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Morphometric characteristics for watershed monitoring using geospatial techniques in VEL river basin Maharashtra India

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Abstract
The Vel River Basin demonstrates diverse geomorphological features, characterized by a moderately steep terrain and a well-developed drainage system. The basin's gentle slopes contribute to a gradual flow of water, which reduces the chances of sudden flooding events. The elongated shape of the basin supports prolonged water retention, allowing for better groundwater recharge and reduced peak discharge. However, the rugged topography and the presence of numerous streams suggest a high potential for erosion and sediment transport, particularly in the steeper regions. These factors make the basin sensitive to changes in land use and rainfall patterns, highlighting the importance of implementing sustainable watershed management practices. Overall, the basin's characteristics suggest a balanced hydrological system but one that requires careful monitoring to mitigate erosion and enhance water conservation efforts.

Keywords: Vel River, morphometric characteristics, watershed monitoring, geospatial techniques

Introduction

It is essential to monitor and manage watersheds to ensure the sustainability of water resources, especially in areas where environmental pressures and water scarcity are prevalent. The quantitative study of landforms known as morphometric analysis has become an effective tool for comprehending the dynamics and features of watersheds (Manjare *et al.*, 2018) [12]. The development of geospatial technology, such as remote sensing and Geographic Information Systems (GIS), has allowed researchers to perform high-resolution morphometric analyses with previously unheard-of efficiency and accuracy (Kadam *et al.*, 2023; Pande *et al.*, 2021) [10, 14]. These cutting-edge methods provide thorough evaluations of watershed characteristics, which improves decision-making for the protection and management of water resources. The diverse geography, fluctuating climate, and rising water demands in Maharashtra make watershed monitoring a top priority. Since the area frequently floods and faces water scarcity, efficient watershed management is essential for maintaining ecological balance, urban growth, and agricultural output (Ahirwar *et al.*, 2019, Kadam *et al.*, 2017) [1, 9]. Because of their varied geological formations and complicated terrain, Maharashtra's watersheds-including the Vel River Basin-need to be thoroughly studied using morphometric techniques to fully comprehend their hydrological potential and behaviour.

Maharashtra's watershed analysis has been completely transformed by GIS and remote sensing technologies, which offer strong analytical tools and high-resolution spatial data. With the aid of these geospatial tools, exact morphometric parameters can be extracted from topographic maps, satellite photos, and digital elevation models (DEMs) (Mahajan and Sivakumar 2018) [11]. GIS makes it possible to integrate several data layers, which makes it easier to conduct in-depth spatial analysis and visualize the features of watersheds. Current data on land use, vegetation cover, and surface water bodies are provided by remote sensing data, which improves the precision of morphometric assessments and makes it possible to track changes in watersheds an overtime (Pasham *et al.*, 2022) [15].

Geospatial techniques are especially useful for morphometric study in basaltic terrain, such as that found in areas of the Vel River Basin, due to the specific challenges presented by the topography. Basaltic rocks are hard and resistant, which effects drainage patterns, slope characteristics, and erosion processes (Kadam *et al.*, 2019) [8].

High-resolution DEMs created from satellite data or LiDAR surveys enable thorough mapping of these complicated terrains. Key morphometric metrics studied in such research include basin area, perimeter, stream order, drainage density, stream frequency, bifurcation ratio, elongation ratio, circularity ratio, and relief features (Diwate *et al*., 2024) [3]. These data, when examined using GIS, provide critical insights into the watershed's hydrological behaviour, erosion vulnerability, and general health. The Vel River Basin's morphometric analysis should concentrate on essential characteristics in the linear, areal, and relief dimensions. Linear features such as stream order, length, bifurcation ratio, and length ratio aid in understanding the structure and development of the basin's drainage network. Areal factors such as drainage density, stream frequency, form factor, circularity ratio, and elongation ratio provide information about the basin's shape, drainage efficiency, and runoff characteristics. These characteristics are critical in determining the watershed's hydrological behaviour and potential response to rainfall events.

Relief aspects, including basin relief, relief ratio, and ruggedness number, are particularly important for the Vel River Basin due to its location in the varied topography of Pune district. These parameters help quantify the basin's steepness and erosion potential, which are critical factors in a region with diverse geological features. Additionally, the analysis should consider the drainage pattern and asymmetry factor to understand geological controls on the basin's morphology (Benzougagh *et al*., 2022) [2]. By utilizing high-resolution digital elevation models and satellite imagery within a GIS environment, these parameters can be accurately calculated and analysed, providing a comprehensive assessment of the Vel River Basin's morphometric characteristics for effective watershed management and planning.

