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GIS-Based Morphometric Analysis of the Arunavati River Watershed: Implications for Hydrological Characteristics and Watershed Management

Dr.Manohar Bansilal Patil

Abstract

In the present study, the morphometric analysis of the Arunavati River watershed was carried out using Remote Sensing (RS) and Geographic Information System (GIS) techniques. The study area had an area of 777.819 km^2, and the drainage network was developed up to seven stream orders with 5350 stream segments and a total length of 2816.337 km. The mean bifurcation ratio of 4.0634 indicated a moderately developed branching drainage network. Areal morphometry indicated a drainage density of 3.6208 km/km^2, stream frequency of 6.8782/km^2 and a form factor of 0.3073, which showed a well dissected and elongated drainage. Relief morphometry indicated a basin relief of 680.77 m, a ruggedness number of 2.4649, and a hypsometric integral of 0.2647, which indicated variation in the topography of the study area and prolonged denudational processes. The results suggested that basin geometry and relief conditions also affect the hydrological attributes of the study area. The study also illustrated the use of GIS in the assessment of morphometrics of a basin for identifying the erosion sensitive areas and improved understanding of runoff behaviors to develop suitable soil and water conservation measures.

Keywords: *Morphometric Analysis; GIS; Hydrological Characteristics; Watershed Management.*

Introduction

Watersheds are units of the drainage division of the earth's surface, over which surface water is moved and collected, and offer a basis for the distribution, transfer and control of water resources. Knowledge of the size, shape and relief of drainage systems and drainage patterns help to assess runoff, erosion and sediment transport. This is important in the management of water resources. Morphometric analysis, based on measurements of length, area, and relief, provides an assessment of the nature, development, and structure of the watershed, among other things, and is useful in planning and management of watersheds and conservation. This includes stream numbers and orders, lengths and bifurcation ratios; drainage density and texture; stream form factor, elongation and circularity; and relief, relief ratio and ruggedness number. Adequate elevation models (e.g., SRTM and ASTER GDEM) are critical to the assessment of watersheds using RS and GIS. GIS-based morphometric analysis is a quantitative approach that analyzes the shapes and sizes of landforms to analyze hydrological and geomorphological characteristics of a drainage basin and is useful in watershed planning and management. It utilizes RS and GIS to derive morphometric parameters such as stream order and length, bifurcation ratio, drainage density, stream frequency, form factor and circulatory ratio.

This data aids in the analysis of the drainage network and potential hydrological behavior of a watershed. It also helps characterize the terrain conditions of a watershed. In the case of the Damodar River sub-watershed in India, ASTER DEM and topographic maps helped illustrate a dendritic drainage pattern, suggesting a homogenous lithology and a gentle regional slope (Kumar et al., 2022). The analysis of the Tamsa River watershed in Uttar Pradesh also documented a low-relief, gently-sloping terrain, and suggested potential runoff concentration and groundwater recharge (Ankit et al., 2026). The Bhadra Watershed study in Karnataka demonstrated the importance of GIS in assessment of drainage and relief parameters, which aids in soil and water conservation (Gouda et al., 2026). The Seonath River Basin study in Chhattisgarh highlighted the impact of drainage patterns on runoff behavior and regional erosion processes (Kuhade et al., 2026). These studies demonstrate the utility of GIS-based morphometric analysis in providing precise and reproducible information on different aspects of a watershed which is vital for the management of soil and water resources, and control of erosion, floods and groundwater recharge (Phalke & SFR, 2025; Langat et al., 2020; Chowdhury et al., 2025). Integration of high-resolution remote sensing with GIS helps in advancing the assessment and management of river basins (Jalem, 2025; Makwana et al., 2018; A. Kumar et al., 2022).

Drainage and hydrological processes are studied in a watershed unit such as the Arunavati River watershed. Runoff, availability of water, and soil erosion are influenced by the geomorphology of a region, types of drainage, topography and physiography. Systematic morphometric analysis of the watershed helps to understand the development of drainage and hydrology of an area, and also aids in identifying high-risk erosion areas and optimal management of the watershed. This study employs Remote Sensing and GIS techniques to study linear, areal, and relief characteristics, determine drainage, and compute drainage and morphology-related parameters and hydrological behavior.

