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Morphometric Analysis of Khandepar River Basin Using Geospatial Technique as The Base for Watershed Planning

Ms. Maithali Padloskar[1] & Mr. Santosh Ghadi[2]

[1]P. G. Geography Dissertation Student, Govt. College, Khandola,

[2]Asst. Prof. of Geography & Research Scholar (CRC Geography), Govt. College, Khandola - Marcela-Goa

Corresponding Author – Ms. Maithali Padloskar

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Abstract:

Watershed Morphometry provides the base to understand the hydrological behaviour, landscape evolution and environmental sustainability. Quantitative analysis of basin geometry is crucial for understanding runoff characteristics, erosion intensity and water resource availability, all of which directly influence environmental stability and sustainable watershed management. This study presents a Morphometric assessment of the Khandepar River basin, a tributary of the Mandovi river, using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Basin boundaries are defined using topographical maps and ASTER DEM (2011) data. Survey of India toposheet no D43C3(48I/3) were used as a base map to extract drainage networks using Strahler's Method (1952) and compute linear, areal and relief morphometric parameters. A total of twenty-six morphometric indices were analyzed to evaluate basin shape, drainage efficiency and terrain characteristics using QGIS 3.14 software and MS Excel. The elongation ratio, form factor and circularity ratio indicate an elongated basin configuration, suggesting moderate runoff response and lower peak flood potential. Hypsometric analysis reveals varying stages of erosional activity, highlighting areas susceptible to moderate soil erosion and land degradation. The findings emphasize the role of morphometric analysis as an effective tool for identifying environmentally sensitive zones and supporting sustainable watershed planning and soil and water conservation strategies.

Keywords: Watershed Morphometry, Remote Sensing, GIS, Hypsometric Analysis, Sustainable Watershed Management.

Introduction:

Excessive and improper use of available natural resources such as water and soil are happening at a rapid pace due to the increasing population which deteriorates their quality needed for the future. The severity of these issues has increased due to unsustainable agricultural practices, over-extraction of resources and poor implementation of watershed management strategies. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behaviour of surface drainage networks (Horton, 1945; Leopold & Maddock, 1953). GIS and remote sensing (RS) techniques are proved to be proficient tools for morphometric characterization of sub-watersheds and prioritization of watersheds with respect to soil erosion (Aher et al., 2010; Rao et al., 2011, Waikar and Nilawar, 2014, Farhan, 2015, Kushwaha et al., 2016, Sharma and Thakur, 2016, Veerana, 2017)

Description of the Study Area:

The Khandepar River Basin is located in the central part of Goa, western India, forming an important sub-basin of the Mandovi River system. The river originates in the Western Ghats near the Goa–Karnataka border close to the Castle Rock range and flows westward through rugged terrain before entering the plains of Ponda taluka. The basin is characterized by several tributary streams that contribute to the main Khandepar River which later merges with the Mandovi River near Khandepar village. The geographical extent of the study area lies approximately between latitudes 15°15′ N to 15°30′ N and longitudes 74°05′ E to 74°20′ E. The basin covers an area of about 350–400 km² with elevation ranging from 5m to over 817 m in the upper Western Ghats region. The climate is tropical monsoon, receiving an average annual rainfall of 3000–3500 mm, mainly during the southwest monsoon. Summers are warm and humid while winters are mild. The location map of the study area is shown in fig 1

