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Morphometric Analysis Of The Sina River Basin, Maharashtra Using Remote Sensing And GIS Techniques

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Abstract

The Sina is one of the most important rivers flowing through the drought-prone areas of Ahilyanagar (Ahmednagar), Beed, Dharashiv (Osmanabad), and Solapur districts of Maharashtra state. (Provide a rough population and area that is dependent on the Sina River water) Most of the population and irrigation are dependent upon the Sina River water.

Morphometric analysis is a quantitative study of the physical characteristics and measurements of a river basin or watershed. These characteristics provide insights into the shape, size, relief, and drainage patterns of the basin, which are essential for understanding the hydrological processes and landform development within the basin.

The geographical information system is a very efficient tool for morphological study. In this study, USGS DEM 30m data is used in ArcGIS 10.5 software to delineate the watershed of the Sina River and create stream order for the study of various morphological parameters, like linear, aerial, and relief morphological aspects. The Sina River is a 7th-order stream, and the area of the basin is 12,364 sq km. Here's an overview of the morphometric analysis of the Sina River Basin.

The Sina River is one of the major tributaries of the Bhima River, flowing through the drought-prone districts of Ahilyanagar (Ahmednagar), Beed, Dharashiv (Osmanabad), and Solapur in southern Maharashtra, India. The region experiences frequent water scarcity, making the river a lifeline for domestic, agricultural, and industrial needs. Morphometric analysis provides a quantitative assessment of the drainage basin's shape, structure, and hydrological characteristics. It helps in understanding surface processes, erosional stages, and groundwater potential. In this study, morphometric parameters were derived using 30 m USGS DEM data processed in ArcGIS 10.5. The Sina River Basin, covering an area of approximately 12,364 km², was delineated and analyzed for linear, areal, and relief aspects following Horton (1945) and Strahler (1964) methodologies. The results reveal that the Sina River is a 7th-order drainage basin with dendritic to sub-dendritic drainage patterns, suggesting homogeneous lithology and moderate infiltration potential. The basin exhibits an elongated shape, low circularity, and moderate drainage density, indicating a relatively mature geomorphic stage with good groundwater recharge potential. These morphometric insights are crucial for regional water resource management and sustainable watershed planning.

Keywords: *Morphometric Analysis, ArcGIS, Remote Sensing, Drainage, Sina River Basin*

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I. Introduction

The Sina River is one of the most important rivers in the drought-prone areas of southern Maharashtra. The Sina River basin is 12364 sq km, and it is a large tributary of the Bhima River, which starts near Ahilyanagar (Ahmednagar) city and meets the Bhima River near the Maharashtra-Karnataka state border in Shree Harihareshwar Temple Sangam, Hattarsang village of Solapur district.

The Sina is the main water resource for irrigation, both domestic and industrial, in parts of the Ahilyanagar (Ahmednagar), Beed, Osmanabad, and Solapur districts of the study area. Studying morphological phenomena helps with water conservation planning and the management of watersheds. This Geomorphological analysis provides a quantitative description of the basin geometry to understand inequalities or slopes in rock hardness, its structural control, and the geological history of the drainage basin (Strahler, 1964).

Groundwater is a vital natural resource, particularly in semi-arid regions such as Maharashtra, India, where surface water availability is limited and erratic rainfall frequently leads to drought conditions. The increasing dependence on groundwater for agricultural, domestic, and industrial uses demands a scientific understanding of groundwater systems, especially in hard rock terrains like the Deccan Traps.

The Sina River Basin, a sub-basin of the Bhima River in southern Maharashtra, is predominantly underlain by basaltic rocks and is characterized by limited perennial surface water bodies. In such hydrogeological settings, groundwater occurs primarily in weathered and fractured zones, which are often discontinuous and variable in yield. Identifying areas with higher groundwater potential is therefore crucial for effective water resource planning and sustainable development.

One of the most efficient ways to evaluate the recharge potential and hydrological behavior of a drainage basin is through morphometric analysis—a quantitative evaluation of the basin's geometric, linear, areal, and relief aspects. With the advent of remote sensing and GIS technologies, morphometric parameters can be extracted accurately and used to interpret the surface and subsurface water movement patterns.

This study focuses on the morphometric analysis of the Sina River Basin using Digital Elevation Model (DEM) data and GIS tools to evaluate its geomorphic characteristics and correlate them with groundwater potential. The analysis provides a scientific basis for delineating priority zones for groundwater recharge and watershed management interventions.

