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Original Article

A Geo-Spatial Based Approach for Morphometric Analysis of Sindphana River Basin in Shirur-Kasar Taluka, M.S., India.

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Abstract - *The present study based on morphometric analysis in the Sindphana River Basin was carried out for the delineation of areas for the natural water resources and long-term sustainability in Shirur-Kasar Taluka of Beed district, Maharashtra, India. The linear, areal, drainage and relief aspects were analyzed with the help of SRTM DEM data using Remote Sensing and GIS techniques. The total basin length is 44.24 km, and 1078 km^2 is the total basin area of the Sindphana River Basin in Shirur-Kasar Taluka. In the study area dendritic to sub-dendritic drainage patterns were observed with homogenous lithology and maximum seventh-order stream networks. The mean bifurcation ratio is 4.51 which suggests the basin is not structurally controlled. Water storage capacity in flat areas and runoff in steep areas are indicated by Rho values and mean stream length. The elongation and circulatory ratio values are 0.472 and 0.62, respectively, which suggests the river basin has an elongated shape and very fine drainage texture. The river basin area reveals that 2.26 km^{-1} drainage density value which suggests a moderate infiltration rate and is feasible for soil and water resource structures for further growth of groundwater. This study is beneficial for delineating the water resource areas for the conservation and management of the basin.*

Keywords - *DEM, GIS, Morphometry, Sindphana River Basin, Shirur-Kasar.*

1. Introduction

The scientific study of the chemical and physical processes at or near the Earth's surface that develop into topographic features is termed Geomorphology. Understanding these processes and geomorphology helps in understanding and identifying the features and changes in topography. [1] The quantitative and qualitative morphometric analysis measures the shape, size, and geological and geomorphological features like mountains, drainage patterns, faults and landforms. [2, 3] Using remote sensing and GIS techniques, scientists can uncover important information that might not be easily visible through conventional qualitative observations. [4] A thorough morphometric analysis of a basin clarifies how drainage morphometry impacts landform, shape, size, the drainage system's characteristics, and the Earth's surface topography. It is also a vital tool for evaluating the dynamics of the basin. [5, 6] Recent advances in Remote Sensing and Geographical Information System (GIS) technology have made it easier, quicker, and more cost-effective to analyze stream networks by allowing access to free Digital Elevation Model (DEM) data. It is highly productive for morphometric studies. [7] Well-known DEM sources are Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission (SRTM). [8] However, SRTM-SEM is more commonly used because of its greater spatial resolution as compared to GDEM-ASTER, particularly at the basin scale.

In GIS software, hydrology tool processes were used to determine the basin area, stream network and drainage patterns using DEM data. [9] These extracted morphometric parameters are used to measure mathematical and geometric values using geospatial technology. [10]. Basin length, basin area, stream order, stream length, bifurcation ratio, elongation ratio, and basin relief are key parameters analyzed through GIS software. Extensive morphometric studies of drainage basins have been performed globally using SRTM-DEM and GIS software, addressing a spectrum of environmental, climatic, geologic and hydrologic conditions. [11] Morphometric analysis is carried out efficiently by assessing various parameters, including linear, areal, drainage, and relief. [12,13,14] In the present study, morphometric parameters were analyzed with the help of GIS and remote sensing techniques in the Sindphana River Basin in Shirur-Kasar Taluka of Beed district, Maharashtra, India, for delineating water resource areas for conservation and management of the basin.

2. Study Area

The Sindphana River Basin in Shirur-Kasar Taluka, Beed District, Maharashtra State. The area spans approximately 75°10'00" E to 75°36'00" E and 19°13'00" N to 18°52'00" N, covering 1078 km^2 area. The river originates from ~890m above Mean Sea Level (MSL) in the Balaghat ranges. Balaghat Range in Beed District is one of the eastward extensions of the Sahyadri Mountain Ranges. The overall flow trend of the river is east-flowing, but in Shirur-Kasar, it first flows northward, and then it takes a right turn towards the East, where the river is joined by its tributary Sina River. Sindphana River is the right tributary of the Godavari River. The study area is classified under the semi-arid region; hence, the river has seasonal flow and it is mostly dry in the summer. [15] Geologically, the Sindphana River Basin area is covered by Upper Cretaceous to Lower Eocene aged Deccan Basalt or Deccan Trap. [16] The study area mainly contains Vesicular and Massive Basalt, which provide a multi-layered aquifer system. The water-bearing capacity of the Massive Basalt depends on the joints and fractures present in the strata, which are secondary as the Massive Basalt has no primary porosity and depends on the weathering depth. [17. 18] The water-bearing capacity of the Vesicular Basalt relies on the interconnectivity of the vesicles present in it. [19]

