

Quantitative analysis of morphometric parameters for prioritization of Warana river basin using remote sensing and GIS



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Summary

An attempt has been made in this paper to study the morphometric characteristics and prioritization of watersheds of the Warana river basin, which falls in the districts of Ratnagiri, Kolhapur, and Sangli and is a major one among five river basins of Maharashtra state, India. As a result, the entire research area has been subdivided into 15 sub-watersheds for prioritization based on morphometric analysis utilizing GIS and remote sensing techniques. The compound parameters were calculated by averaging the priority based on the severity ranking of each watershed. The watersheds were given ultimate priority based on the values of compound parameters. The compound parameter ranged from 6.5 to 9.83 for all 15 watersheds. The watershed 8th (compound parameter value 6.5) obtains the greatest priority value and hence becomes a prospective and prioritized candidate for adopting soil conservation measures, whilst the other watersheds with lesser priorities experience less erosion. Such watershed prioritization is beneficial to overall watershed management planning. The morphometric parameters established for this basin as a whole and each watershed will be important for sound water harvesting and groundwater recharge project design on a watershed basis.

JAE 2024, Vol 18

Received: 20 March 2024

Accepted: 09 April 2024

Published: 30 May 2024

<https://doi.org/10.58628/JAE-2418-105>

Associated Editor: Dr. Anita Meena

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Keywords: Watershed prioritization, Morphometry, Watershed, remote sensing and GIS

Introduction

Morphometric analysis is the study and measurement of the three-dimensional geometry of landforms such as watersheds, drainage systems, and hill slopes. Even without considering the soil map, it is an important tool for prioritizing sub-watersheds for successful watershed management (Biswas et al. 1999). The morphometric study entails measuring linear characteristics, channel network gradients, and drainage basin contributing ground slopes (Nautiyal 1994). The effectiveness of watershed development programmes is dependent on the conservation of soil and water resources within the watershed; hence watersheds must be prioritized based on conservation and development needs. River basins are discrete physical zones with particular implications for drainage patterns and geomorphology (Doornkamp et al. 1971; Strahler 1957). Prioritization of sub-watersheds in a river basin based on morphometric analysis is critical for successful water resource management, particularly in areas where water shortage is a problem. This

prioritization allows for the identification of the most endangered and ecologically significant places in need of rapid conservation interventions. Remote sensing and geographic information systems (GIS) have been shown to be valuable tools for river basin morphometric analysis, providing precise and trustworthy data for the computation of morphometric parameters (Maheshwari et al. 2008; Pandey et al. 2014; Lallawmzuali & Pal. 2023). Morphometric factors such as drainage density, stream frequency, slope, and relief are required for sub-watershed prioritization (Singh et al. 1997; Horton 1945).

Materials and Methods

Study Area

The Warana river basin in Maharashtra's Ratnagiri, Kolhapur, and Sangli districts has been chosen for the study. The research region is located between latitude 16°0'47" N and longitude 73°30'15" E. The Warana River basin is located in a tropical and subtropical climatic zone, hence it has pleasant temperatures all year. The temperature in the basin can fluctuate between 30°C and 40°C. The Warana River basin has an area of 1,965 square km. Figure 1 depicts the research area's location map.

