OPEN ACCESS
Quick Response Code:
Website: https://wgges.us

Manuscript ID:
IJWGAFES-2025-021217

DOI: 10.5281/zenodo.21642678

DOI Link:
https://doi.org/10.5281/zenodo.21642678

Volume: 2
Issue: 12
December
Year: 2025
E-ISSN: 3066-1552

Submitted: *08 Nov.2025*

Revised: *12 Nov.2025*

Accepted: *05 Dec 2025*

Published: *31 Dec. 2025*

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How to cite this article:
Misar, J. V. & Nikam, S. N. (2025). Hydrological and Morphometric Analysis of the Manyad River Basin Using Remote Sensing and ASTER DEM Data with GIS Techniques. International Journal of World Geology, Geography, Agriculture, Forestry and Environment Sciences, 2(12), 91–97.
https://doi.org/10.5281/zenodo.21642678

Hydrological and Morphometric Analysis of the Manyad River Basin Using Remote Sensing and ASTER DEM Data with GIS Techniques

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Abstract

The Nandgaon region in Nashik, Maharashtra faces severe water scarcity. We wanted to understand how the Manyad River Basin's shape and structure affect its water availability and flood risk. Using ASTER DEM satellite data at 30-meter resolution and GIS tools, we analyzed the basin's morphometric characteristics. What we found is interesting: the basin has 3,528 streams organized in a 6th-order drainage network, with 2,701 first-order tributaries (76.56%) concentrated in the upland areas. The basin's highly elongated form (elongation ratio: 0.40; form factor: 0.13) means runoff takes longer to concentrate, which actually reduces flood severity. The moderate drainage density (2.75) indicates that rainfall infiltrates fairly well. However, high drainage texture (19.90) and a ruggedness number of 1.91 show steep, erosion-prone terrain in upstream zones. This information will help identify where to construct recharging structure, the region require protection from soil conservation measures and measures for reducing the down stream risk in time of flooding. Remote sensing & GIS technique for water resource planning under drought scenario have been established in this work.

Keywords: *Manyad River Basin, Morphometric analysis, ASTER DEM, Elongated watershed, Groundwater management, Remote sensing, Semi-arid hydrology, Water resource planning*

Introduction

In India, freshwater scarcity has become a critical problem. Population growth, expanding cities, and intensive agriculture have all intensified demand for water. The pressure on both surface water and groundwater is mounting, especially in semi-arid regions where rainfall is unpredictable and concentrated in just a few months (Shukla & Gedam, 2018). The Nandgaon region in Nashik District is exactly this kind of place water-scarce, drought-prone, and struggling to support a growing population.

Typically in places like these, we see a predictable pattern emerge. First, communities use the surface water via dams and canals. As those supplies become insufficient, communities depend more on groundwater, eventually exceeding rates of recharge. Monsoon rains are unpredictable and can fluctuate wildly from year to year (Singh, V. P. 1997). During drier years, groundwater becomes critical. But a higher volume of pumping has already depleted the water table, raising issues of water for farming and for consumption (Dangar et al., 2021). Additionally, dams and diversions have changed water flow to areas downstream and undermined many traditional methods of managing water.

We can't just keep building more dams or drilling deeper wells. Instead, we need to understand the basin itself, how rainfall moves through the landscape, where water concentrates, which areas are at risk for erosion, and where groundwater recharge is most likely. That's where morphometric analysis comes in. By quantifying the basin's shape, its drainage network structure, and its topography, we can identify the best locations for water conservation structures and understand flood risks. (Miller, V. C. 1953)