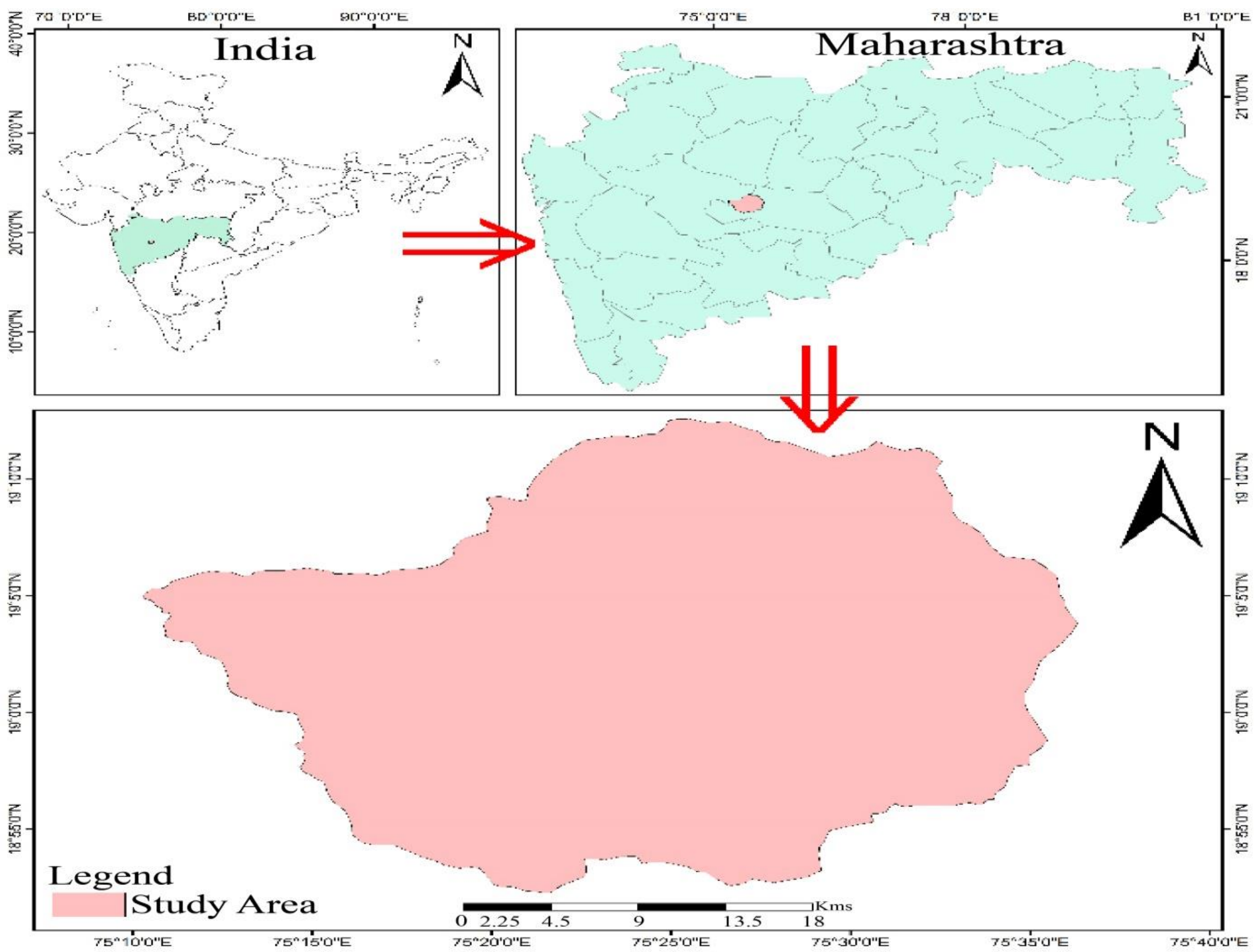

Fig. 1 Location map of the study area

3. Materials and Methods

SRTM 1 Arc-second global data with 30m resolution was used to conduct drainage basin Morphometry, available at the USGS website (https://earthexplorer.usgs.gov). Using the ArcGIS 10.8 software, a DEM map was created. A stream drainage network was extracted in ArcGIS 10.8 using Hydrology tools in the Arc Tool Box. In Figure 3 detailed methodology for drainage extraction processes such as fill, flow direction, flow accumulation, stream order, and stream feature is shown. Using standard formulae, a quantitative morphometric analysis was performed to determine various parameters, including linear, areal, drainage, and relief matrices (Table 3). The location map, Digital Elevation Map (DEM), and drainage map are prepared using Arc-GIS 10.8 software.