The present study was conducted in the Arunavati River Watershed, located in Maharashtra, India. Geographically, watershed extends between 21°17′14″ N and 21°36′42″ N latitudes and 74°48′13″ E and 75°12′ 54″E longitudes cover 777.8188 Sq.km. The watershed north eastern part extends in Madhya Pradesh, while remain in Maharashtra state. The watershed represents an important geographical unit for analysing drainage patterns, topographic characteristics, and hydrological processes. The area exhibits variations in elevation, slope, and drainage characteristics, which influence surface runoff and soil erosion.

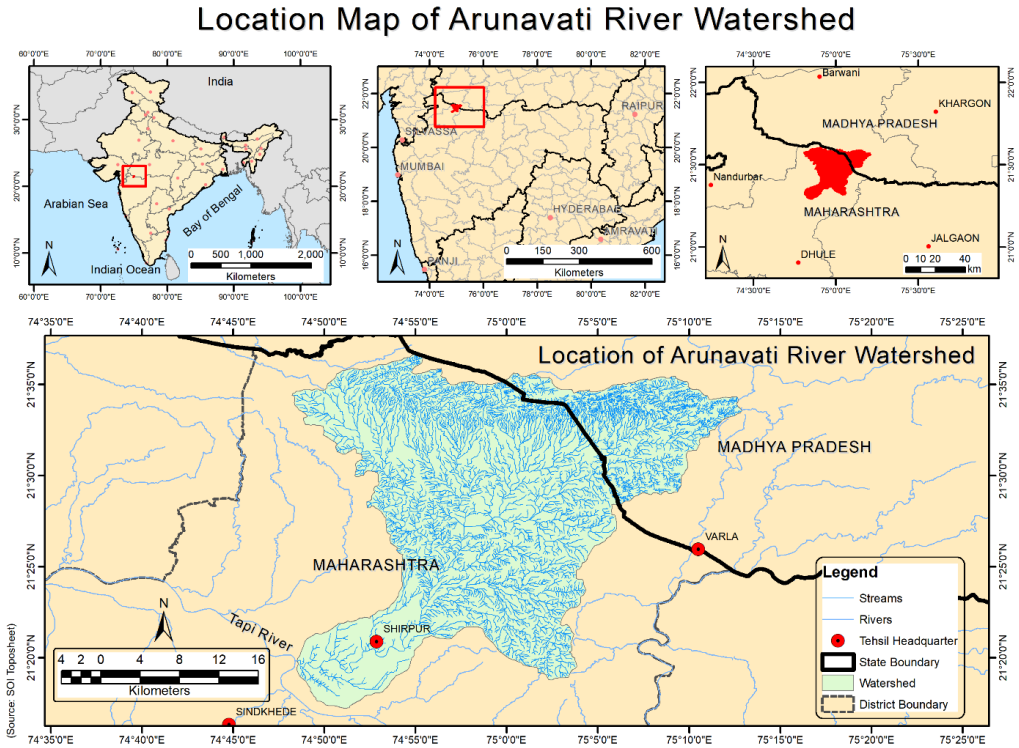

Figure 1 Location Map of the Arunavati River Watershed

Objectives

The major objectives of the present study are:

1. To demarcate Arunavati River watershed using Digital Elevation Model (DEM), SOI Toposheet data and GIS techniques.
2. To compute linear, areal and relief morphometric parameters of the watershed.
3. To evaluate geomorphological characteristics and hydrological behavior of the watershed based on morphometric properties.
4. To evaluate the implications of morphometric characteristics for soil and water conservation and sustainable watershed management.

Materials and Methods

Methods

This study integrated the use of remote sensing (RS) and geographic information system (GIS) to characterize the morphometric parameters of the Arunavati River watershed. The watershed boundary and the drainage network were delineated using DEM data and SOI Toposheet in QGIS, the drainage network was extracted and classified by Strahler stream ordering, and the morphometric parameters were calculated for linear, areal, and relief aspects. The computed parameters were examined to understand the drainage characteristics and geomorphological development of the study area, and to interpret the runoff behavior and hydrological responses of the watershed. The results allowed for a more robust characterization of watersheds and a basis for the sustainable management of soil and water resources of the study area.

Materials

This study is based on secondary data collected from various authoritative sources. The major datasets required for the analysis are as follows.

Table 1 Details of datasets and their sources used for GIS-based morphometric analysis of the Arunavati River watershed.