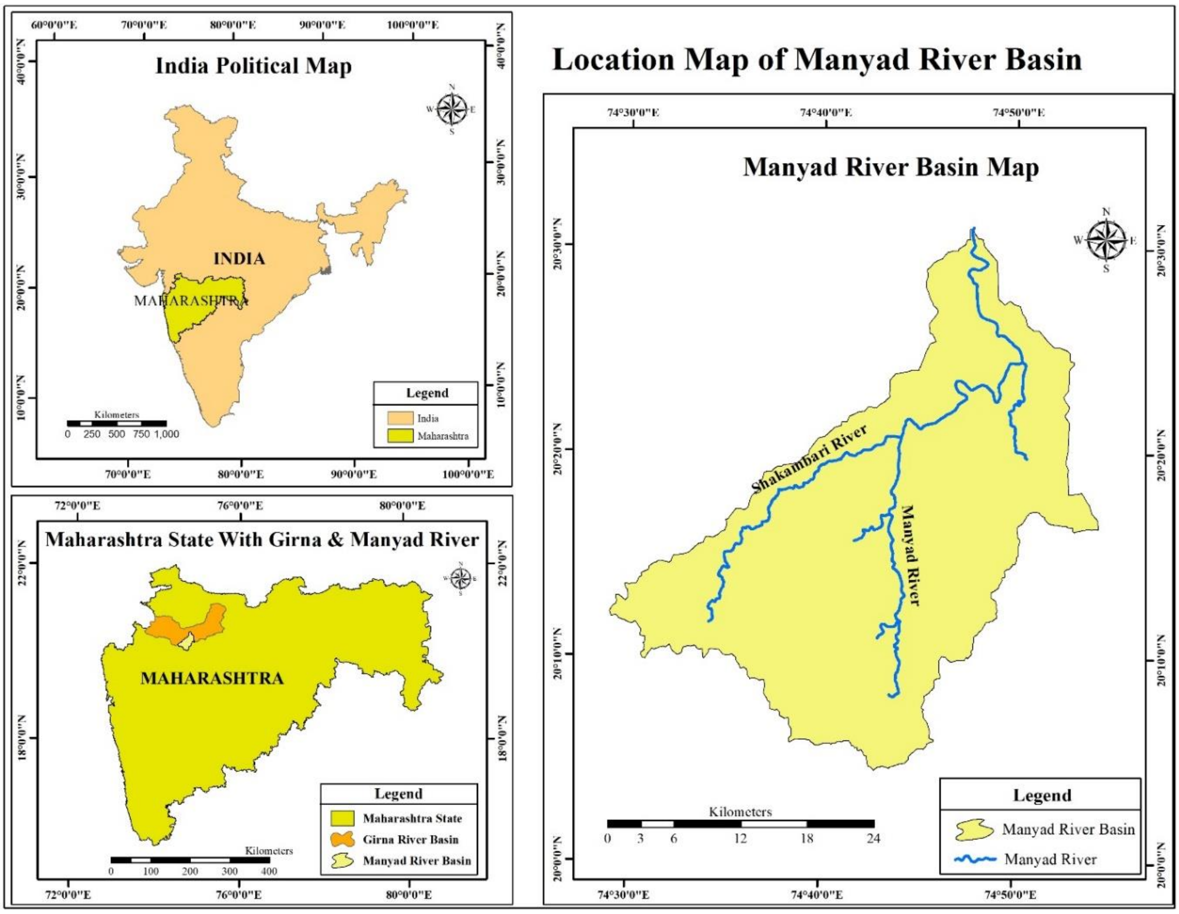
We applied this approach to the Manyad River Basin. We used ASTER satellite data and GIS tools to calculate key morphometric indices: stream order, bifurcation ratio, drainage density, form factor, elongation ratio, and relief parameters. These numbers tell us how the basin responds to rainfall how fast runoff concentrates, how much water infiltrates, where erosion is most likely, and what kinds of infrastructure would work best (Mesa, L. M. 2006). The results show that this basin has some natural advantages for water management, advantages we can leverage with targeted interventions.

Study Area:

Manyad River is one of the streams in Nashik District in Maharashtra. This stream starts near Rajapur village of Yeola Taluka in the Satmala Range. At this origin, its geographic coordinates are 20^0 09' 35" N latitude and 74^0 36' 14" E longitude. From here, the direction of flow is defined by the rocks and physiography of the land below the river course.

At the beginning, it flows east in stony lands in upland area, but turns towards North-East once it enters into Nandgaon Taluka. At a narrow gorge in the Satmala Range (near Manikpunj), the river passes north through the hill and finally falls in the Sakambari Nala in North-Direction near the village Nandgaon.

