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# Prioritization of sub-watersheds in semi arid region, Western Maharashtra, India using Geographical Information System

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***Abstract:* -** The study area is one of the sub-river basin of Krishna river, covering an area of 3035 km² and lies in west part of Maharashtra state bounded by Latitude $16^0$ 55' to $17^0$ 28' N and Longitude $74^0$ 20' to $74^0$ 40' E. Poor soil cover, sparse vegetation, erratic rainfall and lack of soil moisture characterize the study area for most part of the year. Due to unavailability/poor managed of surface water storage structures, more than 50% area depends upon groundwater for their daily needs. Recurring drought coupled with increase in ground water exploitation results in decline in the ground water level. So the entire study area has been further divided into 9 sub-watersheds named SWS1 to SWS9, ranging in geographical area from 76 km² to 492 km² and has been taken up for prioritization based on morphometric analysis using Geographical information system (GIS) and remote sensing techniques. The drainage density of sub-watersheds varies between 2.07 to 3.26 km/km² and low drainage density values of sub-watershed SWS5 indicates that it has highly resistant, impermeable subsoil material with dense vegetative cover and low relief. The elongation ratio varies from 0.2 to 0.35 which indicates low relief and gentle ground slope. The high value of circularity ratio for SWS 8 sub-watershed 0.6 indicates the late maturity stage of topography. This anomaly is due to diversity of slope, relief and structural conditions prevailing in this sub-watershed. The compound parameter values are calculated and the sub-watershed with the lowest compound parameter is given the highest priority. The sub-watershed SWS3 has a minimum compound parameter value of 1.68 and SWS 8 has a maximum compound parameter 3.08. Hence it should be provided with immediate soil conservation measures because sedimentation is the major problem for surface water storage structures.

***Keywords:* -** *Morphometric analysis, GIS, prioritization, remote sensing, sub-watersheds, soil conservation, compound parameters*

## I. INTRODUCTION

The available surface and ground water resources are inadequate to meet the growing water demands due to rapid urbanization and increasing population. The demand for water has increased over the years, due to which the assessment of quantity and quality of water for its optimal utilization has become essential.

Identification and outlining of various ground features such as geological structures, geomorphic features and their hydraulic characteristics may serve as direct or indirect indicators of the presence of ground and surface water. The geomorphic conditions are essential pre-requisites in understanding the water bearing characteristics of hard rocks. The role of rocks types and geologic structure in the development of stream networks can be better understood by studying the nature and type of drainage pattern and by a quantitative morphometric analysis. The morphometric parameters of a watershed are reflective of its hydrological response to a considerable extent and can be helpful in synthesizing its hydrological behaviour. A quantitative morphometric characterization of a drainage basin is considered to be the most satisfactory method for the proper planning of watershed management because it enables us to understand the relationship among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes.

Krishna basin is located at $73^0$ E to $78^0$ E and $15^0$ N to $19^0$ N of Maharashtra covering total area about 90,000 sq km. In Maharashtra it covers an area of 15116sq km in the district of Satara, Sangli, Kolhapur. It is the fourth largest river basin in India. It has an average rainfalls ranging between 600 mm to 1900 mm per annum. The origin of the river is located at Mahabaleshwar having the height of 4500 ft above MSL. The Krishna basin running across Maharashtra, Karnataka, Andhra Pradesh and has an area of 2, 58,948 sq km i.e.7.9 % of India's surface area. The length of the Krishna River within Maharashtra is 304 kms. The term morphometry is the measurement and mathematical analysis of configuration of earth's surface, shape and dimension of its landform (Clark 1966). In the present study, Geographic Information System technique has been used to assessing various terrain and morphometric parameter of drainage basins and watershed. Linear, relief and aerial morphometric parameters are evaluated for development planning of sub watershed in Krishna Basin. Linear parameter analyzed includes stream order (u), stream length ($L_u$), mean stream length ($L_{sm}$) and bifurcation ratio ($R_b$).

