GEOGRAPHICAL ANALYSIS

RESEARCH ARTICLE

Hydrological Insights from Morphometric Analysis of the Mandovi River Basin: A Geospatial Approach

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Abstract

The assessment of the hydrological characteristics of the surface water basin requires morphometric analysis since it is essential for comprehending the hydrological process. With the help of topographical maps and data from the Advanced Space-borne Thermal Emission and Reflection Global Digital Elevation Model (ASTER GDEM), morphometric analysis is used to ascertain the drainage characteristics of the Mandovi watershed. In this study, morphometric properties of a mountain stream at the micro-watershed level are extracted using ASTER GDEM data. Thirty micro-watersheds make up the sub-watershed. There is a Seventh-order stream in the sub-watershed. Streams dominate the sub-watershed with lower stream orders, particularly first-order streams. Slope and local relief regulate how stream segments develop. The sub-overall watershed's drainage pattern is dendritic. The sub-mean watershed's bifurcation ratio is 2.14, but its fluctuation across the different stream orders points to structural control over the growth of the stream network. The form variables reveal the sub-watershed elongation. The relief ratio reflects the sub-significant watershed's groundwater potential and high discharge capabilities. This study can aid planning techniques for the prevention of soil erosion and soil conservation.

Keywords: Morphometric Analysis; Watershed; Mondavi River Basin

1 Introduction

Topography, climate, and geology are the three main drivers that affect the fluvial system's drainage pattern, density, and geometry [(1)]. The drainage characteristics show how these determinants vary from location to location. In-depth morphometric investigations shed light on the development of drainage morphometry on landforms and their properties, as well as the evolution of the basin [(2)]. It is an essential instrument in any hydrological inquiry, including pedology, environmental assessment, and evaluation of groundwater potential and management. It is an area of interest to both geomorphologists and hydrologists [(3)]. Numerous significant hydrologic phenomena can be connected with the physiographic features of drainage basins, such as the size, shape, slope, drainage density, size, and length of streams [(4)]. The geologic and geomorphic history of the drainage basin is explained by the morphometric parameters, which describe and compare the basin's properties. Determining the watershed dynamics requires a morphometric study as a first step. Drainage basin morphometry makes an effort to explain and forecast long-term basin dynamics that result in morphological changes within the basin and to define physical changes that occur over time to the drainage system as a result of natural or man-made disturbances[5].

As an indirect method for soil estimate, mapping landslide susceptibility, estimating groundwater movement, and assessing topography, morphometric analysis is extensively employed in a wide range of earth science and engineering applications[1]. Since the Shuttle Radar Topography Mission (SRTM) DEM is less accurate in hilly and complicated terrain than the Advanced Space-borne Thermal Emission and Reflection Global Digital Elevation Model (ASTER GDEM), this work tries to use it to analyze the morphometric characteristics[1]. ASTER GDEM is used for drainage network delineation, extraction of terrain parameters, including slope, and sub-watershed boundary delineation. The hydro spatial analysis uses a geographic information system (GIS) (Topno et al., 2022). By examining topographical maps and ASTER GDEM data, the drainage properties of the Mandovi sub-watershed are investigated in order to describe and assess its hydrological characteristics. ASTER GDEM is used for drainage network delineation, extraction of terrain parameters including slope, and sub-watershed boundary delineation. Hydro spatial analysis is carried out using a geographic information system (GIS)[6]. By examining topographical maps and ASTER GDEM data, the drainage properties of the Mandovi sub-watershed are investigated in order to describe and assess its hydrological characteristics.

2 Materials and methods

2.1 Study Area

The study area Mandovi watershed falls in Goa, Karnataka, and Maharashtra state of India with areas 198 of 34.55 km^2. The extent of the watershed is between 15°15' to 15°43' N and 73°47' to 74°27' E. The highest and lowest elevation is 1030 and 1 meter above MSL.

ASTER GDEM Resolution 30 meters and use to SOI toposheet (1:50000) scale.

