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Prioritization of Sub-Watersheds Using Morphometric Characteristics of Vashishti River Basin, Western Ghats, India

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Abstract:
Watershed prioritization is an essential approach for sustainable soil and water conservation, especially in regions vulnerable to high runoff and erosion. This study analyzes the Vashishti River Basin, Western Ghats, India, which comprises seven sub-watersheds (SW1–SW7). Morphometric parameters were derived from SRTM-DEM using GIS techniques, with emphasis on linear, areal, and shape characteristics. Four key parameters—drainage density, stream frequency, form factor, and elongation ratio—were selected for prioritization due to their hydrological significance and ability to indicate erosion susceptibility. The sub-watersheds were ranked using a compound factor (CF) approach. Results reveal that SW5, SW6, and SW4 exhibit higher vulnerability and thus demand immediate conservation planning, while SW2 is the least susceptible. The findings highlight that integrating morphometric analysis with GIS provides a practical framework for prioritizing watersheds, enabling targeted management and resource planning in the Western Ghats.

Keywords: *Vashishti River Basin, Morphometric Analysis, Sub-watershed Prioritization, Drainage Density, Stream Frequency, GIS, Western Ghats.*

1. INTRODUCTION

Watersheds constitute the basic hydrological units controlling surface runoff, groundwater recharge, and sediment yield. Morphometric analysis, which quantifies the geometry of drainage networks and basin shape, has long been recognized as a reliable method for assessing watershed characteristics and their influence on hydrological processes (Horton, 1945; Strahler, 1952). Such analysis is particularly valuable for prioritization, as it provides indicators of erosion susceptibility and runoff potential. The Western Ghats, a UNESCO World Heritage Site and biodiversity hotspot, are marked by steep slopes, heavy monsoonal rainfall, and fragile landscapes, making them highly prone to soil erosion, landslides, and flash floods (Myers et al., 2000). Within this physiographic setting, the Vashishti River Basin in Maharashtra is of ecological and socio-economic significance, supporting agriculture, fisheries, and settlement activities. However, increasing anthropogenic stress and climate variability necessitate systematic watershed prioritization for effective conservation and resource management.

Prioritization of sub-watersheds using morphometric parameters enables focused interventions, allowing decision-makers to allocate resources efficiently in areas that are more vulnerable to runoff and erosion (Singh et al., 2021). This study examines seven sub-watersheds of the Vashishti Basin, applying linear, areal, and shape indices, and computing a compound factor to establish priority rankings for conservation.

2. STUDY AREA

The Vashishti River Basin lies in the Konkan region of Maharashtra and represents a vital segment of the northern Western Ghats. Geographically, it extends from 73°04′54″E to 73°43′48″E longitude and 17°53′36″N to 17°24′04″N latitude, encompassing parts of Chiplun, Guhagar, Khed, and Dapoli tehsils in Ratnagiri district. Prominent settlements such as Khed, Chiplun, and Dabhol highlight the basin's socio-economic importance through agriculture, fisheries, and trade. Physiographically, the basin is defined by rugged terrain, steep escarpments, and deeply entrenched valleys characteristic of the Western Ghats. Elevation ranges from 1,213 m in the upstream hilly regions to sea level at Dabhol, where the river discharges into the Arabian Sea. This variation exerts a strong influence on runoff dynamics, sediment transport, and geomorphic processes. The basin covers approximately 2,197 km², with a length of 46.87 km and a maximum stream order of six. Its drainage network, extending over 1,572 km, indicates a high degree of dissection and rapid hydrological response to rainfall. The humid tropical climate, combined with intense monsoonal precipitation, amplifies erosional activity and underscores the need for morphometric assessment and prioritization (Fig. 1).

Figure 1: Study Area

3. RESEARCH METHODOLOGY

Database Preparation

The morphometric and prioritization analysis of the Vashishti River Basin and its seven sub-watersheds (SW1–SW7) was carried out using both spatial and non-spatial datasets. The primary dataset was the SRTM-Digital Elevation Model (DEM) with a spatial resolution of 30 m, obtained from the USGS Earth Explorer platform. This DEM served as the base for deriving topographic and drainage characteristics. Supplementary datasets, including Survey of India topographic maps, administrative boundaries, and reference layers, were used for cross-verification and cartographic visualization.
All spatial operations—such as watershed delineation, drainage extraction, and thematic map generation—were performed in a GIS environment (ArcGIS with Arc Hydro tools). Morphometric computations were initially organized within attribute tables, and final statistical processing was carried out in Microsoft Excel.