Relief parameter analyzed includes Basin Relief ($B_h$) and Ruggedness number ($R_n$). Relief aspect of watersheds plays an important role for computing, surface and subsurface water flow, permeability, landform development, Drainage density ($D_d$), stream frequency ($F_s$), Texture ratio(T), Form factor ($R_f$), circulatory ratio($R_c$) and Constant Channel Maintenance (C) which helps for drainage development. Drainage density is one of the important indicators of the landform element. It provides a numerical measurement of landscape dissection and runoff potential. The drainage pattern differs a lot in linear, relief and areal morphometric parameters due to difference in geological structure, land form configuration, slope, vegetation and rainfall distribution.

## II. STUDY AREA

The study area lies in west part of Maharashtra state bounded by Latitude $16^0$ 55' to $17^0$ 28' N and Longitude $74^0$ 20' to $74^0$ 40' E. falling in part survey of India topographical sheet no 47 K – 5, 6, 7, 8, 10, 11, 12 and 47 L - 9 on the scale 1:50,000 it covers total area of 3035 $km^2$ includes two districts (Satara and Sangli) in Maharashtra.

The average annual rainfall increases from 1200 mm in the western side to 300 mm in the east side. Geology of the area is dominantly covered by basaltic rock. The area has suffered a lot by tectonic movement in the past as evidenced by varying fold, fault and lineament association with hills located in the western side of study area (Figure 1).

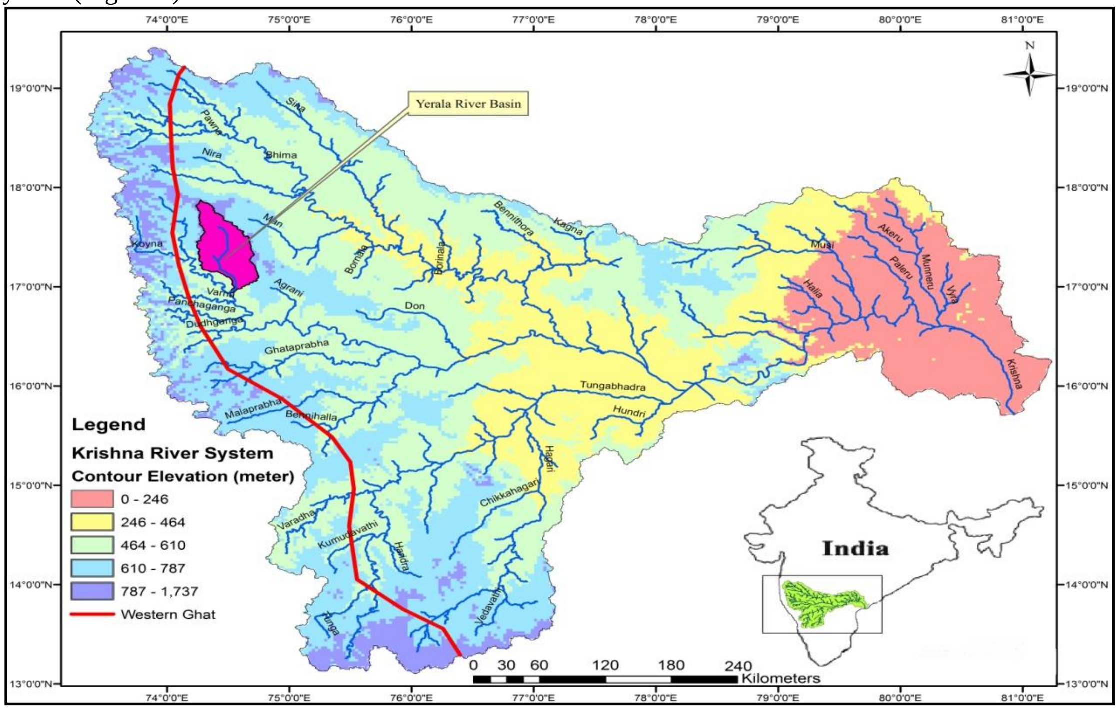


**Fig. 1** Index map of Yerala river basin

## III. METHODOLOGY

In the present study, the parameters considered for prioritization of sub-watersheds are from the natural resources thematic data, including drainage density, groundwater prospects, irrigated area, forest cover and wastelands derived from satellite imagery and socioeconomic data. The thematic maps are derived from SOI topographic maps on 1:50000 scale. For better accuracy of the thematic map, ground truth check is done for verification and necessary modifications are made in thematic maps during post interpretation.

