length, is 0.00199. This very low value indicates a low slope gradient, which in turn reduces the velocity of surface runoff and promotes greater infiltration. The relief ratio also serves as an indicator of the watershed's geological maturity; low values are typically associated with mature watersheds that exhibit limited susceptibility to rapid erosion or landslides. This suggests that the Lower Vellar Watershed is in a mature stage of geomorphic evolution, with a stable and relatively low erosion rate.

Slope

The slope map illustrates the gradient of the terrain within the lower Vellar watershed, measured in degrees. Slope, a critical factor influencing surface runoff, soil erosion, and sediment transport, is categorized into distinct ranges: areas with gentle slopes (≤ 1.04°) are ideal for water accumulation and sediment deposition, resembling floodplains and lowlands; those with moderate slopes (1.04–1.80°) exhibit moderate runoff, making them suitable for agriculture with minimal erosion risk; moderately steep slopes (1.80–2.80°) experience noticeable runoff and necessitate soil conservation measures; steep slopes (2.80–4.02°) are prone to significant runoff and erosion, acting as pathways for sediment transport towards streams; and very steep slopes (> 4.02°) are highly susceptible to erosion and rapid water flow, contributing to downstream sediment deposition.

Aspect

Aspect maps, which display the compass direction of each slope, provide valuable insights into hydrological studies, aiding in understanding flow patterns, erosion dynamics, and solar exposure effects on the terrain. The slopes are categorized into five primary direction ranges: northeast-east, southeast, south, southwest-west, and northwest. Each aspect influences solar exposure, water flow, and erosion potential. Slopes facing northeast to east (≤ 71.54°) exhibit specific characteristics, while those facing southeast (71.54–143.08°) may channel water flow towards southeastern parts of the watershed. South-facing slopes (143.08–214.63°) experience high solar radiation during the day, affecting soil moisture retention. Slopes facing southwest and west (214.63–286.17°) influence the direction of runoff water and erosion towards western boundaries. Northwest-facing slopes (> 286.17°) contribute to runoff towards the northwest (Figure. 4).

Ruggedness Number (Rn)

The ruggedness number (Rn), calculated as the product of basin relief and drainage density, is 24.77. This relatively high value indicates moderate terrain roughness, influenced by both relief and the density of the drainage network. While the ruggedness number suggests some susceptibility to erosion, the overall low drainage density in the Watershed helps minimize sediment transport and reduces the impact of surface runoff on soil erosion. The ruggedness number reflects the Watershed's transitional geomorphic status, characterized by a balance between more rugged terrain in the upper reaches and flatter areas downstream.

Hypsometric Curve and Integral

The hypsometric curve is a graphical representation of the area-altitude distribution within the watershed. The hypsometric integral for the Lower Vellar Watershed is 0.50 (Table 5). This value suggests a moderately dissected basin in a state of geomorphic equilibrium. The watershed has undergone significant erosion but retains some relief in the upper reaches, indicating that fluvial processes are still active but have slowed over time. The hypsometric analysis points to a basin in a mature stage of geomorphic development, characterized by balanced erosion and deposition processes. The dominance of mid-elevation zones and the gradual slope profiles emphasize the watershed's efficiency in sediment redistribution. These findings align with other morphometric parameters, suggesting that the watershed is stable yet dynamic, making it suitable for sustainable water and soil management (Figure 5).

Hydrological Implications of Relief Parameters

The moderate basin relief and low relief ratio indicate that surface runoff velocity is reduced, allowing for more infiltration. This dynamic decreases the risk of flash flooding and enhances groundwater recharge within the Watershed. The low relative relief and moderate ruggedness number suggest that the Watershed is not prone to severe erosion; however, localized areas with steeper slopes may still be vulnerable and may require soil conservation measures. The hypsometric integral further supports the notion of a watershed in equilibrium, where sediment delivery to downstream areas occurs in a gradual and predictable manner. This balanced condition reduces the likelihood of sediment-related issues in reservoirs or agricultural lands, contributing to long-term stability and sustainable land use practices.

CONCLUSION

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This study presents a comprehensive morphometric analysis of the Lower Vellar Watershed in Tamil Nadu, India, utilizing geospatial technologies to assess its morphometric characteristics in linear, aerial and relief aspect. The morphometric analysis of the watershed reveals critical insights into its hydrological characteristics and geomorphological dynamics.