Study area

The Vel River Basin, located in western India, is an important watershed for agricultural, domestic, and industrial activity. The Vel River, a tributary of a larger river system, is distinguished by its seasonal flow pattern, which is strongly impacted by monsoon rainfall. The extents between from 74º07′37.69" to 74º09′47.51"E and 18º39′43.04" to 18º41′53.56"N and Survey of India Toposheets no. 47J/2, for scale 1:50,000.

The river basin is critical in water resource management, notably irrigation and groundwater recharge. The basin's terrain varies, with highlands contributing to surface runoff and lowlands serving as zones for water collection and retention.

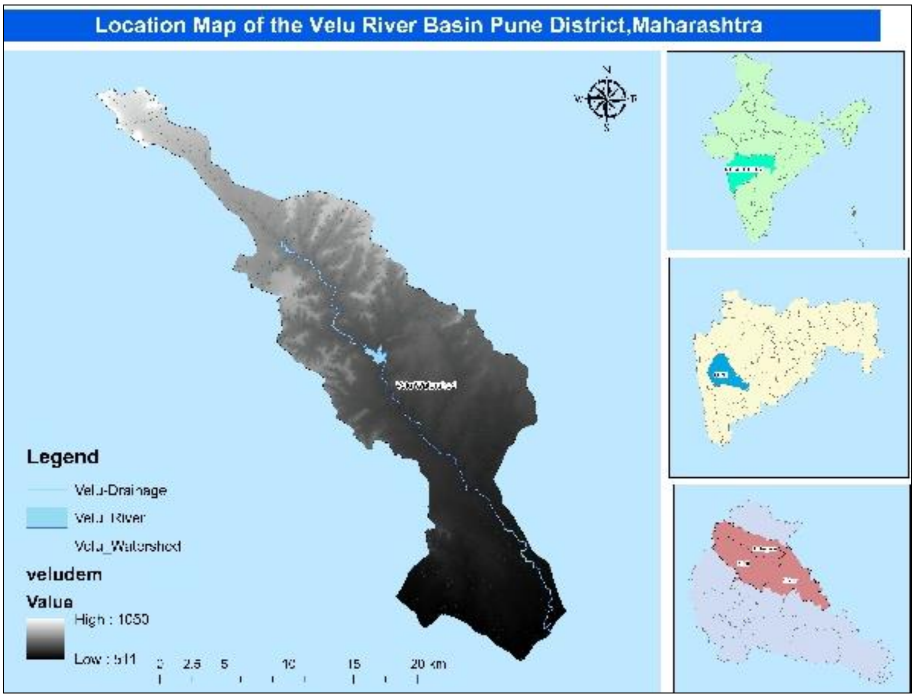

Fig 1: Location map of Vel river basin

The climate of the Vel River Basin is tropical monsoon with distinct wet and dry seasons. The yearly rainfall average is between 600 and 1200 mm, with the southwest monsoon months of June through September seeing most of the precipitation. Because of height variations, the basin's rainfall intensity varies greatly, with higher areas receiving more rain. Water management and storage are vital for the area because the post-monsoon season brings dry weather and little rainfall to the area. In the milder months, the temperature is 20 °C; in the summer, it is over 35 °C.

The topography and land usage of the Vel River Basin influence the different types of soil. While the middle and lower parts of the basin feature deeper alluvial soils suited for agriculture, the top portions of the basin are usually characterized by shallow and stony soils. These agricultural regions are mostly made up of sandy loam, clay loam, and black cotton soils, which are suitable for crops including sugarcane, rice, wheat, and vegetables. In recent decades, the basin's land use has changed because of a growth in urbanization and industrial development, especially in the lower parts. Deforestation in the upper catchment as a result has altered the normal hydrological cycle and contributed to soil erosion. Reforestation and water harvesting are two examples of sustainable land use techniques that are being explored to lessen these problems and guarantee.

The Vel River Basin's land use has changed significantly in recent years because of growing urbanization and agricultural activity. Changes in land cover influence the basin's natural hydrology, which affects soil erosion, river sedimentation, and patterns of water flow. Many communities have challenges from seasonal floods, especially during the monsoon season, which calls for the use of efficient flood management techniques. Sustainable management of water resources is essential for the long-term health of the environment in the Vel River Basin and the livelihoods of those who depend on it, as is the preservation of ecological balance.