The digitization of sub-dendritic drainage pattern was carried out in GIS environment (Figure 2). The stream ordering is carried out using Horton's law. The fundamental parameters namely: stream length, area, perimeter, number of streams and basin length are derived from the drainage layer. The morphometric parameters for the delineated watershed area are calculated based on the formula suggested by (Horton, 1945), (Strahler, 1964), (Schumm, 1956), (Nookaratnam et al., 2005) and (Miller, 1953) given in table 1. Morphometric parameters like stream order, stream length, bifurcation ratio, drainage density, drainage frequency, relief ratio, elongation ratio, circularity ratio and compactness constant are calculated. Prioritization rating of all the nine sub-watersheds of Yerala watershed is carried out by calculating the compound parameter values. The sub-watershed with the lowest compound parameter value is given the highest priority.

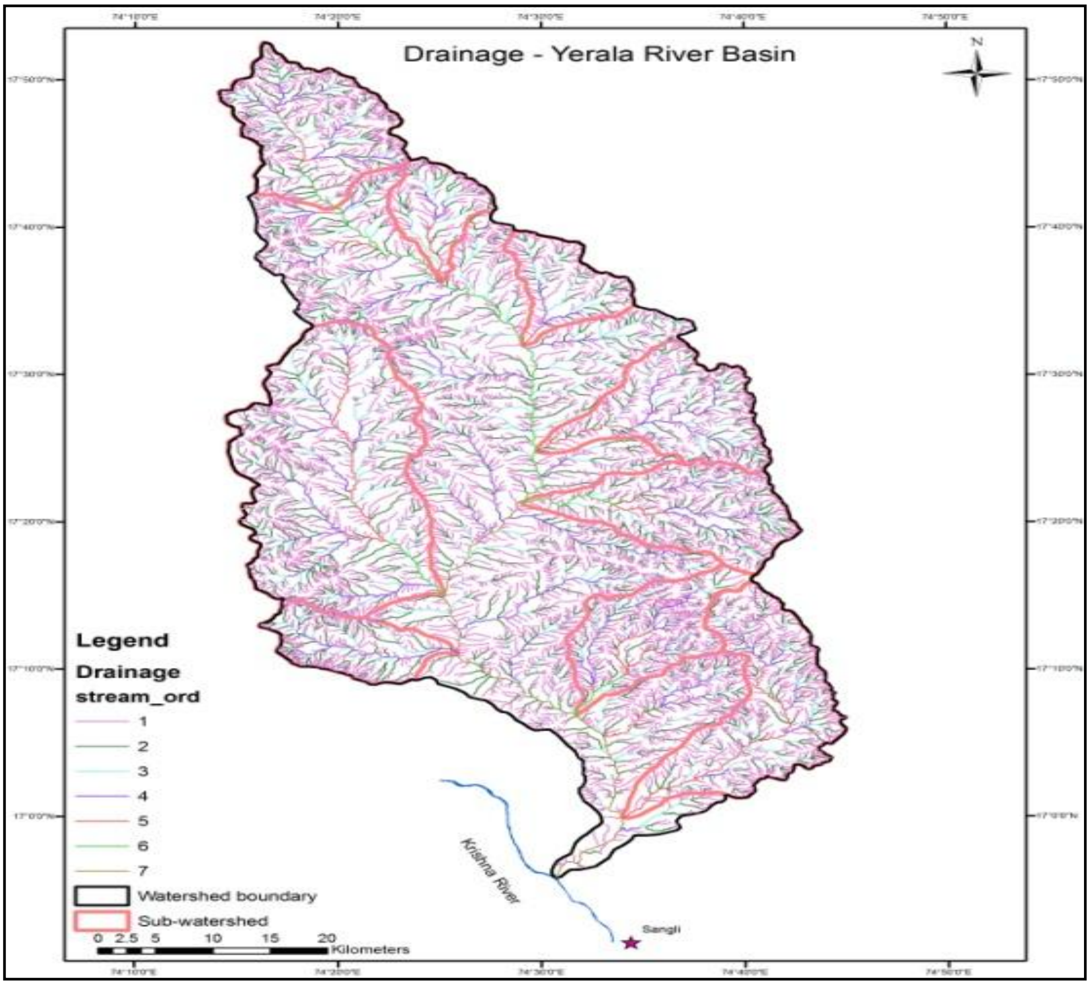


Figure 2 Driange network of Yerala river basin

## IV. RESULTS AND DISCUSSION

Drainage pattern is characterized by irregular branching of tributaries in many directions with an angle less than 90º. The watershed is divided into nine sub-watersheds with codes SWS1 to SWS9.

### 4.1. Linear Aspect

The linear aspects of the channel system are stream order (U), stream length (Lu) and stream frequency (Fs). ***Stream order (U):*** The Yerala River is a 7$^{th}$ order stream covering an area of 3035 km². The sub-watershed SWS9 (Sonhira Odha) is having 4$^{th}$ order streams covering an area of 99 km². The sub-watersheds SWS1, SWS3, SWS4, SWS5 and SWS8 (Dargoba Odha, Darjai Odha, Kapur Nala, Krishnabai Odha and Ner Doha) is having 5$^{th}$ order streams covering an area of 175 km², 76 km², 242 km², 86 km² and 157 km² respectively. The variation in order and size of the sub-watersheds is largely due to physiographic and structural conditions of the region.

**Table - 1** Formulae adopted for computation of morphometric parameters

| SN | Morphometric | Formula | Reference |
|---|---|---|---|
| 1 | Stream order (u) | Hierarchical rank | Strahler (1964) |
| 2 | Stream length (Lu) | Length of the stream | Horton (1945) |
