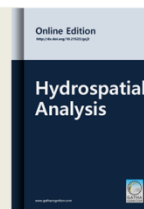




Hydrospatial Analysis

Homepage: www.gathacognition.com/journal/gcj3
<http://dx.doi.org/10.21523/gcj3>



Technical Paper

Multi-criteria Prioritization for Sub-watersheds in Medium River Basin using AHP and Influence Approaches



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Abstract

Watershed is unique bio-physical unit of the Earth surface and source of resources to the human, animal and plants. AHP based multi-criteria analysis is suitable for prioritization of sub-watersheds in medium river basin for planning, management and development. Twenty five criterion i.e. area, P, D_d, T, L_b, R_c, C_c, R_f, R_e, L_u, N_u, F_s, L_{sm}, RL, R_b, R_t, B_s, I_f, R_{h1}, R_n, geology, slope, soil, rainfall and population density were selected for prioritization of medium watersheds of Upper Mula basin in Maharashtra (India). Correlation analysis is suitable for ranking the criterion selected for prioritization. Texture ratio (25.94%), drainage texture (12.97%), stream order (8.65%), total stream length (6.49%) and ruggedness number (5.19%) show higher influences on development of watershed structure in the study area. Further, criterion like rainfall, soil and population were show considerable influence in prioritization of sub-watersheds in medium river basin. Influences were estimated based on weights calculated using AHP technique. Values of influences were normalized using distribution of particular criterion within sub-watersheds. Watersheds are classified into high, moderate and low priorities. The methodology formulated in this study can be effective tool for quick prioritization of medium and major watersheds for planning and management for development.

Article history

Received: 16 November 2018
 Revised: 15 December 2018
 Accepted: 23 December 2018

Keywords

Prioritization;
 Ranking;
 Multi-criteria analysis;
 Correlation matrix;
 AHP;
 Weights;
 Influence.

Editor(s)

P. S. Hire

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1 INTRODUCTION

Physiographic, morphometric (Zolekar and Bhagat, 2015) and social parameters have close association with watershed planning and development. Gharde and Kothari (2016), Gabale and Pawar (2015), Ali and Ali (2014), Rao and Yusuf (2013), Rekha *et al.* (2011), Romshoo *et al.* (2012), Singh and Singh (2011), Sharma *et al.* (2009), Vandana (2013), Zende *et al.* (2013), Aravinda and Balakrishna (2013), Khare *et al.* (2014), etc. have been used linear, aerial and relief aspects for prioritization of watersheds for development projects. Rao *et al.* (2014), Aouragh and Essahlaoui (2014), Raja and Karibasappa (2014) and Kiran and Srivastava (2014) have used linear and aerial aspects for this purpose. Further, Gebre *et al.*, (2015) have used information about relationship of soil types and soil

texture with morphometric parameters. Vulevic *et al.* (2015) have used many parameters for watershed prioritization based on multi-criteria decision analysis. Some of the researchers have reported relationship of land use/cover characteristics with morphology, slope, soil, land surface processes, climate, hydrology, etc. as well as human activities (Mishra and Nagarajan, 2010; Panhalkar 2011; Romshoo *et al.*, 2012; Gumma *et al.*, 2014; Gashaw *et al.*, 2017). Parameters like geology and rainfall show less variation and influences on development of micro watersheds. Previous study on prioritization of sub-watersheds in small river basin using multi-criteria decision analysis has been reported efficient observations (Gaikwad and Bhagat, 2017). They have used information about morphometric

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<http://dx.doi.org/10.21523/gcj3.18020105>

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parameters of sub-watersheds (Rai *et al.*, 2014; Gajbhiye *et al.*, 2014). However, parameters like geology and rainfall show considerable influence in formation and variation in characteristics of sub-watersheds in medium and major river basins (Rai *et al.*, 2014; Gajbhiye *et al.*, 2014). Further, population pressure is one of the causes for over exploitation of natural resources. Therefore, morphometric parameters are used with geology, rainfall and population distribution successfully for prioritization of sub-watersheds in medium river basin using multi-criteria decision analysis.

2 STUDY AREA

Upper section of Mula River basin ($19^{\circ} 03'45.00''$ N to $19^{\circ} 30'02.00''$ N and $73^{\circ} 33'45.00''$ E to $74^{\circ} 37'31.00''$ E) in Ahmednagar district (India) distributed within Akole, Sangamner, Parner and Rahuri talukas was selected for prioritization of sub-watersheds for development and planning purposes (Figure 1). The Mula River originates in *Ajoba Dongar* near *Harishchandragad* located in Sahyadri range and contributes water to Pravara River. The height varies from 512 to 1472.7m and rainfall from 504 to 4845mm. About 86.38% area is classified in the class 0 to 10° , 11.75% in 10 to 22° and 1.57% in 22 to 33° slopes. The study area is the part of Deccan trap with compound pahoehoe flows and *som Aa* flows,

Megacryst Compound pahoehoe basaltic flows and Alluvium type geology (Figure 2). Slightly deep, well drained, fine, moderately calcareous soils on very gently sloping land are observed (1717.48km^2) with moderate erosion (Figure 3). Further, very shallow excessively drained, loamy soils (422.85km^2) on moderately sloping undulating land with severe erosion and strong stoniness are also observed. Rice is the major crop in the kharip (rainy) season for Western part of the basin whereas Cereals like Bajra, Pulses and Groundnuts are observed as major crops in the kharip season and Jawar, Wheat, Maize and Sunflower, Vegetables in rabbi (winter) season for Eastern part. Western part shows subsistence type of agriculture fully depend on rainfall and only small patches near streams in Eastern part observed seasonal irrigation for vegetables. The Upper Mula basin has been divided into 140 sub-watershed [SW0 to SW139] (Figure 4) for analysis and prioritization (Zende *et al.*, 2013). Villages like Bramhanwada, Belapur, Ghargaon, Kotul, Sakur, Bota, Khandarmal, Pimpalgaon Depa, Baragaon Nandur, Palashi, Goregaon, Takali Dhokeshwar, Dhavalpuri, Kanhoor, Khadakwadi, Waranwadi, Karjule Harya, Wasunde and Ane located in Eastern part have comparatively dense population than villages in Western part of the region.