Delineation of Sub-Watersheds and Drainage Network

Watershed delineation was performed using the ArcGIS. Terrain pre-processing followed a sequential workflow of Fill, Flow Direction, and Flow Accumulation, which removed sinks and established a continuous flow surface. Pour points (outlets) were manually identified at topographic lows and major flow accumulation sites, serving as the basis for extracting the boundaries of the Vashishti River Basin and its seven sub-watersheds. Stream networks were generated by applying a threshold to the flow accumulation raster, followed by segmentation and vectorization. Stream ordering was carried out using Strahler's (1952) classification, in which fingertip tributaries are designated as first-order streams and stream order increases when two streams of the same order converge. The final outputs included a stream order map (Fig. 2) and sub-watershed map (Fig. 3), which formed the basis for morphometric analysis.

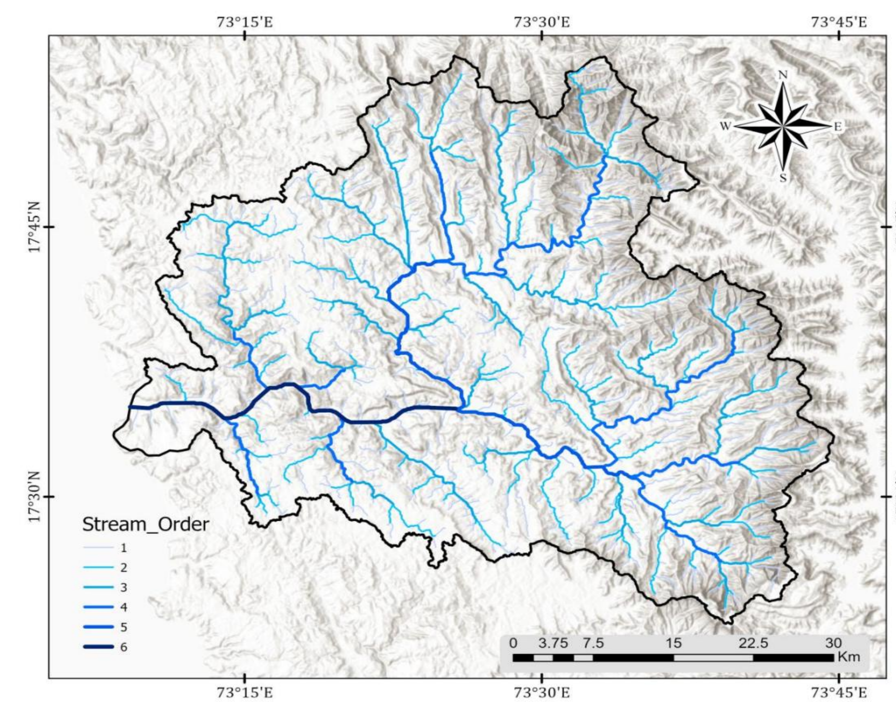

Figure 2: Stream Order of Vashishti River

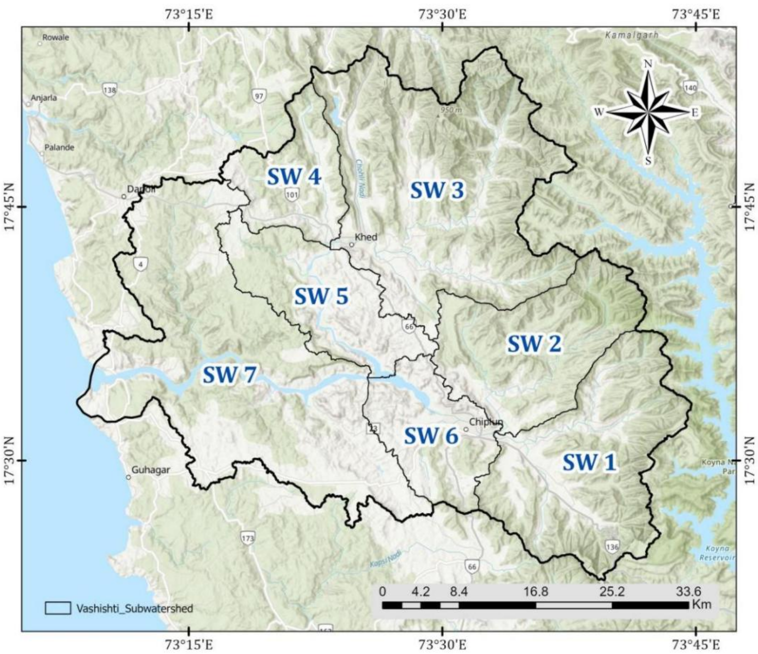

Figure 3: Sub-Watershed of Vashishti River

Computation of Morphometric Parameters and Watershed Prioritization

Morphometric analysis was undertaken to evaluate the drainage characteristics and hydrological behavior of the basin. Parameters were grouped into three categories:

Linear parameters – reflecting branching patterns and structural controls (Horton, 1945; Strahler, 1964).