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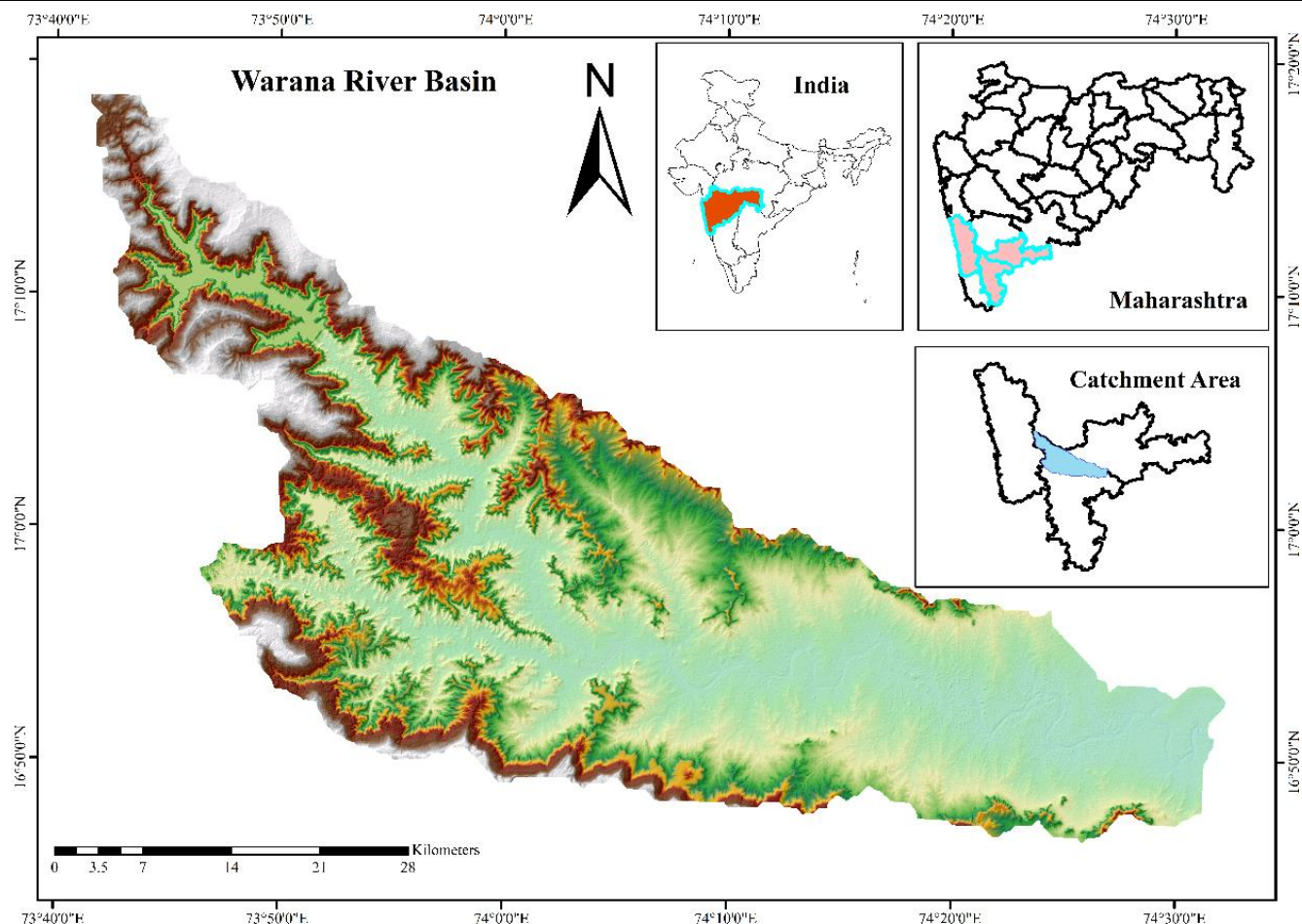


Figure 1. Location map of the study area

Data Collection

The study's diverse information was gathered from a variety of sources.

The following is an overview of the data to be collected:

Land Use and Land Cover (LULC): Data on the physical and biological properties of the Earth's surface derived via supervised classification of Bhuvan and MODIS sentinel 2 images.

Precipitation: CHIRPS (Climate Hazards Group Infrared Precipitation with Station data) statistics on rainfall patterns and quantities overtime during the previous 30 years.

Soil: Open Land Map, a free and open-source global soil information system, provides data on soil qualities such as texture.

Digital Elevation Model (DEM): SRTM data on the topography and elevation of the Earth's surface.

Boundaries: Data on watershed boundaries for spatial analysis and mapping purposes from WWF HydroSHEDS.

RS and GIS were used to create a map of the drainage pattern of the research region. Each stream was given an order using Strahler's (1964) stream ordering approach. Using GIS and Table 1, the linear parameters stream order, stream length, bifurcation ratio, stream length ratio, and length of overland flow, stream frequency, areal parameters such as stream frequency, drainage density, texture ratio, elongation ratio, circularity ratio, form factor, and compactness coefficient, and relief parameters relief, relative relief, relief ratio, channel slope, and ground slope or watershed average slope were determined. The compound parameter values are used to calculate the prioritization rating of all fifteen watersheds in the Warana river basin.

Software used

The programme ArcGIS 10.5 version was used to process remotely sensed data in order to delineate watersheds and generate various maps such as stream order maps, land use land cover maps, soil maps, and so on.