| 3 | Mean stream length ($L_{sm}$) | $L_{sm} = L_u / N_u$ Where,<br>$L_{sm}$ = Mean stream length<br>$L_u$ = Total stream length of order 'u'<br>$N_u$ = Total no. of stream segments of order 'u' | Strahler (1964) |
| 4 | Stream length ratio ($R_L$) | $R_L = L_u / L_u - 1$ Where,<br>$R_L$ = Stream length ratio<br>$L_u$ = Total stream length of the order 'u'<br>$L_u - 1$ = Total stream length of next lower order | Horton (1945) |
| 5 | Bifurcation ratio ($R_b$) | $R_b = N_u / N_u + 1$ Where,<br>$R_b$ = Bifurcation ratio<br>$N_u$ = Total no. of stream segments of order 'u'<br>$N_u+1$ = No. of segments of the next higher order | Schumn (1956) |
| 6 | Mean bifurcation ratio | $R_{bm}$ = Average of bifurcation ratios of all orders | Strahler (1957) |
| 7 | Relief ratio ($R_h$) | $R_h = H / L_b$ Where,<br>$R_h$ = Relief ratio<br>H = Total relief (Relative relief) of the basin (km)<br>$L_b$ = Basin length | Schumm (1956) |
| 8 | Drainage density ($D_d$) | $D_d = L_u / A$ Where,<br>$D_d$ = Drainage density<br>$L_u$ = Total stream length of all orders<br>A = Area of the basin (km2) | Horton (1932) |
| 9 | Stream frequency ($F_s$) | $F_s = N_u / A$ Where,<br>$F_s$ = Stream frequency<br>$N_u$ = Total no. of streams of all orders<br>A = Area of the basin (km2) | Horton (1932) |
| 10 | Drainage texture ($R_t$) | $R_t = N_u / P$ Where,<br>$R_t$ = Drainage texture<br>$N_u$ = Total no. of streams of all orders<br>P = Perimeter (km) | Horton (1945) |
| 11 | Form factor ($R_f$) | $R_f = A / L_b^2$ Where,<br>$R_f$ = Form factor<br>A = Area of the basin (km2)<br>$L_b^2$ = Square of basin length | Horton (1932) |
| 12 | Circularity ratio ($R_c$) | $R_c = 4 * Pi * A / P^2$ Where,<br>$R_c$ = Circularity ratio<br>Pi = 'Pi' value i.e., 3.14<br>A = Area of the basin (km2)<br>$P^2$ = Square of the perimeter (km) | Miller (1953) |
| 13 | Elongation ratio ($R_e$) | $R_e = 2 / L_b$ Where,<br>Re = Elongation ratio<br>A = Area of the basin (km2)<br>Pi = 'Pi' value i.e., 3.14<br>$L_b$ = Basin length | Schumn (1956) |
| 14 | Length of overland flow ($L_g$) | $L_g = 1 / D * 2$ Where,<br>$L_g$ = Length of overland flow<br>D = Drainage density | Horton (1945) |