Fig. No.: 01



After Nandgaon, the river forms the boundary between Nashik and Jalgaon districts. It continues flowing north before entering Jalgaon District at Chalisgaon Tehsil, where it finally joins the Girna River downstream of Saygaon village. The entire main channel stretches 84.53 km from source to outlet, with the basin covering 908.21 km². The perimeter is 177.26 km. The elevation range is significant—the highest point in the basin reaches 941 meters, while the outlet is at 248 meters, giving a relief of 693 meters.

Most significant structure in the river, the Manyad dam, completed in 1965, a medium size irrigation dam creating storage reservoir of 53.95 MCM covering 460.19 hectares, it facilitates for downstream agriculture as well as regulate downstream flows. Basin reflect the geological feature of Deccan Traps consisting of elevated plateau surfaces giving rise to steep valley walls, gorges etc. In the upper reaches of the area, dry deciduous forests cover the area which in turn transform into scrub vegetation and cultivated fields at lower reaches. The area is characterized by intense seasonal rainfall during the summer months of July and September, and nine months of the year are almost arid resulting in severe water stress condition.

Database and Methodology:

We had a simple Geospatial workflow for that: Remote sensing, topography and hydrological datasets were collected, processed on GIS software and morphometric indices derived to describe the structure and function of the basin's hydrological behaviour.

Table No.: 01 Data Sources

Sr. No.	Data/ Software	Specification	Source
1	Aster DEM	Resolution-30m	United States Geological Survey (USGS) https://earthexplorer.usgs.gov/
2	SOI Toposheets	1: 50,000	Survey of India (SOI) https://www.surveyofindia.gov.in/
3	Geology Map	Shape file	Bhukosh https://bhukosh.gsi.gov.in/Bhukosh/MapViewer.aspx
4	Hydrology Data/ Map	Tiff/ Watershed	India WRIS https://indiawris.gov.in/wris/,
5	Arc-GIS software	ArcGIS software 8.1	http://desktop.arcgis.com/

Our approach involved several steps. First, we imported the ASTER DEM into ArcGIS and cleaned it up removing spurious depressions and correcting artifacts. Next, we computed flow direction and flow accumulation grids, which allowed us to automatically delineate the stream network. We defined the basin boundary by tracing the watershed divide from the computed accumulation grid. To extract individual streams, we used threshold accumulation values and applied Strahler's (1952) stream order classification system to each stream reach. Finally, we calculated morphometric indices using established mathematical formulae. The result was a complete quantitative characterization of the basin's structure.

Linear Aspects of Basin Morphometry:

The way streams are organized how they connect, how many there are at each level tells us a lot about how the basin works hydrologically. We'll look at these characteristics in detail.