Methodology

Using geospatial tools, a morphometric investigation of the Vel River Basin was carried out to assess its physical and hydrological properties. Accurate topography mapping and border delineation of the basin were achieved by the utilization of satellite data and Digital Elevation Models (DEM). Stream networks were automatically created, and flow direction and accumulation data were taken from the DEM to comprehend water movement within the basin. These actions provided information about the drainage pattern of the basin and the Vel River system's water flow.

To categorize the stream network of the Vel River Basin, important morphometric metrics were computed, such as stream order, stream length, and bifurcation ratio. The form factor and elongation ratio were used to evaluate the basin's shape, while the drainage density and stream frequency were used to determine how well the basin handled runoff. The vertical terrain variation, which affects both water runoff and erosion processes, was assessed by measuring the relief parameters, such as roughness number, relief ratio, and basin relief. The flood potential and hydrological dynamics of the basin were clearly understood thanks to these measurements.

An analysis of the land use/land cover (LULC) patterns within the Vel River Basin was also performed to assess the impact of human activities on the watershed. Changes in land cover due to urbanization and agricultural practices were mapped using remote sensing data. This analysis, when integrated with the morphometric findings, revealed critical areas prone to flooding or erosion, and potential zones for water conservation and groundwater recharge were identified. Overall, the results of the study offered crucial insights for the sustainable management of the Vel River Basin, ensuring a balanced approach to both environmental preservation and resource utilization.

Morphometric parameter

Result and discussion

Linear aspects

The Vel River Basin's stream order classification offers a thorough understanding of the hierarchical organization and structure of the river network. There are 728 streams at the first-order level, totalling 446.85 kilometres in length. These streams are the most common and usually come from a variety of places, like tiny runoff areas or springs (Horton 1945; Strahler 1957) [6, 17]. They stand for the first phase of the river network, during which time water starts to gather and move into more definite channels. Because of its richness, the river system begins with a dense network of little tributaries that contribute to the basin's general hydrological regime (Pastor *et al*., 2024) [23]. As streams join, they form second-order streams. The Vel River Basin has 284 of these streams, extending 154.14 km.

Table 1: Liner aspects of Vel River basin

	Parameter	Formula	Explanation
Linear Aspects			
1	Stream Order (S)	-	Strahler's stream order Strahler (1964) [18] classification using the stream network derived from the DEM.
2	Stream Length (L)		Calculate the total length of streams in each order.
3	Bifurcation Ratio (Rb)	($Rb = N_o/N_o+1$).	Ratio between the number of streams in successive orders Schumm (1956) [16]
4	Length of Overland Flow (Lg)	(Lg = 1/2D, where D is drainage density)	Measure half the distance between the divides and the stream channels Horton (1945) [6]
Areal Aspects			
5	Drainage Area (A)		Total area of the watershed derived from the boundary.
6	Drainage Density (Dd)	(Dd = L/A)	Ratio of total stream length to the watershed area Horton (1932) [5]
7	Stream Frequency (Fs)	(Fs = N/A).	Number of stream segments per unit area Horton (1932) [5]
8	Form Factor (Rf)	($Rf = A/L^2$, where L is the basin length).	Measure of the shape of the watershed Horton (1945) [6]
9	Elongation Ratio (Re)	($Re = 2\sqrt{(A/\pi)}/L$)	Ratio of the diameter of a circle with the same area as the watershed to the length of the basin Schumm (1956) [16]
10	Circularity Ratio (Rc)	($Rc = 4\pi A/P^2$, where P is the perimeter)	Ratio of the watershed area to the area of a circle having the same perimeter Miller (1953) [13]
Relief Aspects			
11	Basin Relief (H)		Difference between the maximum and minimum elevation within the watershed. Strahler (1957) [17]
12	Relief Ratio (Rr)	(Rr = H/L).	Ratio of basin relief to basin length Schumm (1956) [16]
13	Ruggedness Number (Rn)	($Rn = H \times Dd$).	Product of basin relief and drainage density Schumm (1956) [16]