Areal parameters – assessing runoff potential and drainage efficiency (Schumm, 1956). **Shape indices** – providing insights into basin geometry and flood susceptibility (Horton, 1932; Schumm, 1956).

The parameters were derived from stream and watershed shapefiles generated in ArcGIS. Tabular and statistical calculations were performed in Microsoft Excel using established morphometric formulae. A summary of the parameters, their formulae, and references is presented in **Table 1**.

For watershed prioritization, four key parameters were selected: drainage density, stream frequency, form factor, and elongation ratio. These indices were chosen because they directly represent hydrological response, erosion susceptibility, and basin geometry, thereby offering a reliable basis for prioritization (Biswas et al., 1999). Other parameters such as stream number or basin area, while useful descriptively, were excluded as they do not independently quantify erosion risk.

Each sub-watershed was ranked for the four parameters: higher values of Dd and Fs (indicating greater runoff and erosion potential) received higher priority, whereas lower values of Rf and Re (indicating elongated basins prone to peak flows) were also ranked higher. The compound factor (CF) was computed as the average of parameter ranks, with sub-watersheds having the lowest CF values considered most vulnerable and thus requiring urgent conservation measures.

The CF was calculated using the formula:

$$CF = \frac{\sum R_i}{n}$$

Where: n = total number of parameters considered

R_1 = rank of the sub-watershed for each parameter

Thus, sub-watersheds with the lowest CF values were assigned the highest management priority.

Table 1: Morphometric Parameters: Formulas with Authors

No.	Parameter	Formula	Reference
1	**Stream Order (U)**	Hierarchical order of streams using branching logic	Strahler (1952)
2	**Stream Number (Nu)**	Count of streams in each order	Horton (1945)
3	**Stream Length (Lu)**	Total length of streams in a particular order	Horton (1945)
4	**Mean Stream Length (Lsm)**	$Lsm = Lu / Nu$	Strahler (1964)
5	**Basin Area (A)**	Measured area drained by the watershed	Standard GIS-derived
6	**Basin Length (Lb)**	Longest flow path from outlet to boundary	Schumm (1956)
7	**Drainage Density (Dd)**	$Dd = \sum Lu / A$	Horton (1945)
8	**Stream Frequency (Fs)**	$Fs = \sum Nu / A$	Horton (1945)
9	**Form Factor (Rf)**	$Rf = A / Lb^2$	Horton (1932)
10	**Elongation Ratio (Re)**	$Re = (2 \times \sqrt{(A/\pi)}) / Lb$	Schumm (1956)

4.RESULTS AND DISCUSSION

Morphometric Analysis of Sub-watersheds

The morphometric analysis of the Vashishti River Basin demonstrates considerable variability across its seven sub-watersheds (SW1–SW7) (Table 2). The maximum stream order (U) ranges between 4 and 6, indicating a mature and well-organized drainage system. Sub-watersheds SW5 and SW7 attain the highest order of 6, reflecting advanced tributary development and structural control over drainage evolution.

The total number of streams (ΣNu) varies markedly, from 57 in SW4 to 240 in SW7. High stream counts in SW3 and SW7 highlight dense drainage networks, typically linked to greater runoff potential and rapid surface water response (Strahler, 1964; Nag & Chakraborty, 2003).

Drainage density (Dd) values range from 0.699 km/km² (SW7) to 0.740 km/km² (SW5 and SW6). Relatively high Dd values suggest dissection of the terrain, reduced infiltration capacity, and higher susceptibility to soil erosion, consistent with earlier observations by Biswas et al. (1999) and Clarke (1996). Stream frequency (Fs) follows a similar trend, ranging from 0.358 streams/km² (SW2) to 0.446 streams/km² (SW4), reflecting variability in drainage texture and runoff behavior across the basin.

