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Relief Analysis for Soil Conservation Planning in the Mulshi Reservoir Catchment Using a Digital Elevation Model (DEM)

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Abstract:

Terrain characteristics strongly influence soil erosion and sediment transport within watersheds, affecting reservoir sedimentation and storage capacity. This study applies Digital Elevation Model (DEM)–derived relief and morphometric parameters to assess soil erosion susceptibility in the Mulshi Reservoir catchment. The catchment covers an area of 250.25 km², with elevations ranging from 504 m to 1071 m above mean sea level, resulting in a basin relief of approximately 567 m. Watershed-scale parameters including basin relief, relief ratio, mean slope, drainage density, ruggedness number, and dissection index were calculated and analysed. The results show a mean slope of 21.87%, drainage density of about 2.09 km/km², relief ratio of ~0.03, ruggedness number of ~1.18, and dissection index of ~0.53, indicating moderate to high terrain dissection. Steep slopes near the reservoir and efficient drainage connectivity suggest a high potential for sediment transfer within the catchment.The study demonstrates that DEM-based relief analysis provides a simple, rapid, and cost-effective approach for soil conservation planning and preliminary assessment of reservoir sedimentation risk, especially in data-scarce regions.

Keywords: Relief analysis; Digital Elevation Model (DEM); Soil erosion susceptibility; Reservoir sedimentation; Morphometric analysis; Watershed.

Introduction:

Soil erosion is a major environmental problem that affects land productivity, degrades water quality, and accelerates sedimentation in reservoirs. Sediment accumulation in reservoirs reduces storage capacity, affects water supply, and shortens the functional life of hydraulic structures. Among the various factors influencing erosion, terrain characteristics such as relief, slope, and drainage pattern play a fundamental role by controlling runoff velocity, erosional energy, and sediment transport pathways.

The quantitative study of drainage basins began with Horton (1945), who established relationships between drainage characteristics and erosion processes. Strahler (1952, 1964) further developed morphometric concepts by integrating relief, drainage density, and basin geometry to explain geomorphic evolution. Basin relief and relief ratio are widely used to describe overall terrain steepness and erosional energy (Schumm, 1956; Singh, 1992), while drainage density reflects runoff efficiency and degree of landscape dissection (Horton, 1945).

Integrated parameters such as ruggedness number combine relief and drainage density to indicate terrain instability and erosion susceptibility (Strahler, 1964). The dissection index is used to evaluate the degree of vertical erosion and geomorphic maturity of landscapes

(Mesa, 2006). With the advancement of GIS and the availability of DEM data, morphometric analysis has become a widely applied approach for soil erosion assessment and watershed management, particularly in regions where field data are limited (Nag & Chakraborty, 2003; Thomas et al., 2010; Agarwal et al., 2013).

Although many recent studies focus on sub-watershed prioritization or complex erosion models, watershed-scale relief analysis remains important for understanding overall erosion behaviour and sediment delivery to reservoirs. This study demonstrates that DEM-derived relief parameters alone can provide meaningful insight into soil erosion susceptibility and reservoir sedimentation risk, offering a practical framework for soil conservation planning.

Description of Study Area:

The area selected for the present study is a catchment area of Mulshi reservoir, located in the Mulshi taluka of Pune district. The total geographical area is 250.25 Square Kilometres and has latitudinal extend from 18°25´18´´N to 18°39´59´´N and longitudinal extend from 73°20´25´´E to 73°31´18´´E.The climate of the study area is of tropical monsoonal type characterized by the well-defined seasons like summer, rainy and winter seasons. The average annual rainfall in the study area varies between 2654 to 3747mm.

In addition, researched drainage basin (catchment) faces east and drains into the Mulshi-Lake, the biggest reservoir of the Mula-River system. Moreover, the study area spans about 250.25 Square Kilometres and it has altitude between 504 to1,071 metres from mean sea level. The catchment depicts a typical Mulshi reservoir landscape shown in the (figure 1).