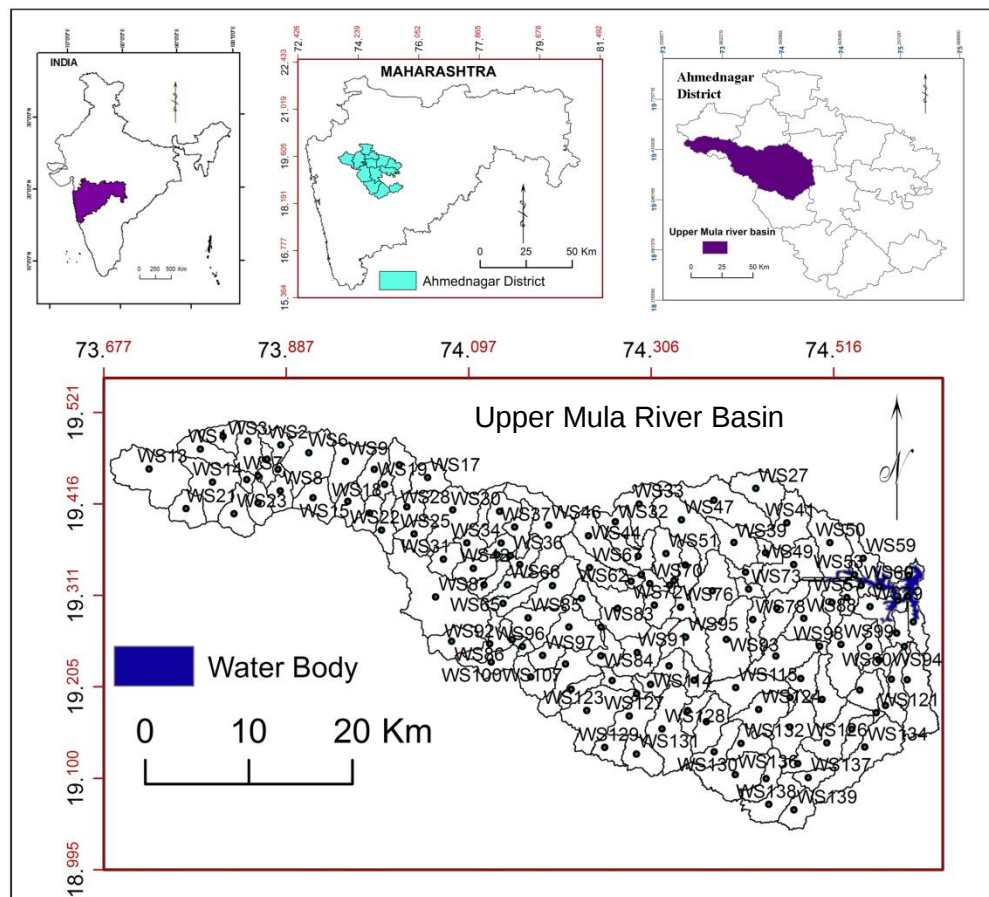


Figure 1. Study area: Upper Mula River Basin

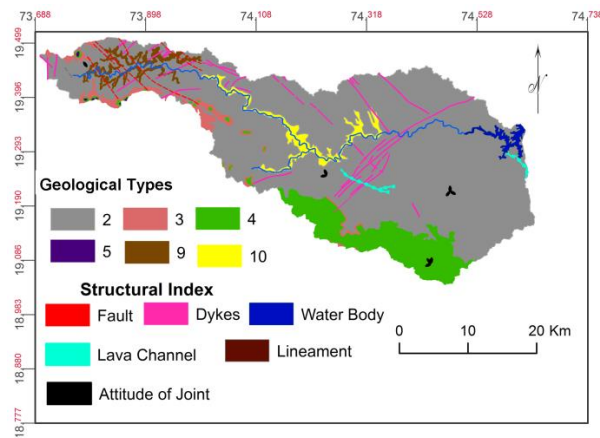


Figure 2. Geology

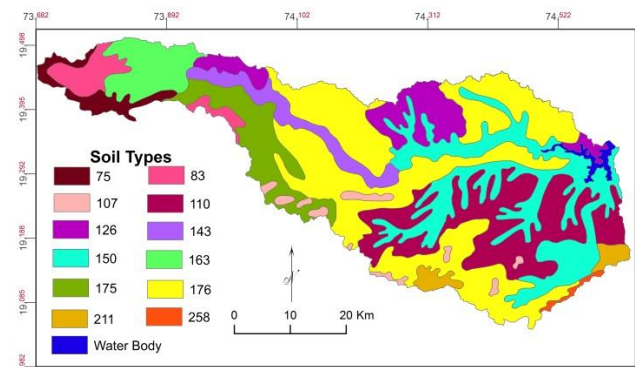


Figure 3. Soils

Table 1. Soil groups

Soil Code*	Soil characteristic	Area	
		Km ²	%
75	Loamy soils: on moderate steep slopes (north) of Sahyadri Ghat; dissected escarpments with severe erosion; very shallow, extremely well drained with moderate erosion.	59.55	1.75
83	Clayey soil: shallow and well drained; on highly dissected ranges on north Sahyadri Ghat with moderate erosion.	59.55	1.75
107	Calcareous soils: on gently sloping peaks/spurs with moderate erosion; slightly deep; shallow well drained with moderate erosion.	83.95	2.47
110	Loamy and calcareous soils: on gently sloping undulating land with severe erosion; very shallow and highly drained.	37.92	1.12
126	Excessively drained loamy and well drained fine calcareous soils: slightly deep; on gently sloping land with severe erosion and slightly deep well drained fine calcareous soils with moderate erosion.	368.87	10.85
143	Shallow and well drained loamy and calcareous soils: on very gently sloping plains with moderate erosion.	166.09	4.89
150	Deep and well drained loamy and calcareous soils: on very gently sloping land with slight and moderate erosion.	100.75	2.96
163	Very shallow excessively drained loamy soils: on moderately sloping land, mesas and buttes with severe erosion.	422.85	12.44
175	Very shallow and excessively drained loamy and calcareous soils: on gently sloping with mesas and buttes with severe erosion; very shallow, excessively drained, loamy soil with very severe erosion and moderate stoniness.	152.59	4.49
176	Slightly deep, well drained and fine calcareous soils: on very gently sloping land with mesas and buttes; slight deep, well drained and fine with moderate erosion.	159.45	4.69
211	Slightly deep, well drained, fine, moderately calcareous soils: on very gently sloping land, slightly deep, well drained, fine soil with moderate erosion.	1717.48	50.52
216	Shallow, well drained, clayey moderately calcareous soils: on gently sloping land, moderate stoniness, slightly deep, well drained, fine and salinity moderately calcareous soils with moderate erosion.	53.1	1.56
258	Fine calcareous soils: deep, fine moderately well drained soil on gently sloping land with moderate erosion; on plains and valleys with moderate erosion.	10.04	0.30

*Based on map from National Bureau of Soil Survey and Land Use Planning, India

3 METHODOLOGY

Multi-criteria analysis based on AHP and influence techniques was used for prioritization of sub-watersheds in Mula River basin, medium watershed located in

Western Maharashtra. The prioritization was performed through eight steps: 1) delineation of sub-watersheds with help of DEM, 2) selection, measurements and analysis of criterion, 3) ranking of criterion, 4) pairwise

comparison, 5) normalization on pairwise comparison matrix, 6) calculations of weights, 7) sub-watershed wise normalization of calculated influences, and 8) prioritization of sub-watersheds.

3.1 Data

Information about geology, morphometric parameters, soil characteristics, rainfall and population density was used for multi-criteria and AHP analysis for prioritization of medium watershed. Geology is mapped (Figure 2) based on map procured from NIGS [National Institute of Geological Survey, Nagpur (India)]. Morphometric parameters: areal, linear and relief were calculated (Table 2) and mapped based on topographic maps (47E/10, 47E/11, 47E/14, 47E/15, 47I/2, 47I/3, 47I/4, 47I/6, 47I/7, 47I/8, 47I/10, 47I/11 and 47I/12) procured survey of India. Watershed boundaries were delineated using ASTER DEM data and soil map (Figure 3) prepared using map procured from NBSS and LUP [National Bureau of Soil Survey and Land Use Planning], India. Rainfall map (Figure 26) was prepared using the data recorded at raingauge stations (1992-2013) located from the study area and based on World climate data (mean rainfall from 1970 to 2000). Population data is taken from census report, 2011.

3.2 Criterion

Spatial variations in geology, morphometric parameters, soils, rainfall and population were used for multi-criteria analysis using AHP and influence technique (Figure 4).

3.2.1 Geology

Watershed characteristics define due to nature of geology including subsurface materials and structure (Flint *et al.*, 2013; Aouragh and Essahlaoui, 2014). Rate of infiltration, run-off, level of groundwater and hydraulic conductivity of surface are dependent on geology of the region (Engelhardt *et al.*, 2011; Olden *et al.*, 2012; Dhanalakshmi and Shanmugapriyan, 2015). The study area shows compound pahoehoe flows (12 to 15m) and some Aa flows, megacryst compound pahoehoe basaltic flows (50 to 60m), 5 Aa and 1 compound pahoehoe basaltic flows (up to 150m) and alluvium type geology (Figure 2). The hydrogeological properties of rocks and soils govern the occurrence, movement and storage of groundwater. Alluvial deposits are unconsolidated in nature and therefore act as good aquifers. Alluvium type of geology is more suitable for groundwater recharge and movements. However, literature reveals considerable variation in the hydrogeological properties of alluvium (Rao and Thangarajan, 1999; Raza *et al.*, 2003; Watts, 2005; Kim *et al.*, 2005). Further, Aa shows groundwater only in upper weathered, fractured and vesicular layers. Aa flows in the region can be classified as simple and compound types. The simple flows show thin blocky vesicular upper part and lower part is compact and fine-

grained (Subbarao and Hooper, 1988; Ray *et al.*, 2006; Mahoney *et al.*, 2000; Melluso *et al.*, 1995; Powar, 1987; Cox and Hawkesworth, 1985; Beane *et al.*, 1986; Bodas *et al.*, 1988; Khadri *et al.*, 1988). Compact flows often show columnar jointing with weathered and fractured upper layers. Therefore, this type is considered as key criteria in this analysis.

3.2.2 Morphometric Parameters

Morphometric parameters like linear, areal and relief were processes in GIS environment (Gabale and Pawar, 2015) for multi-criteria analysis. We have used these morphometric parameters for prioritization of sub-watersheds successfully (Gaikwad and Bhagat, 2017).

3.2.2.1 Linear Aspects

The scholars like Khare *et al.* (2014), Rao *et al.* (2014), Aouragh and Essahlaoui, (2014), Farhan and Anaba, (2016) were used Linear morphometric parameters including stream orders, stream length (L_u), mean stream length (L_{sm}) (Wilson *et al.*, 2012), stream length ratio (R_L), bifurcation ratio (R_b) show relationship with erodibility of land surface. Therefore, many scholars have used these parameters as criterion for prioritization watersheds (Table 2).

a) Stream Orders (U)

The hierarchical stream ordering is first step of drainage basin analysis (Iqbal and Sajjad, 2014; Raja and Karibasappa, 2016). Lithology, structure and uniformity of rocks in the region can determine using the analysis of stream orders (Shing and Shing, 2011; Vandana, 2013; Chitra *et al.*, 2011; Zende *et al.*, 2013; Ali and Ali, 2014). First order streams in the region are 7682 (69.29 %); second order streams are 2676 (24.14%); third order streams are 554 (5%); fourth order streams are 103 (0.93%); fifth order streams are 56 (0.51); sixth order streams are 15 (15%) and seventh order streams is 1 (0.009%) (Figure 5).

b) Mean Stream Length (L_{sm})

L_{sm} (Equation) is useful to understand the dimensional properties of the drainage basin, size of the drainage network and topography of the basin (Kulkarni, 2015; Iqbal *et al.*, 2013; Singh and Singh, 2011; Pareta and Pareta, 2011). L_{sm} of the given order is higher than the earlier and lower than the next order (Farhan and Anaba, 2016; Kaur *et al.*, 2014; Rai *et al.*, 2014; Yunus *et al.*, 2014; Aher *et al.*, 2014; Rao and Yusuf, 2013; Mishra and Nagarajan, 2010). It is negatively related with stream frequency, drainage density and length flow (Khare *et al.*, 2014; Rekha *et al.*, 2011). It varies from 0.00 to 2.02 with cumulative L_{sm} of 0.80km in the basin (Figure 6).