Table No.: 02 Linear Morphometric Analysis Results

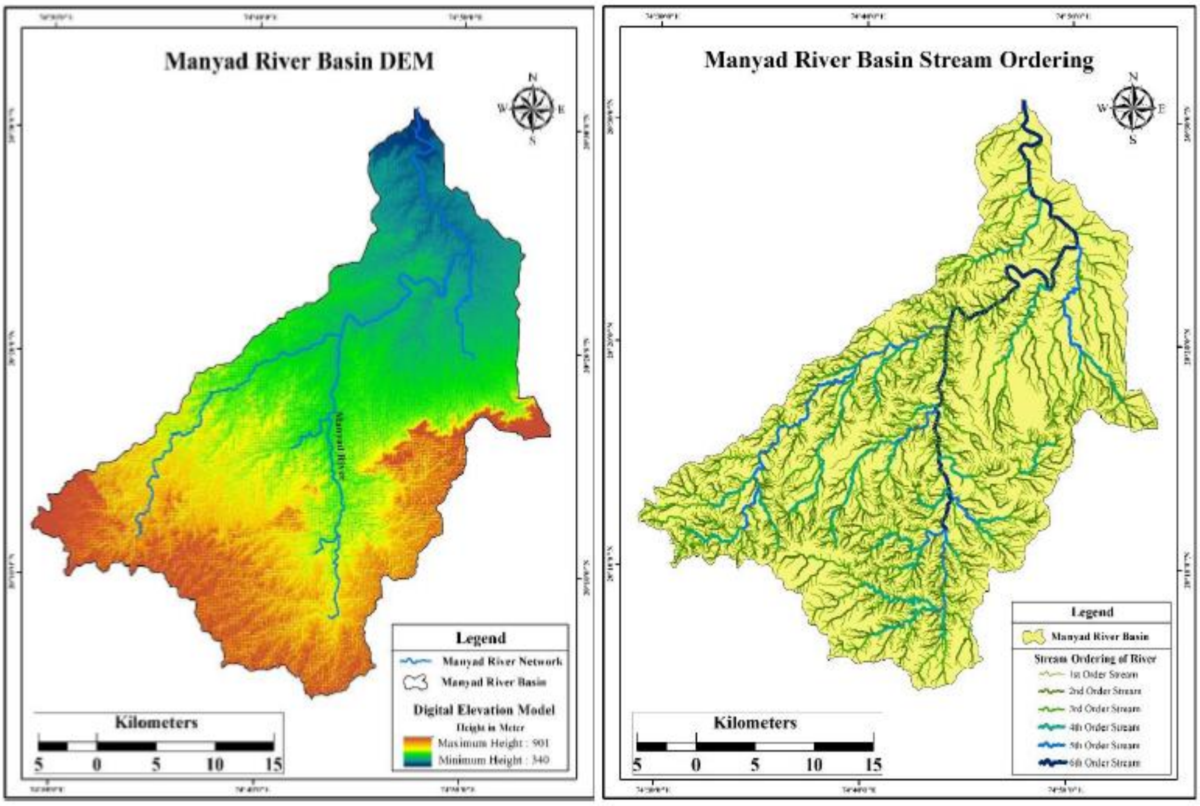
Linear Parameters	References	Formula	Stream Order	Result
Stream Order (u)	Strahler (1952)	(Nu)	1st Order	2701
			2nd Order	619
			3rd Order	175
			4th Order	27
			5th Order	05
			6th Order	01
Stream Length (Lu)	Horton (1945)	(Lu)	1st Order	1437.95
			2nd Order	515.63
			3rd Order	285.40
			4th Order	144.50
			5th Order	60.79
			6th Order	55.46
Mean Stream Length (Lum)	Strahler (1964)	Lsm = Lu / Nu,	1st Order	-
			2nd Order	01.56
			3rd Order	01.96
			4th Order	03.28
			5th Order	02.27
			6th Order	04.56
Stream Length Ratio (Lurm)	Horton (1945)	Rl = Lu / Lu – 1,	1st Order	00.53
			2nd Order	00.83
			3rd Order	01.63
			4th Order	05.35
			5th Order	12.16
			6th Order	55.46
Bifurcation Ration (Rb)	Horton (1932)	Rb = Nu / Nu + 1,	1st Order	04.36
			2nd Order	03.52
			3rd Order	06.25
			4th Order	04.50
			5th Order	02.50
			6th Order	-

1. **Stream Order Classification:**

We classified streams using Strahler's system. The smallest permanent streams are 1st-order. When two 1st order streams meet, they create a 2nd order stream. This pattern continues up the hierarchy. What's important is that if a smaller stream joins a larger one, the larger order is preserved it doesn't automatically become a higher order.

In the Manyad basin, we identified a 6th order drainage network. This is the highest order present meaning runoff from across the entire basin eventually concentrates into this main stream. The basin contains 3,528 individual stream segments across all six orders. This hierarchical structure reflects decades or centuries of erosional processes, shaped by climate, geology, and topography.

Fig. No.: 02



2. **Stream Numbers and Horton's Law:**

The basin has many small streams more than any of other orders combined. There are 2,701 first order streams in the basin, and that number falls to just 619 second order streams and a single 6th order main channel. The decrease with order is actually a well-known trend in nature.