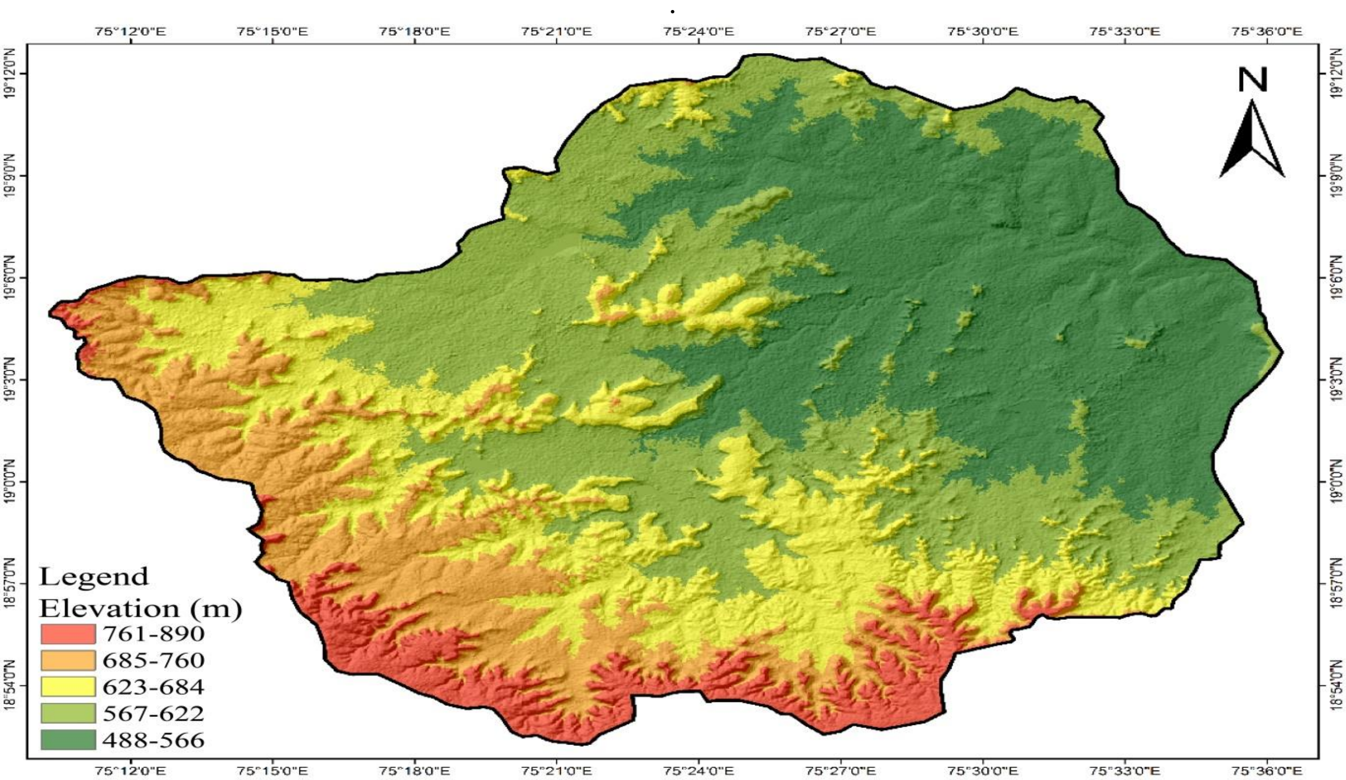

Fig. 2 Digital Elevation Model (DEM) of the Sindphana River Basin in Shirur-Kasar