II. Study Area

The Sina River Basin is in this proposed study. Sina River is the major left tributary of the Bhima River. It lies in drought-prone areas of Maharashtra. The study region extended from 17° 22'43" North Latitude to 19°09'09" North Latitude and 74°43'11" East Longitude to 75°53'48" East Longitude. The total geographical area of the river basin is about 12364 sq. Kms. The study area is bounded by Rahuri tehsil of Ahilyanagar (Ahmednagar) district to the North, Beed and Dharashiv (Osmanabad) districts to the East, Karnataka state to the South, and Malshiras and Pandharpur tehsils of Solapur district to the West. The relief of the basin ranges from 417 m to 979 m. The study area is located in the Survey of India Toposheet no no. 1. The location map of the Study area.

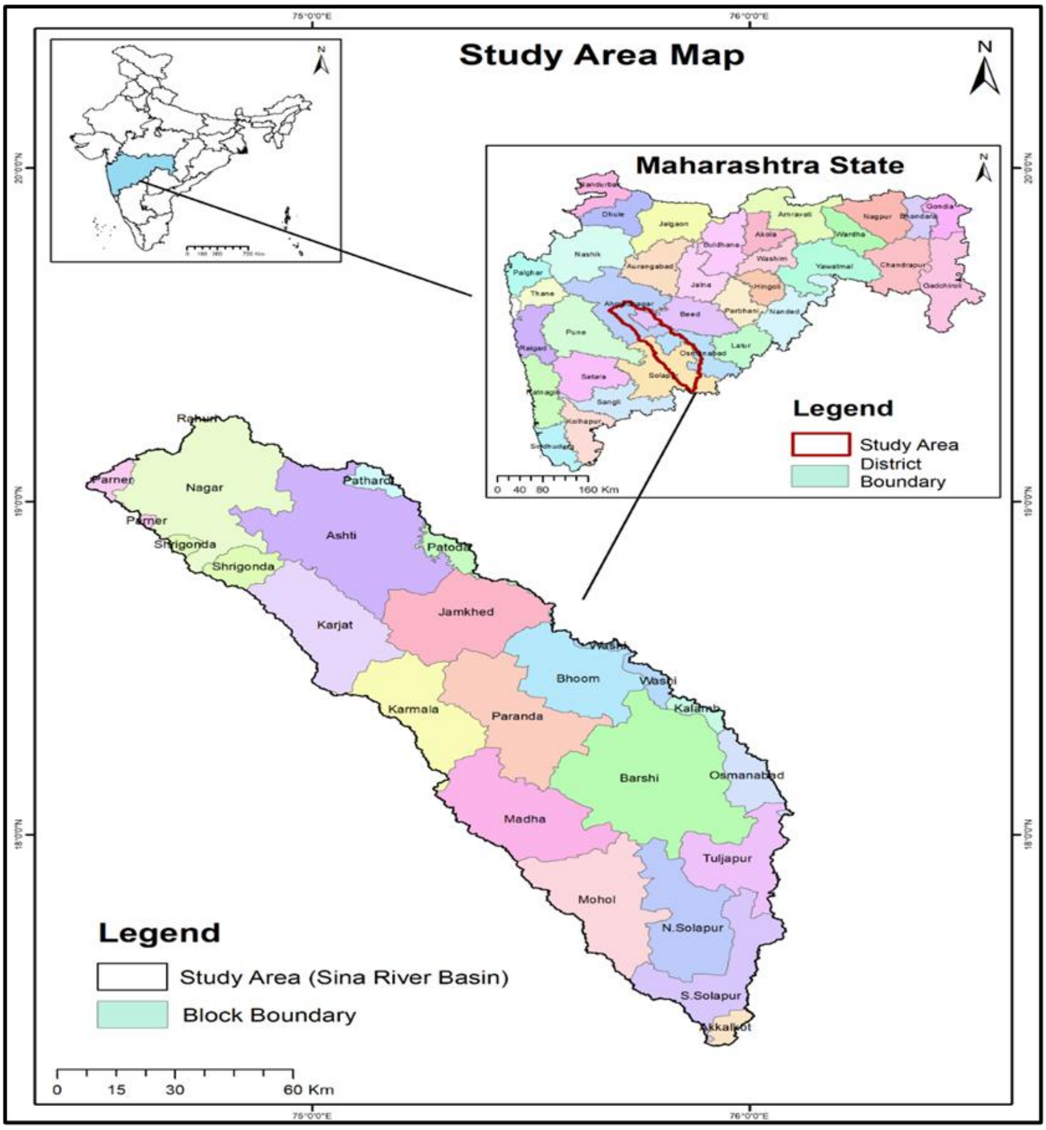


Fig. No. 1. Location map of the Study area

III. Methodology And Analysis

The morphometric analysis provides methodical and accurate information about the drainage basin. There are several formulas for quantifying hydrological parameters that have been used in this study. These formulas are mentioned below in Table 1.