The many first order streams feed into slightly less numerous, second order streams that do the same, and then third order, on and on, until they reach the large main river channel that cuts through the middle of the basin. The number of first order streams as a percent of all stream channels (76.56%) suggests that our watershed is quite young and the upper reaches are still actively being shaped by surface erosion and runoff. This means a large amount of the runoff in our drainage basin is not channeled into well-defined river system until down toward the middle to the bottom of the basin.

3. **Stream Length Distribution:**

Total stream length increases as we go from lower to higher orders. First-order streams aggregate to 1,437.95 km total length that's a lot of small channels spread across the headwaters. Second-order streams total 515.63 km, then 285.40 km for 3rd-order, 144.50 km for 4th-order, 60.79 km for 5th-order, and finally 55.46 km for the 6th-order main stem.

Many short tributaries distributed across wide areas add up to more total length than a few long channels. The main river is long, but there's only one of it. The geometric reality of drainage networks is that you get total length peak at lower orders, then it decreases as channels integrate.

4. **Stream Length Ratio and Basin Geology:**

In this basin, the stream length ratios (the length of one stream order divided by the length of the next lower stream order) vary from 1.56 to 4.56. This variation is not arbitrary. It is related to changing slope and lithology in downstream directions.

Low values in low orders imply a high frequency of short streams, which we'd expect in steep terrain such as headwaters or a mountain environment. High values in upper orders imply that downstream channels are elongated and well developed; a meandering or braiding river would have this property as would a river flowing over more gentle topography. This increasing tendency means that the morphology of the basin changes from a steep area in the upper orders of a river system to a flatter region further downstream.

5. **Mean Stream Length:**

The mean stream length (mean length of each stream for each order) ranges from 0.53 km for first-order streams to 55.46 km for the sixth-order main stream. It has increased over a hundredfold between first- and sixth-order channels. This means that with decreasing downstream, smaller streams have been joining up and the basin is integrating itself into larger ones.

The merger itself adds stream length and capacity to. Higher rates of increases denote efficiency; more uniform slopes indicate efficient network organization. The Manyad basin is consistently growing exponentially indicating an efficiently organized basin.

6. **Bifurcation Ratio:**

The bifurcation ratio gives us a good idea of how many smaller tributaries come together to form each larger one. It's generally in the 3 to 5 range in most undeveloped areas, and tends to stay quite close. In the Manyad, it ranges from 2.50 to 6.25 with the greatest at 6.25, and is in the range 3 to 4. The variations indicate there are some structural and geologic control on these mergers. Our average value of 4.23 is not high, so the basin is not structurally severely constrained, but it is not fully randomized.

Areal Aspects of Basin Morphometry:

The speed at which rainfall turns to runoff, how much soaks into the ground and how high flood peaks get are all dominated by the size and shape of the basin. We can measure areal metrics to evaluate those controls.

Table No.: 03 Areal Morphometric Analysis Results

Areal Parameters	References	Formula	Result
Basin Area (A)	Horton (1945)	A	908.21 Sq. Km.
Length of the Basin (Lb)	Schumm (1956)	Lb	84.53 Km.
Basin Perimeter (P)	Schumm (1956)	P	177.26 Km.
Stream Frequency (Fs)	Horton (1932)	$Fs = \Sigma Nu / A$	03.88
Drainage Density (Dd)	Horton (1932)	$Dd = \Sigma Lu / A$	02.75
Drainage Texture (Dt)	Horton (1945)	$Dt = Nu/ P$	19.90
Drainage Intensity (Di)	Faniran (1968)	$Di = (Fs/Dd)$	01.41
Infiltration Number (If)	Faniran (1968)	$If = Dd * Fs$	10.70
Elongation Ratio (Re)	Schumm (1956)	$Re = 1.128\sqrt{A} / Lb$	**00.40**
Form Factor (Rf)	Horton (1945)	$Rf = A / Lb2$	00.13

1. **Basin Area and Magnitude of Runoff:**

The Manyad basin covers 908.21 square kilometers. That's a medium-sized basin, large enough to accumulate substantial runoff but not so massive that precipitation patterns vary widely across it. Basin area directly scales with discharge magnitude: all else equal, larger basins produce larger floods. Understanding the basin's size helps us estimate how much water we're dealing with during different rainfall scenarios.