Table 1. Data sources

Data	Software
• ASTER DEM with 30-meter Resolution	• ArcMap10.5 with ArcSWAT tools, ArcHydro.
• Toposheet of 1:50000 (SOI)	• Advance Excel

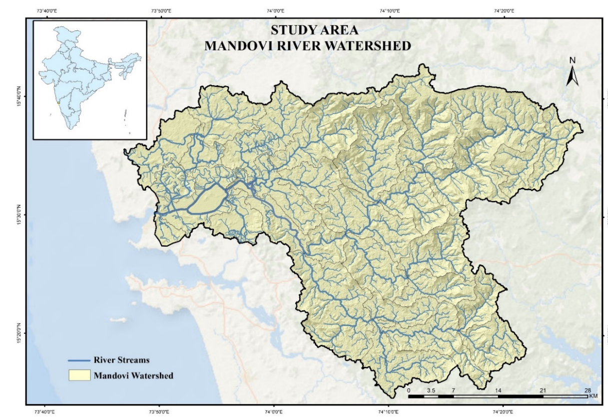

Fig. 1. Study Area map (Mandovi River Basin)

2.2 Methodology

The definition of the Mandovi watershed is based on the Survey of India (SOI) topographic maps at a scale of 1:50,000 (48E/14, 48 F/15, 48 I/2, and 48 I/3) and the ASTER GDEM (WGS84) at a resolution of 30 m. Using the Erdas Imagery Software ASTER data is pre-processed. For rectification and geolocation, ground control points are gathered using topographic maps at a resolution of 1:50,000. The data was filtered with a low-pass 3 * 3 filter. Arc Map 10.8.2 ASTER GDEM is used for data extraction and analysis, Reconditioning of DEM, and processing is done by filling the sinks. Grids for flow accumulation and flow direction are produced. Morphometric parameters (Liner, Areal, and Relief) were used in the research paper.

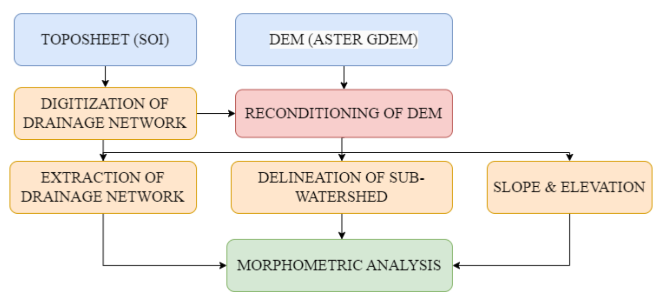

Fig. 2. Research Methodology flowchart

3 Result and Discussion

3.1 Drainage Network of Mandovi Watershed

A survey of India toposheets digitized and restored DEM in the ArcGIS 10.8.2 platform was used to build the Mandovi watershed drainage map. The toposheets were then updated and confirmed using the most recent digital elevation model

(DEM) data, and they were further georeferenced and mosaiced. Using the ArcGIS Spatial Analyst tool, a total of 2884 streams from the DEM were calculated. According to Figure 3, the entire watershed features a dendritic stream pattern, with the highest stream being 7th-order.

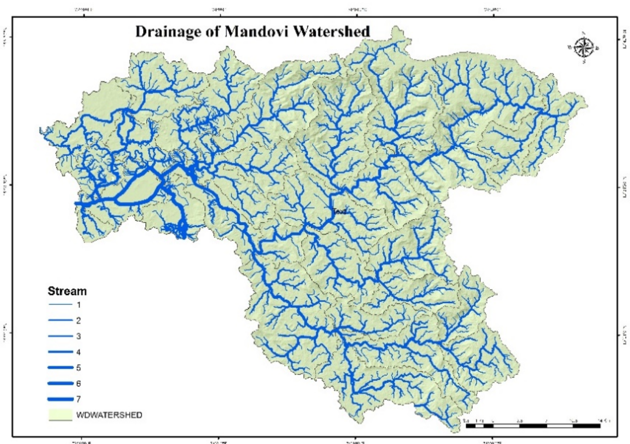

Fig. 3. Drainage Map

3.2 Morphometric Analysis

It uses linear, areal, and relief parameters to analyze drainage basins' three-dimensional characteristics quantitatively. Horton (1945) created a collection of quantitative techniques for examining the drainage characteristics in various basins. For the prioritizing of 30 sub-watersheds (designated SW-1 through SW-30) in the current study, the linear, areal, and relief characteristics were determined, as indicated in Table 2.