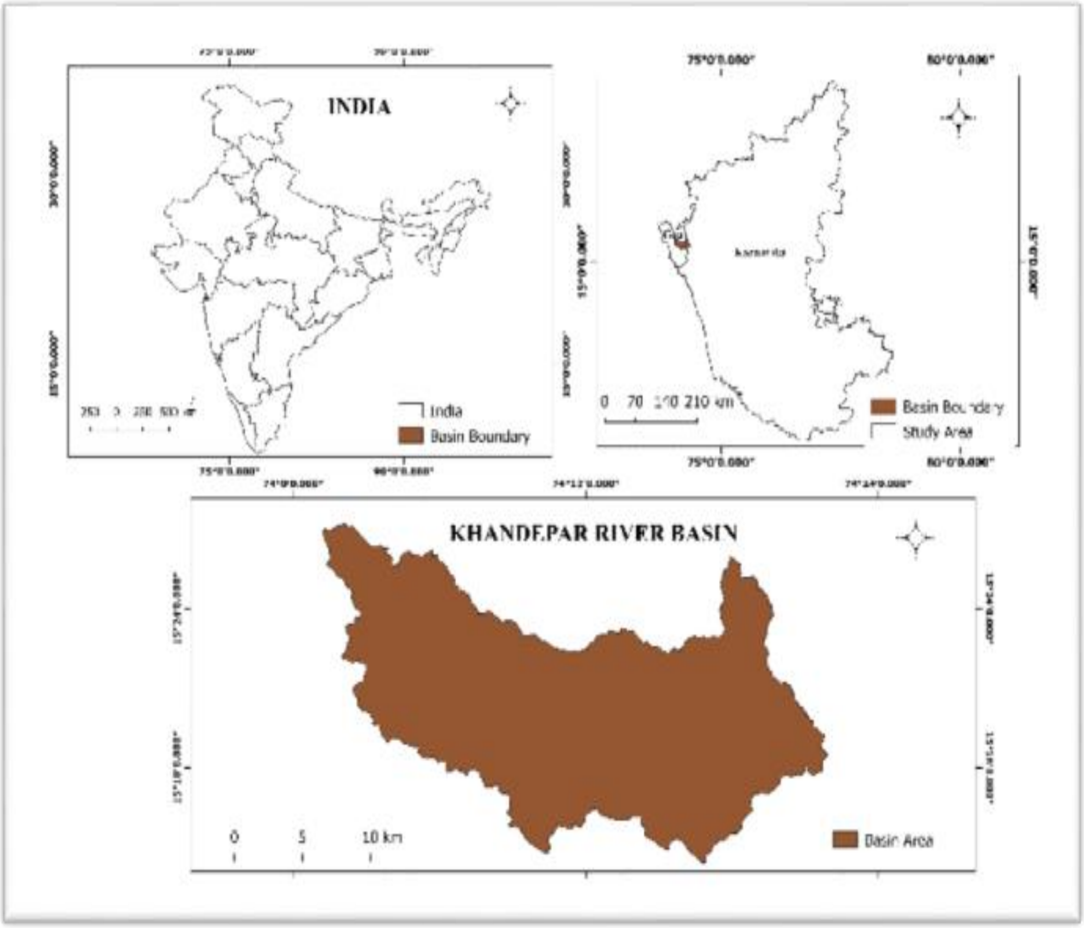

Figure 1: Study Area Map

Source: Prepared by Authors in Qgis 3.14 version, SOI

Materials and Methods:

Keeping the view of the objectives, relevant data has been collected from various secondary sources. For delineating the basin boundary and drainage network the Hydrology tool inside the Spatial Analysis Tools is used acquiring the ASTER DEM 2011 data and later stream ordering have been done using Strahler's Method (1945) in QGIS 3.14 software and ArcMap 10.8 software. The morphometric analysis provides quantitative and accurate information about the drainage basin. There are several formulas for quantifying hydrological parameters which have been used in this study, different methods are used for calculating all the three morphometric parameters that is Linear, Areal and Relief such as stream ordering, stream length, Bifurcation Ration, Drainage density etc are evaluated using the formulae given by Gravelius (1914), Horton (1945), Miller (1953), Schumm (1956), Smith (1956), Strahler (1957), Faniran (1968). These formulas are mentioned below in Table 1. Additionally Slope map, Slope Aspect map, Elevation map and Drainage density map of Khandepar River Basin have been prepared. Around 26 parameters are calculated.

Table 1: Formulas and Parameters for computation of morphometric analysis.

Morphometric Parameter	Formulae	Reference
LINEAR PARAMETERS		
Stream Order	Hierarchical Order	Strahler (1952)
Stream Numbers	Based on stream orders	Strahler (1952)
Stream Length	Length of stream (Field Calculator - QGIS Software	Horton (1945)
Stream Length Ratio	Ri= Lu/Lu-1	Horton (1945)
Stream Frequency	Fs=N/A	Horton (1945)
Mean Bifurcation Ratio	Average of all Bifurcation Ratio	Strahler (1952)
Basin Length	L=A/S	Sreedevi
Main Channel	Automatically calculated in Field Calculator in QGIS Software	
Length of Overland	Lg= 1/D×2	Horton (1945)
AREAL PARAMETERS		
Basin Area	Automatically calculated in Field Calculator in QGIS Software	
Basin Perimeter	Automatically calculated in Field Calculator in QGIS Software	
Drainage Density	Dd=L/A	Horton (1945)
Drainage Texture	T=N/P	Horton (1945)
Form Factor	$Ff=A/L^2$	Horton (1945)
Elongation Ratio	Re=2√A/π/Lb	Schumm (1956)
Circulatory Ratio	$Rc=4\Pi a/P^2$	Miller (1953)
Compactness	Cc=0.2821P/√A	Gravelius (1914)
Infiltration Number	If =Dd×Fs	Faniran (1968)
Drainage Intensity	Di= Fs/Dd	Faniran (1968)
Texture Ratio	Rt = N/P	Horton (1945)
Constant of channel Maintenance	C= 1/Dd	Horton (1945)
RELIEF PARAMETER		
Basin Relief	$H= H_{high} - H_{low}$	Schumm (1956)
Relief Ratio	H=h/Lb	Schumm (1956)
Relative Relief	R_{Ra}=H/A	Smith (1935)
Ruggedness Number	R_n= h×Dd	Strahler (1952)
Melton Ruggedness	MRN=H/√A	Melton (1957)

