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Prioritizing Sub-Watersheds Based on Morphometric Characteristics of Shastri River Basin, Maharashtra, India

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Abstract:
Morphometric analysis, when integrated with geographic information systems (GIS) and remote sensing (RS) techniques, provides a scientific framework to assess watershed characteristics and identify erosion-prone zones. This study evaluates the Shastri River Basin in Maharashtra, India, using quantitative morphometric methods to prioritize its three sub-watersheds (SW1, SW2, SW3) for conservation planning. Ten morphometric parameters, across-the-board linear, areal, and shape indices, were derived from DEM (Digital Elevation Model) data using ArcGIS. Sub-watershed prioritization was performed using the Compound Factor (CF) approach. Findings reveal that SW1, with the highest drainage density and stream frequency, is most susceptible to erosion and runoff. SW3 ranks moderate, while SW2, exhibiting favorable morphometric conditions, is the least vulnerable. The study underscores the utility of morphometric analysis in preliminary watershed management, especially in data-scarce regions.

Keywords: *Morphometric Analysis, Watershed Prioritization, GIS and CF, Erosion Vulnerability.*

INTRODUCTION

Watersheds are fundamental units of hydrological systems, influencing surface runoff, infiltration, and sediment transport. Understanding their geomorphological characteristics is essential for effective water and soil conservation, particularly in erosion-prone and flash-flood susceptible regions. Morphometric analysis, introduced by Horton (1945) and refined by Strahler (1964), provides a quantitative framework to assess watershed form and drainage patterns, which helps predict runoff potential and erosion risk.

With advancements in GIS and RS, morphometric studies have become more accurate and efficient. High-resolution DEM, like SRTM, enable precise extraction of watershed boundaries and drainage networks that were once manually delineated. Studies such as Nag and Chakraborty (2003) and Biswas et al. (1999) demonstrated the effectiveness of GIS-based morphometric techniques in assessing watershed behavior across diverse Indian terrains.

Recent research, including Marwade et al. (2024) in the Warana Basin, Maharashtra, has applied similar approaches to prioritize flash-flood vulnerable watersheds using total ranking methods. Likewise, Adhikari (2020) and Sharma et al. (2021) highlighted how morphometric parameters strongly correlate with erosion and flash-flood susceptibility in Himalayan basins.
Given the Western Ghats' ecological sensitivity, the Shastri River Basin in Maharashtra faces challenges like deforestation, soil erosion, and intense monsoon-induced runoff. In such contexts, morphometric analysis using GIS offers a practical, cost-effective method for preliminary watershed prioritization, especially in data-limited scenarios. This study aims to evaluate critical morphometric parametrs of the Shastri River Basin's three sub-watersheds and prioritize them based on their erosion vulnerability using the Compound Factor (CF) approach. The results will assist in identifying critical zones for targeted watershed management and sustainable development planning.

Study Area

The present study is focused on the Shastri river, situated in the middle of Konkan region of Maharashtra, India. The basin lies between 17°00'N to 17°30'N latitude and 73°12'E to 73°50'E longitude, covering an area of 2164 km2 with a perimeter of 384 kilometers. The basin is located along the western escarpment of the Sahyadri, with the maximum elevation reaching around 1040 meters above sea level. The Shastri River originates near Prachitgad, a fort on the western scarp, and flows westward into the Arabian Sea. The stream pattern is primarily dendritic to sub-dendritic, reflecting relatively uniform geology and terrain. However, trellis and sub-parallel patterns are also observed in structurally controlled zones. Based on Strahler's stream ordering, the basin includes streams up to the sixth order, indicating a mature and well-developed drainage system. A location map of the study region is provided in figure 1, showing the river course, elevation zones, and geographical context.

MATERIALS AND METHODS

Database Preparation

To perform the morphometric and prioritization analysis of the Shastri River watershed and its three sub-watersheds (SW1, SW2, and SW3), a combination of spatial and non-spatial datasets was utilized. The primary data source was the SRTM-DEM with a spatial resolution of 30 meters, downloaded from the USGS Earth Explorer platform. This DEM formed the foundation for deriving topographic and drainage features essential for morphometric evaluation. Supplementary GIS layers, including administrative boundaries and reference toposheets, were also employed for visualization and map preparation. The data processing, visualization, and map generation were performed using ArcGIS, while parameter-based tabular calculations were conducted in Microsoft Excel.