SRTM (Shuttle Radar Topographic Mission) DEM at 30 m spatial resolution has been downloaded from the USGS (United States Geological Survey) Earth Explorer website (http://earthexplorer.usgs.gov/). For delineating the basin boundary and drainage network, the Hydrology tool inside the Spatial Analysis Tools of ArcGIS desktop software has been used. Additionally, the Slope map, Aspect map, Elevation map, and Drainage Density map of the Sina River basin have been prepared. Morphometric parameters of the drainage basins are analyzed by GIS and RS, where DEM (USGS Aster-30m) data is used for Morphometric analysis.

Data used DEM (USGS Aster-30m) data were used for the Morphometric analysis. Fig. No. 2. shows the Digital Elevation Model (DEM) map of the Study area

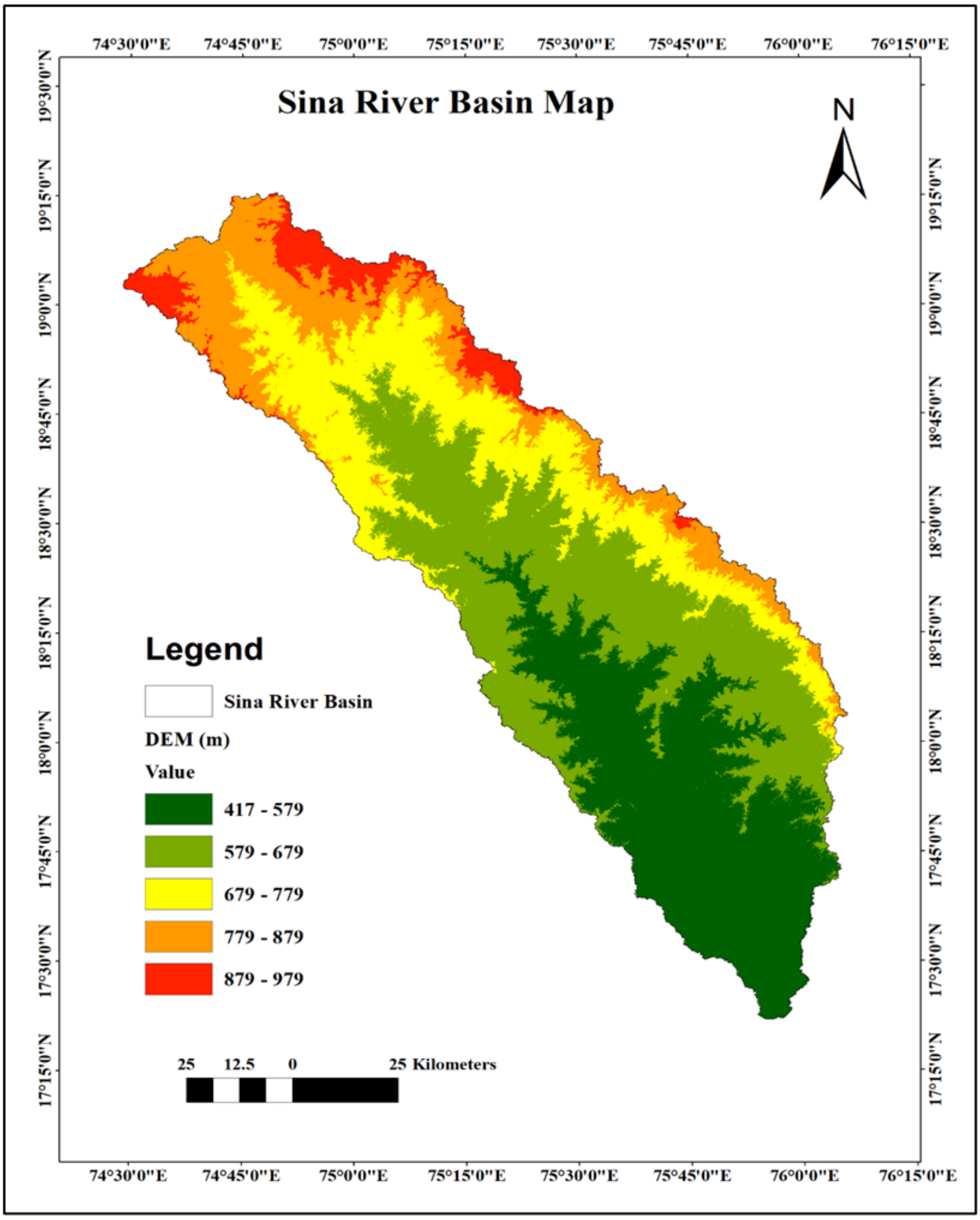


Fig. No. 2. Digital Elevation Model (DEM) map of the Study area

Analysis and Process

The hydrological tools in ArcGIS Spatial Analyst were utilized to perform the following steps:

- DEM preprocessing to remove sinks and ensure hydrological correctness.
- Flow direction and flow accumulation analysis to identify drainage paths.
- Watershed delineation to define the boundary of the Sina River Basin.
- Stream ordering using Strahler's hierarchical method.
- Computation of morphometric parameters under three categories: linear, areal, and relief aspects.

The parameters were calculated using standard formulae proposed by Horton (1932, 1945), Strahler (1964), and Schumm (1956). The relationship between morphometric indices and hydrological behavior was analyzed to interpret the basin's groundwater potential.

Morphometric analysis of a drainage basin requires the delineation of all the existing streams; digitization of the drainage basin is carried out for morphometric analysis using ArcGIS 10.5 software. SRTM DEM (30m) data from USGS were utilized in ArcGIS 10.5 for watershed delineation and morphometric analysis. Hydrological tools facilitated the extraction of stream networks and the derivation of slope, aspect, and drainage density maps (Jenson & Domingue, 1988). Morphometric parameters were calculated following standard methods (Horton, 1945; Strahler, 1964; Schumm, 1956). Fig. No. 3 shows the Stream order map of the Sina River basin.

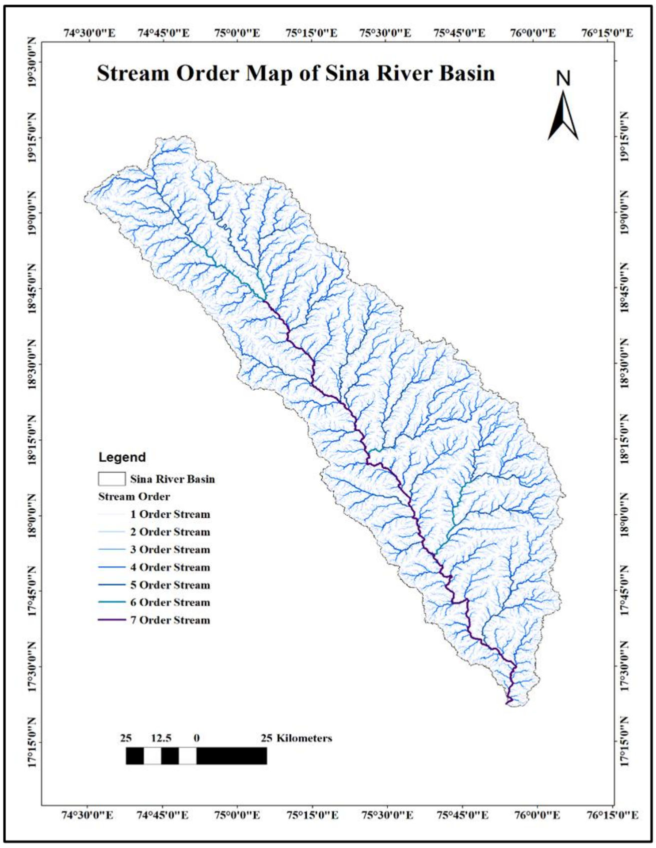


Fig. No. 3. Stream order map of Sina River Basin

IV. Result And Discussion

The present study has been carried out for Morphometric analysis of the Sina River basin; this process is done by the applicability of Horton's laws of stream numbers and lengths of streams of each order. The basin Morphometric analysis can deal with the three parameters that are Linear, Aerial, and Relief aspects.

LINEAR ASPECTS	AERIAL ASPECTS	RELIEF ASPECTS
1. Stream order (U)	1. Basin area	1. Basin relief
2. Stream number (Nu)	2. Drainage density (Dd)	2. Relief ratio (Rh),
3. Stream Length (Lu)	3. Basin length	3. Ruggedness number (Rn)
4. Mean Stream Length (Lsm)	4. Stream frequency (Fs)	
5. Stream Length Ratio (RL)	5. Form factor (Ff)	
6. Bifurcation ratio	6. Circularity ratio (Rc)	
	7. Elongation ratio (Rc)	
	8. Length of overland flow (Lof)	