Table 2. Description of Morphometric Formula

Parameters	Formulae	
Stream Order	Hierarchical rank	(Strahler,1964)
Stream Length	Length of the Stream	(Strahler,1964)
Steam Length Ratio (RL)	RL= Lu/Lu- 1	
Bifurcation Ratio (Rb)	Rb = Nu/Nu+ I	(Schumm &Schumm, 1956)
Drainage density (D_d)	D_d = L/A	(Strahler,1964)
Stream frequency (F_u)	F_u = N/A	(Horton, 1932)
Drainage Texture ratio (T)	T=N/P	(Horton, 1945)
Form factor (R_f)	$R_f = A/(L_b)^2$	(Horton, 1932)
Elongation ratio (R_e)	$R_e = (2/L_b)^* \text{p}A/\pi$	(Schumm &Schumm, 1956)
Length of overland flow (Lg)	Lg=1/Dd*2,	(Horton, 1945)
Constant Channel Maintenance (C)	C=1/Dd	
Compactness Coefficient (Cc)	C=1/Dd	(Horton, 1945)
Basin Relief (Bh)	Highest Relief-Lowest Relief	
Relief Ratio (Rh)	Rh=Bh/Lb	
Regardless of Number (Rn)	Rn=Bh/Dd	
Rho Coefficient	Mean Stream Length Ratio/Mean Bifurcation Ratio	
Relative Relief	Bh/p	

3.2.1 Liner Parameters

The following stream metrics were calculated: stream order, stream length, mean stream length, stream length ratio, and bifurcation ratio.

- Stream Order and Stream Length

According to the[4] method of stream hierarchical ranking, the designation of stream order was given. Higher frequency is noted in the case of the first order stream, it has been reported. Additionally, it was discovered that stream order grows as stream frequency falls. A higher stream order is related to a higher discharge[2]. A high stream frequency denotes limited permeability and infiltration capacity as a large portion of the water will be swiftly drained via the stream networks. The Mandovi river has a dendritic to sub-dendritic drainage structure and is a 7th -order river. The river basin is made up of 1395 1st -order drainages, 709 2nd -order drainages, and 360 3rd -order drainages. The 4th, 5th and 6th-order drainages total approximately 253, 94, and 25, respectively. In the case of the 7th (24) order drainages, only a few stream numbers are present.

- Stream Length

A basin's surface runoff features are correlated with stream length[3]. 1st order has a longer stream length, which reduces as the stream order increases[7]. Small stream lengths represent high slopes and fine texture, while large stream lengths represent smoother slopes. The link between the number of streams and stream length is seen in Fig. 5. The 4th, 5th, 6th, and 7th order drainages are characterized by soft and flat surfaces. In contrast, the 1st, 2nd, and 3rd -order drainages are confined primarily to mountainous locations. The length of all stream orders combined is 2213.88 Km. About 70% of the overall stream length is made up of the streams in the 1st and 2nd orders, with the remaining 30% being shared by all other stream orders combined.

- Mean Stream Length

The mean stream length was computed by dividing the overall length of the stream order by the total number of streams of order[4]. The mean stream length is found to be largest in lower-order streams and lowest in higher-order streams. This is primarily attributable to the area's varied topography and slope. The mean stream length and mean annual runoff are directly correlated; a high mean stream length denotes a comparatively large mean annual runoff. According to[4], the relatively low mean annual runoff corresponds to a smaller mean stream length. The average annual discharge is higher in 3rd to 7th-order streams in the Mandovi river basin. In the 1st and 2nd -order streams, there is hardly much runoff.

- Stream Length Ratio

The higher-order of stream length is divided by the subsequent lower-order stream segments to calculate the stream length ratio (Horton1932, n.d.). According to[8], the stream length ratio has a significant impact on the basin's surface flow, discharge, and erosional features. Because of variations in slope and terrain, as well as changes in stream length ratios from one order to another, the ratio between the streams of different orders reveals significant changes in the basin[8]. The stream length ratio ranges from 0.53 to 1.28 in the Mandovi river basin, with the 7th-order streams having a greater ratio and the 6th-order streams having a lower one.

- Bifurcation Ratio

The bifurcation ratio is defined as the ratio of the number of stream segments in one order to the number of segments in the next higher order[9]. The bifurcation ratio is primarily influenced by the physiography, climate, and slope of the terrain. A drainage network's branching structure and bifurcation ratio are related. The early hydrograph peak shown by the relatively high bifurcation ratio indicates the possibility of flash flooding during storm events. The mean bifurcation ratio's relatively low value shows the basin's geological heterogeneity, increased permeability, and lessened structural control[10]. In general, bifurcation ratio values between 3 and 5 show that the drainage pattern is not primarily influenced by the geologic features. The bifurcation ratios range from 1.04 to 3.76 with a mean of 2.14 in the Mandovi river basin.

3.2.2 Areal Parameters

- Area and Perimeter

The basin's area and the total runoff are directly correlated with the storm's hydrograph peak[10]. The size of a river basin and mean annual discharge are strongly correlated. The basin boundary's overall length is referred to as the perimeter. The Mandovi river basin has a surface area of 1983.45 km2 and a perimeter of 413.95 km.