Source: Compiled by Authors

Results and Discussion:

The quantitative description of basin geometry provided by morphometric parameters, when integrated with geomorphological characteristics, geological settings and hydrological responses across different flow regimes, enables a comprehensive understanding of the structural and functional behaviour of the Khandepar River Basin.

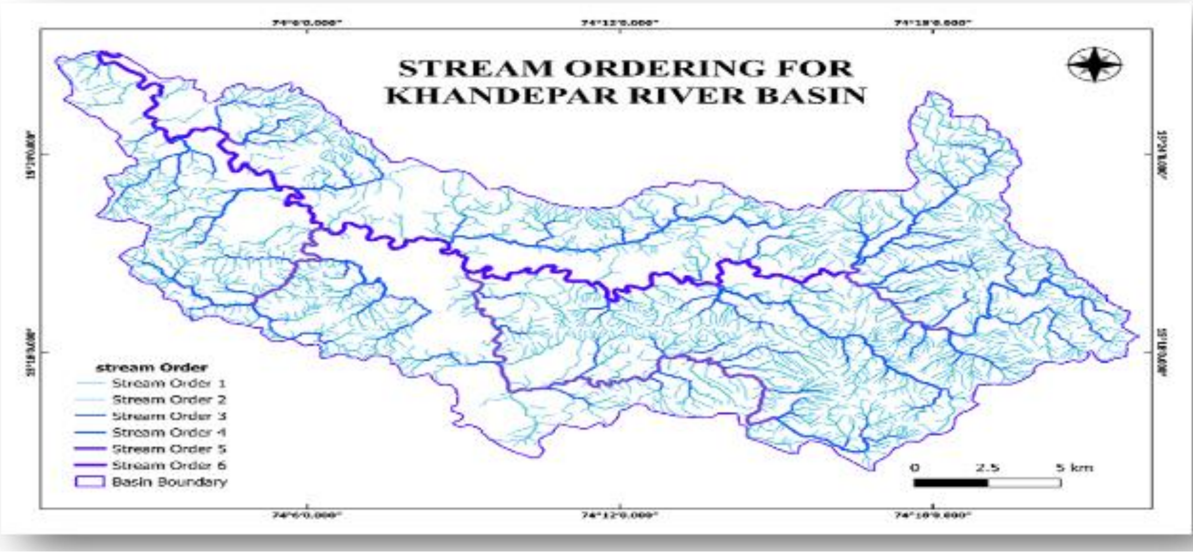

Figure 2: Stream Order for Khandepar Basin

Source: Prepared by the Authors in Qgis 3.14 version using SOI Toposheet

Table 2: Stream Details for Khandepar River Basin

Stream Order	Stream Number (Nµ)	Stream Length (Lµ)	Mean Stream Length	Bifurcation Ratio (RL)
1	1640	626	0.38	-
2	367	205	0.56	4.47
3	103	141	1.37	3.56
4	24	70	2.92	4.29
5	6	45	7.50	4.00
6	1	47	47	6
Total	∑Nµ2141	∑Lµ1134		∑Rbm3.72

Source: Compiled by Authors

Table 3: Morphometric parameters of Khandepar River Basin

Sr. No	Parameters	Results
1	Perimeter (P)	139.48km
2	Basin Area	440.23km
4	Drainage Density (Dd)	3km/km^2
5	Stream Frequency (Fs)	4.86streams/km^2
6	Drainage Texture (Rt)	15.35km
7	Drainage Intensity (Di)	1.89
8	Elongation Ratio (Re)	0.50
9	Circulatory Ratio (Rc)	0.28
10	Compactness Coefficient (Cc)	1.88
11	Infiltration Number (If)	12.56
12	Form Factor (Rf)	0.20
13	Texture Ratio (Rt)	15.35
14	Basin Relief	817m
15	Relief Ratio (Rr)	17.38m/km
16	Relative Relief	1.86m/km^2
17	Ruggedness Number (Rn)	2.451
19	Length of Overland Flow	194m

Source: Compiled by Authors

The morphometric analysis of the basin provides key findings on its hydrological behaviour, geomorphic evolution and susceptibility to erosion and runoff processes (Horton, 1945; Strahler, 1952; Schumm, 1956). The basin covers an area of 440.23 km² with a perimeter of 139.48 km, indicating a moderately large drainage basin capable of significant surface runoff under intense rainfall conditions (Leopold et al., 1964). The drainage network analysis reveals a sixth-order basin, reflecting a well-developed and mature drainage system characteristic of geomorphologically evolved watersheds (Strahler, 1952).