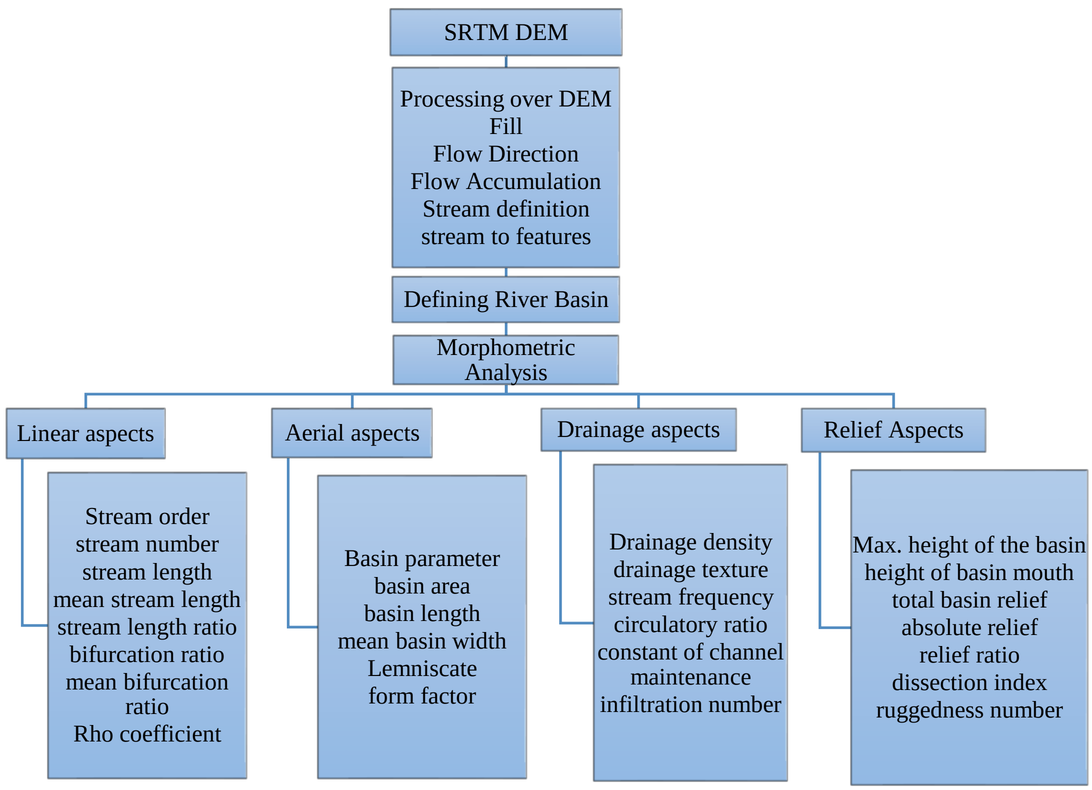

Fig. 3 Flow chart for extraction of stream network

4. Results and Discussion

The morphometric parameters of a watershed provide information about climate, local geological formation, structural activities and land degradation. These parameters reveal the watershed's hydrological features and are classified into four categories: i) linear parameters, ii) areal parameters, iii) drainage texture analysis, and iv) relief characterization.

4.1. Liner Parameters

Linear parameters, namely Stream Order (U), Stream Number (N_u), Stream Length (L_u), Mean Stream Length (L_{um}), Stream Length Ratio (L_{ur}), Bifurcation Ratio (R_b), Mean Bifurcation Ratio (R_{bm}) and Rho Coefficient (ρ). The results of these parameters are given in Table 2.

4.1.1. Stream Order (U) and Stream Number (N_u)

Horton (1932) introduced stream ordering, which was further developed by Strahler (1952). Stream order is determined by hierarchical rank and its position compared to other streams. [20] The two first-order streams meet each other, form a second-order stream and so on for the higher-order streams by Strahler classification. A higher-order stream, when joined by a lower-order stream, follows the order of the higher-order stream. The study area indicates 5288 first-order streams, 680 second-order streams, 146 third-order streams, 30 fourth-order streams, 7 fifth-order streams, 2 sixth-order streams and 1 seventh-order stream.