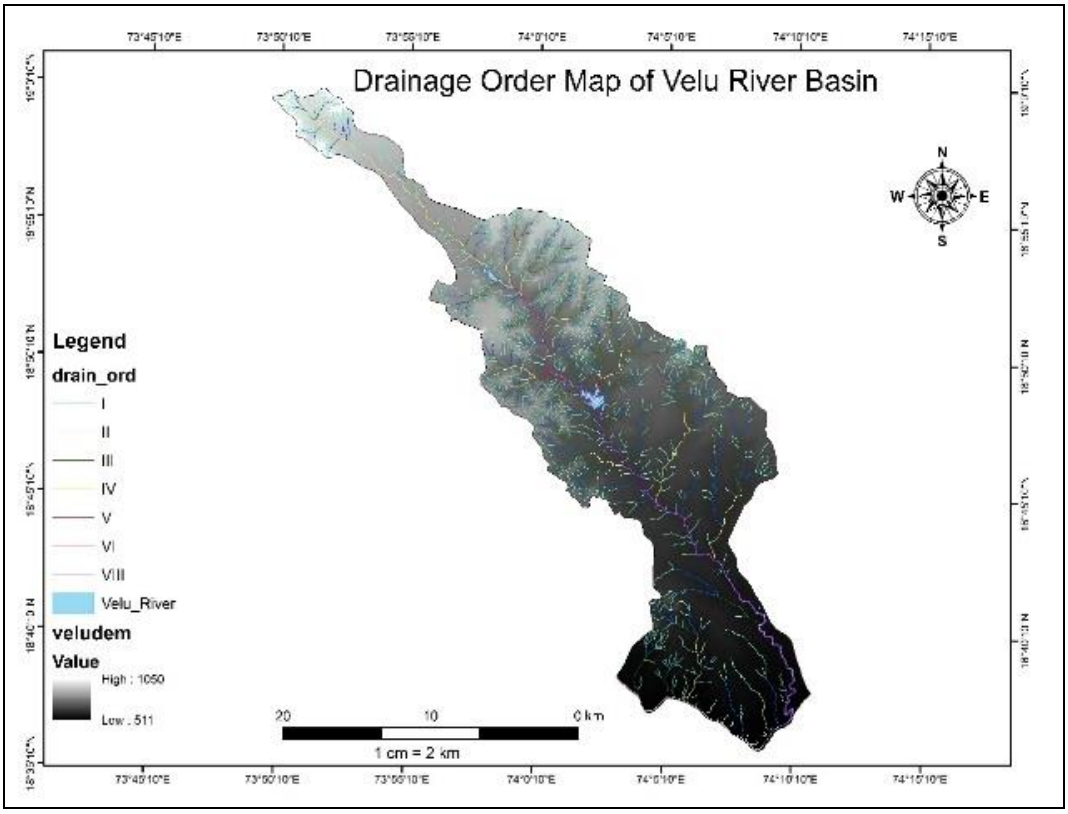

Fig 2: Drainage map of Vel river basin

Table 2: Stream Order Characteristics: Number of Streams, Total Length, and Bifurcation Ratios

Stream Order (u)	Number of streams Nu	Total length of streams in km	Bifurcation Ratio
1	728	446.85	
2	284	154.14	2.56
3	103	76.57	2.76
4	24	24.27	4.29
5	3	14.52	8.00
6	1	13.24	3.00

The bifurcation ratio of 2.56 indicates that each second-order stream is formed by the confluence of approximately 2.56 first-order streams. This branching reflects the transition from smaller, numerous streams to slightly larger ones, as water from multiple first-order streams combines. This stage of the river network marks a significant increase in stream size and volume, enhancing the basin's drainage capacity. Moving up to third-order streams, the Vel River Basin contains 103 of these, with a total length of 76.57 km. The bifurcation ratio for third-order streams is 2.76, suggesting that each third-order stream receives flow from about 2.76 second-order streams. This ratio indicates a more complex network with increased stream consolidation and larger tributaries. The presence of third-order streams represents a more developed stage of the river system, where water flow is further concentrated, and the stream network becomes more integrated (Kaliraj *et al*., 2015) [24]. The basin's fourth-order streams number 24, with a combined length of 24.27 km.

These streams are formed by the merging of third-order streams, and the bifurcation ratio of 4.29 means that each fourth-order stream is fed by approximately 4.29 third-order streams. This high ratio reflects a high level of consolidation and branching in the river network, leading to fewer but larger streams. The fourth-order streams play a crucial role in the river system, as they represent a more advanced stage of stream development, carrying larger volumes of water and contributing significantly to the basin's hydrological dynamics.