Data type	Source	Purpose
Digital Elevation Model	SRTM / ASTER GDEM / ALOS	Watershed delineation and relief

(DEM)	PALSAR	analysis
Satellite imagery	Landsat 8/9 or Sentinel-2	Drainage interpretation
Topographical maps	Survey of India (SOI)	Drainage network verification
Administrative boundaries	Survey of India (SOI) Toposheet	Geographical reference

(Source: Compiled by the author from SRTM/ASTER GDEM/ALOS PALSAR data, Landsat 8/9 or Sentinel-2 satellite imagery, and Survey of India (SOI) topographical maps.)

Spatial datasets have been processed using GIS software such as QGIS, whereas DEM-derived terrain parameters have been used for watershed delineation and drainage network extraction. Morphometric measurements have been calculated using standard mathematical formulae established in geomorphological studies.

Results and Discussion

Linear Morphometric Analysis

Table 2 Linear morphometric parameters of the Arunavati River watershed.

Stream Order	**No. of Streams**	**Stream Length (km)**	**Avg. Stream Length (km)**	**stream length ratio**	**Bifurcation Ratio**	**Mean Basin Area (sq.km)**	**Mean Channel Slope (Degree)**
1	4247	1605.0941	0.3779		5.0984	0.1044	3.1247
2	833	540.2376	0.6485	1.716	4.1238	0.7113	1.9174
3	202	305.0062	1.5099	2.3282	4.2083	3.3502	1.1024
4	48	195.0694	4.0639	2.6915	3.2	15.2211	0.8209
5	15	87.8641	5.8576	1.4414	3.75	50.3252	0.4228
6	4	49.2252	12.3063	2.1009	4	192.1182	0.3154
7	1	33.8405	33.8405	2.7499		777.8188	0.1551
Total / Mean	5350	2816.337	0.5264	2.1713	4.0634	777.8188	1.1227

(Source: Prepared by the author using GIS-based drainage network analysis and standard morphometric formulae, following Horton (1932, 1945), Strahler (1952, 1964), and Schumm (1956).)

The Arunavati River Watershed is a seven-order drainage system with 5,350 stream segments and a total stream length of 2,816.337 km (linear morphometric study). The number of stream segments decreased with increasing order: 4,247 first-order streams (79.38%), 833 second-order streams, 202 third-order streams, 48 fourth-order streams, 15 fifth-order streams, 4 sixth-order streams and 1 seventh-order stream. This high number of low order channels gathered the runoff of the watershed.

The total length of first-order streams was 1,605.0941 km; the length of second-order streams was 540.2376 km; the length of third-order streams was 305.0062 km; the length of fourth-order streams was 195.0694 km; the length of fifth-order streams was 87.8641 km; the length of sixth-order streams was 49.2252 km; and the length of seventh-order streams was 33.8405 km. The mean length of the stream was 0.5264 km, rising from 0.3779 km (first order streams) to 33.8405 km (seventh order streams). Long, high-order streams exhibited a well-developed drainage network, whereas shorter, low-order streams accumulated runoff and drained it to the principal streams.

Ratios of stream lengths ranged from 1.4414 to 2.7499, with an average of 2.1713. The highest ratio of 2.7499, was in the sixth and seventh order streams. The lowest ratio of 1.4414, was in the fifth and sixth order streams. Variations in mean stream length, indicated that mean length did not increase uniformly in all stream orders. This is due to differences in lithology, relief and local geological structures. The average bifurcation ratio was 4.0634, with ratios ranging from 3.20 to 5.0984. A low bifurcation ratio indicated that the drainage was naturally formed, and there was no major distortion of the basin at the watershed scale. However, variations in stream orders showed that local geological conditions and geomorphology influenced the drainage network.

It was shown that drainage basins of higher order streams had larger basins. The drainage basins of first order streams had a mean area of 0.1044 km², and seventh order streams had a mean area of 777.8188 km². This showed that drainage basins of higher order streams had larger drainage basins. Higher order streams were important to collect and transport runoff from a larger part of the watershed. Information on the order of streams had importance in the management of the main drainage channels.

The mean channel slope was 3.1247° for first-order streams and 0.1551° for the seventh-order stream with a general mean of 1.1227°. Lower-order streams are found in less steep regions and higher-order streams are found in steeper regions. Steeper slopes in the upper catchment could have led to rapid runoff, erosion and incision. Gently sloping lower catchment could have resulted in slower runoff and sediment and caused deposition. Variability in topographic conditions influences hydrologic conditions of the catchments.