Watershed Delineation and Stream Ordering

Using the Hydrology toolbox in ArcGIS, the terrain pre-processing was performed through a sequence of steps: Fill, Flow Direction, and Flow Accumulation. The pour points (outlets) for the main Shastri River basin and its three sub-watersheds (SW1, SW2, SW3) were manually defined based on topographic lows and flow accumulation paths. Subsequently, the watershed boundaries were extracted using the Watershed tool. Stream extraction involved thresholding the flow accumulation raster, followed by stream segmentation and vectorization. Stream ordering was assigned using Strahler's (1952) hierarchical classification, where the smallest fingertip tributaries are assigned order 1, and the confluence of two streams of the same order results in an increase in stream order by one. The finalized maps such as Location Map, Sub-watershed Map and Stream Order Map were generated for cartographic presentation and interpretation.

Computation of Morphometric parameters

Morphometric analysis was conducted to assess the drainage characteristics and hydrological behavior of the Shastri River watershed and its three sub-watersheds (SW1, SW2, SW3). The analysis was grouped into three categories: linear, areal, and shape parameters. A total of ten morphometric parameters were selected based on their effectiveness in hydrological and watershed studies. The linear parameters include stream number, stream length, mean stream length, stream length ratio, and bifurcation ratio. The areal parameters comprise basin area, basin length, drainage density, and stream frequency, while the shape parameter used is form factor. These values were calculated using geometric data derived from stream and watershed shapefiles processed in ArcGIS. Attribute tables were used to extract necessary values, and final calculations were performed in Microsoft Excel using standard morphometric formulae. The formulae and corresponding references are listed in table 1.

Watershed Prioritization using Compound Factor (CF)

To establish an objective ranking of the Shastri River Basin's sub-watersheds for conservation planning, this study employed the CF method. The CF technique synthesizes multiple morphometric parameters into a single prioritization score, providing a systematic approach to identify erosion-prone areas. For each morphometric indicator, sub-watersheds were assigned ranks based on their erosion sensitivity. Parameters such as Dd and Fs, which are positively associated with higher surface runoff and reduced infiltration, were ranked in ascending order where a higher value indicates greater erosion risk. Conversely, parameters that enhance infiltration and water retention, like Re, were ranked inversely.

The **CF** for every sub-watershed was calculated by averaging the ranks across all selected parameters using the formula:

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

Where:

Ri= rank of the sub-watershed for each parameter

n = total number of parameters considered

The sub-watershed with the lowest CF value is assigned highest priority, as it is considered more susceptible to degradation and in need of immediate conservation efforts.

RESULTS

Watershed Extraction and Stream Network

Using the DEM-derived hydrological tools in ArcGIS, three sub-watersheds (SW1, SW2, SW3) of the Shastri River basin were delineated (Fig. 2). Each sub-watershed showed distinct morphometric behavior based on stream order, flow accumulation, and topographic characteristics. The stream network extracted using the Strahler method revealed a dendritic to sub-dendritic pattern, typical of homogeneous terrain.

Morphometric Characteristics

Ten morphometric parameters were calculated, covering linear, areal, and shape characteristics (Table 1). The results (Table 2) reveal significant variation among the sub-watersheds. SW1 exhibits the highest drainage density (0.609 km/km^2) and stream frequency (0.285), suggesting an intensely dissected terrain with limited infiltration and higher runoff potential. In contrast, SW2 records the lowest values for these indices, indicating greater infiltration capacity and a more stable hydrological regime. SW3 presents intermediate values, reflecting moderate susceptibility to erosion. These differences highlight the influence of underlying topography and lithology on watershed behavior.

Watershed Prioritization

To assess erosion and runoff vulnerability, sub-watersheds were prioritized using the CF derived from normalized morphometric ranks (Table 3). SW1 (CF = 1.75) ranked highest in vulnerability due to its dense drainage and compact shape, making it the top priority for conservation. SW3 (CF = 2.25) showed moderate risk with an intermediate morphometric profile. SW2 (CF = 2.50) ranked lowest in vulnerability, indicating favorable morphometry for water retention and low erosion potential. These prioritization results are visually represented in Figure 4.

Critical Interpretation

The prioritization indicates that SW1 is the most erosion-prone, necessitating immediate soil and water conservation measures such as check dams, gabion structures, and vegetative barriers.

Its higher stream frequency and drainage density suggest fast runoff and low infiltration, especially during monsoon.

In contrast, SW2, with its low drainage metrics and more circular shape (Rf = 0.378), is better equipped to handle rainfall events without significant erosion. However, even this area may benefit from long-term water resource planning, such as percolation tanks and contour bunds.
Importantly, the analysis reveals how form factor and elongation ratio—shape-based parameters—strongly influence runoff behavior. While previous studies (e.g., Nag 1998; Mesa 2006) have emphasized linear parameters, our results show that shape indices also play a pivotal role in watershed responsiveness, especially in small- to medium-sized basins like this.