Basin shape parameters further highlight hydrological contrasts. Sub-watersheds SW5 (Rf = 0.264, Re = 0.489) and SW6 (Rf = 0.436, Re = 0.450) are elongated, which typically produces lower flood peaks and delayed runoff concentration. In contrast, SW3 (Rf = 0.501) exhibits a more circular form, favoring quicker hydrological response and higher flood risk (Schumm, 1956). These results emphasize the significant role of linear and shape parameters in governing runoff, erosion susceptibility, and watershed prioritization.

Table 2: Morphometric Analysis Table

Parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7
Max Stream Order (U)	5	4	5	4	6	5	6
Total Stream Number (ΣNu)	130	90	211	57	80	63	240
Stream Length (Lu, km)	1→109.5 2→61.17 3→37.48 4→27.035→3.0 **Σ=238.18**	1→80.24 2→55.55 3→17.11 4→27.81 **Σ=180.71**	1→184.6 2→95.5 3→59.24 4→46.9 5→3.0 **Σ=389.24**	1→46.61 2→16.8 3→28.14 4→0.19 **Σ=91.74**	1→64.7 2→30.8 3→21.6 4→0 5→21.12 6→0.15 **Σ=138.37**	1→57.3 2→28.05 3→6.0 4→0.02 5→18.0 **Σ=109.37**	1→207.2 2→100.8 3→51.3 4→31.9 5→0 6→33.9 **Σ=427.1**
Mean Stream Length (Lsm, km)	1→1.15 2→2.45 3→5.35 4→13.52 5→3.0	1→1.20 2→3.09 3→4.28 4→27.81	1→1.13 2→2.73 3→6.58 4→15.63 5→3.0	1→1.04 2→1.87 3→14.07 4→0.19	1→1.12 2→2.05 3→5.40 4→-0 5→10.56 6→0.15	1→1.12 2→3.12 3→6.0 4→0.02 5→18.0	1→1.13 2→2.46 3→5.70 4→7.98 5→0 6→33.9
Basin Area (A, km²)	334.003	251.546	537.629	127.829	187.129	147.810	610.986
Basin Length (Lb, km)	28.0	22.56	32.76	18.33	26.63	18.4	46.87
Drainage Density (Dd, km/km²)	0.713	0.718	0.724	0.718	0.740	0.740	0.699
Stream Frequency (Fs, streams/km²)	0.389	0.358	0.393	0.446	0.428	0.426	0.393
Form Factor (Rf)	0.426	0.492	0.501	0.381	0.264	0.436	0.278
Elongation Ratio (Re)	0.675	0.809	0.663	0.728	0.489	0.450	0.603

Prioritization of Sub-watersheds

Sub-watershed prioritization was performed using four key morphometric parameters—Dd, Fs, Rf, and Re. These parameters were selected because they are widely recognized as effective indicators of hydrological behavior and erosion susceptibility (Horton, 1945; Strahler, 1964). Higher values of Dd and Fs generally signify greater dissection of terrain, limited infiltration capacity, and higher soil erosion risk, while lower values of Rf and Re represent elongated basins, which typically respond more rapidly to rainfall events and enhance runoff potential (Biswas et al., 1999).

Table 3: Parameter-wise Ranking Table for Watershed

Sub-watershed	Dd (km/km²)	Rank (Dd)	Fs (streams/km²)	Rank (Fs)	Rf	Rank (Rf)	Re	Rank (Re)
SW1	0.713	6	0.389	6	0.426	3	0.675	3
SW2	0.718	4	0.358	7	0.492	5	0.809	7
SW3	0.724	2	0.393	5	0.501	6	0.663	4
SW4	0.718	4	0.446	1	0.381	2	0.728	5
SW5	0.740	1	0.428	2	0.264	1	0.489	2
SW6	0.740	1	0.426	3	0.436	4	0.450	1
SW7	0.699	7	0.391	4	0.278	2	0.603	6

For each sub-watershed, ranks were assigned according to parameter values, and a CF was computed as the mean of the four ranks (Table 3). The results reveal that SW5 exhibits the highest priority (CF = 1.50), followed by SW6 (CF = 2.25) and SW4 (CF = 3.00). In contrast, SW2 registers the lowest priority (CF = 5.75) (Table 4). These findings are consistent with earlier studies that emphasized the vulnerability of sub-watersheds characterized by dense drainage networks and elongated basin shapes (Fig. 4). Accordingly, SW5, SW6, and SW4 require immediate soil and water conservation interventions to mitigate erosion hazards and ensure sustainable watershed management.