In the context of watershed management, for conservation, it was shown that all orders of draining streams require appropriate measures. For the lower order streams, afforestation and vegetation barriers, as well as soil and water conservation measures such as construction of terraces and contour bunds, and gully plugs in the upper catchment, may slow surface runoff and reduce soil erosion. For upper order streams, bank protection structures should help control sediment and improve drainage stability.

The line morphometric analysis indicated that the Arunavati River watershed had a well-structured seven order drainage network with a predominance of lower order streams, a greater mean stream length, a moderate bifurcation ratio, greater contributing basin areas, and a lower channel slope, which were the result of the combined influence of topography, geology,

and the evolution of the drainage network. The findings served as a basis for assessing hydrological characteristics of the watershed and provided clues for taking rational soil and water conservation measures.

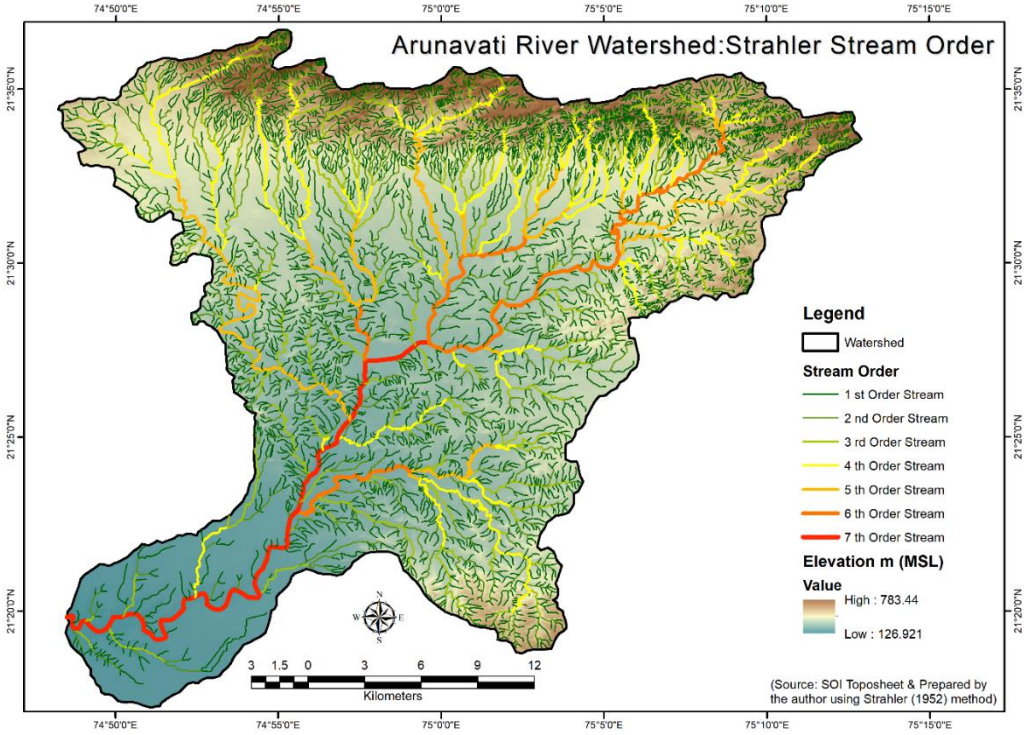

Figure 2 Strahler Stream Order of Arunavati River Watershed

Areal Morphometric Analysis

The morphometric analysis of the Arunavati River watershed was performed using GIS tools to characterize the shape and size of the watershed, as well as other characteristics related to drainage. The area of the Arunavati River watershed is 777.819 km2, the perimeter is 177.983 km, the length is 50.307 km, the width is 15.461 km, which is an elongated shape. The morphometric characteristics of the watershed are related to the development of drainage in the basin and the run-off generating capacity.

The drainage density is 3.6208 km/km^2, which is moderately higher (indicating more development of the drainage network), or a relatively higher length of streams in the watershed. The type of rainfall, nature of soil and vegetation, relief, and other geographical conditions (especially the geology of the area) will all affect drainage density. Higher drainage density indicates a greater rate of collection of surface run-off and greater soil infiltration, and generally indicates a greater potential for soil erosion, with steepness of slope and nature of surficial deposits also being factors.