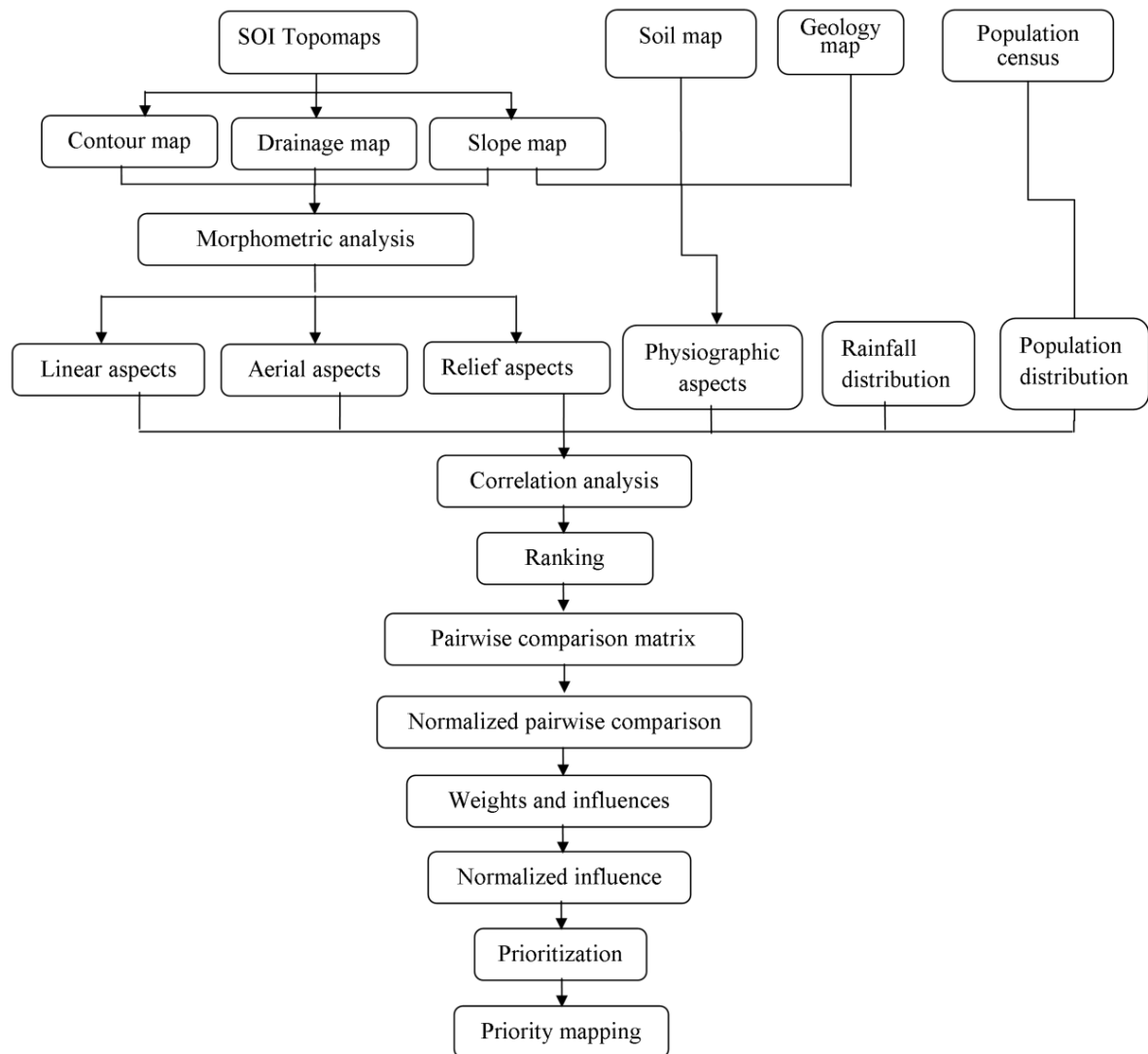


Figure 4. Methodology

Table 2. Formulae used for computation of morphometric parameters

Aspects	Parameters	Equation	Description	Author
Linear	Stream order (U)	Hierarchical rank	The first step of drainage basin analysis.	Iqbal and Sajjad (2014); Raja and Karibasappa (2016); Rekha <i>et al.</i> (2011); Zende <i>et al.</i> (2013); Farhan and Al-Shaikh (2017)
	Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$	L_u = stream length of order 'U' N_u = number of stream segments	
	Bifurcation ratio (R_b)	$R_b = (N_u) / (N_u + 1)$	R_b = bifurcation ratio N_u = number of stream segments	Kulkarni (2015); Chitra <i>et al.</i> (2011); Romshoo <i>et al.</i> (2012); Jagadeesh <i>et al.</i> , (2014); Aravinda and Balakrishna (2013); Schumn (1956); Kedareswarudu, <i>et al.</i> (2013), Iqbal and Sajjad (2014)
	Stream length (L_u)		L_u = stream length in km	

Continued

Aerial	Basin area (A)	$A = a \times n \times 10^{-6}$	a : cell area(m ²) n : number of watershed cells	Romshoo <i>et al.</i> (2012); Thakur (2013)
	Basin length (L_b)		L_b = farthest distance from watershed ridge to outlet	Thakur (2013)
	Basin perimeter (P)	$P = d \times np \times 10^{-3}$	d :cellsize(m) np : number of watershed edge cells	Nagal <i>et al.</i> (2014); Thakur (2013)
	Shape factor (B_s)	$B_s = L_b^2 / A^h$	Bs=shape factor, A= area of the basin (km ²), L_b^2 = Square of the basin length	Patel <i>et al.</i> (2013); Kulkarni, (2015)
	Drainage density (D_d)	$Dd = \sum L_u / A_u$	Dd = drainage density L_u = total stream length A_u = basin area	Kulkarni, (2015); Nongkynrih and Husain (2011); Nagal <i>et al.</i> (2014); Aravinda and Balakrishna (2013); Shing and Shing (2011)
	Stream frequency (F_s)	$Fs = \sum N_u / A_u$	Fs = stream frequency N_u = number of stream segments A_u = basin area	Kulkarni, (2015); Nongkynrih and Husain (2011); Nagal <i>et al.</i> (2014); Aravinda and Balakrishna (2013); Shing and Shing (2011)
	Form factor (R_f)	$Rf = (A_u / L_b + 1)^2$ or $Rf = A / L_b^2$	Rf = form factor A_u = basin area L_b = farthest distance from watershed ridge to outlet or A = area of the basin and L_b = axial length of the basin.	Rao and Alia (2013); Ali <i>et al.</i> (2014); Kedareswarudu <i>et al.</i> , (2013); Zende <i>et al.</i> (2013); Nagal <i>et al.</i> (2014); Iqbal and Sajjad (2014)
	Circularity ratio (R_c)	$Rc = 4\pi(A_u / A_u)^2$	Rc = circularity ratio A_u = basin area P = basin perimeter (km)	Rao and Alia (2013); Iqbal and Sajjad (2014); Ali <i>et al.</i> (2014);
	Elongation ratio (R_e)	$R_e = \frac{2}{\pi} \sqrt{\frac{A_u}{(L_b)^2}}$ or $R_e = 2 \sqrt{\frac{A}{\pi} / L_u}$	R_e = elongation ratio $\pi = 3.14$ A_u = basin area or L_u = Total stream length.	Aravinda and Balakrishna (2013); Schumn (1956); Kedareswarudu <i>et al.</i> , (2013); Thakur (2013)
	Compactness coefficient (C_c)	$Cc = 0.2821 \frac{P}{A} 0.5$	Cc = compactness coefficient A = area of the basin, km ² P = basin perimeter, km	Iqbal and Sajjad (2014)
Relief	Drainage texture (D_t)	$Dt = Nu / P$	Nu = total no. of streams of all orders P = basin perimeter, km	Iqbal and Sajjad (2014); Zende <i>et al.</i> (2013)
	Texture ratio (T)	$T = Dd \times Fs$	Dd = drainage density Fs = stream frequency	Nagal <i>et al.</i> (2014); Kedareswarudu <i>et al.</i> , (2013)
	Drainage intensity (D_i)	$Di = Fs / Dd$	Di = drainage Intensity Fs = stream frequency Dd = drainage density	Nagal <i>et al.</i> (2014); Kedareswarudu <i>et al.</i> , (2013); Ali <i>et al.</i> (2014)
	Relief ratio (R_{h1})	$Rh1 = Bh / Lb$	$Rh1$ = relief ratio Bh = basin height Lb = basin length (Lb)	Schumn (1956); Nagal <i>et al.</i> (2014)
	Ruggedness number (R_n)	$Rn = Dd \times (\frac{R}{1000})$	Rn = ruggedness number Dd = drainage density R = relief	Kaur <i>et al.</i> (2014); Aouragh and Essahlaoui (2014)

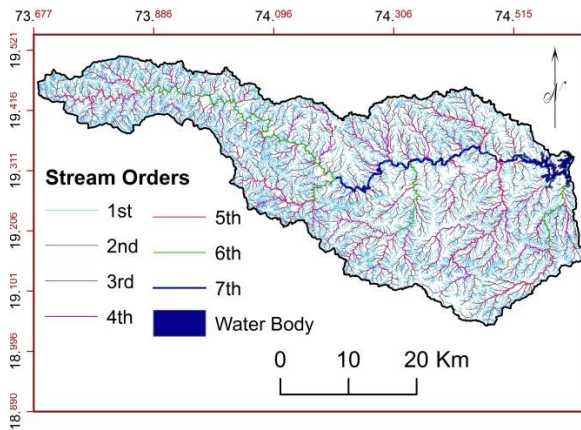


Figure 5. Stream orders

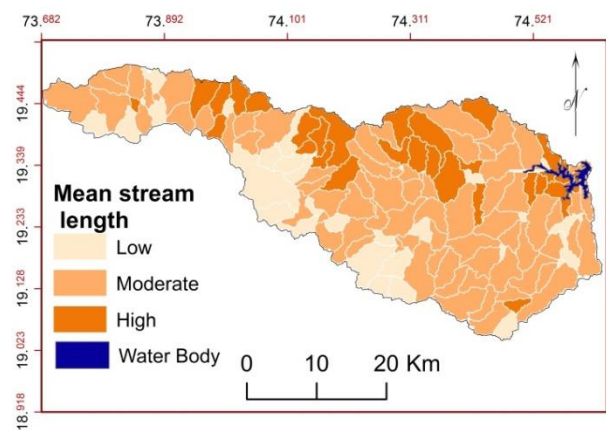


Figure 6. Mean stream length

c) Stream Length Ratio (R_L)