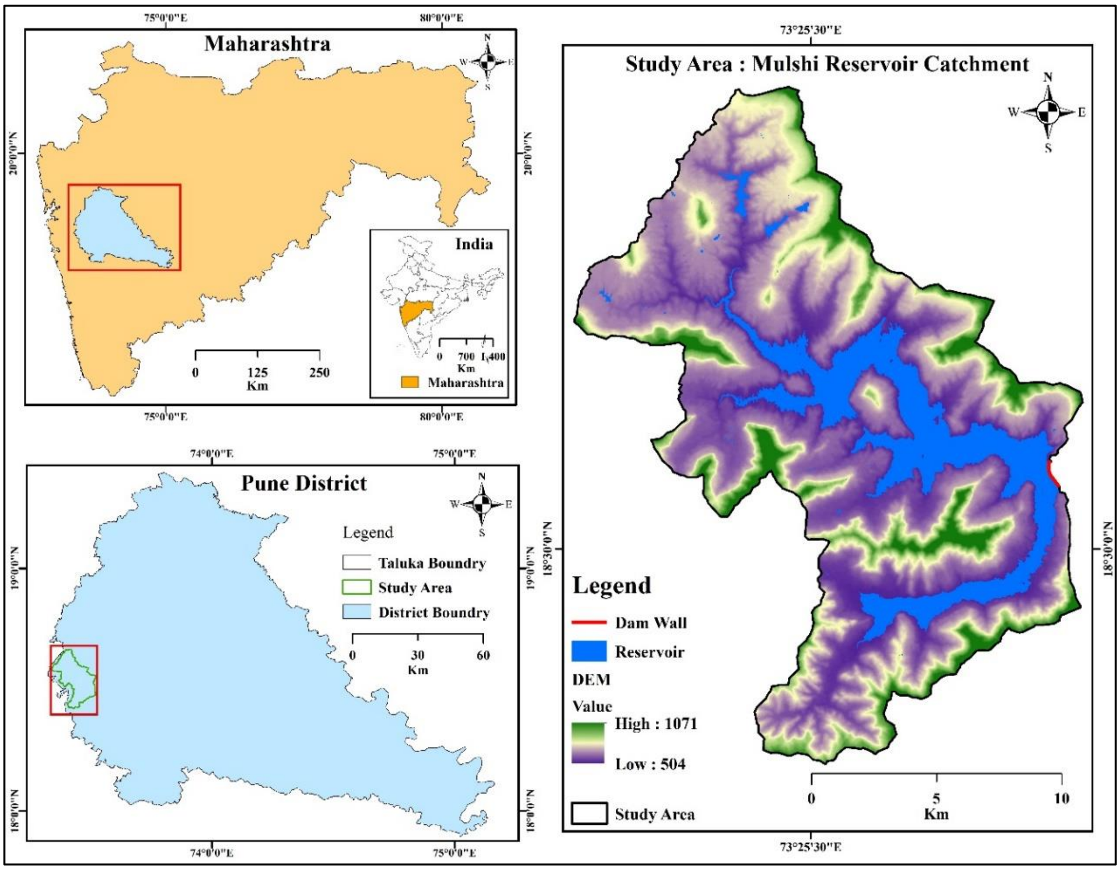

Figure 1: Study area map

Database and Methodology:

1. Database:

The study is based primarily on **Digital Elevation Model (DEM) data**, which was used to derive terrain and drainage characteristics of the Mulshi Reservoir catchment. The DEM provided elevation information required for calculating relief, slope, and morphometric parameters. All spatial layers, including the watershed boundary and drainage network, were generated from the DEM using standard GIS procedures and maintained in a common coordinate system to ensure consistency.

2. Methodology:

The overall workflow adopted for DEM-based relief analysis of the Mulshi Reservoir catchment is summarized in Figure 2.