Table 1. Morphometric parameters

S. No.	Morphometric characteristics	Formula / Definition
Linear aspects of Drainage networks		
1	Basin Perimeter	ArcGIS measures basin's watershed perimeter along its dividing ridge.
2	Basin Length	Stream length is the straight-line distance from the mouth to the farthest point of its drainage divide.
3	Stream Order	Stream order ranks streams by size and branching, starting with first-order tributaries in a drainage basin.

4	Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, N_u = Number of stream segments presenting the given order, N_{u+1} = Number of segments of the next higher order
5	Stream Length (L_u)	Length of the Stream (km)
6	Stream Length Ratio (R_L)	$R_L = L_u / L_{u-1}$ Where, L_u = Total stream length of order (u), L_{u-1} = The total stream length of its next lower order
Areal aspects of watershed		
7	Area of watershed (A)	ArcGIS estimates watershed area in hectares using the vertical projection of its drainage divide on a horizontal plane.
8	Form Factor (R_f)	$R_f = \frac{A}{L_b^2}$ Where, A = Area of watershed L_b = Length of the basin
9	Circularity Ratio (R_c)	$R_c = 4 \pi A / P^2$ Where, A_u = Basin Area (km^2), P = Perimeter of the basin (km) $\pi = 3.14$
10	Elongation Ratio (R_e)	$R_e = 4 \pi A_u / L_b^2$ Where, A_u = Area of the Basin (km^2), L_b = Maximum Basin length (km) $\pi = 3.14$
11	Drainage Density (D_d)	$D_d = \frac{L}{A}$ Where, D_d = Drainage density, L = Total length of the stream, A = Area of the basin.
12	Stream Frequency	It is defined as the number of streams segmented per unit area.
13	Length of main channel	Main stream length is the longest distance from a stream's confluence to its upper limit, calculated by measuring the total length of higher-order streams.
Relief aspects of channel network		
14	Maximum watershed relief (H)	Maximum watershed relief (H) is the elevation difference, measured in meters, between the discharge point and the highest point on a basin's perimeter.
15	Relative Relief (R_R)	$R_R = \frac{H}{L_p} \times 100$ Where H = Watershed relief, L_p = Length of the perimeter.
16	Relief Ration (R_r)	$R_r = \frac{Bh}{L_b}$ Where, B_h = Watershed relief, L_b = Basin Length
17	Ruggedness Number (R_N)	$RN = B_h \times D_d$ Where, D_d = Drainage density, B_h = Basin relief.

Result and Discussion

The basin is split into 15 watersheds, denoted by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15.

Linear aspects of the watershed

The topological properties of the stream segments in terms of open linkages of the stream network system are analysed in the linear aspects of the 15 watersheds,

which are connected to the channel patterns of the drainage network. Table 2 summarises the findings for the entire watershed and its sub-watersheds. Strahler's widely used approach was applied in this investigation. The drainage basin study area encompasses 1,965 km^2 . Lower runoff is likely in shorter streams (Chitra et al. 2011).

Table 2. Morphometric parameters of watersheds of Warana River basin

Aspects	Watersheds														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Linear Aspects															
Length of Overland Flow (Km)	0.19	0.14	0.17	0.19	0.27	0.11	0.14	0.23	0.19	0.25	0.15	0.27	0.16	0.26	0.15
Bifurcation Ratio	3.3	3.1	1.5	2.1	1.8	2.3	2.7	2.8	3.4	1.5	3.0	2.9	3.1	1.5	3.0