R_L is the ratio of mean length of the stream to the length of the stream from lower order (Khadri and Thakur, 2013; Wilson *et al.*, 2012; Nongkynrih and Husain, 2011; Gray, 1961). R_L shows relationship with bifurcation ratio, surface flow and erosional processes (Gebre *et al.*, 2015; Jagadeesh *et al.*, 2014; Rao and Yusuf, 2013; Iqbal *et al.*, 2013; Rosso and Bacchi, 1991). Sub-watersheds like WS35, WS36, WS52, WS55, WS71 show low R_L and only four sub-watersheds (WS7, WS69, WS72, WS94) show higher R_L (Figure 7). The difference between R_L of 2nd and 4th order streams show high relief and steepness. Therefore, sub-watersheds with moderate R_L can be considered for development and management of resources with priority.

d) Bifurcation Ratio (R_b)

R_b indicates the shape, pattern and erosion activity in the basin. Higher R_b indicates an elongated shape of the basin (Chitra *et al.*, 2011; Khare *et al.*, 2014) with more structural control over total drainage system (Chitra *et al.*, 2011) and lower value shows less structural conflicts (Strahler, 1964) with stable drainage (Pareta and Pareta, 2011). R_b is the ratio of total number of streams of first order to the number of streams from next higher order in the basin (Pareta and Pareta, 2011; Iqbal and Sajjad, 2014). R_b values in the basin varies from 0.50 to 1.00 with low erosional activity and less troubling drainage pattern (Strahler, 1957; Rai *et al.*, 2014). Sub-watersheds are classified (Figure 8) into six classes: poor (0.15), very low (1.5-3.35), low (3.35-3.88), medium (3.88-4.80), high (4.80-6.00) and very high (6.00-9.63) (Rekha *et al.*, 2011).

e) Stream Length (L_u)

L_u reveals physical characteristics: lithology, topography and steepness (Nongkynrih and Husain, 2011; Iqbal and Sajjad, 2014). L_u is measured from topographical maps (Nagal *et al.*, 2014). Longer streams

show more permeable bedrock with well-drained network (Kulkarni, 2015). Stream lengths are observed higher for first order and decreases according to increasing stream order. Total length of first ordered streams is measured of 4096.95km (54.80%), second order 1876.33km (25.10%), third order 856.55km (11.46%), fourth order 3.20.5km (4.29%), fifth order 156.99km. (2.10%), sixth order 113.03 km (1.51%) and seventh order 53.57 (0.72%). Stream lengths in the basin are classified (Figure 9) into three classes: low (<49.82), moderate (49.83-123.28) and high (>123.29). Sub-watersheds of 2nd, 3rd and 4th orders are more suitable for soil and water conservation.

3.2.2.2 Aerial Aspects

Areal aspects describe areal elements, law of stream areas, relationship between stream area and stream length, relationship of area to the discharge, basin shape, drainage density, etc. (Aher *et al.*, 2014; Gaikwad and Bhagat, 2017). Therefore, areal aspects: basin area (A), basin length (L_b), basin perimeter (P), shape Factor (B_s), drainage density (Dd), stream frequency (F_s), form factor (R_f), circularity ratio (R_c), elongation ratio (R_e), compactness coefficient (C_c), drainage texture (Dt), texture ratio (T) and infiltration number (I_f) are analyzed for prioritization of sub-watersheds in the basin.

a) Basin Area (A)

Basin area indicates the size of basin (Strahler, 1957). It is useful to calculate the drainage density (Dd), stream frequency (F_s), form factor (R_f), circularity ratio (R_c), elongation ratio (R_e), compactness coefficient (C_c) and lemniscate's (k) (Gabale and Pawar, 2015). The size of the basin is 2339.7 km² distributed within 140 sub-watersheds. These watersheds are classified (Figure 10) into three classes: low (<0.19 Km²), moderate (0.19-25.07 Km²) and high (>25.07 Km²).

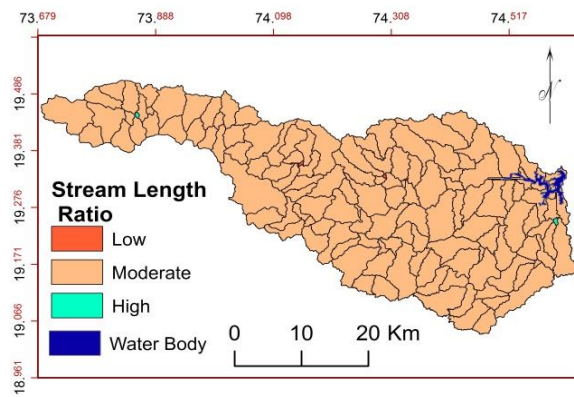


Figure 7. Stream length ratio

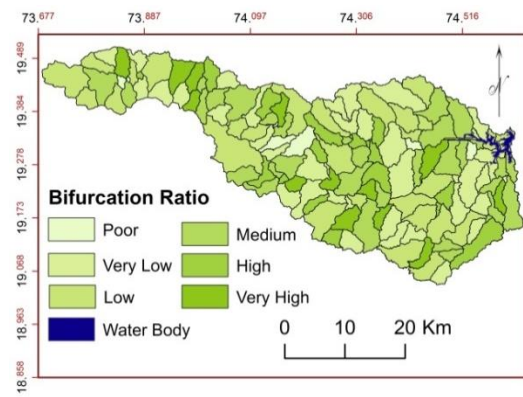


Figure 8. Bifurcation ratio

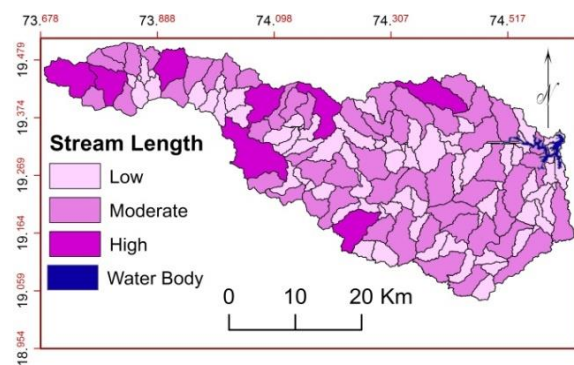


Figure 9. Stream length

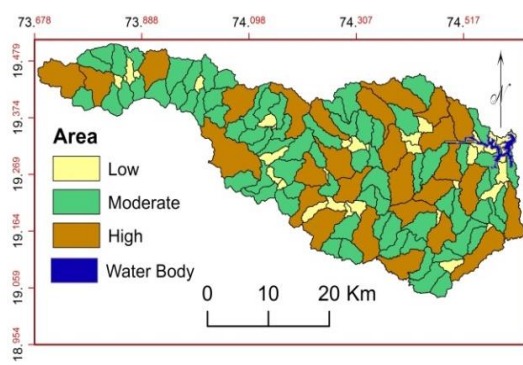


Figure 10. Watershed area

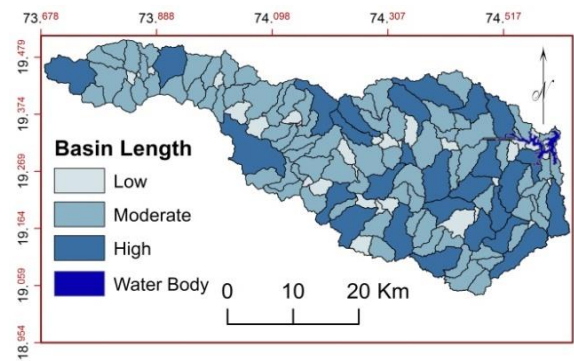


Figure 11. Basin length

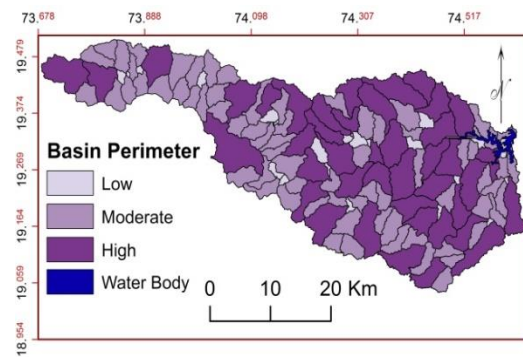


Figure 12. Basin perimeter

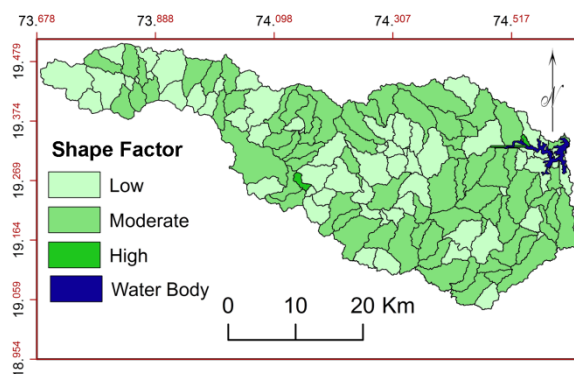


Figure 13. Shape factor

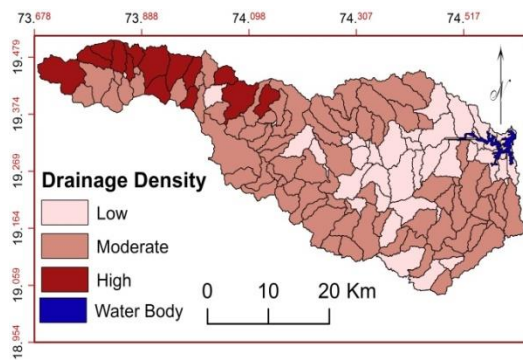


Figure 14. Drainage density

b) Basin Length (L_b)