- Drainage Density

The drainage density is determined as the sum of all streams' lengths relative to the drainage area (Horton1932, n.d.). Climate, rock type, relief, infiltration capability, vegetation cover, surface roughness, and run-off intensity index all affect drainage density[1]. Low relief, dense vegetation cover, and low drainage density are all signs of extremely resistant or permeable subsoil[8]. The strong or impermeable underlying material, little vegetation, and high relief are all indicators of high drainage density[10]. The Mandovi River Basin has a drainage density of 1.12 km/km2.

- Drainage Texture

The number of stream lengths in all orders per area perimeter is used to calculate drainage texture[11]. When drainage density is low, the drainage texture is coarse, and when drainage density is great, the drainage texture is fine. The texture ratio was employed by Smith et al.[11] to quantify the proximity of one stream to another. The drainage texture is divided into five categories: extremely coarse (2), coarse (between 2 and 4), moderate (between 4 and 6), fine (between 6 and 8), and very fine (> 8). The Mandovi river basin's drainage texture is 6.91, which is considered to be of fine texture.

- Steam frequency

The total number of stream segments for all orders in a given unit of area can be used to compute the stream frequency[7]. According to Arulbalaji & Padmalal[8] and Chatterjee & Tantubay[12], drainage density and stream frequency is positively correlated. In its catchment, the Mandovi river exhibits low stream frequency (0.14).

- Elongation Ratio

The ratio between the diameter of a circle with the same area as the drainage basin and the basin's greatest length is known as the elongation ratio[9]. According to Strahler[4], an elongation ratio close to 1 denotes very low relief, while 0.6 to 0.8 denotes significant relief and a moderate to steep ground slope. Based on the elongation ratio, the shape of the river basin can be classified as circular (> 0.9), oval (0.9 - 0.8), and elongated (0.7)[8]. The Mandovi river basin has an elongation ratio of 0.70, which is within the elongation entity.

- Circulatory Ratio

The circulatory ratio can be understood as the watershed's ability to discharge water[13]. The basin's length and stream frequency, geological formations, land use and cover, climate, relief, slope, and drainage pattern all affect the circulatory ratio[14]. From 0 to 1, the circulatory ratio ranges. Inversely, the basin will be more circular the greater the value (Miller 1953). The Mandovi river basin's circulatory ratio, which is 0.15, shows that the basin is more elongated in shape.

- Form Factor

The form factor, which is referred to as the shape of the basin, was established by dividing the basin area by the square of the basin length (Horton1932, n.d.). The flow intensity of a basin is represented by the form factor. Low-form factors have lower peak flows with longer durations, while high-form factors have greater peak flows with shorter durations [15]. The Mandovi river basin has a 0.39 form factor. Lower peak flows with a longer duration are impacting the Mandovi river basin.

- Length of overland flow

The distance that water travels above the earth before it is focused into a specific stream channel (Horton1932, n.d.). This element has a strong negative relationship with the average slope of the channel and is essentially synonymous with the length of sheet flow. It roughly equates to the reciprocal drainage density divided by two (Horton1932, n.d.). The length of the overland flow in the Mandovi river basin is 0.45.

- Constant of channel maintenance (C)

As the inverse of drainage density, the constant of channel maintenance is defined. As erodibility reduces, the constant of channel maintenance also goes down. More area is needed to produce surface flow when C is higher in value. Less percolation or infiltration is possible with lower values of C, which promotes greater surface runoff. The maintenance channel constant fluctuates between 0.90 and 0.95.

3.2.3 Relief Parameter

- Basin Relief

To comprehend the geomorphic process and landform characteristics of the river basin that is the focus of the inquiry, basin relief is used. Peak run-off rates and sediment delivery are two indices of basin response where the influence of relief is more significant than other indices since it is closely linked to other basin parameters [8]. Since the basin has a relief of 1029 meters, the Mandovi river basin typically experiences higher erosion forces and mean depositional rates.

- Relief Ratio

In general, when the drainage area and river basin size decrease, the relief ratio rises. The relief ratio's maximum value implies a steep slope and high relief, whilst its lowest value denotes a low slope. The Mandovi river basin has a relief ratio of 0.014, which denotes a higher degree of slope in most of the river basin.

- Ruggedness Number

When drainage density and basin relief are both measured in the same unit, the result is the ruggedness number [4]. There has a very high toughness number value. when the slope is typically steep and both variables are big [13]. The roughness Number for the Mandovi river basin is 921.90.