Table 1. Stream order and stream number

Sr. No.	Stream Order	Stream Number
1	I	5288
2	II	680
3	III	146
4	IV	90
5	V	7
6	VI	2
7	VII	1

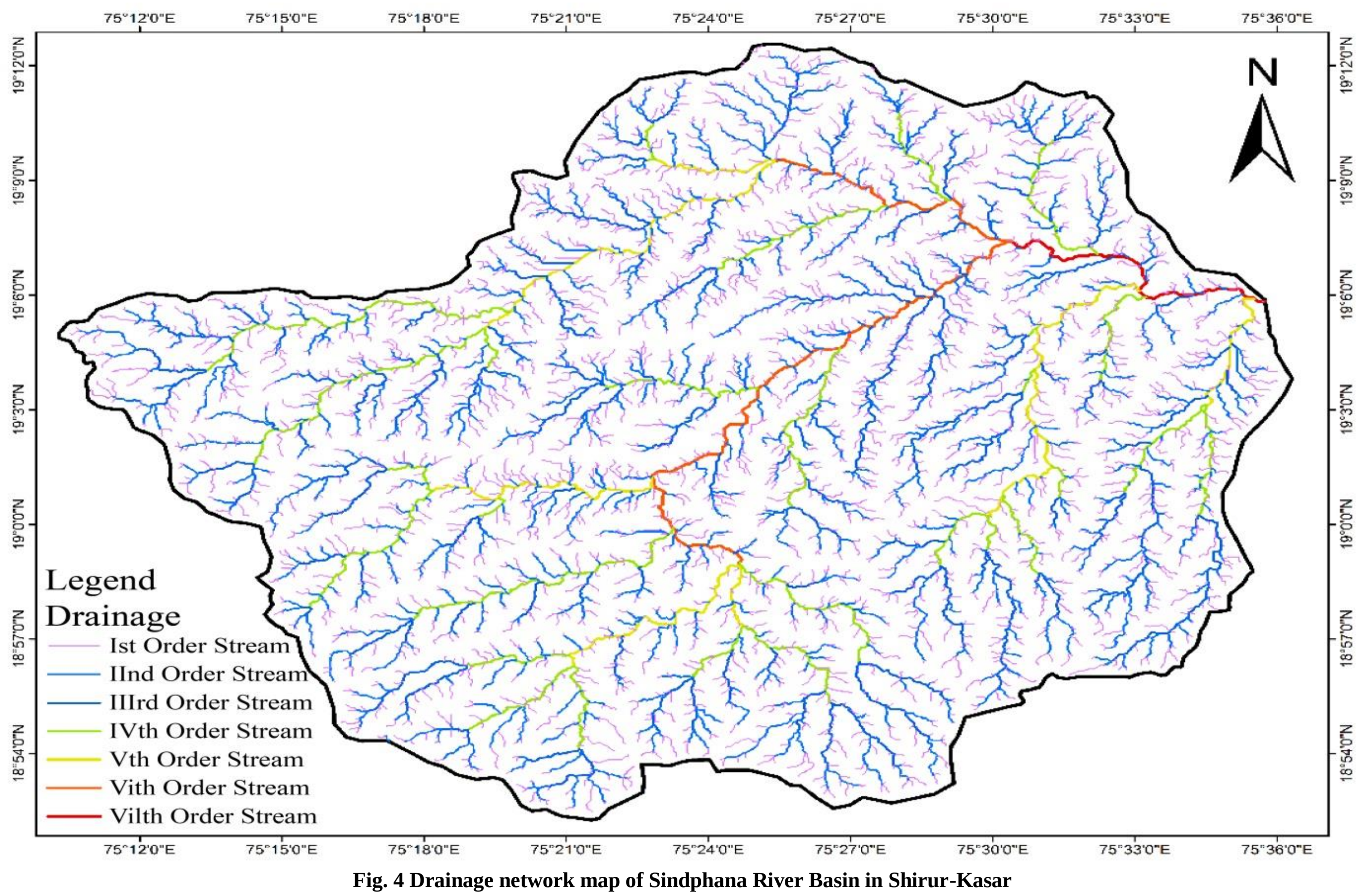

Fig. 4 Drainage network map of Sindphana River Basin in Shirur-Kasar

4.1.2. Stream Length (L_u)

The Sindphana River Basin in Shirur-Kasar Taluka has a total stream length of ~2430.473 km. The sum of first-order streams is ~1204.999 km, second-order at ~620.89 km, third-order at ~320.061 km, fourth-order at ~167.574km, fifth-order at ~71.63 km, sixth-order at ~40..193 km and seventh-order at ~13.122 km. The bedrock with low porosity produces a very high number of streams having short lengths and bedrock with relatively higher porosity has less number of streams with comparatively longer lengths. [21] Stream Length was calculated using the ArcGIS software.