L_b is useful to understand the basin shape and hydrological characters (Chitra *et al.*, 2011), lemniscate's value, form factor and elongation ratio of the basin (Pareta and Pareta, 2011). L_b varies from 1.03 to 15km and classified (Figure 11) into three classes: low, moderate and high. Average length of class, 'low' is 2.67km, 'moderate' is 6.49km and 'high' is 11.08km. Moderate values indicate more texture, infiltration number and perimeter relation.

c) Basin Perimeter (P)

P is the outer boundary of watershed indicates size, shape and drainage density of the basin (Strahler, 1957). The perimeter of study area is 3901.58km. P of sub-watersheds varies from 7.54km for WS4 to 69.82km for WS87 and classified (Figure 12) into three classes: low (<17.97km), moderate (17.97-33.58km) and high (>33.58km). However, most of the sub-watersheds in the classes: 'moderate and 'high' trends to be elongated with longer duration of low peak flow (Farhan and Al-Shaikh, 2017). 27 sub-watersheds show 'low' basin perimeter (11.06km), 72 show 'moderate' (25.59km) and 41 show high basin perimeter (42.94km).

d) Shape Factor (B_s)

B_s is the ratio of square of length and area of the basin (Horton, 1945). The calculated values of B_s varies from 0.05-13.55 (Patel *et al.*, 2013; Sepehr *et al.*, 2017). These values indicate the elongated shape of the basin with flatter peak flow for longer spell (Patel *et al.*, 2013). B_s is suitable for the morphometric classification of drainage basins. These parameters are controlling the runoff pattern, sediment yield and hydrological condition of the basin (Iqbal *et al.*, 2013, Ali and Ali, 2014). About 63 sub-watersheds show 'low' and 74 show 'moderate' B_s (Figure 13). The shape of sub-watersheds is elongated and suitable for resource planning and management.

e) Drainage Density (D_d)

D_d is useful to understand the terrain, rocks, relief, soils, groundwater, erodibility and discharge of water and sediment (Pareta and Pareta, 2011; Engelhardt *et al.*, 2012, Kaur *et al.*, 2014; Gebre *et al.*, 2015; Gabale and Pawar, 2015). Higher values of D_d indicates moderate slopes (Vandana, 2013; Argyriou *et al.*, 2016) with semi-permeable hard rock, coarse textures, favorable conditions for groundwater conservation (Khare *et al.*, 2014; Gebre *et al.*, 2015; Gabale and Pawar, 2015). Gebre and Pawar (2015) have classified D_d as very coarse from 2.17 to 3.92 km/km² and moderate for 3.29 km/sq. to 4.18 km/sq. km. Therefore, sub-watersheds in the basin are classified (Figure 14) into three classes: low (0.00-2.69km/sq. km), moderate (2.69-4.22km/sq. km) and high (4.22 -9.80km/sq. km).

f) Stream Frequency (F_s)

F_s depends on lithology, relief, subsurface permeability, infiltration capacity, drainage network, rainfall, vegetation cover, etc. (Wilson *et al.*, 2012; Aouragh and Essahlaoui, 2014; Gabale and Pawar, 2015; Kulkarni, 2015; Raja and Karibasappa, 2016; Argyriou *et al.*, 2016) therefore, useful to understand physiography, infiltration rate, permeability, number of streams and vegetative cover (Chatterjee and Tantubay, 2000; Pareta and Pareta, 2011; Singh and Singh, 2011; Romshoo *et al.*, 2012; Vandana, 2013; Patel *et al.*, 2013; Iqbal and Sajjad, 2014; Rai *et al.*, 2014; Kaur *et al.*, 2014; Farhan and Al-Shaikh, 2017). Stream frequency in the region varies from 1.52 to 14.53km/km². Sub-watersheds are classified (Figure 15) into three classes: low (<4.07), moderate (4.07-8.23) and high (>8.23). Higher stream frequencies of WS2 (13.90), WS121 (9.09), WS 127 (8.98) and WS129 (14.53) indicate impermeability and less infiltration capacity of subsurface and higher relief with thin vegetation cover. Sub-watersheds with dense forest show less frequency of streams whereas agricultural lands show higher frequency (Zende *et al.*, 2013).

g) Form Factor (R_f)

R_f shows the shape (Rai *et al.*, 2014) and basin length (Patel *et al.*, 2013). The elongated watershed estimates less value and nearly circular watersheds show the higher ($R_f = 0.75$) (Gabale and Pawar, 2015) (Figure 16). R_f for sub-watersheds in the basin varies from 0.07-0.78. Out of them 31 sub-watersheds show elongated shapes with longer duration of flow and 81 sub-watersheds are moderate elongated shaped with moderate peak flow. These elongated and moderate elongated sub-watersheds are suitable for natural resource management. 28 sub-watersheds has near circular shape indicates high peak flow of shorter duration. Moreover, these sub-watersheds are not suitable for natural resource management.

h) Circularity Ratio (R_c)

R_c shows amount of discharge, erosion activity (Patel *et al.*, 2013; Rao and Yusuf, 2013) and nature of topography (Gray, 1961; Ali and Ali, 2014; Farhan and Anaba, 2016). R_c is dependent on length and frequency of tributaries, geology, relief, climate, land use/land cover, etc. of the region (Mishra and Nagarajan, 2010; Nongkynrih and Husain, 2011; Iqbal *et al.*, 2013; Kaur *et al.*, 2014). Estimated R_c (0.30 to 0.54) for sub-watersheds show higher erosion activity with permeable homogeneous geology (Aravinda and Balakrishna, 2013; Wilson *et al.*, 2012). These sub-watersheds are classified (Figure 17) into three classes: low (0.08-0.22), moderate (0.22-0.30) and high (0.30-0.54). Sub-watersheds with low and moderate R_c show young and progressive stages of landform and prone to more erosion.

i) Elongation Ratio (R_e)

R_e is the ratio of diameter and the maximum length of the basin (Nongkynrih and Husain, 2011; Strahler, 1964) and show slope, shape of basin, hydrology, rate of infiltration and runoff (Kaur *et al.*, 2014; Iqbal and Sajjad, 2014; Zende *et al.*, 2013; Wilson *et al.*, 2012; Mishra and Nagarajan, 2010). Higher R_e shows more infiltration capacity of land with less runoff (Iqbal and Sajjad, 2014). Calculated R_e are classified into three classes: low (0.31-0.76), moderate (0.76-1.36) and high (1.36-4.83) (Figure 18). Sub-watersheds with higher relief and steep slopes should be selected for conservation purpose with high priority. 93 sub-watersheds are elongated with higher relief and steep slopes and 45 sub-watersheds shows moderate relief with moderate slope. Therefore, sub-watersheds from low and moderate classes are suitable for watershed management.

j) Compactness Coefficient (C_c)

C_c is depend on size and slopes in the basin and useful to understand risk of erosion with their hydrologic relationship (Ali *et al.*, 2014; Iqbal *et al.*, 2013; Patel *et al.*, 2013). Estimated C_c vary from 1.60 to 2.48 (Figure 19) and classified into three classes: low (1.60-1.67), moderate (1.67-1.90) and high (1.90-2.48). Low C_c values indicate more elongation and higher erosion in the basin (Farhan and Al-Shaikh, 2017). 67 sub-watersheds show low C_c with more elongation and higher erosion whereas 06 sub-watersheds show low elongation and less erosion. Therefore, low and moderate sub-watersheds are suggested for watershed management.

k) Drainage Texture (D_t)

D_t values show lithology (Rao and Yusuf, 2013) and depend rock, soil, infiltration capacity, relief, climate, vegetation, etc. (Kulkarni, 2015; Vandana, 2013; Iqbal *et al.*, 2013; Chatterjee and Tantubay, 2000). 71 sub-watersheds in the basin show very coarse drainage textures with hilly terrain showing steep crumbs and 55 sub-watersheds observed coarse drainage textures with massive and resistant rock structures (Figure 20). Therefore, sub-watersheds with very coarse and coarse drainage textures are suitable for watershed and resource management.

l) Texture Ratio (T)

The values of T estimated for the basin indicate morphometry, runoff and texture of basin (Farhan and Anaba, 2016) and depends on the lithology, infiltration capacity and relief (Khare *et al.*, 2014; Rekha *et al.*, 2011; Pareta and Pareta, 2011). Smith (1950) has classified calculated values of T into four categories: coarse (0-4), intermediate (4-10), fine (10-15) and ultra-

fine (>15). Calculated T (Figure 21) in the basin varies from 0.11 (SW74) to 10.55 (SW52). 126 sub-watersheds are unaffected and covered by massive bolder. The group, 'intermediate' includes 13 sub-watersheds with classic densities and weathered rocks, therefore these regions are favorable for resource management.

m) Infiltration Number (I_f)

I_f of watershed can be defined as the product of drainage density and stream frequency. I_f indicates infiltration characters, runoff, vegetation cover and permeability of the land surface (Rao and Yusuf, 2013; Ranjan, 2013; Singh and Singh, 2011). Estimated values of I_f vary from 0.0 to 72 and classified into three classes: low, moderate and high (Figure 22). 63 sub-watersheds show low I_f indicating highly permeable soil materials under dense vegetation and 65 sub-watersheds show moderate I_f with favorable conditions for gully erosion and high runoff.