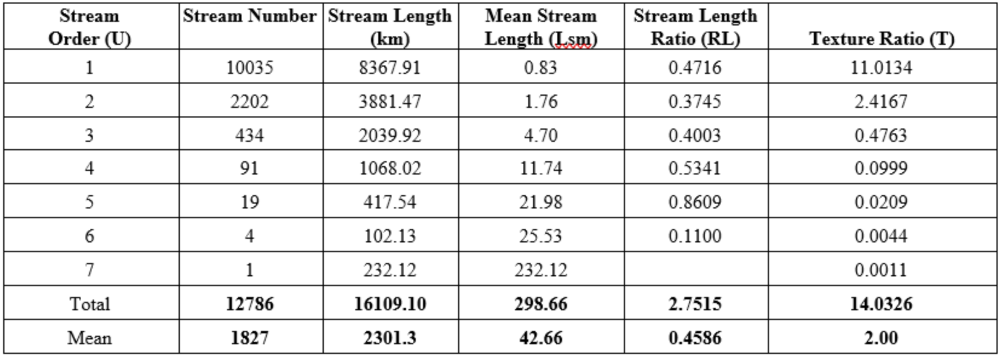
Linear Aspects

Stream Order (U)

Stream order is a way of classifying the hierarchical arrangement of streams or rivers within a watershed. The basic idea is that smaller streams are combined to form larger streams which are then combined to form even larger Streams and so on. Stream Ordering was proposed by Strahler (1964). It is a hierarchical relationship between stream segments and their connectivity to each other. Sina River has a 7th-order of stream. Fig. No. 3. shows the Stream order map of the Sina River basin.

The drainage pattern in the study is dendritic to sub-dendritic. All orders of stream numbers are different from the First order to the Seventh order. The drainage and stream order map of the study area is shown in Fig. 3.

Table 1. Morphometry of the basin



Stream Order (U)	Stream Number	Stream Length (km)	Mean Stream Length (Lsm)	Stream Length Ratio (RL)	Texture Ratio (T)
1	10035	8367.91	0.83	0.4716	11.0134
2	2202	3881.47	1.76	0.3745	2.4167
3	434	2039.92	4.70	0.4003	0.4763
4	91	1068.02	11.74	0.5341	0.0999
5	19	417.54	21.98	0.8609	0.0209
6	4	102.13	25.53	0.1100	0.0044
7	1	232.12	232.12		0.0011
Total	**12786**	**16109.10**	**298.66**	**2.7515**	**14.0326**
Mean	**1827**	**2301.3**	**42.66**	**0.4586**	**2.00**

Stream Number (Nu)

Stream Segments are often used to divide a river system into smaller parts for analysis purposes. Stream segment number refers to a unique identifier assigned to each segment of the river basin. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order numbers. Table no.1 shows the stream order. The total no of streams is 12786 in the Sina River basin. The total number of streams is 12786 in that 10035 are 1st order, 2202 are 2nd order, 434 are 3rd order, 91 are 4th order, 19 are 5th order,4 are 6th order and 1 is 7th order.

Stream Length (Lu)

It is measured for stream orders by using GIS Software which is proposed by Horton (1945). Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watersheds of increasing order (Strahler, 1964). Table no.1 shows the Stream length of the 1st-order to 7th-order streams. The total stream length of the Sina River basin is 16109.10 km.

Mean Stream Length (LSM)

The mean stream length of a channel is the characteristic size of drainage network components and its contributing basin surface (Strahler, 1964). It is calculated by dividing the total stream length of order “u” by the number of streams of segments in the order. The mean stream Length of the Sina River basin is 298.66 km.

Stream Length Ratio (RL)

Horton (1945) states that the length ratio is the ratio of the mean of segments of order to the mean length of segments of the next lower order, which tends to be constant throughout the successive orders of a basin. Stream length ratios tend to be more sinuous and have a higher potential for erosion and sediment transport conversely streams with a lower length ratio tend to be straighter and have a lower potential for erosion and sediment transport. The mean stream length ratio of the Sina River basin is 0.4586.

Bifurcation Ratio (RB)

The bifurcation ratio is the ratio of the number of stream segments of a given order to the number of streams in the next higher order (Horton 1945). The higher values of Rb indicate strong structural control on the drainage pattern, while the lower values indicate watersheds that are not affected by structural disturbances. The lower bifurcation ratio values are characteristics of the watershed, which has suffered less structural disturbances and the drainage pattern has not been distorted by the structural disturbances. The bifurcation ratio is an indicative parameter of the shape of the basin.

The Rb is a dimensionless property. There are two classes of Rb value: low and high. Low class means the drainage pattern is not affected by the geologic structures, whereas the high class means the drainage pattern is controlled by the geologic structures. The value range of the Rb classifications varies among the researchers; there is no statement about it. Based on some papers, it can be concluded that less than five may be classified as low, and more than five into high. The average bifurcation ratio of the Sina River basin is 4.66 which indicates the drainage pattern is not affected by the geologic structures.