***Stream length (Lu):*** The stream length was computed on the basis of the law proposed by (Horton, 1945), for all the 9 sub-watersheds. Generally, the total length of stream segments decrease as the stream order increase. In 9 sub-watersheds the stream length followed Horton's law (Table 2).

**Table 2** Stream Analysis

| Sub Watershed | | Stream numbers | | | | | | Stream Length | | | | | | Length ratio | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 2/1 | 3/2 | 4/3 | 5/4 | 6/5 |
| SWS 1 | Chand Nadi | 397 | 101 | 29 | 7 | 1 | - | 242.94 | 73.9 | 54.38 | 29.12 | 1.15 | - | 0.30 | 0.73 | 0.53 | 0.03 | 0.00 |
| SWS 2 | Dargoba Odha | 309 | 70 | 26 | 8 | 3 | 1 | 176.42 | 48.54 | 28.15 | 12.15 | 13.82 | 4.05 | 0.27 | 0.57 | 0.43 | 1.13 | 0.29 |
| SWS 3 | Darjai Odha | 114 | 35 | 14 | 3 | 1 | - | 91.67 | 31.19 | 25.65 | 6.9 | 8.8 | - | 0.34 | 0.82 | 0.26 | 1.27 | 0.00 |
| SWS 4 | Kapur Nala | 543 | 145 | 37 | 11 | 1 | - | 362.15 | 117.18 | 66.59 | 21.77 | 9.94 | - | 0.32 | 0.56 | 0.32 | 0.45 | 0.00 |
| SWS 5 | Krishna Odha | 144 | 48 | 11 | 5 | 1 | - | 102.22 | 36.78 | 25.69 | 9.94 | 3.4 | - | 0.35 | 0.69 | 0.38 | 0.34 | 0.00 |
| SWS 6 | Mahadev Odha | 464 | 136 | 31 | 10 | 2 | 1 | 267.48 | 103.54 | 46.91 | 20.16 | 9.95 | 7.93 | 0.38 | 0.45 | 0.42 | 0.49 | 0.79 |
| SWS 7 | Nani Nadi | 826 | 226 | 71 | 19 | 4 | 1 | 593.36 | 234.06 | 115.3 | 63.11 | 10.12 | 9.19 | 0.39 | 0.49 | 0.54 | 0.16 | 0.90 |
| SWS 8 | Ner Odha | 490 | 179 | 56 | 21 | 3 | 1 | 299.99 | 114.32 | 51.81 | 28.54 | 9.33 | 8.25 | 0.38 | 0.45 | 0.55 | 0.32 | 0.88 |
| SWS 9 | Sonhira Odha | 226 | 62 | 22 | 2 | 0 | - | 147.7 | 72.08 | 28.04 | 5.8 | - | - | 0.48 | 0.38 | 0.20 | 0.00 | 0.00 |

***Stream Length ratio (Rl):*** Horton's law of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams. The stream length ratio between different sub-watersheds showed an increasing and decreasing trend in the length ratio from lower order to higher order and in the sub-watersheds SWS1, 2, 3, 4, 5, 7, 9 there was a change from one order to another order indicating the late youth stage of geomorphic development of streams in the inter basin area.