3.2.2.3 Relief Aspects

a) Relief Ratio (R_{h1})

R_{h1} is useful to understand slope, relief and erosion activity in the basin (Strahler, 1957; Sharma *et al.*, 2009; Engelhardt *et al.*, 2011; Wilson *et al.*, 2012; Vandana, 2013; Kaur *et al.*, 2014; Yunus *et al.*, 2014). It is the ratio between the total relief and the longest dimension of the basin. Calculated R_{h1} vary from 7.84 to 322.70. R_{h1} normally increases with decreasing drainage area and size of the basin. 94 sub-watersheds show low R_{h1} (7.84 to 42.64) indicates presence of base rocks, overall steepness and intensity of erosion and 37 sub-watersheds show moderate R_{h1} (42.64 to 107.60) with moderate slopes, gentle relief and moderate erosion. 9 sub-watersheds in the region show high R_{h1} (107.60 to 322.70) with steep slopes, brushy vegetation and thin soils (Patton and Baker, 1976) (Figure 23).

b) Ruggedness Number (R_n)

R_n is the product of basin relief and drainage density and useful to understand the relationship with steepness and length (Kaur *et al.*, 2014). R_n shows relief, drainage density, slope, soil erosion and discharge (Pareta and Pareta, 2011; Rao *et al.*, 2004; Nagal *et al.*, 2014; Gaikwad and Bhagat, 2017). Calculated R_n values are classified into three classes: low, moderate and high (Figure 24). 89 sub-watersheds show low ruggedness values (0.00 to 908.84) with irregular topography, lithological heterogeneity, high drainage density and high soil erosion. 42 sub-watersheds show moderate value (908.84 to 2204.45) with flat surface, valley topography and moderate to moderately high degree of dissection and moderate to soil erosion and 9 sub-watersheds show high value (2204.45 to 4734.21) with very steep slopes and more peak discharges flows.

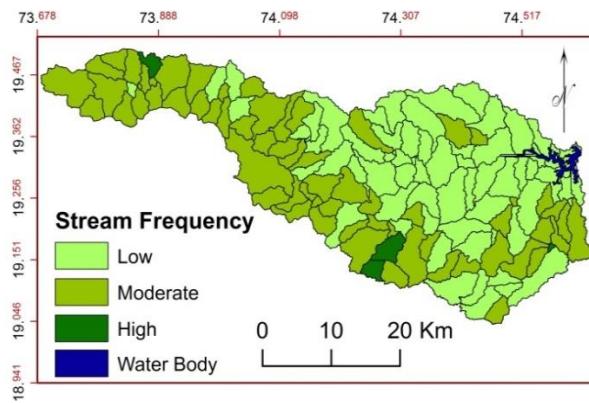


Figure 15. Stream frequency

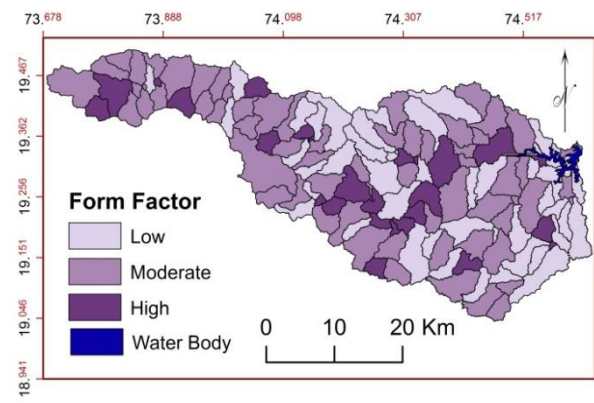


Figure 16. Form factor

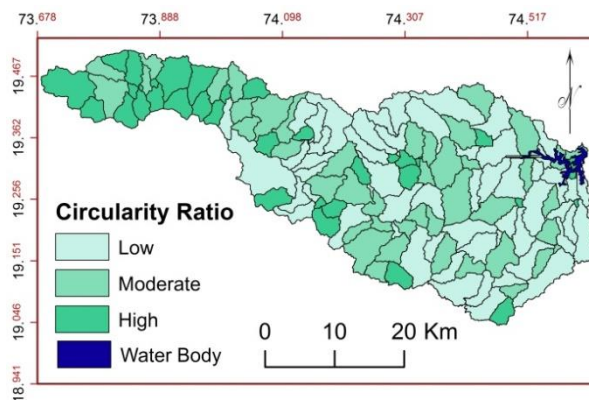


Figure 17. Circularity ratio

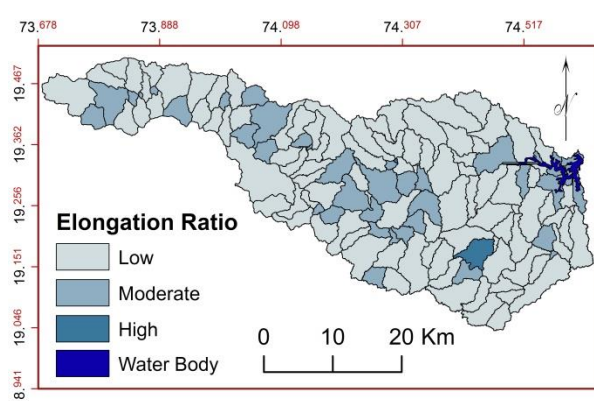


Figure 18. Elongation ratio

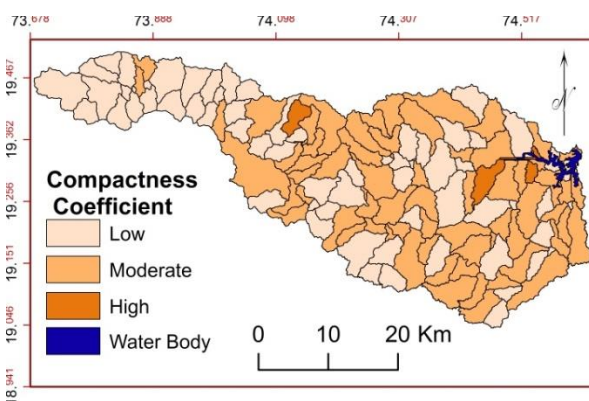


Figure 19. Compactness coefficient

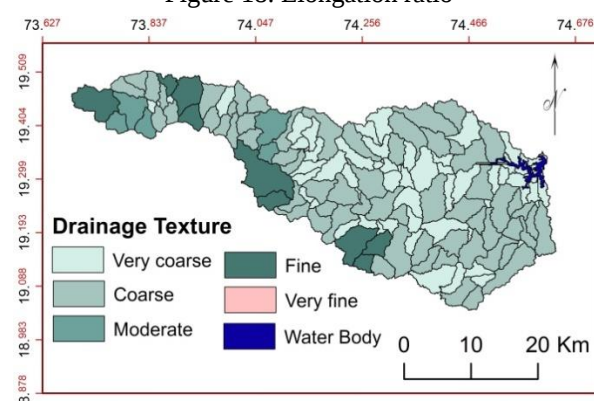


Figure 20. Drainage texture

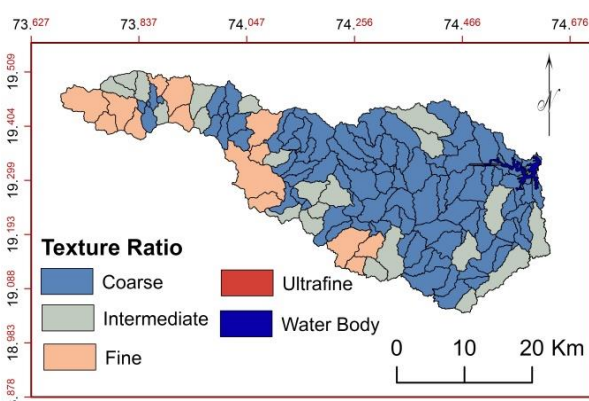


Figure 21. Texture ratio

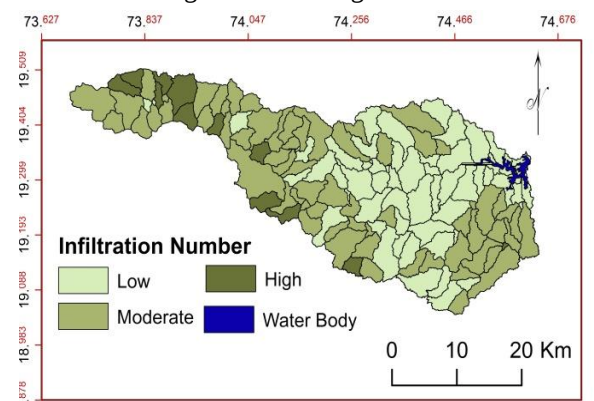


Figure 22. Infiltration number

c) Slope

The slope analysis is useful to detect suitable sub-watersheds for planning and management for development (Zolekar and Bhagat, 2015; Argyriou *et al.*, 2016). Slopes in the basin play key role in runoff formation, infiltration rate (Sepehr *et al.*, 2017), flow density (Kaur *et al.*, 2014; Rekha *et al.*, 2011; Wilson *et al.*, 2012), floods and erosion. Water can be stored at the bottom of the valley with gentle slopes (Emamgholi *et al.*, 2007). Slope determines the soil depth, vegetation cover, ground water recharge, surface runoff, etc. (Shinde *et al.*, 2010; Zolekar and Bhagat, 2015; Khare *et al.*, 2014; Rezaei *et al.*, 2013; Rekha *et al.*, 2011). Sub-watersheds with moderate slopes (10° - 22°) are suitable for micro level planning and management (Figure 25). 20 sub-watersheds in the region are more suitable for conservation.

3.2.3 Soils

Soil is significant natural resource for life systems and socio-economic development of the region (Ranjan, 2013). Erosion of top layer of soil for texture, structure, organic matter content and permeability is major cause of land degradation and decline in productivity (Yeole *et al.*, 2012; Shinde *et al.*, 2010; Capodici *et al.*, 2013). Clayey, loamy, calcareous, fine-loamy and fine calcareous soil groups (Table 2) are observed in the basin (Figure 4).

3.2.4 Rainfall

Rainfall plays a significant role in life system and top soil erosion (Petkovsek and Mikos, 2004) and varies for amount, intensity and distribution. The region receives rainfall during the Southwest monsoon season (June to October) and show high variation from 467 mm at Eastern part to 1505mm at West (World climate data, mean rainfall 1970 to 2000) (Figure 26). Eastern part of the basin is known as 'rain shadow' zone of Sahyadri Ghats. It is severe drought prone area in the state of Maharashtra (India). Higher variations in rainfall distribution can be useful for periodization of sub-watersheds in the basin.