2. **Basin Dimensions:**

The length of the basin (the longest direction in a line, parallel to the axis of the major channel) is 84.53 km. The perimeter of the basin (the length of its boundary) is 177.26 km. These values of length and perimeter indicate a measure of how large a basin is and how compact its shape is. A high ratio of length to perimeter means a long basin; a ratio closer to 0.2 means a circular basin. In this case, they indicate a moderately stretched basin.

3. **Stream Frequency:**

Stream frequency of 3.88 streams per square kilometer represents the number of channel segments distributed across the basin area. This metric captures the spatial density of streams. Higher frequencies mean streams are more closely spaced. In the Manyad basin, a frequency of 3.88 indicates moderate channel density means not extremely dense but well-developed. This correlates with rainfall patterns, geology, and slopes that collectively support this density of permanent and semi-permanent channels.

4. **Drainage Density:**

Drainage density of 2.75 km of stream per square kilometer is classified as "coarse." It means there's about 2.75 kilometers of stream channel for every square kilometer of basin area. Coarse drainage density indicates that rainfall infiltrates fairly readily into the soil rather than rushing into channels. The basin has moderate flood risk. Rainfall doesn't concentrate instantly into streams, which gives water time to soak in and recharge groundwater. This happens due to the semi-dry climate (less intense rainfall, less erosion) and partly to geology and slopes that allow infiltration.

5. **Drainage Texture:**

The drainage texture index of 19.90 falls precisely between the boundary for a fine texture (15.38 and greater) and a coarse texture. This means the basin is composed of both relatively flat terrain with coarse soils and some regions with very closely spaced drainage networks in steeper upland areas with soils with poor permeability. This indicates a blend of drainage patterns; channels in soils with low permeability are more closely concentrated than channels in soils where flow infiltrates the ground easily and they can spread out in a more dendritic manner.

6. **Drainage Intensity:**

The value of drainage intensity (1.41) has been found to be the ratio of stream frequency and drainage density which can also be considered as a factor showing how much effectively precipitation in the basin appears in the form of runoff. Moderate values of drainage intensity shows balance between conditions where there is effective concentration of runoff so as to ensure non-water-logged condition and simultaneously not to obstruct infiltration to take place. This shows the occurrence of surface runoff along with ground water contribution, none having complete supremacy in the Manyad basin.

7. **Infiltration Number:**

An infiltration number of 10.70 indicates relatively low infiltration capacity water doesn't readily penetrate the soil, especially in lower basin zones. This makes sense because lower-lying areas often have clay-rich soils and may be seasonally saturated. However, remember this is a basin average. Upstream zones with rocky soils infiltrate readily. Lower-basin zones with clay soils infiltrate poorly. For water management, this tells us that artificial recharge structures should be located in upper basin zones where permeable soils can accept infiltrated water.

8. **Elongation Ratio:**

An elongation ratio of **0.40** indicates that the basin has a distinctly elongated shape rather than a circular one. Such a basin generally reflects the influence of geological structures, topographic controls, and drainage development on its morphology. Hydrologically, the elongated shape increases the travel time of runoff from the upper reaches to the basin outlet, resulting in a lower peak discharge and a more gradual flow response during rainfall events. Consequently, the basin exhibits comparatively lower flood susceptibility and improved runoff distribution than more circular basins.

9. **Form Factor:**

This low value for form factor (0.13) corroborates what the elongation ratio revealed about the Manyad basin: it's a very elongated basin. Basin shapes with a form factor less than 0.5 are elongated; shapes closer to 1 are circular. at 0.13, the basin is clearly very elongated.

The implication for flooding is that peak discharge is naturally reduced in such basins. When a rain event occurs, the runoff doesn't all reach the downstream end of the basin at the same time; it comes in waves as it moves downstream, spreading out the runoff over time and thus reducing flood peak flow rates. It's like the geometry of the basin is providing an inherent flood reduction capacity. (Hadley & Schumm, S. A. 1961).