Implications and Limitations
This morphometric-based prioritization is a rapid and cost-effective approach for preliminary watershed planning. However, it does not directly account for land use, soil type, or rainfall variability, which can further influence erosion and hydrological dynamics. Future studies can integrate these layers using weighted overlays or hydrological modeling (SWAT) to enhance decision-making.

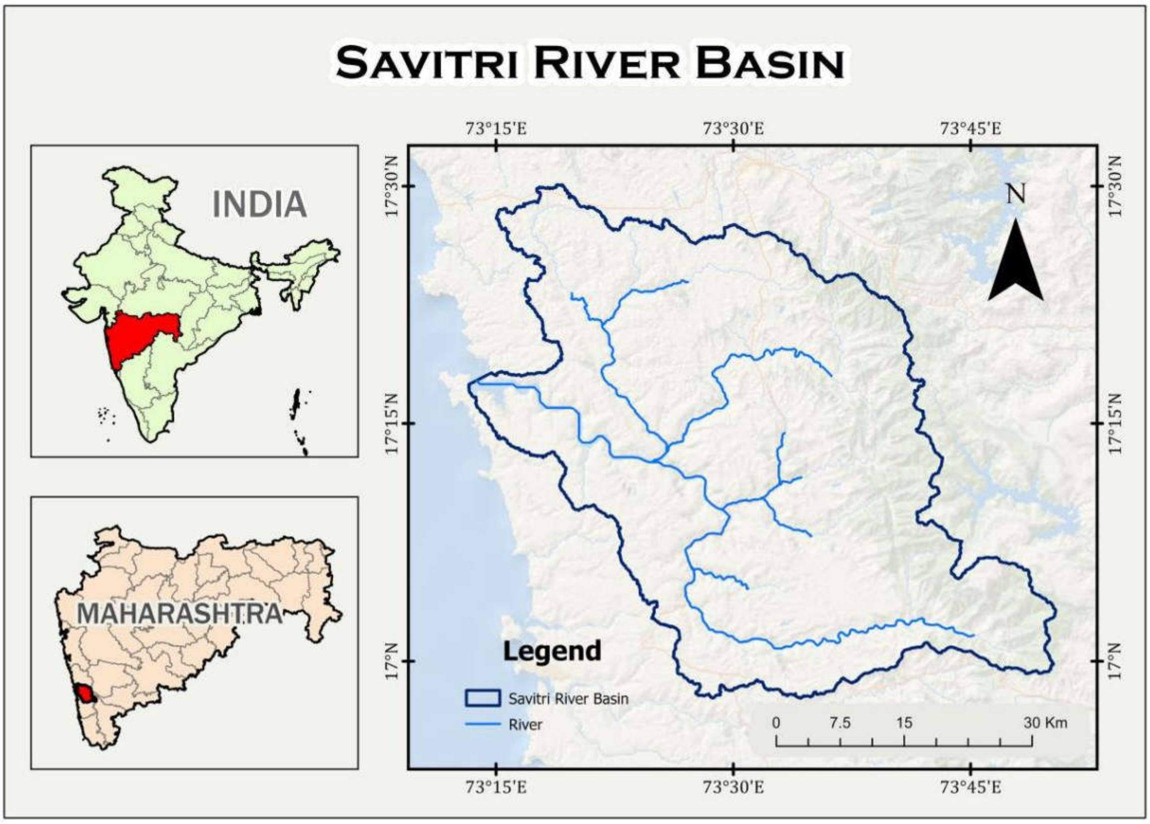

Figure 1: Location Map of the Study Area

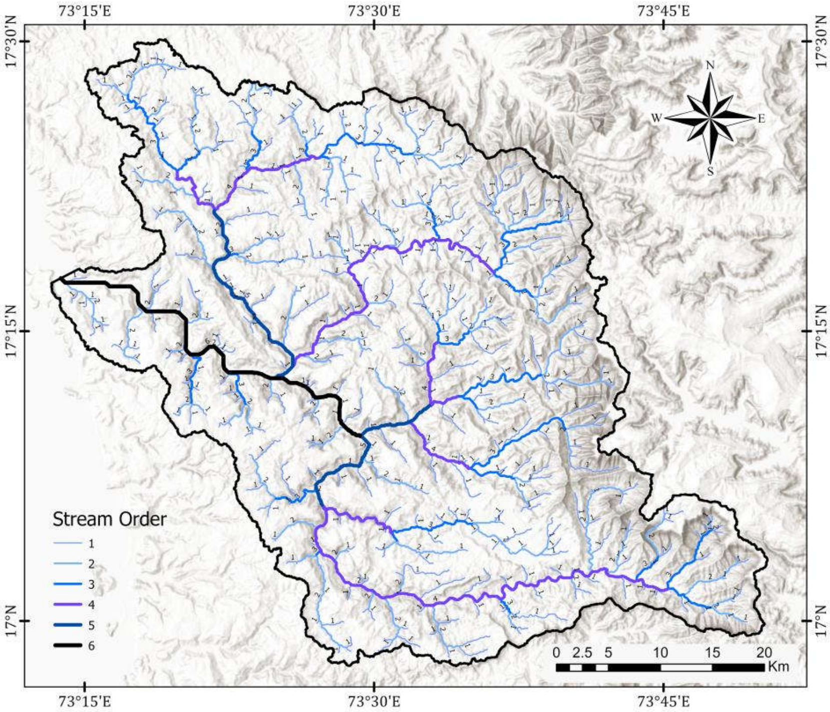

Figure 2: Stream Order

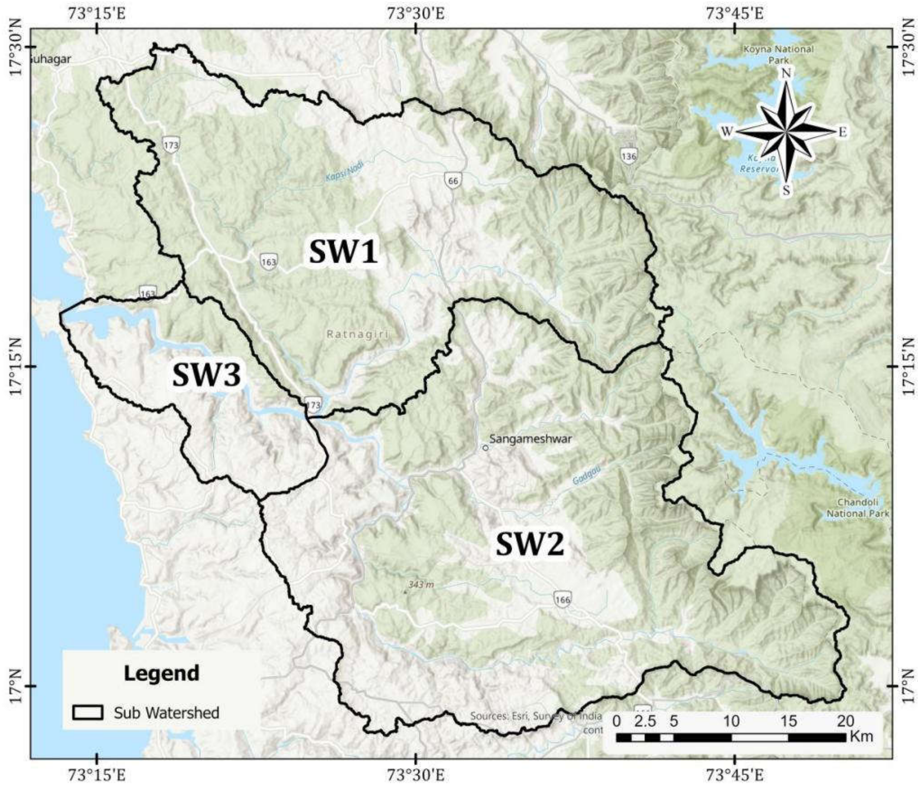

Figure 3: Sub-watershed

Table 1: Morphometric Parameters: Formulas with Authors

No.	Parameter	Formula	Proposed By / 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)

Table 2: Morphometric Analysis Table: SW1, SW2, SW3

Parameter	**SW1**	**SW2**	**SW3**
Max Stream Order (U)	5	6	6