3.3 Sub-watershed analysis

The geo-environmental context of the Mandovi river basin is distinctive. Mandovi watershed falls in Goa, Karnataka, and Maharashtra states. The results of the morphometric analysis show that the drainage networks in the sub-watersheds 12, 14, 19, 22, 23, 24, 26, and 29 have the highest values, while the networks in the other sub-watersheds have lower values. The fluctuation in stream sequence and stream count reveals the basin's physiographic and structural reliance. The presence of numerous streams in a watershed indicates that the landscape is gently sloping but prone to erosion. If the situation is reversed, with fewer streams, it indicates that the topography has been developed [8]. A developed topography is shown by the opposite situation, which is one with fewer streams [8]. The sub-watersheds have streams that range in length from 216.87 km to 1080.52 km. For the 1^{st} and 2^{nd} -order streams, the stream length is greater. Since the 1^{st} -order stream length is greater than 50%, such streams are mostly governed by the terrain's slope and topography (Table 3). In comparison to the other sub-watersheds, the sub-watersheds SWS 1, SWS 8, SWS 16, SWS 28, SWS 20, SWS 29, SWS 6, SWS 27, and SWS 12 have higher mean stream lengths and runoff.

The sub-watershed drainage densities range from 0.83 to 2.28. In comparison to the other sub-watersheds, the drainage density is relatively high in the sub-watersheds 1, 4, 6, 8, 12, 16, 27, and 29–27. The sub-watershed drainage texture has a minimum value of 0.81 and a maximum value of 4.25. The sub-watersheds 3, 8, 10, 15, 16, 17, 25, 28, 29, and 30 exhibits coarse texture among the many sub-watersheds that were taken into consideration for this study, whereas 1, 4, 5, 9, 11, 12, 18, 20, 21 & 27, and 2, 6, 7, 13, 19,22, 23, and 24 demonstrate moderate and fine textures, respectively. It goes without saying that a fine texture indicates low infiltration whereas a coarse texture favours high infiltration. The sub-watershed stream frequency ranges from 0.91 to 4.68. In comparison to the other sub-watersheds, the sub-watersheds 3, 8, 12, 15, 16, 18, 25, 28, and 30 have high stream frequency values, which reflect moderate to high erosion and sediment transport.

The sub-watershed elongation ratio ranges from a minimum of 0.52 to a maximum of 0.86. While the other sub-watersheds display somewhat high relief and moderate ground slope, the sub-watersheds 7, 10, 11, and 27 have relatively low relief. All sub-watersheds fall under the category of lower peak flows with a longer duration, with a form factor ranging from 0.52 to 0.81. Every sub-watershed has an extended shape, and the circulatory ratio varies from 0.16 to