4.1.3. Mean Steam Length (L_{sm})
To calculate the Mean Stream Length (L_{sm}), the total length of the stream (L_u) is divided by the total number of streams (N_u). In the study area, L_{sm} values range from 0.227 km to 20.096 km, and the mean stream is 348.353 km.

4.1.4. Stream Length Ratio (L_{ur})
Horton (1945) stated that the ratio between the mean stream length of an order of stream to the next mean stream length of the lower order of the stream is called as Stream Length Ratio (L_{ur}). Change in the stream length ratio from one order to another represents the youth stage. The Stream length ratio values of the study area vary from 0.33 to 0.56, with 0.48 as the mean stream length ratio.

4.1.5. Bifurcation Ratio (R_b) and Mean Bifurcation Ratio (R_{bm})
Horton (1945) stated Bifurcation ratio is a measure of relief and dissection. Strahler (1957) suggested that distinct regions in various conditions show relatively minor differences in the Bifurcation ratio.

If the Bifurcation ratio exceeds 5, it shows structural control and vice versa. [22] If the Bifurcation ratio varies from 3 to 5, it shows a negligible impact of structural control on the drainage basin. [23] The mean Bifurcation ratio of 4.51 of the Sindphana River Basin in Shirur-Kasar Taluka indicates negligible structural control on the branching pattern. [24] However, the bifurcation values are higher in lower-order streams, a product of accelerated erosion in the corresponding area. [25]

4.1.6. Rho Coefficient (ρ)
The Rho coefficient values indicate the relation between drainage density and physiographic development with the evaluation of drainage network and basin storage capacity. [26] The Rho coefficient value of 0.106 indicates weak hydrological storage during flood conditions. The rho coefficient is influenced by Geomorphological, Climatic, Geological and Anthropogenic factors. [27]

4.2. Areal Parameters
Areal parameters include Basin Perimeter (P), Basin Area (A), Basin Length (L_b), Mean Basin Width (W_b), Lemniscate (K) and form factor (R_f). The calculated values are given in the Table 3.

4.2.1. Basin Perimeter (P)
The perimeter line of a watershed is generally considered as the divide between watersheds—the perimeter value measured in ArcGIS 10.8 software, i.e., 148 km of the study area.

4.2.2. Basin Area (A)
The Basin Area is the total area bounded by the perimeter boundary. The Basin Area value measured in ArcGIS 10.8 software i.e., 1078 sq. km of the Sindphana River Basin in Shirur-Kasar Taluka.

4.2.3. Basin Length (L_b)
The basin length (L_b) was calculated in ArcGIS 10.8 at a value of 44.24 km of the study area as the longest dimension of the basin aligned parallel to the mainstream. [37]

4.2.4. Mean Basin Width (W_b)
The Mean Basin Width (Wb) of the Sindphana River Basin was calculated in ArcGIS 10.8 at a value of 24.37 km.

4.2.5. Lemniscate (K)
Lemniscate of the Sindphana River basin in Shirur-Kasar Taluka is calculated to be 1.81 using ArcGIS-10.8 software, which suggests that the basin is elongated. The value increases proportionally with the increasing difference between the length and width of the basin. [28]

4.2.6. Form Factor (Rf)
The Form Factor (Rf) value of 0.55 of the Sindphana River Basin in Shirur-Kasar Taluka suggests the oval shape of the basin, and it takes a medium time for the medium peak flow. [29] A high Form Factor value indicates high surface runoff in a short duration of time. [30]

4.3. Drainage Texture Analysis
Drainage Texture Analysis includes Drainage Density (D_d), Drainage Texture (D_t), Stream Frequency (F_s), Circulatory Ratio (R_c), Constant of Channel Maintenance © and Infiltration Number (I_f). The calculated values are given below in the Table 3.

4.3.1. Drainage Density (D_d)
The calculated drainage density of the Sindphana River Basin in Shirur-Kasar Taluka is 2.26, which suggests moderate drainage density. Basin is categorized into 4 classes based on drainage density, namely low (<2), moderate (2-4), high (4-6) and very high (>6). [33] The total length of all the streams divided by the total basin area gives Drainage Density [30] and it reflects the concentration and proximity of channels in the region. [31]

Mountainous region with significant precipitation and varied terrain has high drainage density, which signifies a well-developed and dense network of streams. A less developed and sparser stream network, commonly seen in arid or flat regions, signifies low drainage density. [32] High drainage density produces fine drainage texture, whereas low drainage density produces coarse drainage texture.