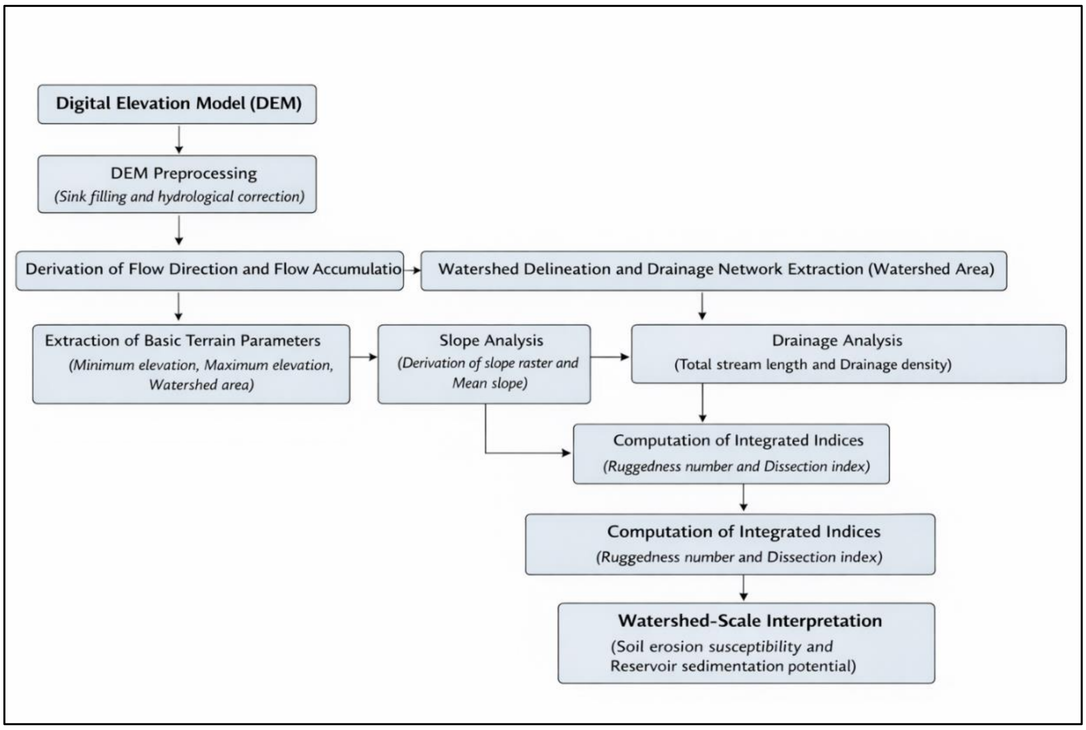

Figure 2: Methodology

Result:

The relief and morphometric characteristics of the Mulshi Reservoir catchment were analysed using eight DEM-derived thematic maps, including basin relief, absolute relief, relative relief, relief ratio, dissection index, ruggedness index, drainage density and slope (in percent). These maps collectively represent the spatial variability of terrain and drainage conditions within the catchment.

The absolute relief map depicts elevation values ranging from 520 m to 1100 m above mean sea level (Figure. 3), highlighting the overall topographic framework of the catchment. Higher elevations are concentrated in the upland regions, while lower elevations occur toward the reservoir and downstream areas. The basin relief map, derived from elevation extremes, indicates a total vertical relief of approximately 567 m, reflecting substantial vertical variability across the watershed (figure. 4).