Linear Morphometric Characteristics:

Stream order is a hierarchical ranking of streams based on their position within a drainage network. According to Strahler's method, streams with no tributaries are designated as first-order streams and the joining of two streams of the same order forms a higher-order stream (Strahler, 1952). The stream order analysis, using Strahler's hierarchical classification method shows a clear dominance of lower-order streams with first-order streams (1640) constituting the majority of the total stream number (2141). This inverse relationship between stream order and stream number conforms to Horton's laws of drainage composition and indicates active dissection of the terrain (Horton, 1945). The total stream length of 1134 km decreases progressively with increasing stream order.

The mean stream length increases from 0.38 km in first-order streams to 47 km in the sixth-order stream, reflecting the progressive integration of flow and increasing channel stability in higher-order streams (Horton, 1945). The bifurcation ratio is the ratio of the number of stream segments of a given order to those of the next higher order. It is an important indicator of structural and geological control on drainage development (Schumm, 1956). The bifurcation ratio (Rb) ranges from 3.56 to 6.0 with a mean value of 3.72. Such values suggest moderate structural control on drainage development, indicating that geological structures and tectonic disturbances do not exert dominant influence on basin evolution (Strahler, 1957).

Areal Morphometric Characteristics:

Drainage density is defined as the ratio of the total length of all streams in a basin to the total basin area. It reflects lithology, permeability, vegetation cover, and runoff characteristics (Horton, 1945). The drainage density (Dd = 3 km/km²) indicates a moderate to high drainage density, suggesting the presence of impermeable sub-surface materials, sparse vegetation cover and moderate relief conditions. The drainage texture (15.35) and texture ratio (15.35) classify the basin as having a very fine drainage texture, which is commonly associated with weak lithology, high relief and intense erosional activity The drainage intensity (Di = 1.89) further indicates moderate runoff generation, reflecting a balance between infiltration and overland flow under prevailing geomorphic conditions.

The elongation ratio (Re = 0.50), form factor (Rf = 0.20) and circularity ratio (Rc = 0.28) collectively indicate an elongated basin shape. Elongated basins generally experience longer concentration times, lower peak discharge and reduced flood hazards compared to circular basins. This geomorphic configuration suggests that the basin exhibits moderate runoff response rather than sudden flash flooding. The compactness coefficient (Cc = 1.88) further confirms deviation from a circular basin form reinforcing the elongated nature of the watershed (Gravelius, 1914).

Relief Morphometric Characteristics:

The basin exhibits a total relief of 817 m, indicates elevation variation and strong erosional potential. The relief ratio (17.38 m/km) reflects moderately steep slopes that enhance runoff velocity and soil erosion, particularly during high-intensity rainfall events. The relative relief (1.86 m/km²) suggests moderate terrain ruggedness across the basin. The ruggedness number (Rn = 2.451) which combines drainage density and basin relief is relatively high and indicates a terrain highly susceptible to soil erosion, landslides and sediment transport.

The length of overland flow (194 m) is relatively short, implying rapid movement of rainfall to stream channels and increased runoff efficiency. Further, the infiltration number (If = 12.56) suggests low infiltration capacity.