4.3.2. Drainage Texture (D_t)
The calculated drainage texture of the Sindphana River Basin in Shirur-Kasar is 41.6, which suggests a very fine drainage texture. Basin is categorized into 5 classes based on drainage texture, namely very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). Drainage texture is influenced by the terrain's relief, water capacity and lithology. [34]

Table. 2 Linear morphometric parameters of Sindphana River in Shirur-Kasar Taluka

Stream Order	No. of Streams	Minimum length of the stream (km)	Maximum length of the stream (km)	Mean stream length (km)	Total length of the stream (km)	Stream length ratio	Bifurcation ratio
I	5288	0.021	2.486	0.227	1204.999	-	7.78
II	680	0.021	2.781	0.913	620.894	0.52	4.66
III	146	0.03	10.87	2.192	320.061	0.511	4.87
IV	30	0.03	15.139	5.585	167.574	0.52	4.28
V	07	3.51	17.636	10.232	71.63	0.43	3.5
VI	02	11.955	28.238	20.096	40.193	0.56	2
VII	01	13.122	13.122	13.122	13.122	0.33	-
Total	6154	-	-		2438.473	2.87	27.09
Mean	-	-	-		348.353	0.48	4.515

Table 3. List of formulae used to calculate morphometric parameters

Morphometric Parameters		References	Formulae	Results
Linear Parameters	**Stream order (U)**	Strahler (1964)	Hierarchical rank	I – VII
	Stream Number (Nu)	Horton (1945)	Nu = N1+N2+...+Nn	6154
	Stream length (Lu)	Horton (1945)	Using ArcGIS Software	2438.473 km
	Mean stream length (Lsm)	Strahler (1964)	Lsm = Lu/Nu	0.227-20.096 km
	Stream length ratio (Lur)	Horton (1945)	Lur = Lu / Lu-1	0.33 – 0.52
	Bifurcation ratio (Rb)	Schumm (1956)	Rb = Nu/Nu+1	2 – 4.66
	Mean bifurcation ratio (Rbm)	Strahler (1957)	Rbm = Average of Rb of all order	4.51
	Rho Coefficient (ρ)	Horton (1945)	ρ = Lur / Rb	0.106
Areal Parameters	**Area (A)**	-	-	1078 sq. km
	Perimeter (P)	-	-	148 km
	Basin length (Lb)	-	-	44.24 km
	Mean basin width (Wb)	Horton (1932)	Wb = A / Lb	24.37 km
	Lemniscate's (k)	Chorley (1957)	$k = Lb^2 / A$	1.81
	Form factor ratio (Rf)	Horton (1932)	$Rf = A / Lb^2$	0.55
Drainage Texture Analysis	**Drainage density (Dd)**	Horton (1932)	Dd = Lu/A	2.26
	Drainage texture (Dt)	Horton (1945)	Dt = Nu / P	41.6
	Stream frequency (Fs)	Horton (1932)	Fs = Nu / A	5.71
	Circularity ratio (Rc)	Miller (1953)	$Rc = 12.57 * (A / P^2)$	0.62
	Elongation Ratio (Re)	Schumm (1956)	$Re=2(\sqrt{A/\pi})/Lb$	0.472
	Constant of channel maintenance (C)	Schumm (1956)	C = 1 / Dd	0.44
	Infiltration number (If)	Faniran (1968)	If = Fs * Dd	12.90
Relief Characterization	**Maximum height of the basin (Z)**	-	GIS analysis / DEM	890 m
	Height of basin mouth (z)	-	GIS analysis / DEM	488 m
	Total basin relief (H)	Strahler (1952)	H = Z – z	402 m
	Absolute relief	-	GIS analysis / DEM	890 m
	Relief ratio (Rh)	Schumm (1956)	Rh = H / Lb	9.09
	Dissection index (Dis)	Singh (1994)	Dis = H / Ra	0.45
	Ruggedness Number (Rn)	Strahler (1968)	Rn = Dd * (H / 1000)	0.91

4.3.3. Stream Frequency (F_s)

The stream frequency of the Sindphana River basin in Shirur-Kasar Taluka is calculated at 5.71. Horton (1932, 1945) derived stream frequency as the total number of streams divided by the total area of the basin. Stream frequency and drainage density are proportional to each other.