3.2.5 Population Density

The growth of global population needs effective management of decreasing pressure on natural resources available for agricultural (Mishra and Nagarajan, 2010; Gumma *et al.*, 2014). About 70% of population of India depends on agriculture, directly or indirectly (Rao *et al.*, 2010). Total population of the basin was 254901 in 2001 and increased to 289211 in 2011 (Census, 2011). Majority of population is belongs to tribal community living in about 50% villages (165) at Western part of the basin. This is hilly region and people facing many problems like lack of educational, transportation, medical facilities, etc. It is notable that 39 villages show decreasing trends of population from 2001 to 2011 due

to outmigration. Further, Eastern part is drought-prone and people are migrating for their sustenance, occasionally. Therefore, population distribution (Figure 27) is significant criteria for analysis of prioritization of watersheds for natural resource management and planning.

3.3 Analytic Hierarchy Process for Watershed Prioritization

Analytic Hierarchy Process is processed for prioritization of sub-watersheds as: (1) determination of ranks, (2) pairwise comparison matrixes, (3) normalization of pairwise comparison matrix, (4) calculation of weights and influence, (5) normalization of sub-watershed wise influences, and (6) prioritization of sub-watersheds.

3.3.1 Determination of Ranks

Statistical approach was used for assigning the ranks for 25 criterion using weighted analyses. We have used correlation techniques for robust ranking of parameters for water prioritization of watersheds using AHP based influence approach (Gaikwad and Bhagat, 2017). This was used by Zolekar and Bhagat (2015) for land suitability analysis using AHP based weighted overlay technique. Calculated significant correlation coefficients of the criteria with criterion in the group were summed up for ranking the selected criterion (Aher *et al.*, 2014). Pearson's correlation technique (Yin *et al.*, 2012) (Table 2) was used for correlation analysis and 1 to 24 ranks were assigned (Table 3) (Ranjan, 2013; Zolekar and Bhagat, 2015; Gaikwad and Bhagat, 2017). Maximum sum of corrections was estimated for texture ratio (25.94), drainage texture, (12.97), total streams (8.65), stream length (6.49), ruggedness number (5.19), drainage density (4.32) and therefore 1 to 6 ranks given, respectively (Table 4). Ranks, 7 to 13 were given to criterion estimated moderate values for basin length, area, infiltration number, perimeter, bifurcation ratio, stream frequency and rainfall whereas population density, slope, soil, relief ratio, elongation ratio, circulatory ratio, form factor, shape factor, mean stream length, compactness ratio, stream length ratio and geology were ranked least.

3.3.2 Pairwise Comparison Matrix (PCM)

Multiple criteria decision-making and pairwise comparison matrix are useful for prioritization of sub-watersheds (Sepehr *et al.*, 2017; Ghanbarpour and Hipel, 2011; Rekha *et al.*, 2011; Feizizadeh *et al.*, 2014). The influences of criterion were estimated based weights given in pairwise comparison matrix (Zolekar and Bhagat, 2015). Emamgholi *et al.* (2007) and Ranjan (2013) have used PCM to understand the relationship between the criterion and surface erosion for conservation of natural resources in the watershed.

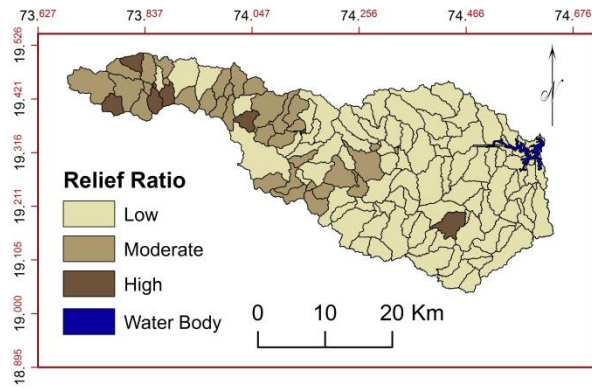


Figure 23. Relief ratio

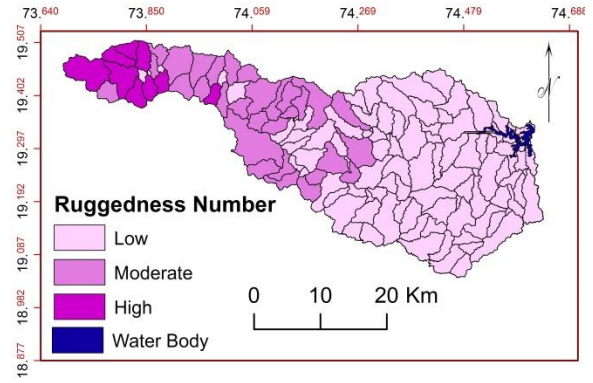


Figure 24. Ruggedness number

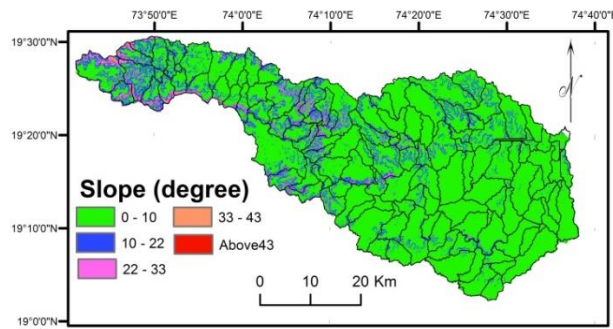


Figure 25. Slope

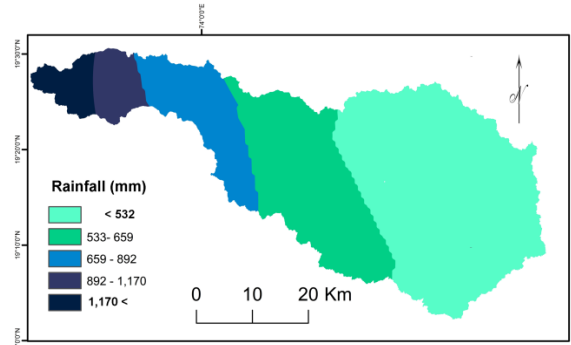


Figure 26. Rainfall

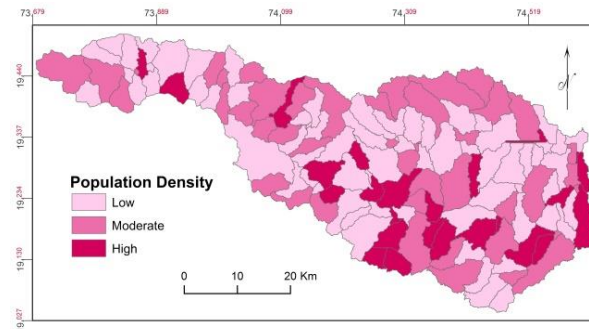


Figure 27. Population density

The values of the criterion in matrix were divided by total of the column to calculate cell values (Table 5).

3.3.3 Weights and Influences

Weights of criterion were estimated based on weights and influences calculated in normalized pairwise comparison matrix after Gaikwad and Bhagat (2017) (Table 4). Influences of criterion were estimated by calculating the cell values (%) in PCM (Gaikwad and Bhagat, 2017) (Equation 1):

$$C_i = \frac{W_c}{W_s} \times 100 \quad (1)$$

C_i = Normalized influence of criterion based on AHP.

W_c = Estimated weights of criterion.

W_s = Sum of estimated weights for all criterions.

C_i = Indicate the share of criterion in total influence (100%) of criterion which can be distributed within the

criterion according to estimated weights (Gaikwad and Bhagat, 2017).

3.3.4 Watershed Based Normalized Influence of Criterion

The influences of criterion interpret the share of individual criteria in formation of watershed characteristics (100%) and vary according to sub-watersheds (Silva *et al.*, 2007; Gaikwad and Bhagat, 2017). Here, sub-watershed wise influences of criterion were normalized (equation 2) (Gaikwad and Bhagat, 2017).

$$NI_w = \frac{C_w}{C_s} \times C_i \quad (2)$$

NI_w = Sub-watershed wise normalized influence.

C_w = Cell value of criterion for the watershed

C_s = Sum of cell values of criterion.

C_i = Estimated influence of criterion based on AHP.