Fifth order and sixth-order streams in the Vel River Basin are even more specialized. There are only 3 fifth-order streams, to taling 14.52 km, with a bifurcation ratio of 8.00. Each fifth-order stream is formed by the confluence of about 8 fourth-order streams. The single sixth-order stream, with a length of 13.24 km, has a bifurcation ratio of 3.00, indicating it is fed by 3 fifth-order streams. These higher-order streams represent the most developed and largest components of the river network, integrating substantial flow from multiple tributaries and playing a crucial role in the basin's water management and sediment transport. The hierarchical structure of the stream orders illustrates the increasing complexity and consolidation of the river system as one moves from smaller, numerous streams to fewer, larger ones (Rai *et al*., 2017) [25].

Areal aspects

The total area of the Vel River Basin indicates the extent of the watershed that drains into the Vel River. A larger area can contribute more surface runoff during rainfall events, affecting the river's flow volume and flood risks. In this case, the basin covers 352.13 sq km, which is moderately sized and capable of influencing local water availability and groundwater recharge. The perimeter is the total boundary length of the basin. A longer perimeter, as seen here, can suggest an irregular or elongated shape, which impacts the travel time of water from different parts of the basin to the main river channel. Drainage density is the total length of streams and rivers per unit area of the basin. A value of 2.07 km/sq. for the Vel River Basin indicates a moderately dense drainage network, meaning that water is efficiently drained from the surface into the stream system. A higher drainage density suggests quicker surface runoff, which can lead to rapid river response during storms but may also increase erosion risks. Stream frequency refers to the number of streams per unit area in the basin. A value of 3.25 suggests a relatively high number of streams, which supports the idea of a well-developed drainage network. Higher stream frequency can contribute to rapid water flow but also highlights the potential for sediment transport and erosion within the basin.

Table 3: Areal aspects of Vel River basin

Morphometric parameters	Results
Area (Sq. km)	352.13
Perimeter (km)	132
Drainage density (km/sq. km)	2.07
Stream frequency	3.25
Texture ratio	5.52
Basin length (km)	55.98
Elongation ratio	0.37
Circularity ratio	0.25
Form factor ratio	0.11

The texture ratio is the number of first-order streams per unit length of the basin's perimeter. A value of 5.52 indicates a moderate to high dissection of the landscape, meaning the basin is characterized by rough terrain with numerous smaller tributaries contributing to the main river. This increases surface runoff and sediment transport, especially during heavy rainfall. Basin length is the longest distance from the basin's headwaters to its outlet. A longer basin length, such as 55.98 km for the Vel River Basin, suggests a more elongated watershed, which influences the time it takes for water to reach the main river. Elongated basins tend to have lower peak discharges but more prolonged runoff periods. The elongation ratio compares the shape of the basin to a circle. A value of 0.37 indicates that the Vel River Basin is elongated rather than circular. This suggests that the basin experiences slower, more prolonged water movement and a lower likelihood of sudden, high-intensity floods compared to circular basins, which concentrate water more quickly.

The circularity ratio is a measure of how close the shape of the basin is to a circle. A low value of 0.25 indicates that the Vel River Basin is highly elongated. This elongation reduces the potential for high flood peaks, as water takes longer to concentrate in the river system compared to more circular basins. The form factor ratio is the ratio of basin area to the square of its length. A value of 0.11 confirms that the basin is elongated. Elongated basins tend to have less intense flooding as water is spread over a larger distance, resulting in a lower peak discharge rate compared to more compact basins.

Relief aspects

The morphometric analysis of the Vel River Basin yielded several important quantitative parameters. The Basin Relief (H) was calculated as the difference between the maximum elevation (1,059 m) and minimum elevation (535 m), resulting in a value of 524 m. This relief value was then used to compute the Relief Ratio (Rr), which is the ratio of basin relief to basin length (Schumm 1956, Chopra *et al*. 2005, Rudraiah *et al*. 2008) [16, 20]. Given the basin length of 55.98 km, the Relief Ratio was determined to be 0.00936 or 9.36 m/km. Finally, the Ruggedness Number (Rn) was calculated by multiplying the Basin Relief (524 m) by the Drainage Density (2.07 km/sq km), resulting in a value of 1,084.68 m/km. These calculations provide quantitative measures of the watershed's topographic characteristics, which are essential for understanding its hydrological behaviour and susceptibility to erosion processes (Selvan *et al*. 2011, Gutema *et al*. 2017) [21, 22].