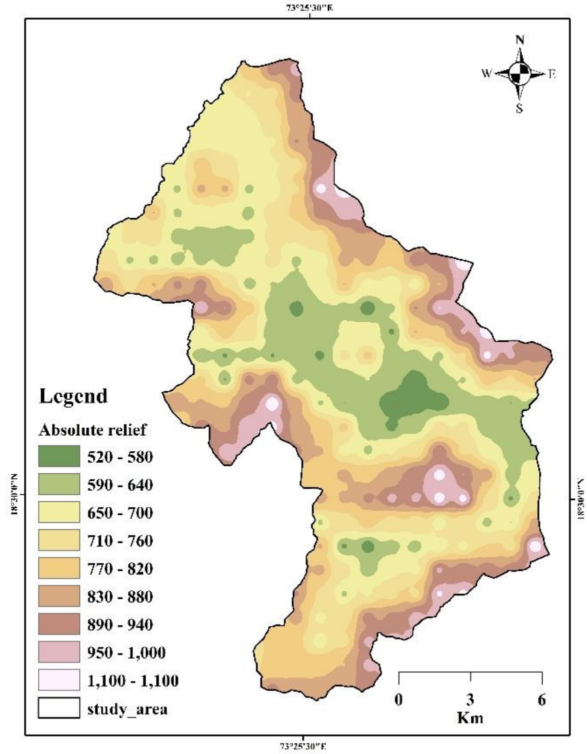

Figure 3: Absolute relief map

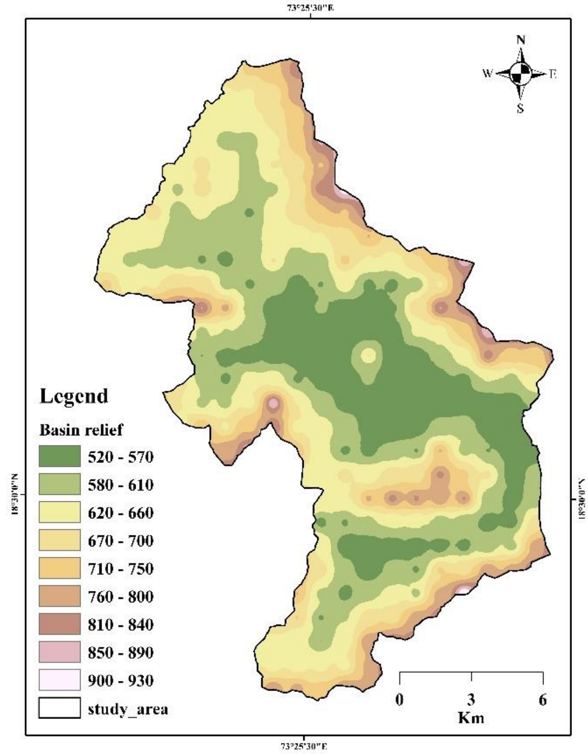

Figure 4: Basin relief map

The **relative relief map** illustrates local elevation differences within the catchment and reveals areas with pronounced relief contrasts, particularly in zones of steep terrain. These variations indicate uneven distribution of relief, with higher relative relief values occurring in dissected upland areas and lower values in comparatively gentle terrain, as referred in figure 5.

The **relief ratio map**, representing the ratio of basin relief to basin length, shows a value of approximately **0.03**, indicating moderate overall basin steepness, as referred in figure 6. Although the relief ratio is uniform at the watershed scale, its spatial representation helps contextualize the overall gradient conditions of the catchment.

Slope analysis based on the **slope (%) map** indicates that the catchment is dominated by **moderate to steep slopes**, with a **mean slope of 21.87%**, as referred in figure 7. Steeper slopes are more prominent near the reservoir margins and along incised valley sides, while moderate slopes characterize much of the upland terrain. Gentle slopes are limited in extent and occur mainly in localized low-relief areas.

The **drainage density map**, generated using the total stream length of **519.62 km** over a catchment area of **250.25 km²**, shows a drainage density of approximately **2.09 km/km²**, as referred in figure 8. The spatial pattern of drainage density reflects a moderately well-developed drainage network, with relatively higher densities in areas of steeper slopes and dissected terrain.