Relief Aspects of Basin Morphometry:

The basin's elevation, how high it rises and how steep its slopes are drives water movement and erosion. Relief metrics quantify this topographic character.

Table No.: 04 Relief Morphometric Analysis Results

Relief Parameters	References	Formula	Result
Relief (R)	Strahler (1957)	R = H− h	693
Ruggedness Number (Rn)	Strahler (1964)	Rn = R × Dd	1.91

1. **Basin Relief and Topographic Gradient:**

941 meters above the sea is the height of the highest point of the basin; The mouth is 248 meters. The distance is 693 meters. This distance can be used to promote the transport and erosion of the water in the basin. That's substantial relief, enough to create steep slopes in upstream zones. Distributed across the basin's 84.53 kilometer length, this relief produces an average gradient of about 8 meters per kilometer. That's steep steep enough to generate significant runoff energy and erosional capacity, especially during monsoon rains. The relief explains why upstream zones are so active hydrologically and geomorphologically.

2. **Ruggedness Number:**

Ruggedness (relief drainage density = 693 x 2.75 / 1000 = 1.91) measures the relative steepness and dissected nature of the terrain. The value is moderately- neither low (relatively flat basin), nor high (highly dissected terrain). In the case of the Manyad basin, the high ruggedness, along with moderate drainage density, suggests a relatively localized and energetic topographic setting, particularly in the upstream areas.

Erosive stress here acts on a moderately large channel network, not over a very fine network of gullies. For water resources purposes, moderate ruggedness means the higher upstream regions should be targeted for soil conservation. These high energy areas are susceptible to erosion and should have check dams, terraces and vegetation barriers.

Strategies for Water Management:

The outline a basin and morphometric figures which has several characteristic features with significant consequences in water management. Construction of Artificial recharge structures, such as Check Dams, Percolation Tanks and Recharge Shafts, in the upstream zones, owing to High rainfall, rocky pervious lands and slopes. The check dams arrest the monsoon flows enabling them to seep in the sub-surface. Improvement of Flood mitigation measures using basin physiography Small reservoirs and Check dams constructed in upstream areas would further prolong the runoff time stream flow hydrograph thereby reducing peak flows in lower regions of the basin. Improvement of the water security for Agriculture-In the lower reaches of the basin, though ground water used for irrigation is limited, there is sufficient permeability, thereby artificial recharging of the monsoon runoff in upstream areas becomes indispensable for sustainable use of ground water in agriculture for the year-round farming with expansion of agriculture area. Protection of soil in the upstream region - due to high roughness and relief, erosion in the upstream regions is very high and, therefore, terracing, vegetal cover and check dam will check the transport of sediment from areas to river.

Conclusion:

Quantitative morphometric analysis, enabled by modern remote sensing and GIS technology, provides an evidence-based framework for these decisions. Instead of guessing where to invest water management resources, we can use morphometric indices to identify priority zones and design interventions suited to each zone's hydrological and geomorphological character. That's the value of this approach for water-scarce semi-arid regions.

The First thing, the basin has moderate density (2.75) and moderate to fine texture (19.90), indicates some opportunity for infiltration. It means water doesn't instantaneously run into the channels. There's time for infiltration, groundwater recharge, and maintenance of base flow in the dry season, which is critical in a drought-prone area.

Second, significant relief (693 m) and moderate ruggedness (1.91) indicate that upstream zones are high-energy, erosion-prone areas. Soils in these zones are being actively eroded and need protection. Simultaneously, these zones receive higher rainfall (150-200 mm more per year at elevation) and have highly permeable rocky soils. They're ideal for artificial recharge structures.

Acknowledgment

I express my sincere gratitude to my respected Research Guide, Dr. Subhash N. Nikam, Principal, MGV's Maharaja Sayajirao Gaikwad College, Malegaon Camp, for his constant guidance, valuable suggestions, scholarly insight, and continuous encouragement throughout the completion of this research work.

Financial support and sponsorship
Nil.

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

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