Table 2: Bifurcation Ratio and Values

Bifurcation Ratio (Rb)	Value
1&2	4.56
2&3	5.07
3&4	4.77
4&5	4.79
5&6	4.75
6&7	4.00
Mean Bifurcation Ratio	**4.66**

Aerial Aspects

Drainage Density (DD)

Drainage density is a term used in geomorphology to explain the degree of branching of a drainage network, such as a river basin or watershed; it is defined as the total length of all Streams and rivers in a drainage network divided by the total area of the basin.

High drainage density is often associated with areas of steep topography and high rainfall while low drainage density is more commonly found in areas of gentle slopes and low precipitation. The drainage density of the Sina River basin is 1.30 per km. The drainage density map of the Sina River Basin is shown in Fig. 4

Drainage Frequency (FS)

Stream/Drainage Frequency is the total number of all the streams in the watershed to the area of the watershed. A large basin may contain as many fingertip tributaries per unit of area as a small drainage basin, and in addition, it usually contains a larger stream or streams (Horton,1945). The Stream/drainage density values of the basins exhibit a Positive correlation with the stream frequency, indicating there is an increase in stream population with respect to increasing drainage density. In this study found a Stream/Drainage Frequency (FS) of 1.03 per km2.

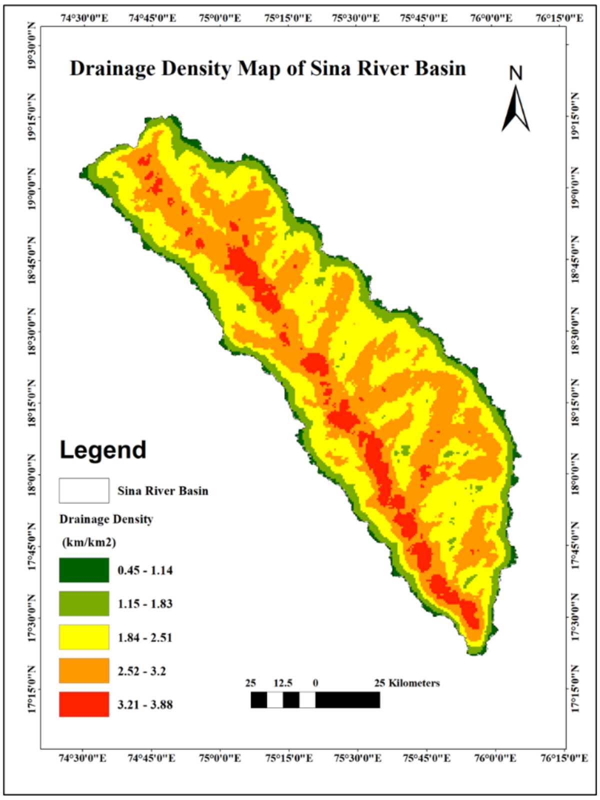


Fig. No. 4. Drainage Density map of Sina River Basin

Texture Ratio (T)

It is the total number of stream sequences of all orders per perimeter of that area (Horton 1945). According to Horton (1945), infiltration capacity is the single important factor that influences drainage texture and considers drainage texture which includes drainage density and stream frequency. According to Schumm (1965), texture ratio is an important factor in the drainage morphological analysis which is dependent on the underlying lithology, infiltration capacity, and relief aspect of the terrain. mean texture ratio of 0.4627 per km.

Form Factor (RF)

Form factor is defined as the ratio of basin area to the square of the basin length (Horton 1932). The smaller the value of the form factor, the more elongated the basin will be. The basins with high form factors have high peak flows of shorter duration. Sina basin has 0.200872

Circulatory Ratio (RC)

Circularity ratio is the ratio of the basin area to the area of the same circumference perimeter as the basin and expresses the degree of circularity of the basin (Miller 1953). He described the basin of the circularity ratios range 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials. The circulatory ratio depends on the length and frequency of streams, geological structures, land use/land cover, climate, relief, and slope of the basin in the case of the Sina River basin circulatory ratio is 0.18198

Elongation Ratio (RE)

It is the ratio between the diameter of the circle of the drainage basin and the maximum length of the basin (Schumm,1956). Values near to 1.0 are in the region of very low relief, while values in the range of 0.6 - 0.8 usually occur in the areas of high relief and steep ground slope (Strahler 1964). These values are further categorized as circular (>0.9), oval (0.9-0.8), and less elongated (<0.7). The Sina River basin has a 0.1472 elongation ratio. It means watersheds have elongated shape. It is a ratio between the diameter of a circle of that basin area to the length of the basin. It is approximately equal to half of the reciprocal of drainage density (Horton, 1945). In this research study found elongation ratio is 0.142

Constant Channel Maintenance (C)

Constant Channel Maintenance inverse of drainage density or the constant of channel maintenance as a property of landforms (Schumm, 1956). The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). In this study, constant channel maintenance is 2.048127.