4.3.4. Circulatory Ratio (R_c)

The circulatory ratio compares the area of the circle with the same perimeter as the basin. [29, 35] A value 1 of the circulatory ratio suggests the basin is perfectly circular, and a value of the ratio below 1 suggests irregularity in the basin shape. [36] If the R_c value approaches 0, then the complexity of the basin increases with a more elongated nature.

The circulatory ratio value of the study area is 0.62, which suggests that the basin is more or less elongated. The R_c value is influenced by topography, lithological changes, climatic conditions, land cover changes and the slope of the basin.

4.3.5. Elongation ratio (R_e)

Schumm (1956) classified the basin into 4 classes based on R_e values, i.e., elongated (<0.7), less elongated (0.8-0.7), oval (0.9-0.8) and circular (>0.9). [37] The study area shows a 0.472 R_e value, suggesting the shape of the basin is elongated

4.3.6. Constant of Channel Maintenance (C)

The constant channel maintenance value for the Sindphana River Basin in Shirur-Kasar is 0.44, which indicates a moderate slope, moderate surface run-off, and moderate to high permeability. The higher C values suggest increased rock permeability, while lower C values suggest reduced rock permeability. [31]

4.3.7. Infiltration Number (I_f)

The Infiltration Number (I_f) value of 12.90 suggests the moderate rate of water absorption by the rock strata, which results in moderate surface run-off.

4.4. Relief Characterization

The relief parameters are: Maximum height of the Basin (Z), Height of basin mouth (z), Total basin relief (H), Absolute relief, Relief ratio (Rh), Dissection index (Dis), and Ruggedness Number (Rn). The Z value of a maximum of 890m and z value of a minimum of 488m above MSL is observed within the study area. The H value is observed to be 402 m using DEM Data in ArcGIS 10.8 software.

4.4.1. Relief Ratio (Rh)

The Rh value of the study area is 9.09, which indicates the high elevation difference relative to its horizontal extent. The slope of the gradient, basement rock types, area of the drainage and overall size of the basin are determined based on the relief ratio value. [38] The steepness and potential for erosion of the drainage basin are derived from the Rh value of the basin. [37]

4.4.2. Dissection Index (Dis)

It is used to evaluate the development stages of the terrain in the physiographic region of the basin. [39] Typically, the dissection index values range from '0' (indicating no vertical dissection or erosion, and thus a flat surface) to '1' (representing areas with significant vertical features such as escarpments on hill slopes or seashores. [40,41] The Dis of the Sindphana River Basin in Shirur-Kasar Taluka is 0.45, this indicates the basin is moderately dissected.

4.4.3. Ruggedness Number (R_n)

Strahler (1958) calculates the R_n values as the product of drainage density and relief of the basin. It highlights the terrain's structural complexity and denudation characteristics. A high Rn value signifies greater structural dominance and a higher likelihood of erosion, while a low R_n value suggests a lower susceptibility to erosion. The Ruggedness number is calculated at 0.91.

5. Conclusion

Sindphana River is a major tributary of the Godavari River, which originates in the Balaghat Range, the eastern extension of the Sahyadri ranges. Sindphana River basin occupies about 1078 sq. km area with 148 km perimeter and 44.24 km basin length of the major stream is elongated shaped. A dendritic drainage pattern composed of 6154 streams with 5288 I order streams, 680 II order streams, 146 II order streams, 30 IV order streams, 07 V order streams, 02 VI order streams and 01 VII order streams.

The Sindphana River basin in Shirur-Kasar Taluka is classified as the VII order basin. The length of higher-order streams is less than the lower-order streams. The R_{bm} value of the present study is 4.51 which suggests the basin is less structurally controlled and does not control the drainage pattern. The texture ratio of the basin is very fine. The elongation ratio and circulatory ratio indicate the slight elongation of the basin.

The Rho values and mean stream length value of the study area suggest runoff in steep areas and water storage capacity. The Constant Channel Maintenance and the Infiltration ratio values suggest that the given basin has moderate surface runoff. The Ruggedness Number value of the present study suggests the slope is moderate and the presence of hard resistance rock.

The Dissection Index value indicates that the basin is moderately dissected. The Relief ratio suggests a moderate to high elevation difference relative to its horizontal extent.

Runoff in steep areas and water storage capacity are indicated by mean stream length and Rho values. This study is beneficial for delineating the water resource areas for the conservation and management of the basin.

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