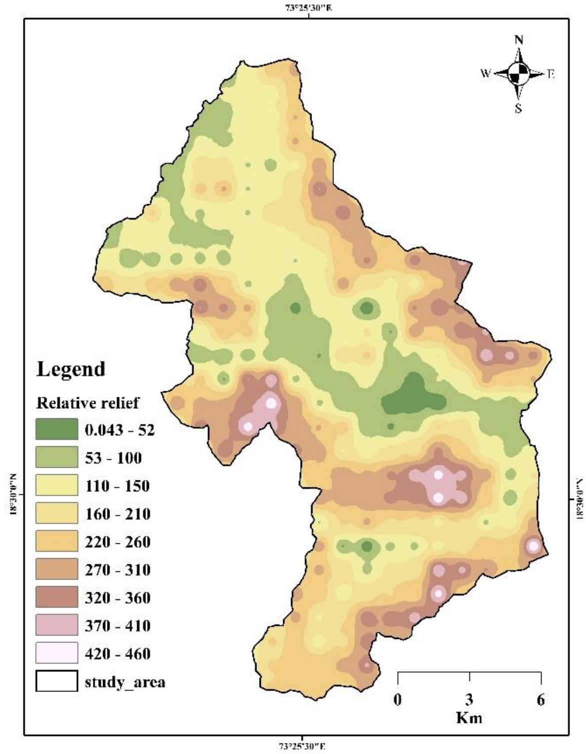

Figure 5: Relative relief map

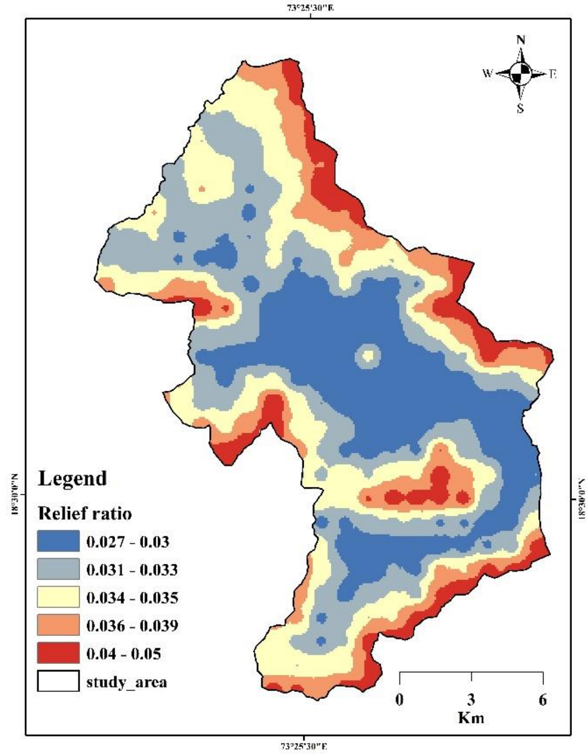

Figure 6: Relief ratio map

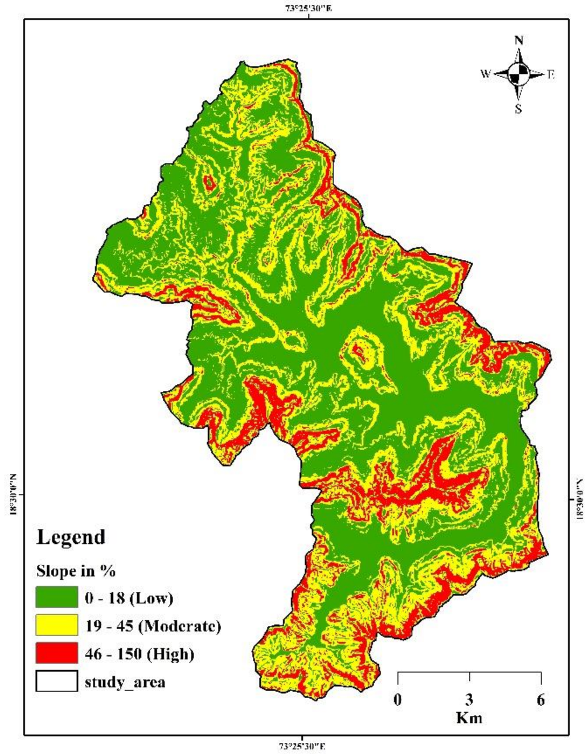

Figure 7: Slope map

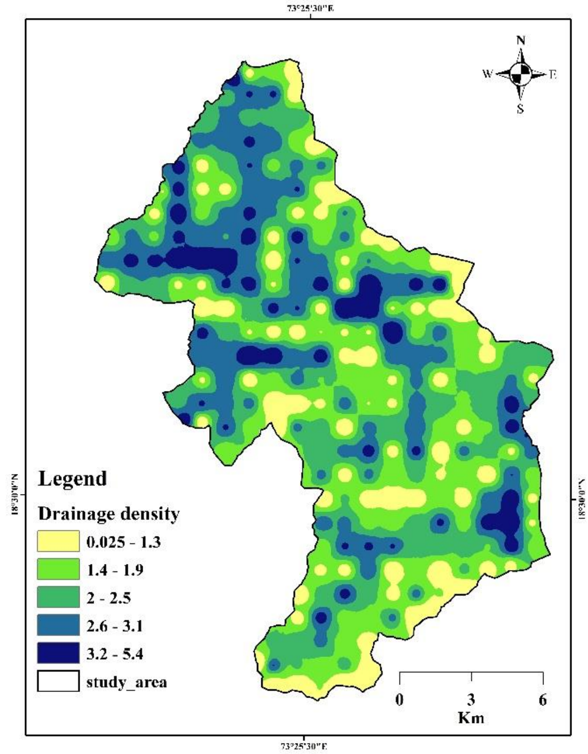

Figure 8: drainage density map

The **ruggedness index map**, integrating basin relief and drainage density, displays values of approximately **1.18**, indicating moderate to high terrain roughness, as referred in figure 9. Higher ruggedness values correspond to areas of steep slopes and dense drainage, suggesting spatial variability in terrain stability.

Finally, the **dissection index map**, with values around **0.53**, indicates a moderately to highly dissected landscape, as referred in figure

10. Higher dissection values are associated with areas of pronounced valley incision and relief concentration, while lower values occur in less dissected parts of the catchment.