Table 3. Correlations

	Area	P	D _d	T	L _b	R _c	C _c	R _f	R _e	L _u	N _u	F _s	L _{sm}	RL	R _b	R _t	B _s	I _f	R _{h1}	R _n	Geology	Slope	Soil	Rainfall	PD	
Area	1.00																									
P	0.91	1.00																								
D _d	0.15	0.13	1.00																							
T	0.49	0.29	0.49	1.00																						
L _b	0.82	0.87	0.21	0.37	1.00																					
R _c	0.04	-0.19	-0.04	0.45	-0.05	1.00																				
C _c	0.06	0.35	-0.16	-0.44	0.23	-0.46	1.00																			
R _f	0.02	0.02	-0.11	-0.02	-0.26	0.02	-0.02	1.00																		
R _e	0.00	-0.05	-0.15	0.00	-0.39	0.07	-0.14	0.95	1.00																	
L _u	0.90	0.79	0.48	0.61	0.75	0.00	0.00	-0.02	-0.05	1.00																
N _u	0.85	0.73	0.40	0.74	0.70	-0.04	-0.02	-0.02	-0.05	0.91	1.00															
F _s	-0.01	-0.05	0.55	0.63	0.02	-0.10	-0.19	-0.08	-0.09	0.19	0.44	1.00														
L _{sm}	0.09	0.09	0.28	-0.15	0.09	0.17	0.04	-0.10	-0.11	0.14	-0.13	-0.47	1.00													
RL	-0.04	-0.05	0.12	0.00	-0.01	0.01	-0.16	-0.08	-0.10	-0.03	-0.03	0.05	0.17	1.00												
R _b	0.45	0.54	0.37	0.45	0.55	0.02	-0.21	-0.04	-0.07	0.44	0.44	0.24	0.03	0.20	1.00											
R _t	0.49	0.29	0.49	1.00	0.37	0.45	-0.44	-0.02	0.00	0.61	0.74	0.63	-0.15	0.00	0.45	1.00										
B _s	-0.03	0.12	-0.01	-0.16	0.41	-0.12	0.49	-0.29	-0.51	-0.02	-0.03	-0.04	0.00	0.10	-0.02	-0.16	1.00									
I _f	0.03	0.00	0.81	0.63	0.06	-0.07	-0.20	-0.07	-0.07	0.32	0.44	0.89	-0.19	0.04	0.29	0.63	-0.06	1.00								
R _{h1}	-0.21	-0.31	0.15	0.06	-0.39	0.00	-0.05	0.28	0.33	-0.07	-0.05	0.15	-0.10	-0.22	-0.41	0.06	-0.32	0.19	1.00							
R _n	0.22	0.15	0.76	0.49	0.20	-0.03	-0.20	-0.06	-0.06	0.49	0.43	0.41	0.12	-0.01	0.27	0.49	-0.06	0.64	0.43	1.00						
Geology	0.00	0.00	-0.05	-0.01	0.01	-0.01	-0.03	-0.01	-0.02	-0.03	-0.02	-0.03	-0.03	0.00	0.03	-0.01	0.00	-0.05	-0.02	-0.03	1.00					
Slope	0.36	0.28	0.17	0.32	0.26	-0.03	-0.08	-0.04	-0.04	0.40	0.42	0.14	-0.01	-0.01	0.19	0.32	-0.06	0.14	0.03	0.26	-0.02	1.00				
Soil	0.14	0.12	0.15	0.19	0.11	-0.05	-0.04	0.13	0.09	0.18	0.23	0.18	-0.12	0.07	0.12	0.19	-0.04	0.19	0.03	0.14	0.01	0.00	1.00			
Rainfall	0.02	-0.12	0.47	0.41	-0.05	0.01	-0.33	-0.05	0.00	0.24	0.28	0.41	-0.05	0.11	0.08	0.41	-0.15	0.51	0.52	0.75	0.04	0.19	0.11	1.00		
PD*	0.09	0.00	0.28	0.30	0.12	0.16	-0.24	-0.09	-0.08	0.21	0.18	0.17	0.04	-0.01	0.13	0.30	0.02	0.25	0.23	0.39	0.03	0.15	0.09	0.36	1.00	

*PD = population density

Table 4. Ranks

Criterion	T	R _t	N _u	L _u	R _n	D _d	L _b	Area	I _f	P	R _b	F _s	Rainfall	PD	Slope	Soil	R _{h1}	R _e	R _c	R _f	B _s	L _{sm}	C _c	RL	Geology
Sum of significant coefficient of correlation	9.99	9.99	9.97	9.75	8.65	8.46	8.26	8.10	7.99	7.70	7.21	7.10	6.84	5.76	5.68	4.44	4.40	3.45	3.43	3.36	3.26	3.14	3.13	2.82	2.00
Ranks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

*PD = population density

Table 5. Weights and influence

	T	R _t	N _u	L _u	R _n	D _d	L _b	Area	I _f	P	R _b	F _s	Rainfall	PD	Slope	Soil	R _{h1}	R _e	R _c	R _f	B _s	L _{sm}	C _c	RL	Geology	Sum	Weights	Influence (%)	
T	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	6.75	0.26	25.94	
R _t	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	3.37	0.13	12.97
N _u	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	2.25	0.09	8.65
L _u	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.69	0.06	6.49
R _n	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.35	0.05	5.19
D _d	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	1.12	0.04	4.32
L _b	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.96	0.04	3.71
Area	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.84	0.03	3.24
I _f	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.75	0.03	2.88
P	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.67	0.03	2.59
R _b	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.61	0.02	2.36
F _s	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.56	0.02	2.16
Rainfall	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.52	0.02	2.00
PD	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.48	0.02	1.85
Slope	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.45	0.02	1.73
Soil	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.42	0.02	1.62
R _{h1}	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.40	0.02	1.53
R _e	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.37	0.01	1.44
R _c	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.36	0.01	1.37
R _f	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.34	0.01	1.30
B _s	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.32	0.01	1.24
L _{sm}	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.29	0.01	1.13
C _c	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.28	0.01	1.08
RL	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.27	0.01	1.04
Geology	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.26	0.01	1.00

*PD = population density

3.3.5 Weighted prioritization

Spatial variations in geology, morphometric parameters, soils, rainfall and population densities were used for watershed prioritization. These parameters can be useful to decide the level of soil and water degradation and for prioritization of sub-watersheds (Aher *et al.*, 2014) using normalized PCM (Ghanbarpour and Hipel, 2011), calculated influences for criterion and sub-watershed wise normalized influences (Gaikwad and Bhagat, 2017).

$$P_w = \sum_{i=1}^n NI_w \quad (3)$$

P_w = Periodization of watershed

NI_w = Sub-watershed wise normalized influence.

n = Number of criterion

i = Criterion

4 RESULTS

Multi-criteria based AHP technique and calculated influences of criteria are useful for priorities of sub-watersheds for planning and development. Physiographic, morphometric and demographic criterion (25) were selected and ranked using correlation analysis for calculation of weights and influences. Spatial distributions of criterion were considered for estimations of influences for prioritization of sub-watersheds. Priorities were classified into three categories (Figure 28): high, moderate and low priorities (Table 5).

Table 6. Priority classes

Class	Total watershed	Area	%
low	51	722	30
Moderate	53	914	31
High	36	728	39

4.1 Highly Priority

‘Highly priority’ for planning and management of resources was estimated for 36 (26%) sub-watersheds (38.65% area) in the region (Figure 28). Gentle to moderate slopes, very shallow extremely drained loamy calcareous soils and severe erosion activities observed in these watersheds. Many of these watersheds are located in hilly part with high rainfall. The productivity of these soils is very low and natural resources are exploited. Population in the region is belongs to tribal community and economically backward category. These watersheds show out migrations for their livelihood. Therefore, these sub-watersheds should be considered for watershed development projects with high priorities.

4.2 Moderate Priority

‘Moderate priority’ shows for 53 (27.80%) watersheds (30.80% area) with gentle slopes, calcareous soils with moderate erosion. More surface erodibility and runoff for less rainfall can be interpreted based on estimated bifurcation ratio and texture ratio for these watersheds (Gaikwad and Bhagat, 2017). Drought is common phenomenon in the region and population occasionally migrating for livelihood to irrigated and urban areas. Therefore, these watersheds also considered for planning and management of resources in the region.

4.3 Low Priority

‘Low priority’ was estimated for 51 (36%) sub-watersheds covering 30.55% area with less drainage density, plain surface, low erosion activities and comparatively good agriculture. These watersheds are located near to the Major River and dams with good groundwater potentials in rainy season (Figure 28).

5 FINDINGS

1. Multi-criteria analysis using AHP technique with normalized influences is useful for watershed prioritization for management and development.
2. Twenty five criterion i.e area, P, D_d, T, L_b, R_c, C_c, R_f, R_e, L_u, N_u, F_s, L_{sm}, RL, R_b, R_t, B_s, I_f, R_{h1}, R_n, geology, slope, soil, rainfall and population density were used for prioritization.
3. Correlation analysis is useful for robust judgment of ranks.
4. Weights estimated using AHP technique were used for calculations of influences. Further, calculated influences were normalized based on spatial distribution of selected criterion.
5. Sub-watersheds in the basin were classified into high, moderate and low priorities.
6. Distribution of rainfall, soils and population show importance in prioritization of sub-watersheds in medium river basins.
7. The methodology used for present study can be useful tool for rapid prioritization of watersheds.

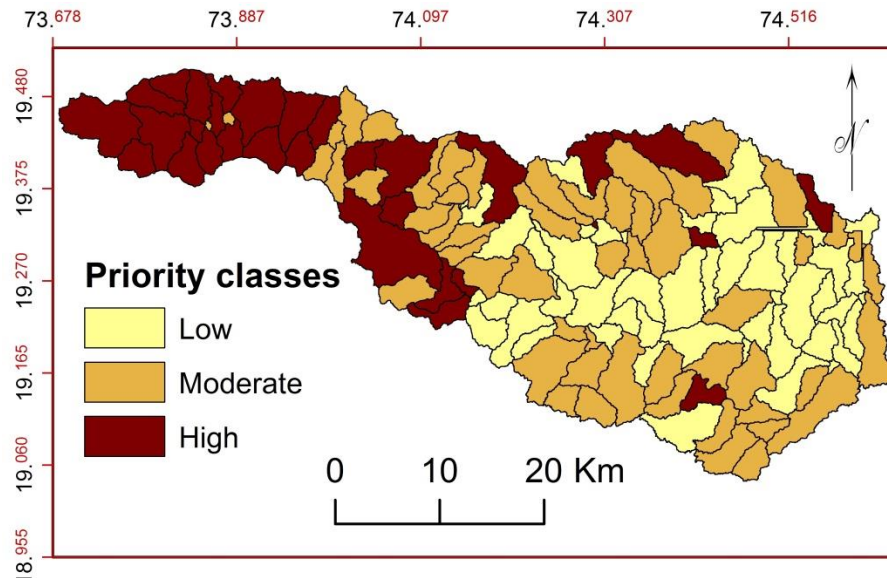


Figure 28. Priority classes

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

Anonymous reviewers thanked for comments and suggestions useful to improve the manuscript.

ABBREVIATIONS

AHP: Analytical Hierarchy Process; **PD:** Population density; **SOI:** Survey of India; **SW:** Sub-watershed.

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