***Stream frequency (Fs):*** The stream frequencies of all the sub-watersheds are mentioned in Table 3. Generally if the sub watersheds having large area under dense forest have low drainage frequency and the area having more agricultural land have high drainage frequency. High value of drainage frequency in SWS 8 and SWS 2 produces more runoff in comparison to others.

### 4.2. Dimensionless factors

***Form factor (Rf):***

The form factor for all sub-watersheds varies from 0.10 – 0.31 (Table3). This observation shows that the sub-watersheds are more or less elongated. The elongated watershed with low value of Rf indicates that the basin will have a flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

***Elongation Ratio (Re):***

The elongation ratio for all sub-watersheds varies from 0.2 – 0.35 which indicates normal relief and gentle ground slope (Table3). The sub-watersheds SWS 2 and SWS 5 has ratio 0.2 and 0.35 respectively.

***Circularity Ratio (Rc):***

It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the watershed. In the present study (Table 3), the Rc value for all sub-watersheds varies from 0.35 to 0.60 which shows that the sub-watersheds are almost elongated. The high value of circularity ratio for SWS 8 indicates the late maturity stage of topography. This anomaly is due to diversity of slope, relief and structural conditions prevailing in this sub-watershed.

### 4.3. Measurement of intensity of dissection

***Drainage density (Dd):***

(Horton, 1932) has introduced drainage density (Dd) as an expression to indicate the closeness of spacing of channels. Drainage density in all the sub-watersheds varies from 2.07 to 3.26 respectively (Table 4). In general it has been observed over a wide range of geologic and climatic types, that low drainage density is more likely to occur in regions of highly permeable subsoil material under dense vegetative cover, and where relief is low. In contrast, high Dd is favored in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Nag, 1998). Hence in this study in order to find out the correlation of Dd with land use/cover, spatial distribution of land use/cover was studied. Low Dd value for sub-watershed SWS 5 indicates that it has highly resistant, impermeable subsoil material with dense vegetative cover and low relief.

**Table 3** Morphometric Parameters of Yerala River

| Sub Watershed | Area (Km²) | Stream Frequency (Km/Km²) | Basin Length (Km) | Form Factor | Elongation ratio | Circulatory ratio |
|---|---|---|---|---|---|---|
| SWS 1 | 172.00 | 3.11 | 26.87 | 0.24 | 0.30 | 0.48 |
| SWS 2 | 98.00 | 4.26 | 30.64 | 0.1 | 0.20 | 0.44 |
| SWS 3 | 76.00 | 2.19 | 18.23 | 0.22 | 0.30 | 0.56 |
| SWS 4 | 242.00 | 3.05 | 47.55 | 0.1 | 0.20 | 0.35 |
| SWS 5 | 86.00 | 2.43 | 16.6 | 0.31 | 0.35 | 0.53 |
| SWS 6 | 183.00 | 3.51 | 33.48 | 0.16 | 0.25 | 0.57 |
| SWS 7 | 492.00 | 2.33 | 44.47 | 0.24 | 0.31 | 0.55 |
| SWS 8 | 157.00 | 4.79 | 24.07 | 0.27 | 0.33 | 0.6 |
| SWS 9 | 99.00 | 3.15 | 22.04 | 0.2 | 0.28 | 0.56 |