Stream Length Ratio	1.4	0.23	0.14	0.56	0.27	0.47	0.78	0.44	0.51	0.35	0.53	0.5	1.23	0.15	0.53
Areal Aspects															
Drainage density (Km/Km ²)	0.67	2.07	0.93	2.12	0.74	1.06	0.19	1.82	3.4	0.97	1.54	0.4	0.19	0.72	1.54
Stream Frequency (1/Km ²)	1.59	1.64	1.68	1.57	1.54	1.78	1.53	1.57	2.63	1.62	1.53	1.52	1.32	1.55	1.53
Elongation Ratio	0.21	0.2	0.22	0.17	0.19	0.23	0.21	0.21	0.17	0.17	0.19	0.2	0.24	0.18	0.19
Circulatory Ratio	0.42	0.4	0.5	0.29	0.34	0.51	0.44	0.44	0.28	0.28	0.36	0.41	0.55	0.32	0.36
Form Factor	0.25	0.53	0.34	0.16	0.16	0.26	0.82	0.27	0.17	0.17	0.59	0.22	0.52	0.16	0.59
Compactness coefficient	1.53	1.57	1.41	1.83	1.69	1.39	1.5	1.5	1.88	1.87	1.65	1.54	1.34	1.75	1.65
Drainage texture (1/Km)	2.75	2.96	3.32	1.8	2.75	2.04	3.62	3.48	3.04	2.47	3	3.49	3.2	2.61	3
Relief aspects															
Relief	0.49 8	0.55 1	0.52 1	0.49 5	0.334	0.19 8	0.28 3	0.283	0.298	0.289	0.48 2	0.35 6	0.45 8	0.49 5	0.48 2
Relative Relief Km/Km	0.10 4	0.10 3	0.09 6	0.09 9	0.195	0.14 1	0.24	0.226	0.174	0.235	0.14 1	0.19 7	0.12	0.13 3	0.14 1
Relief Ratio	0.1	0.1	0.1	0.1	0.19	0.14	0.24	0.23	0.17	0.24	0.14	0.2	0.12	0.13	0.14
Channel Slope Km/Km	0.01 67	0.02 51	0.01 95	0.01 66	0.007 88	0.01 15	0.01 29	0.007 84	0.009 99	0.007 36	0.02 05	0.00 84	0.01 82	0.01 21	0.02 05

Bifurcation ratio

The bifurcation value research reveals that the basin and its watersheds have a well-developed drainage network, as the bifurcation ratio runs between 1.5 and 3.4, indicating a low value.

Stream length ratio

The stream length ratio is defined as the ratio of the mean length of a stream segment from one order to the next lower order (Horton 1945). The stream length ratio ranges from 0.14 to 1.4, indicating that the watershed is still in its early stages of maturation.

Length of overland flow

A greater value of overland flow length suggests a longer flow route and, consequently, smoother slopes (Sethupathi et al. 2011). The length of overland flow for the basin is 0.1913 km, while the length of overland flow for watersheds ranges from 0.11 to 0.27 km. Watersheds 6, 7, 2, 15, and 11 have lower values. Overland flow length is influenced by significant structural disturbance, low permeability, steep to extremely steep slopes, and heavy surface runoff. Other surviving watersheds with overland flow lengths larger than 0.25 have less structural disturbance, less runoff, and higher overland flow. When it is more than 0.25, the basin has less structural disruption, less runoff, and higher overland flow. (Mishra et al. 2011).

Aerial aspects of the Watershed

Areal features of the basin are the elements that are determined by the drainage basin's area. Table 2 displays the results.

Drainage density

Watershed drainage density ranges from 0.19 to 3.4. Because of the existence of impermeable subsurface material, scant vegetation, and steep terrain, watersheds

9, 4, and 2 have high drainage density (more than 2 km/km²). While the remaining watersheds have low drainage density, this indicates that the region has a highly permeable subsurface and thick plant cover (Mishra et al. 2011).

Stream frequency

The stream frequency for watersheds ranges from 1.32 to 2.63, with basin 1.64 having a low frequency due to permeable rocks, minimal surface runoff, and strong infiltration capacity within the research region. The stream frequency for all 15 watersheds in the research region has a positive association with drainage density, indicating that the stream population grows as drainage density increases (Chitra et al. 2011).

Elongation ratio

The basin watersheds' elongation ratios range from 0.17 to 0.24. In nature, all watersheds are elongated. While the remaining are shorter in kind. It is 0.1987 for the basin, suggesting that it is less elongated in character (Nautiyal 1994).

Form factor

The basin form factor is 0.3473, with watershed form factors ranging from 0.16 to 0.82. The watersheds 14, 5, and 4 are circular in form, with less side flow for shorter periods and more main flow for longer periods (Chitra et al. 2011).

Circularity ratio

The dimensionless circularity ratio (R_c) is the ratio of the area of a basin to the area of a circle with the same perimeter as the basin (Strahler, 1964; Miller, 1953). The circularity ratio for watersheds ranges from 0.28 to 0.55, while for basins it is 0.3933, suggesting an elongated form, low discharge of runoff, and good subsurface permeability.

Compactness coefficient

The compactness coefficient for watersheds ranges from 1.34 to 1.88, whereas the compactness value for basins is 1.67. They have an extended form to allow for adequate discharge (Hadely et al. 1961).