Infiltration Number (IN)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency, which gives an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower the infiltration and the higher the run-off. In the present study of the Sina River basin, found Infiltration number of 0.102581

Relief Aspects:

The relief aspects of the area show the relief ratio and ruggedness of the area. The longest basin length measured along the main drainage basin is called the relief ratio (RR).

Relief ratio (Rh):

The relief ratio is covering and maintenance of the drainage basin. It is the difference between the highest and lowest elevations of the basin. The relief ratio describes the grade of a river. The estimated results between the source of the river and the river confluence both are divided by the length of the stream. It is a special case of the slope. According to Schumm, the relief ratio of the study area value is 44.43. The following formula of relief ratio by Schumm H- h/L Where, H=highest elevation of the basin, h=Lowest elevation of the basin, L=Longest axis of the basin.

Basin relief:

Basin relief is an important factor for understanding the Denudational character of the area. Relief is the maximum and minimum elevation of a watershed. Basin should be the study area for a better understanding of the study area.

Ruggedness number:

The drainage density (Dd) and product of maximum basin relief (H) both come under the same parameters and the same unit. The slope grading and length express the extent of the instability of the land surface, it is referred to as the ruggedness. It is the specific area of the research area basin that has rugged topography and structural complexity, soil erosion showing. (Strahler, 1957).

Basin Relief	Relief Ratio	Ruggedness Number
562	0.00227	0.7306

V. Discussion

The dendritic drainage pattern confirms homogeneity in lithology and gentle slope. A moderate drainage density and stream frequency indicate a balanced runoff-infiltration system. The elongated shape and low circularity suggest slow water movement and greater potential for groundwater recharge. The ruggedness and relief values point to moderate slope instability and erosion, especially in upper sub-basins.

The morphometric evaluation of the Sina River Basin reveals significant insights into its hydrological functioning, geomorphic stability, and groundwater potential. The dendritic to sub-dendritic drainage pattern reflects a homogeneous lithological composition and gentle terrain, characteristic of basaltic formations with limited structural control. This uniformity indicates that surface runoff and drainage development are mainly influenced by natural slope and erosional processes rather than tectonic disturbances.

Moderate drainage density (1.30 km/km²) and stream frequency (1.03/km²) values indicate a balanced hydrological regime in which infiltration and runoff are nearly in equilibrium. Such conditions suggest moderate permeability of subsurface materials and the presence of infiltration-prone zones, which enhance the groundwater recharge potential of the basin.

The basin's distinctly elongated form, as indicated by the low elongation ratio (Re = 0.14) and circularity ratio (Rc = 0.18), implies a longer lag time between rainfall and peak discharge. This elongated geometry allows for slower surface flow and higher opportunities for infiltration, making the basin hydrologically resilient to short-term intense rainfall events. The mean bifurcation ratio (Rb = 4.66) further indicates limited structural disturbances, suggesting that the drainage evolution is natural and the landscape has maintained its geomorphic equilibrium.

Relief characteristics support this inference. The moderate basin relief (562 m) and ruggedness number (0.73) suggest that the upper sub-basins are moderately dissected and prone to erosion, while the lower and middle reaches are characterized by gentler slopes favorable for infiltration and recharge. The correlation between low relief and drainage density highlights the spatial variability in runoff potential, where lower relief zones act as key recharge areas.

Integrating these morphometric indicators demonstrates that the Sina River Basin possesses substantial potential for groundwater recharge and moderate erosion susceptibility. Such geomorphic settings are particularly suitable for implementing watershed management and aquifer recharge structures, including check dams, percolation tanks, and recharge trenches.

From a broader sustainability perspective, these morphometric findings have direct relevance to climate resilience and water resource management in semi-arid regions of Maharashtra. As climate variability increasingly affects rainfall intensity and distribution, identifying morphometrically favorable recharge zones becomes vital for adaptive water management. The insights from this analysis can thus support evidence-based planning for climate-resilient watershed development, groundwater sustainability, and land degradation mitigation across the Sina River Basin and comparable basaltic terrains of the Deccan Plateau.