Stream frequency was high (0.9658) and drainage density was high (0.9658), indicating an actively developed drainage system that is influenced by lithology, permeability, topography, and seasonal rainfall. The high stream frequency suggested that surface runoff was rapidly captured and carried by the tributary streams to the main stream. An integrated channel network may promote rapid soil and water movement and call for conservation measures. The drainage texture value was 30.0591 streams/km, suggesting very fine drainage texture. Many stream segments compared to the basin perimeter suggested a highly developed drainage, which is typical of fine drainage texture. The Arunavati river basin is relatively dissected and heavily eroded, considering its relief and the intensity and duration of the rainfall.

Table 3 Areal morphometric parameters of the Arunavati River watershed.

Sr. No.	Morphometric Parameter	Value	Unit	Reference
1	Basin Area (A)	777.819	km^2	Schumm (1956)
2	Basin Perimeter (P)	177.98284	km	Schumm (1956)
3	Basin Length (Lb)	50.306823	km	Schumm (1956)
4	Basin Width (Wb)	15.461496	km	Horton (1932)
5	Drainage Density (Dd)	3.620814	km/km^2	Horton (1932, 1945)
6	Stream Frequency (Fs)	6.878209	streams/km^2	Horton (1932, 1945)
7	Drainage Texture (Dt)	30.059078	streams/km	Horton (1945)
8	Form Factor (Rf)	0.307344	Dimensionless	Horton (1932)
9	Circularity Ratio (Rc)	0.308555	Dimensionless	Miller (1953)
10	Elongation Ratio (Re)	0.625558	Dimensionless	Schumm (1956)
11	Compactness Index (Cc)	1.800255	Dimensionless	Gravelius (1914)
12	Fitness Ratio (Fr)	0.377433	Dimensionless	Melton (1957)

(Source: Prepared by the author using GIS techniques and standard areal morphometric formulae, following Horton (1932, 1945), Miller (1953), Schumm (1956), Gravelius (1914), and Melton (1957).)

A long, thin basin has a form factor of 0.3073. A form factor less than unity indicates an elongated basin; a form factor near unity indicates a more circular basin. The less compact a basin is, the more varied the areas draining to the outlet,

which causes the runoff from those areas to reach the outlet at different times, resulting in a shorter runoff concentration time and greater tendencies to produce high peak discharge. The soil, channel conditions, and location and intensity of the rainfall all affect the flood response of the watershed.

A circularity ratio of 0.3086 less than one indicates the basin is not circular. In Horton's classification, basin shape is primarily influenced by geologic structures, topographic conditions, and the evolution of the drainage network. In this study, a more elongated area likely drains a basin's peak runoff flow.

Elongation ratio was 0.6256, indicating a moderately elongated basin. Influencing surface runoff and concentration may be due to topographic configuration of the watershed. Circular basins concentrate surface runoff quickly and therefore respond to flood peak flows quickly. Elongated basins respond to flood peak flows more slowly, supporting the findings of the form factor.

The compactness coefficient for the Arunavati River watershed is 1.8003. The coefficient is 1 for a circular basin, and the value for the Arunavati River watershed is greater than 1, so the basin is elongated and irregular, which meant that runoff distribution and travel time to the basin outlet varied. The compactness, form factor, and circularity factor values all reflected the elongated shape and lack of circularity.

The fitness ratio was 0.3774, which was low, meaning that the length of the main channel of the basin was relatively small compared to the perimeter of the basin. The observed fitness value showed that the main drainage of the basin was relatively clustered. The fitness ratio also provided an areal indication of the shape and the density of the drainage network of the basin in addition to other areal factors.

Morphometric analysis indicated that soil and water conservation practices were needed in areas of the basin with high drainage density, frequent streams, and high drainage texture where surface runoff and soil erosion needed to be controlled. Runoff control, reduction in runoff volume, and increase in soil moisture and soil moisture infiltration can be achieved using a variety of Best Management Practices (BMPs) such as construction of gully control structures, check dams and contour bunds. Since the basin was long and narrow, conservation planning needed to address the spacing and location of tributaries and contributions from the upper, middle, and lower parts of the basin.

Drainage density and texture, frequency of streams and shape of the Arunavati River basin indicated moderately high drainage density, frequency of streams and texture, elongated shape, low form factor and circularity ratio and high compactness coefficient which indicated less circular basin with irregular shape that would affect hydrologic response. The findings supported water conservation and integrated water-harvesting for the basin management.

Relief Morphometric Analysis

Table 4 Relief morphometric parameters of the Arunavati River watershed.