Table 4: CF & Final Priority Ranking

Sub-watershed	Rank (Dd)	Rank (Fs)	Rank (Rf)	Rank (Re)	Sum	Cp	Priority
SW1	6	6	3	3	18	4.50	5
SW2	4	7	5	7	23	5.75	7
SW3	2	5	6	4	17	4.25	4
SW4	4	1	2	5	12	3.00	3
SW5	1	2	1	2	6	1.50	1
SW6	1	3	4	1	9	2.25	2
SW7	7	4	2	6	19	4.75	6

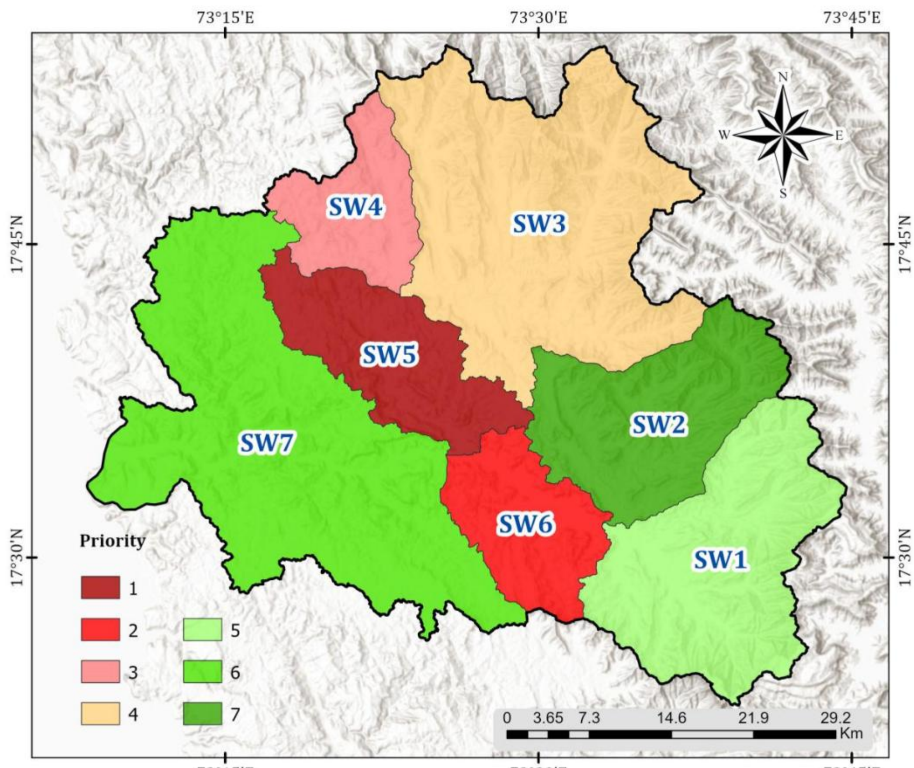

Figure 4: Prioritization of Sub-watersheds

Implications for Watershed Management

The prioritization results provide a scientific framework for targeted soil and water conservation planning in the Vashishti River Basin. High-priority sub-watersheds (SW5, SW6, and SW4), identified through high drainage density, elevated stream frequency, and elongated basin shapes, require urgent interventions such as afforestation, construction of check dams, contour bunding, and gully plugging. These measures can effectively minimize surface runoff, enhance infiltration, and reduce soil erosion. Medium- and low-priority sub-watersheds (e.g., SW1, SW3, and SW2) should not be neglected, but management efforts there can be phased or monitored, as they are comparatively less vulnerable. This morphometric–prioritization approach thus enables efficient resource allocation, ensuring that limited conservation funds and efforts are directed to areas where they can achieve the greatest impact.

5. CONCLUSION

The morphometric analysis of the Vashishti River Basin highlighted distinct variations in drainage characteristics and basin geometry across its seven sub-watersheds. SW5 and SW6 showed the highest drainage density and stream frequency, indicating greater runoff and erosion susceptibility, while elongated basins tended to delay peak flows compared to circular ones.

Prioritization using four key parameters—drainage density, stream frequency, form factor, and elongation ratio—ranked SW5 as highest priority, followed by SW6 and SW4, whereas SW2 had the lowest priority. These findings provide a scientific basis for watershed management, suggesting that high-priority sub-watersheds should be targeted for interventions such as afforestation, check dams, and contour bunding.

CONFLICT OF INTEREST

As the corresponding author of this paper I stated that there is no conflict of interest.

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No funding was received for conducting this study.

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