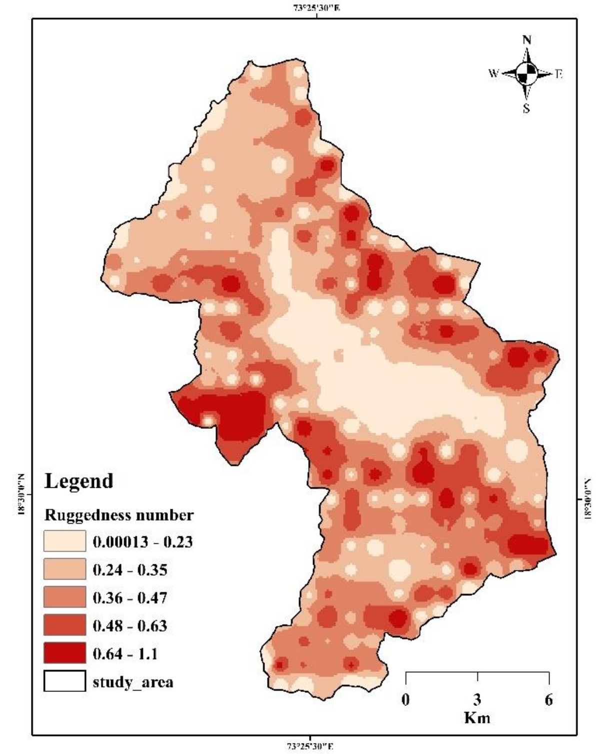

Figure 9: Ruggedness number map

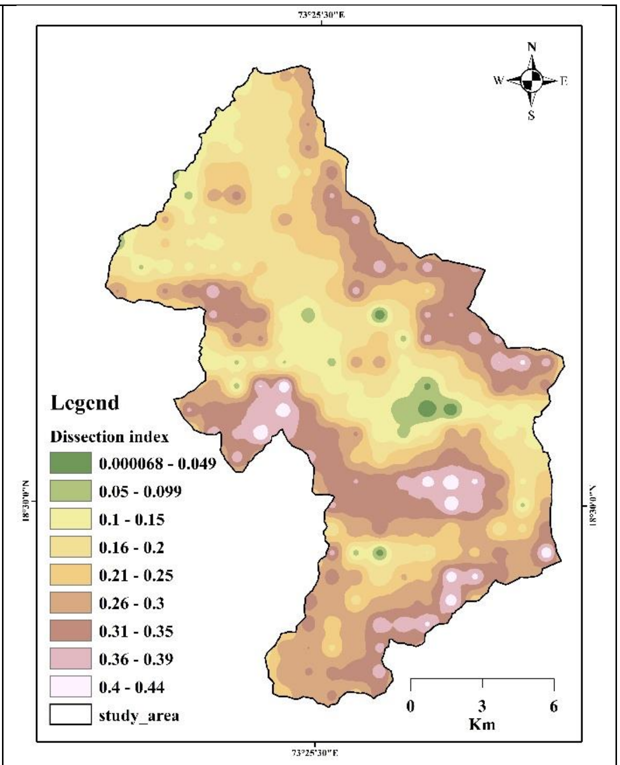

Figure 10: Dissection index map

Overall, the combined analysis of these eight thematic maps reveals that the Mulshi Reservoir catchment exhibits considerable spatial variability in relief, slope, and drainage characteristics. The integrated representation of terrain parameters indicates watershed-scale conditions associated with moderate to high soil erosion susceptibility and effective sediment transfer toward the reservoir.

Discussion:

The results highlight the dominant role of terrain characteristics in controlling soil erosion processes within the Mulshi Reservoir catchment. Although the relief ratio indicates moderate basin steepness, the combination of high basin relief and steep slopes significantly enhances erosional energy. Previous studies have shown that such terrain conditions can produce high erosion susceptibility even when relief ratios are moderate (Schumm, 1956; Strahler, 1964).

Slope is a critical factor influencing erosion intensity. A mean slope exceeding 20% places large portions of the catchment in a category associated with increased soil erosion susceptibility (Wischmeier & Smith, 1978; Lal, 2001). Steep slopes accelerate surface runoff, increase soil detachment, and enhance sediment transport. When such slopes occur near the reservoir, sediment transfer to the reservoir becomes more efficient (Morris & Fan, 1998; Walling, 2006).

Drainage density further strengthens erosion–sediment transfer relationships by controlling runoff efficiency and hillslope–channel connectivity. A well-developed drainage network reduces sediment storage within the catchment and increases sediment delivery ratios

(Gregory & Walling, 1973; Brierley & Fryirs, 2005).

Integrated indices such as ruggedness number and dissection index provide additional insight into terrain instability and geomorphic maturity. Elevated values of these indices are commonly associated with active erosion, channel incision, and slope retreat (Strahler, 1964; Mesa, 2006). These processes continuously supply sediment to the drainage system, particularly during high-flow events.

Although direct measurements of sediment yield or reservoir sedimentation were not available, the observed terrain characteristics suggest a high potential for sediment transfer within the catchment. Similar relief-controlled erosion and sedimentation relationships have been reported in comparable physiographic settings (Morris & Fan, 1998; Walling, 2006). The findings emphasize that sedimentation risk in the reservoir is strongly influenced by inherent geomorphological conditions.

Conclusion:

- The Mulshi Reservoir catchment exhibits high basin relief and predominantly moderate to steep slopes, indicating strong terrain control on soil erosion processes.
- Moderate drainage density and efficient hillslope–channel connectivity favour rapid sediment transfer within the catchment.
- Elevated ruggedness number and dissection index reflect an unstable and actively dissected landscape with high erosion susceptibility.
- Steep slopes near the reservoir enhance sediment transfer efficiency, contributing to reservoir sedimentation risk.

Overall, the study confirms that DEM-derived relief and morphometric parameters provide a reliable, simple, and data-efficient framework for assessing watershed-scale terrain susceptibility to soil erosion, supporting soil conservation planning and reservoir management in data-scarce regions.

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Conflict of Interest: The author proclaimed no conflict of interest.

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