Total Stream Number (Nu)	241	276	58
Stream Length (Lu)	Order-wise (km):	Order-wise (km):	Order-wise (km):
	1 → 236.38	1 → 310.405	1 → 52.645
	2 → 148.48	2 → 170.637	2 → 31.880
	3 → 53.726	3 → 69.990	3 → 10.140
	4 → 53.638	4 → 74.082	4 → 0
	5 → 22.114	5 → 18.332	5 → 0
	6 → 0	6 → 11.474	6 → 27.037
	Total: 514.338 km	**Total: 654.920 km**	**Total: 121.702 km**
Mean Stream Length (Lsm)	Order-wise (km):	Order-wise (km):	Order-wise (km):
	1 → 1.278	1 → 1.478	1 → 1.197
	2 → 3.806	2 → 3.879	2 → 2.898
	3 → 5.373	3 → 5.000	3 → 5.070
	4 → 17.879	4 → 14.816	4 → 0
	5 → 5.529	5 → 9.166	5 → 0
	6 → 0	6 → 11.474	6 → 27.037
Basin Area (A)	844.567 km²	1112.05 km²	211.286 km²
Basin Length (Lb)	51.68 km	51.55 km	25.13 km
Drainage Density (Dd)	0.609 km/km²	0.589 km/km²	0.576 km/km²
Stream Frequency (Fs)	0.285 streams/km²	0.248 streams/km²	0.274 streams/km²
Form Factor (Rf)	0.316	0.418	0.334
Elongation Ratio (Re)	0.635	0.731	0.653