VI. Conclusion

The morphometric evaluation of the Sina River Basin confirms its suitability for groundwater recharge interventions and watershed prioritization. The basin's elongated form, moderate drainage density, and low bifurcation ratio suggest minimal tectonic disturbance and significant infiltration capacity. These findings support planning for sustainable land and water resource management in drought-prone areas. This case study

carried out a Morphological analysis of the Sina River basin of Maharashtra using GIS and RS using ASTER DEM data. Using GIS and RS in Basin Network analysis is more useful compared to any other conventional methods.

The morphometric analysis of the drainage network of the watershed shows Sina River basin is elongated in shape and water flow is very high in elevated areas, which means erosion of soil is higher in those areas. Drainage density is high in the main channel and lower in the outermost part of the basin, as well as rate of Infiltration is the same.

The hydrological and morphological aspects of the watershed can be understood by its drainage morphometric parameters. The current study provides precise data for topography, drainage system, stream length, water division, geomorphologic setup, and other factors crucial for the classification and management of watersheds. The basin's drainage system is primarily of the dendritic type, which aids in understanding a variety of topographical aspects, including infiltration rate and runoff, among others. The measured characteristics in this study highlight regions for surface-water accumulation and recharge-related actions that can be implemented for watershed management.

GIS and remote sensing tools facilitate efficient and accurate morphometric analysis. These parameters offer a scientific basis for effective watershed development, erosion control, and groundwater recharge planning. Planners and decision-makers of sustainable watershed development programs will find this work greatly valuable for managing natural resources at the micro level on any terrain.

Table 3: Morphometric parameter

Morphometric Parameters	Formula	References	Value
Stream Order (U)	Hierarchical Order	Strahler, 1964	Hierarchical Order
Stream Length (Lu)	Total Length of the Stream in km	Horton, 1945	16109.1
Mean Stream Length (Lsm)	Lsm = Lu/Lu Where, Lu = Total stream length of order „u‟; Nu = Total no. of stream segments of order „u‟	Horton, 1945	1.25
Stream Length Ratio (RL)	RL= Lsm / Lsm-1 Where, Lsm=Mean stream length of a given order; Lsm-1= Mean stream length of next lower order	Horton, 1945	0.4586
Bifurcation Ratio (Rb)	Rb = Nu/Nu+1	Schumn, 1956	4.66
Drainage Density (Dd)	Dd = Lu/A	Horton, 1945	1.3
Stream Frequency (Fs)	Fs = Nu/A Where, Fs = Stream Frequency; Nu = Total no. of streams of all orders and; A = Area of the basin (km2)	Horton, 1945	1.03
Texture Ratio (T)	T = Nu /P Where, Nu = No. of streams in a given order; P = Perimeter of basin (km)	Horton, 1945	2
Form Factor (Rf)	Rf = A/Lb^2 Where, A = Area of the basin; Lb = Basin length	Horton, 1945	49.98
Circulatory Ratio (Rc)	Rc = 4πA/ P^2 Where, A = Basin area (km2); P= Perimeter of the basin (km)	Miller, 1953	0.187054
Elongation Ratio (Re	Re= √A /p / Lb Where, A= Area of the basin (km2); Lb= Basin length (km)	Schumn, 1956	7.9794
Length of Overland Flow (Lof)	Lof = 1/ 2Dd Where, Dd = Drainage Density	Horton, 1945	0.3846
Constant Channel Maintenance (C)	C = 1/ Dd Where, Dd = Drainage Density	Horton, 1945	0.7692
Infiltration Number (In)	In = Dd × Fs Where, Dd = Drainage density; Fs = Drainage frequency	Faniran, 1968	1.339
Relief ratio (Rh)	Rr=H/Lb where H=Basin Relief/Lb=basin length	Schumn, 1956	0.00227
ruggedness number (Rn)	Rn=H × Dd where H basin relief and Dd Drainage Density	Patton and Banker,1976	0.7306

Table 4: Different parameters of the basin and values

Parameters	Value
Drainage Density (Dd)	1.3
Basin area	12364.23
Stream Frequency (Fs)	1.03
Length of Overland Flow (Lof)	0.244125
Constant Channel Maintenance (C)	2.048127
Infiltration Number (In)	0.102581
basin Parameter	912.0351
Relief ratio (Rh)	0.00238
Ruggedness number (Rn)	0.28465
Length of Overland Flow (Lof)	0.3846
Elongation Ratio (Re)	0.142

Circulatory Ratio (Rc)	0.18198
Form Factor (Rf)	0.200872
Length of Basin (km)	244.94

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict Of Interest

The authors declare that they have no conflict of interest.

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