Drainage texture

Watershed texture ratios range from 1.8 to 3.62. All watersheds have a mild climate. The remaining watersheds are coarser in character, with less runoff potential. It is 19.3095 for the basin, indicating extremely good nature (Pal et al. 2012).

Relief aspects of the Watershed

In water resource assessments, the relief elements of drainage basins are equally essential. The nature of the slope and angle distributions collected throughout the whole basin is determined by the height distribution inside it.

Relief

The basin has a relief of 0.462 km. The research area is in the high relief zone since it is larger than 0.3 km. The high relief value suggests low water flow gravity as well as infiltration and strong runoff circumstances (Nongkynri et al. 2011). Watershed relief ranges from 0.198 to 0.551 km. Watersheds 6 and 8 are in the low relief zone, 2 and 3 are in the high relief region, and the rest are in the intermediate relief region.

Relief ratio

The relief ratio for watersheds ranges from 0.24 to 0.1, whereas the relief ratio for basins is 0.156. The higher values of the relief ratio showed a steep slope and high relief (7th watershed), whilst the lower values in watershed 4th indicated the existence of basement rocks exposed in the form of minor ridges and mounds with a lower degree of slope (GSI 1981).

Relative relief

Table 3. Final priority of watersheds based on compound parameter

Watersheds	Linear parameters							Shape parameters					Cp	Final Priority
	Rb	Fs	Lg	T	Dd	H	Rhp	Rh	Re	Rf	Rc	Cc		
1	2	6	6	10	12	3	12	12	4	9	6	10	7.67	7
2	3	4	13	9	3	1	13	13	7	4	8	8	7.17	4
3	13	3	9	4	9	2	15	14	3	6	3	13	7.83	8
4	11	7	7	15	2	4	14	15	13	13	13	3	9.75	14
5	12	10	1	11	10	10	5	5	9	14	11	5	8.58	12
6	10	2	15	14	7	15	7	7	2	8	2	14	8.53	11
7	9	11	14	1	14	13	1	1	5	1	4	11	7.08	3
8	8	8	5	3	4	14	3	3	6	7	5	12	6.5	1
9	1	1	7	6	1	11	6	6	14	11	14	1	6.58	2
10	14	5	4	13	8	12	2	2	15	12	15	2	8.67	13
11	5	13	11	7	5	6	8	8	10	2	9	6	7.5	6
12	7	14	2	2	13	9	4	4	8	10	7	9	7.47	5
13	4	15	10	5	15	8	11	11	1	5	1	15	8.47	10
14	15	9	3	12	11	5	10	10	12	15	12	4	9.83	15
15	6	12	12	8	6	7	9	9	11	3	10	7	8.33	9

The relative relief for watersheds ranges from 0.096 to 0.24, whereas the relative relief for basins is 0.1493. Watersheds with greater relative relief have greater runoff potential than others. As a result, watersheds 3 and 4 have the lowest and maximum runoff potential, respectively.

Channel slope

It ranges from 0.00736 km/km to 0.0251 km/km for watersheds and 0.030872 km/km for basins. Higher channel slopes in two watersheds showed a shorter time of concentration, i.e. peak flow happens quickly, but lower slopes in ten watersheds suggested less peaked flow for a longer period of time. As a result, while building water harvesting structures on the channel of Watershed 2, the outlet should be constructed with a larger discharge capacity, and the rest of the components, such as the headwall, sidewall, and wing wall, should be of a higher height to accommodate the specified storage capacity (Suresh 2002). Drop structures in sequence are proposed in this watershed's waterways.

Watershed prioritization

The watershed prioritization is based on linear parameters. The greater the value of these factors, the greater the degree of danger. Shape characteristics such as elongation ratio, circularity ratio, form factor, and compactness coefficient all vary inversely with it (Mishra et al. 2010). The ranking was based on the degree of danger, and the final ranking was based on the compound parameter created by averaging the values of the rankings of the linear and shape parameters assigned to the watersheds (Table 3). Figure 1 depicts the final prioritized map of the research region and watershed prioritization levels.