Table 3: Parameter-wise Ranking Table for Watershed Prioritization

Parameter	SW1 Value	SW2 Value	SW3 Value	Rank SW1	Rank SW2	Rank SW3
Dd	0.609	0.589	0.576	1	2	3
Fs	0.285	0.248	0.274	1	3	2
Rf	0.316	0.418	0.334	2	3	1
Re	0.635	0.731	0.653	2	3	1
Lsm*	Moderate	High	Low	2	3	1
Lu	514.34	654.92	121.7	2	1	3
A	844.567	1112.05	211.286	2	1	3
Lb	51.68	51.55	25.13	2	1	3

Table 4: Compound Factor and Final Priority Ranking

Watershed	Sum of Ranks	No. of Parameters	Compound Factor (CF)	Priority Rank
SW1	14	8	1.75	**1** (High)
SW3	18	8	2.25	**2** (Moderate)
SW2	20	8	2.5	**3** (Low)

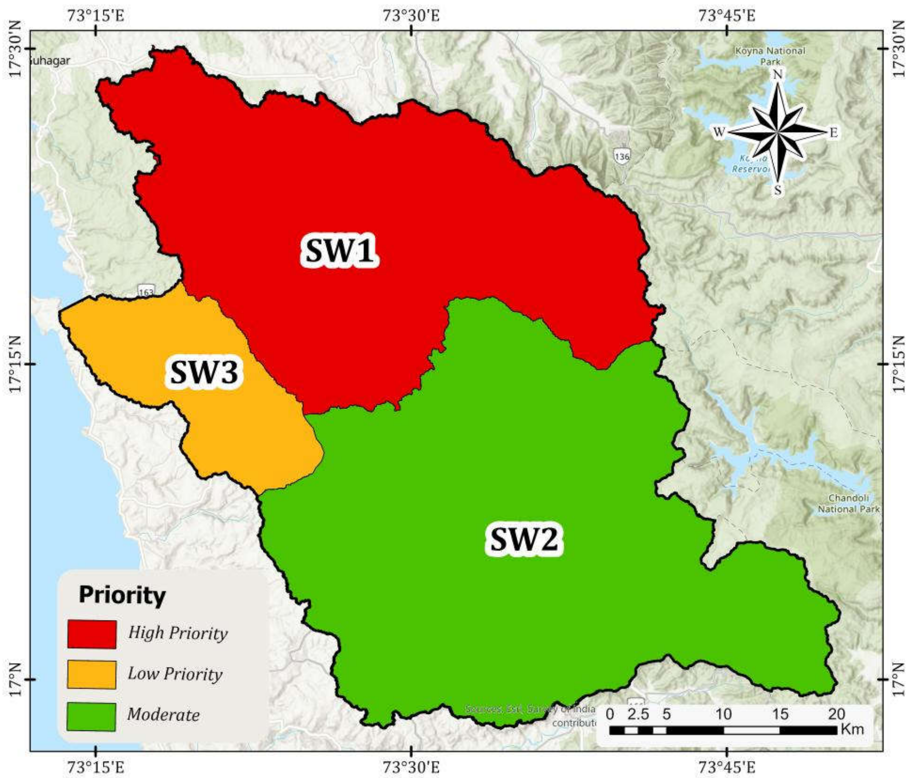

Figure 4: Watershed Prioritization Map

CONCLUSION

This study applied morphometric analysis to evaluate the hydrological behavior and erosion vulnerability of three sub-watersheds of the Shastri River basin. Ten key parameters encompassing linear, areal, and shape aspects were computed using GIS-based techniques. The results revealed notable spatial variation among the sub-watersheds, influenced by their drainage characteristics and terrain morphology. The CF assessment indicated that SW1 is the most erosion-prone, highlighting the need for immediate soil and water conservation interventions. SW3 showed moderate risk, while SW2 emerged as the least vulnerable to erosion. The findings show the effectiveness of morphometric analysis in guiding watershed management and planning, especially in data-scarce environments. Future studies may integrate land use and soil data to enhance prioritization accuracy.

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