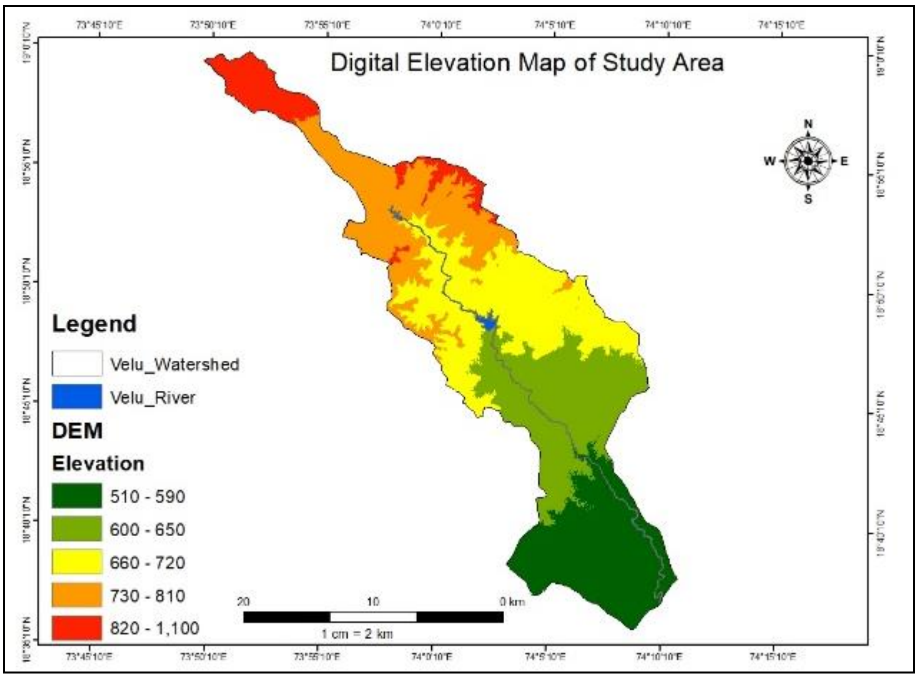

Fig 3: DEM map of study area

The morphometric analysis of the watershed reveals significant insights into its topographic and hydrological characteristics. The Basin Relief (H) of 524 m indicates a moderate elevation difference within the watershed, suggesting a varied topography that can influence runoff patterns and erosion processes. The Relief Ratio (Rr) of 9.36 m/km represents a moderate steepness of the watershed. This value suggests that the basin has a gradual slope profile, which can affect the velocity of surface runoff and the potential for soil erosion.

The Ruggedness Number (Rn) of 1,084.68 m/km is a crucial indicator of the watershed's susceptibility to erosion. This relatively high value implies that the basin has a rugged terrain with a high susceptibility to erosion, particularly during intense rainfall events. The combination of moderate relief and high drainage density contributes to this ruggedness, suggesting that the watershed may experience rapid runoff and potentially high sediment transport during storm events. These morphometric parameters collectively indicate that the Vel River Basin has a complex terrain that requires careful management to mitigate erosion risks and maintain ecological balance.

Conclusion

Stream order is a hierarchical classification system used to understand the structure of a river network. At the lowest level, first order represents the smallest and most numerous channels, forming the basic framework of the river system. second Order streams are created by the confluence of multiple first-order streams and are larger in size, signifying the beginning of network consolidation. As streams merge further, third Order and higher levels represent increasingly larger and more integrated channels, with fourth order and above reflecting more complex and substantial parts of the river network. Each ascending order indicates a greater volume of water flow and a more developed and organized drainage system, with higher orders playing critical roles in the basin's hydrology and sediment transport.

Areal Aspects of morphometric parameters indicate that the Vel River Basin is elongated, with a moderately dense drainage network and numerous streams. This suggests a basin where water flow is relatively quick, though not prone to sudden and extreme floods. However, the elongated shape and moderate drainage density mean that runoff will be distributed over time, making flash flooding less likely but indicating the potential for gradual accumulation of flow. Additionally, the basin’s rough texture and high stream frequency point to significant erosion risks, which will need to be managed through sustainable land and water management practices.

These Relief Aspects assessment indicate a landscape with significant erosion potential, particularly during intense rainfall events. For effective watershed monitoring, it is crucial to implement a comprehensive strategy that includes erosion control measures, regular sediment load monitoring, careful land-use planning, and the establishment of hydrological monitoring stations. Additionally, developing early warning systems for flash floods, promoting soil conservation practices, and conducting periodic assessments of land cover changes using remote sensing techniques are essential. These measures will help maintain the ecological balance of the basin, ensure sustainable water resource management, and mitigate potential hazards associated with its geomorphological features. Continuous monitoring and adaptive management based on these morphometric insights will be key to preserving the long-term health and functionality of the Vel River Basin ecosystem.

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