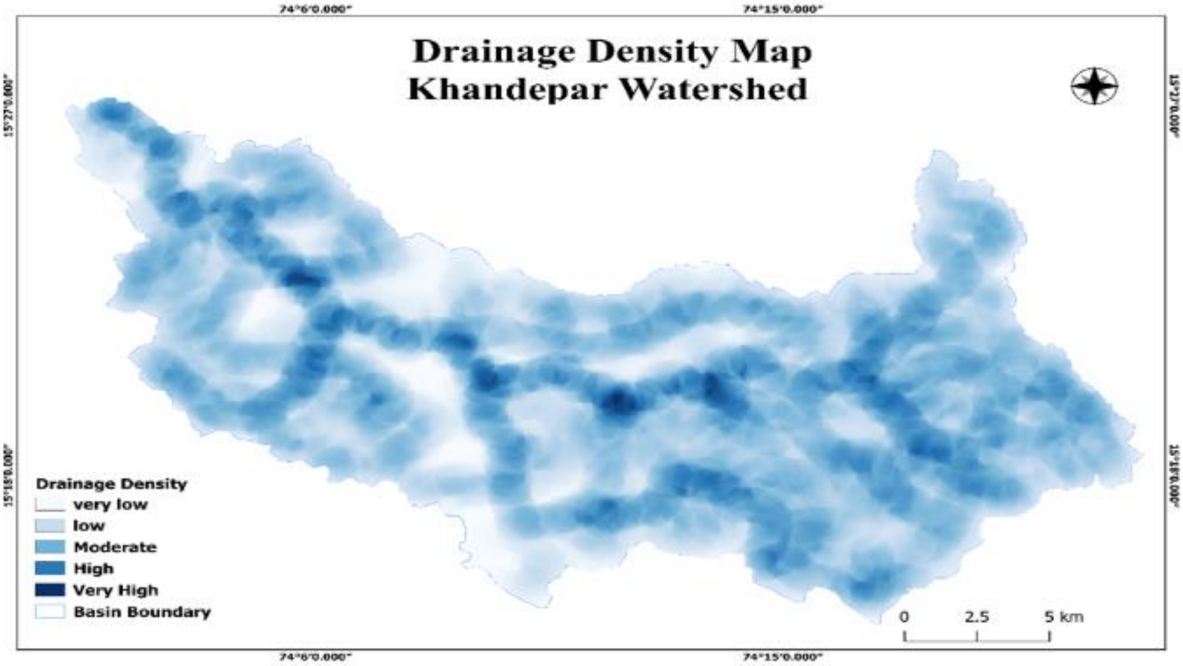

Figure 3 :Drainage Density Map

Source: Prepared by Authors in Qgis 3.14 version, SOI

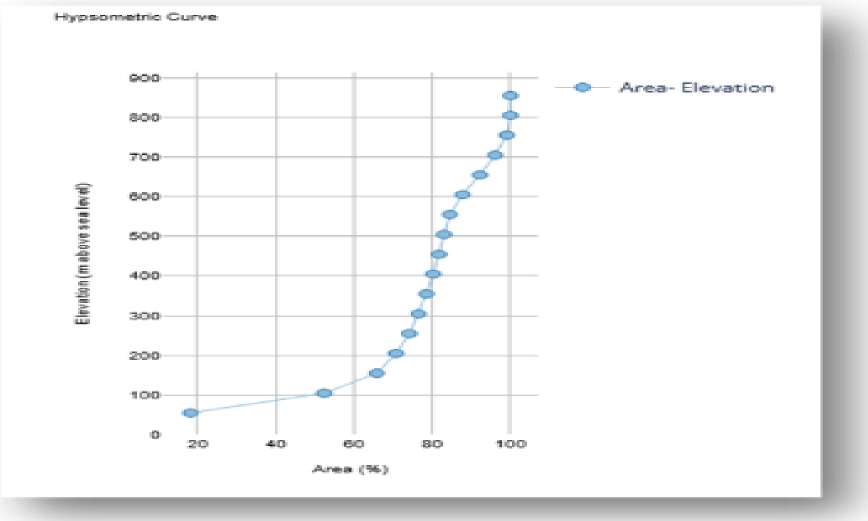

Figure 4 : Hypsometric Curve of Drainage Basin

Source: Prepared by the Authors in Qgis 3.44 version using SOI Toposheet

The hypsometric curve exhibits a moderately convex–concave shape, indicating that the basin is in a mature to late-mature stage of geomorphic development (Strahler, 1952; Schumm, 1956). The gentler slope at lower elevations reflects extensive valley development and depositional surfaces formed through prolonged fluvial erosion. This pattern indicates moderate erosion intensity with ongoing landscape adjustment.

Conclusion:

Morphometric analysis helps to understand the hydrologic characteristics of the watersheds. In this study, hydrologic characteristics of the Khandepar Basin has been studied using the remote sensing and GIS approach. The Khandepar Basin is the 6th order watershed. The total number streams are 2141 respectively. The length of overland flow (194 m) indicates that rainfall travels a short distance over the surface before entering stream channels, suggesting rapid runoff generation and limited infiltration, which increases erosion potential. The present study provides a quantitative technique, for the understanding of Hydrological characteristics of the Khandepar River Basin using different Morphometric Parameters of Linear, Areal and Relief aspects. The findings of the study provide the base for the planners for a better planning and conservation of the natural resources.

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