Table 3. Morphometric Parameters Calculation Table

SWS	Dd	Fu	T	Rf	Re	Cr	C	Cc	Rb	Lr	Lg	Rn	Rh
SWS_1	1.35	1.69	1.17	0.58	0.86	0.47	0.74	1.46	3.71	2.09	0.37	62.23	17.77
SWS_2	1.40	2.10	2.07	0.34	0.65	0.16	0.72	2.48	2.11	0.73	0.36	98.68	9.23
SWS_3	2.23	4.68	4.25	0.54	0.83	0.35	0.45	1.69	1.87	0.66	0.22	41.67	12.63
SWS_4	0.83	0.91	0.81	0.29	0.61	0.16	1.21	2.47	1.94	0.77	0.61	162.16	9.30
SWS_5	1.01	1.18	1.26	0.44	0.75	0.21	0.99	2.17	2.56	0.68	0.50	197.89	16.03
SWS_6	1.51	2.14	1.56	0.36	0.68	0.24	0.66	2.05	3.21	2.00	0.33	111.97	19.12
SWS_7	1.39	2.41	2.54	0.32	0.64	0.16	0.72	2.54	2.34	0.60	0.36	343.12	28.58
SWS_8	2.28	4.14	1.64	0.34	0.66	0.20	0.44	2.22	1.73	1.25	0.22	62.40	26.60
SWS_9	1.39	2.75	2.38	0.54	0.83	0.23	0.72	2.10	1.77	0.65	0.36	212.35	33.55
SWS_10	1.22	1.89	1.56	0.24	0.55	0.21	0.82	2.18	2.75	0.58	0.41	253.43	23.58
SWS_11	1.30	2.00	1.69	0.24	0.55	0.18	0.77	2.36	2.26	0.48	0.39	150.38	13.45
SWS_12	1.06	1.10	1.02	0.00	0.72	0.24	0.95	2.04	3.30	0.98	0.47	572.40	58.06
SWS_13	1.04	1.22	1.49	0.26	0.57	0.18	0.96	2.36	1.88	0.59	0.48	812.60	42.16
SWS_14	1.09	1.95	3.08	0.42	0.73	0.28	0.92	1.89	1.84	0.65	0.46	753.93	50.32
SWS_15	1.07	1.21	1.56	0.30	0.62	0.23	0.94	2.10	2.13	0.49	0.47	534.47	32.61
SWS_16	1.02	1.34	1.07	0.52	0.82	0.26	0.98	1.96	3.76	0.50	0.49	367.15	48.73
SWS_17	1.10	1.28	2.04	0.34	0.66	0.23	0.91	2.11	1.69	0.78	0.46	408.73	22.08
SWS_18	1.13	1.38	1.44	0.35	0.67	0.17	0.89	2.43	2.99	2.42	0.44	534.71	39.64
SWS_19	1.18	1.25	1.22	0.22	0.52	0.16	0.85	2.53	1.67	0.62	0.43	678.99	42.18
SWS_20	1.08	1.26	0.99	0.26	0.58	0.21	0.93	2.20	1.75	0.64	0.47	354.02	31.89
SWS_21	1.02	1.29	1.50	0.37	0.69	0.26	0.98	1.95	1.69	0.77	0.49	437.95	33.93
SWS_22	1.08	1.44	1.24	0.26	0.57	0.20	0.93	2.23	1.62	0.60	0.46	671.38	53.95
SWS_23	1.10	1.37	1.52	0.41	0.73	0.21	0.91	2.16	1.67	0.65	0.46	790.10	66.04
SWS_24	1.02	1.13	1.39	0.47	0.77	0.29	0.98	1.85	1.66	0.84	0.49	874.07	75.65
SWS_25	0.94	1.08	1.47	0.42	0.73	0.19	1.07	2.32	2.35	0.57	0.53	946.16	51.23
SWS_26	0.99	1.18	2.01	0.42	0.73	0.18	1.01	2.36	1.69	0.67	0.50	1004.40	45.09
SWS_27	0.96	1.32	1.06	0.23	0.55	0.18	1.04	2.37	2.29	0.49	0.52	279.10	19.24
SWS_28	0.88	1.24	1.04	0.33	0.65	0.21	1.14	2.19	1.74	0.69	0.57	427.07	33.20
SWS_29	1.06	1.19	0.99	0.34	0.66	0.22	0.94	2.12	4.40	0.44	0.47	694.93	68.33
SWS_30	1.09	1.36	1.56	0.45	0.75	0.30	0.91	1.84	1.53	0.72	0.46	698.46	67.69

0.46.

According to the analysis of the basin's relief, sub-watersheds 6, 10, 25, 27, 29, and 30 have higher erosional forces and denotational rates than sub-watersheds 1, 4, 7, 8, 11, 14, 16, 19, 20, 21, 24, and 28, have moderate forces and denotational rates, and sub-watershed 26 has low forces and denotational rates (Table 3). In terms of relief ratio, sub-watersheds 2, 3, 5, 9, 11, 12, 13, 15, 18, 23, 25, and 26 exhibits low slope, whereas 1, 4, 6, 7, 8, 10, 14, 16, 17, 19, 20, 21, 22, 24, 27, 28, 29, and 30 exhibit intermediate slope. Due to the low level of terrain roughness, the sub-watersheds 5, 23, and 25 have lower toughness numbers. Due to the high level of terrain ablativity, the remaining sub-watersheds have greater toughness ratings.

4 Conclusion

To better understand the hydrological and denudational aspects of the Mandovi river basin and its 30th sub-watersheds, the study's objective is to explore in depth the morphometric parameters of the area. To comprehend the morphometric features of the river basin, thirteen distinct morphometric parameters were examined. The study area's topography, lithology, infiltration capacity, and hydrological characteristics are among the parameters. The Mandovi river is a 7th-order river, and its overall drainage pattern is dendritic, according to Strahler's classification. The Mandovi river basin has an elongated shape, as shown by the form factor, circulatory ratio, and elongation ratio. According to drainage density and stream frequency, the basin has a fairly permeable subsurface and has quite high runoff. According to the high basin relief and roughness number, the peak discharge is substantially larger and the sediment yield per unit area is low.

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