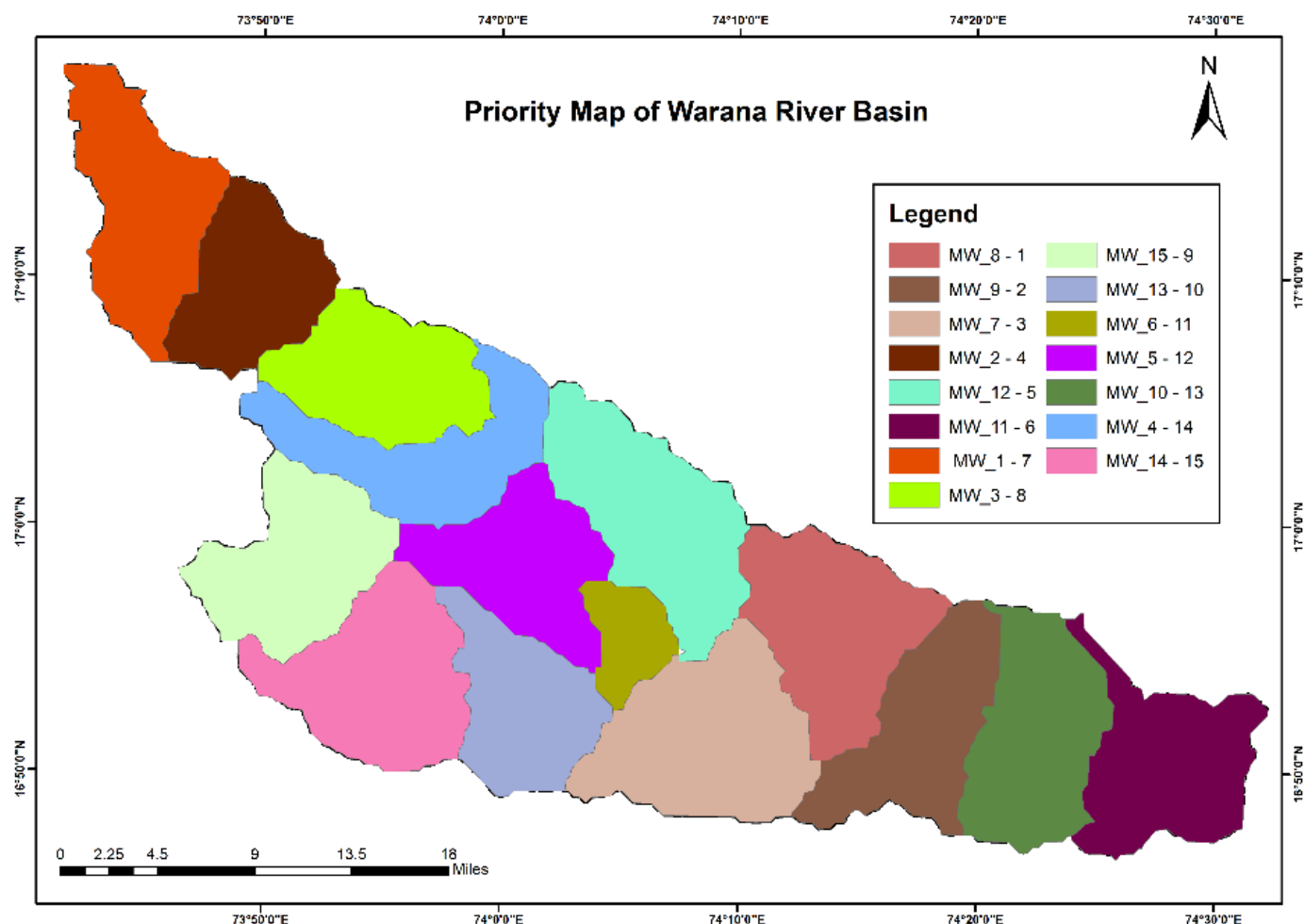


Figure 2. Final priority map of Warana river basin

Conclusions

Any hydrological research usually begins with a morphometric examination of the drainage system. The current work highlights the use of GIS for morphometric analysis and watershed prioritization in the Warana river basin, Maharashtra. Watershed 8th has the highest priority 1, indicating a larger degree of erosion, and therefore becomes a viable candidate for installing soil conservation measures, whereas the other watersheds have a lesser degree of erosion. Thus, the morphometric parameters established for this basin as a whole and for each watershed will be valuable for sound water harvesting and groundwater recharge project design on a watershed basis.

Declaration of Interests

The authors have no conflict of interest to declare.

Data Sharing

All relevant data are within the manuscript.

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