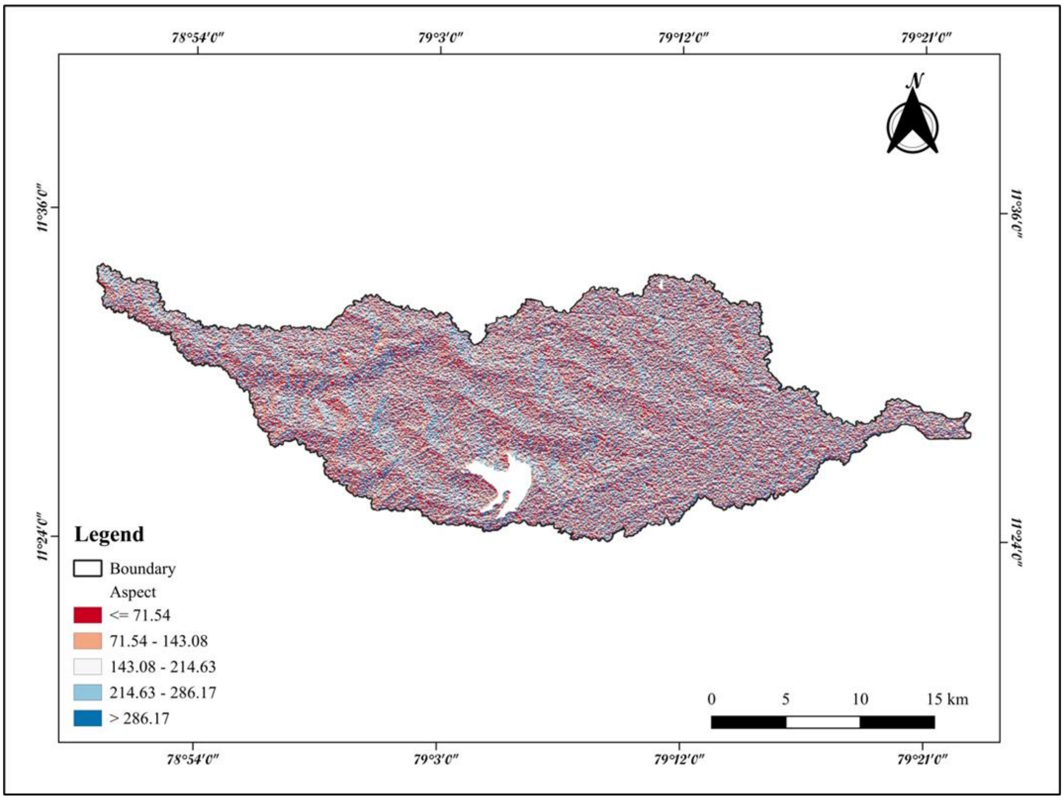

Figure 4. Map representing the Aspect of the Lower Vellar Watershed

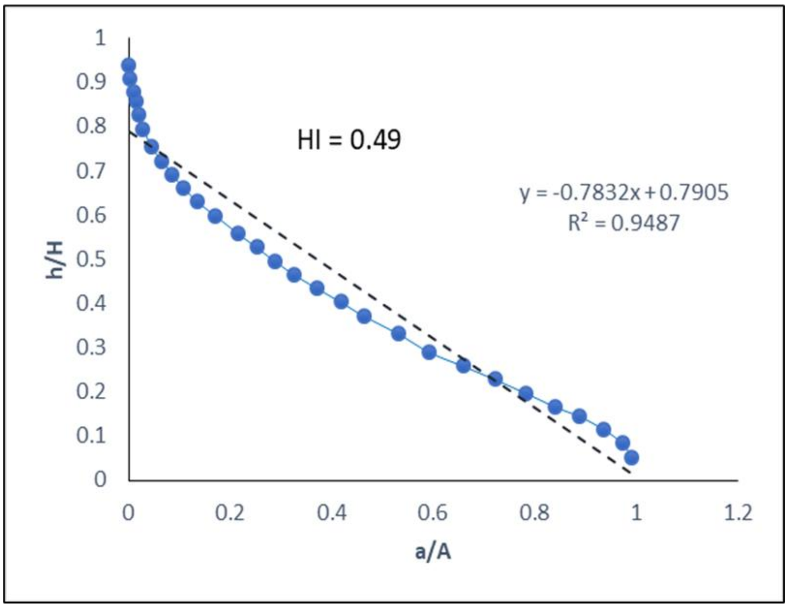

Figure 5. Hypsometric curve

The watershed exhibit the five orders of stream with The watershed exhibits a dendritic drainage pattern. The decrease in the number of streams per order can indicate areas of significant erosion, where smaller channels are eroded or merged into larger ones. With a total area of 573 km² the watershed exhibits a drainage density of 0.20, indicating a relatively well-vegetated and low-erosion environment. The stream frequency and a drainage texture suggest a moderate to low level of surface runoff. The bifurcation ratios, demonstrate a well-developed hierarchical drainage network, with fewer higher-order streams indicating significant confluence. The elongation ratio and form factor suggest an elongated basin, which may result in a delayed peak discharge, important for flood management. The relief parameters, including a relief ratio and ruggedness number to a relatively low relief terrain, influencing the flow dynamics and sediment transport within the basin. The hypsometric curve value along with the moderate basin relief, further highlights the watershed's potential for water retention and soil conservation. Ultimately, the morphometric data generated in this study offer crucial insights for effective watershed management, optimal water resource planning, and flood risk mitigation. The findings emphasize the need for integrated conservation strategies, such as water conservation and soil erosion control, to safeguard the integrity of this well-organized, low-relief watershed, ensuring its long-term sustainability and resilience against erosion and flooding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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