**Table 4** Values of drainage density, texture and bifurcation ratios for Yerala River Sub- watershed

| Sub Watershed | Perimeter | Drainage Density | Drainage texture | Bifurcation ration Rb | | | | | Mean Bifurcation ratio |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1/2 | 2/3 | 3/4 | 4/5 | 5/6 | |
| SWS 1 | 67 | 2.330 | 7.99 | 3.93 | 3.48 | 4.14 | 7.00 | 0.00 | 3.71 |
| SWS 2 | 53 | 2.890 | 7.87 | 4.41 | 2.69 | 3.25 | 2.67 | 3.00 | 3.20 |
| SWS 3 | 41 | 2.160 | 4.07 | 3.26 | 2.50 | 4.67 | 3.00 | 0.00 | 2.68 |
| SWS 4 | 92 | 2.380 | 8.03 | 3.74 | 3.92 | 3.36 | 3.67 | 0.00 | 2.94 |
| SWS 5 | 45 | 2.070 | 4.64 | 3.00 | 4.36 | 2.20 | 5.00 | 0.00 | 2.91 |
| SWS 6 | 63 | 2.490 | 10.22 | 3.41 | 4.39 | 3.10 | 5.00 | 2.00 | 3.58 |
| SWS 7 | 106 | 2.080 | 10.82 | 3.65 | 3.18 | 3.74 | 4.75 | 4.00 | 3.86 |
| SWS 8 | 57 | 3.260 | 13.21 | 2.74 | 3.20 | 2.67 | 7.00 | 0.75 | 3.27 |
| SWS 9 | 47 | 2.560 | 6.63 | 3.65 | 2.82 | 11.00 | 0.00 | 0.00 | 3.49 |

The compound parameter values of all nine sub-watersheds of Yerala watershed are calculated and prioritization rating is shown in Table 5. The sub-watershed SWS 3 with a compound parameter value of 1.68 receives the highest priority followed by SWS 5 and SWS 4. Highest priority indicates the greater degree of erosion in the particular micro-watershed and it becomes potential candidate for applying soil conservation measures. Thus soil conservation measures can first be applied to sub-watershed SWS3 and then to the other sub-watersheds depending upon their priority. The final prioritized map of the study area and prioritization ranks of sub-watersheds is shown in Figure 3.

**Table 5** Prioritization Results of Morphometric Analysis

| Sub Watershed | Dd | Fs | T | Rf | Rc | C | Rb | Rt | Compound parameter | Final Priority |
|---|---|---|---|---|---|---|---|---|---|---|
| SWS 1 | 2.33 | 3.11 | 5.93 | 0.24 | 0.48 | 0.43 | 3.71 | 7.99 | 2.69 | 7 |
| SWS 2 | 2.89 | 4.26 | 5.83 | 0.10 | 0.44 | 0.35 | 3.20 | 7.87 | 2.77 | 8 |
| SWS 3 | 2.16 | 2.19 | 2.78 | 0.22 | 0.56 | 0.46 | 2.68 | 4.07 | 1.68 | 1 |
| SWS 4 | 2.38 | 3.05 | 1.23 | 0.10 | 0.35 | 0.41 | 2.93 | 8.03 | 2.05 | 3 |
| SWS 5 | 2.07 | 2.43 | 2.53 | 0.31 | 0.53 | 0.48 | 2.91 | 4.64 | 1.77 | 2 |
| SWS 6 | 2.49 | 3.51 | 1.80 | 0.16 | 0.57 | 0.40 | 3.58 | 10.22 | 2.53 | 6 |
| SWS 7 | 2.08 | 2.33 | 1.07 | 0.24 | 0.55 | 0.47 | 3.86 | 10.82 | 2.38 | 5 |
| SWS 8 | 3.26 | 4.79 | 2.00 | 0.27 | 0.60 | 0.30 | 3.27 | 13.21 | 3.08 | 9 |
| SWS 9 | 2.56 | 3.15 | 2.42 | 0.20 | 0.56 | 0.39 | 3.49 | 6.63 | 2.16 | 4 |