Sr. No.	Morphometric Parameter	Value	Unit	Reference
1	Absolute Relief (Ar = Zmax)	743.43268	m	Strahler (1952) / Nir (1957)
2	Mean Spatial Absolute Relief (Ar)	249.19827	m	Nir (1957)
3	Basin Relief (H = Zmax - Zmin)	680.77041	m	Strahler (1952)
4	Relief Ratio (Rh = H / Lb)	0.013532	Dimensionless	Schumm (1956)
5	Ruggedness Number (Rn = H_km * Dd)	2.464943	Dimensionless	Strahler (1958)
6	Basin Dissection Index (Di)	0.915712	Dimensionless	Nir (1957)
7	Mean Spatial Grid Dissection Index (Di)	0.043759	Dimensionless	Nir (1957)
8	Mean Basin Slope (Degrees)	5.373714	Degrees	Wentworth (1930)
9	Mean Channel Slope	3.603648	Degrees	Strahler (1952)
10	Valley Floor Width-to-Height Ratio (Vf)	26.252004	Dimensionless	Bull & McFadden (1977)
11	Constant of Channel Maintenance (C)	0.276181	km^2/km	Schumm (1956)
12	Torrentiality Coefficient (Ct)	24.904715	km^-3	Villa (1984)
13	Hypsometric Integral (HI)	0.264684	Dimensionless	Strahler (1952)
14	Percentage Hypsometric Integral (HI%)	26.468406	Percent (%)	Strahler (1952)
15	Elevation-Relief Ratio (E)	0.264875	Dimensionless	Pike & Wilson (1971)

(Source: Prepared by the author using DEM-derived terrain parameters and standard relief morphometric formulae, following Strahler (1952, 1958), Nir (1957), Schumm (1956), Wentworth (1930), Bull and McFadden (1977), and Pike and Wilson (1971).)

Morphometric analysis of the Arunavati River watershed showed topographic attributes such as total vertical extent, absolute relief, mean spatial absolute relief, and relief, which varied due to the nature of the underlying formations, erosional processes, and evolution of the landscape, and long-term modifying factors that affect surface runoff, velocity, and direction as well as the development of the drainage network.

The relief ratio was 0.0135. The relief across the basin was very gentle, but may contribute to some soil erosion on localized steep slopes. The ruggedness number was 2.4649, which suggests the basin is moderately rugged and susceptible to erosion and runoff and potentially high soil erosion during extreme events.

The basin dissection index (0.9157) is greater than 1, indicating high relief dissection and expression (Nir, 1957). The mean spatial dissection index (0.0438) also shows high relief dissection and variable expression. The pattern and expression of relief shows high dissection in the basin and spatially non-uniform. Variable dissection may be caused by lithology and erosion variations.

Estimates of the mean basin slope (5.3737°) indicated a moderately sloping landscape, while mean channel slope (3.6036°) showed that the channels followed a slope flatter than that of the basin surface, a difference that may be caused by the shape of the basin surface and the maturity of the drainage network, or it may indicate that the basin is made up of multiple segments in which the steeper and higher segments promote rapid flow and erosional activity, while the lower and flatter segments promote low flow and deposition. As a result, slope variation and differences were given more scrutiny in terms of the movement of runoff, erosion, and deposition. Soil and water conservation targeted areas of prior erosion.
The ratio of Valley floor width to height was 26.2520, indicating broad valley floors relative to the height of the valley. The Vf ratio is high for a wide valley floor with minimal vertical incision and low for a narrow valley floor with active vertical incision (Bull and McFadden, 1977); thus, the wide floor sections likely result from widening and fluvial processes (erosion), and the morphology may differ across drainage divides.