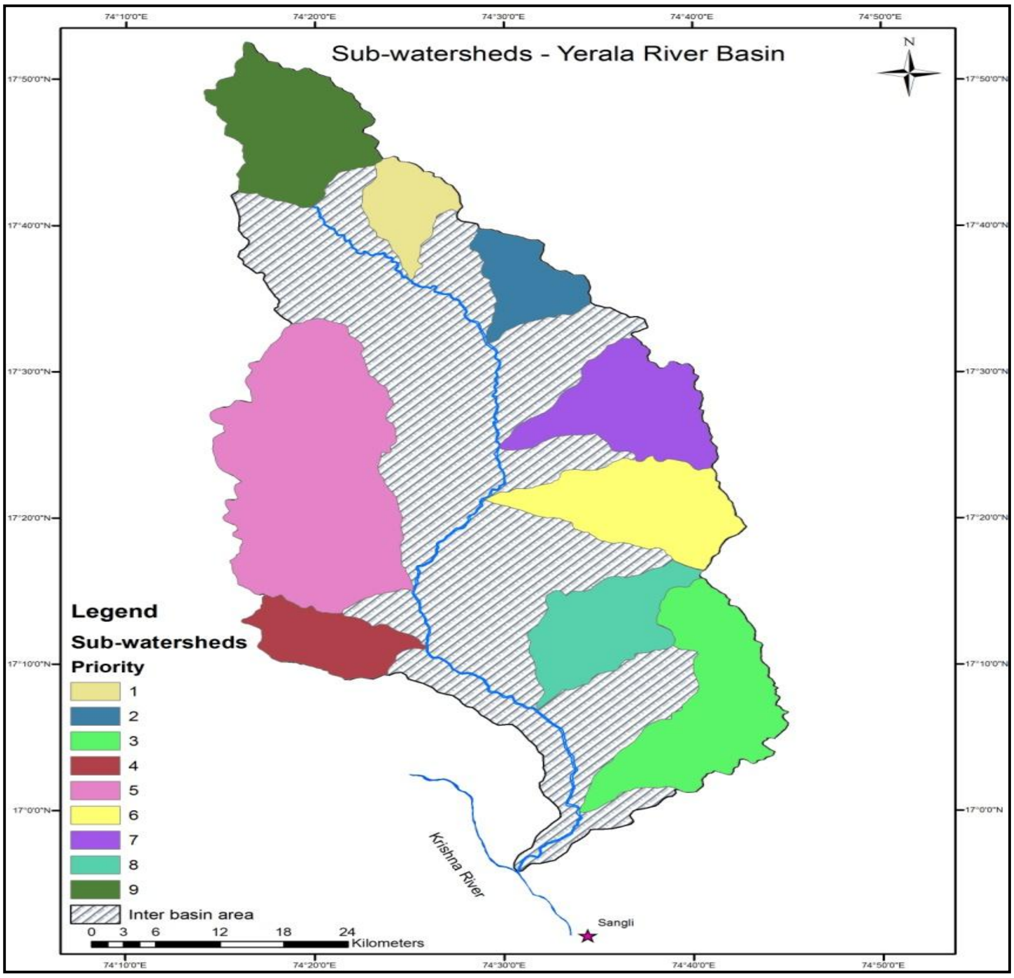


**Figure 3** Prioritized sub-watershed map of Yerala watershed

## V. CONCLUSION

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes. The present study demonstrates the usefulness of GIS for morphometric analysis and prioritization of the sub-watersheds of Yerala watershed of Western Maharashtra, India. The morphometric characteristics of different sub-watersheds show their relative characteristics with respect to hydrologic response of the watershed. Morphometric parameters coupled with integrated thematic map of drainage density land use can help in decision making process for water resources management. Results of prioritization of sub-watersheds show that sub-watersheds SWS 3 and SWS 5 are more susceptible to soil erosion. Therefore, immediate attention towards soil conservation measures is required in these sub-watersheds to preserve the land from further erosion and to alleviate natural hazards.

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