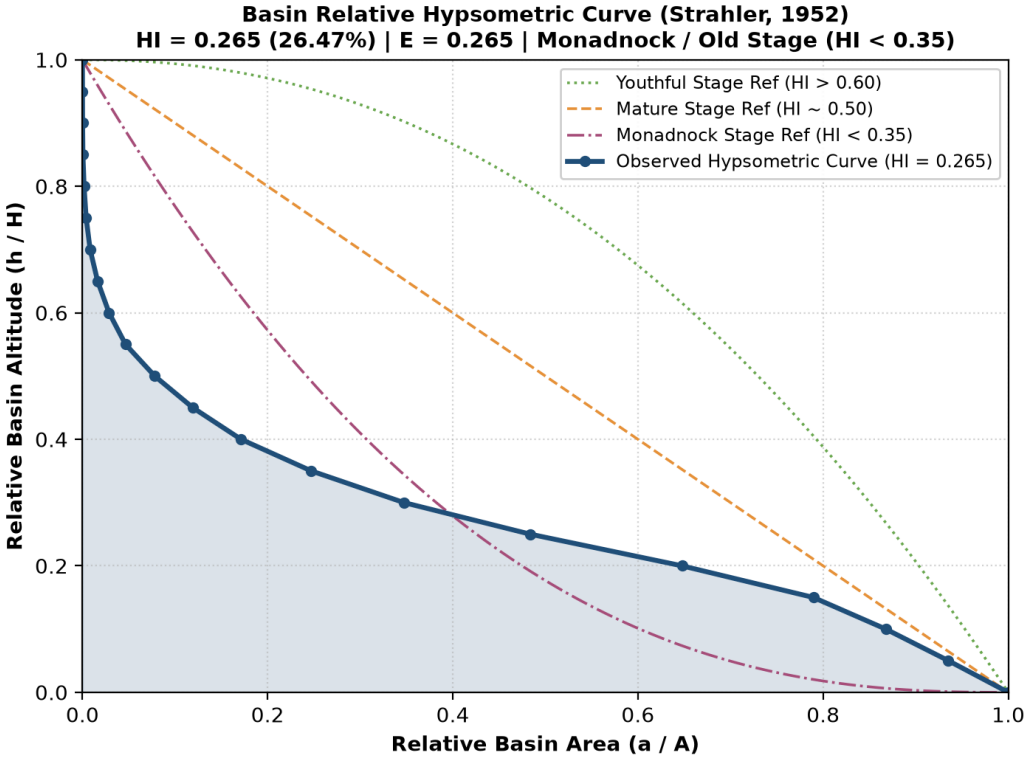

Figure 3 Relative Hypsometric curve of the Arunavati River watershed

The channel maintenance coefficient was 0.2762 km²/km, which means one unit length of stream channel is maintained by 0.2762 km² of basin area, indicating a strongly integrated drainage basin as would be expected from the overall drainage density of 3.6208 km/km² found in the morphometric analysis of drainage basins.
The ruggedness or torrentiality coefficient was 24.9047 km^{-3}, which means that the area has a high ruggedness and drainage combination and may have runoff concentration and erosion processes, which might require some type of conservation/management interventions to reduce their effects on steep slopes and incised drainage channels with poor vegetation cover.

The watershed hypsometric integral (HI) was 0.2647 (26.47 %) and the elevation relief ratio was 0.2649. Low hypsometric integral values (<0.5) indicate infant hypsometric stage of erosion, whereas high values (>0.5) indicate a mature hypsometric stage of erosion (Strahler, 1952). From the above, it may be concluded that the Arunavati river basin has a mature to old and eroded, dissected landscape. Hypsometric stages are broad and may require interpretation. The morphometric and relief analysis shows that land use and conservation practices should be tailored to the needs of different topographical scenarios, with steep areas needing contour and ridge bunding, afforestation, terracing, and vegetative barriers and gully plugs, moderate relief needing soil and water conservation practices, and broad valley floors needing water conservation land use practices.
Based on relief-morphometric analyses, the Arunavati river basin was found to have moderate relief, gentle basin slopes, and low hypsometric integral due to long-term erosional and fluvial processes, making the region susceptible to soil erosion and surface runoff. This helped develop appropriate on-site soil and water conservation practices. Relief-feature analysis in conjunction with other analyses helped identify dominant hydrological features of the watershed with major implications to integrated watershed management and planning.

Conclusion

The GIS-based morphometric analysis of the Arunavati River basin captured the drainage network, basin geometry, and topographic relief, revealing a well-developed seven-order drainage network with a mean bifurcation ratio of 4.0634, a relatively well-dissected and elongated basin reflected in a drainage density of 3.6208 km/km² and a form factor of 0.3073, and a significant elevation difference, moderate ruggedness number of 2.4649, and a relatively low hypsometric integral of 0.2647.

The integrated morphometric analysis of drainage network and basin indicate that the watershed behavior is controlled by network and basin shape, slope and relief conditions. This implies that the integrated management of the watershed needs to be followed with tree plantations, terracing, construction of check dams, plugging of gullies, and other soil and water conservation measures. The study also illustrates the use of GIS for morphometric analysis of the Arunavati River watershed to identify areas of high surface runoff, high erosion potential and high-water stress, and how to develop a sustainable development of water resources.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of thesis paper.

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