Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2020, Volume 9, Issue 1, pp. 3321-3330
ISSN 2320 – 0243, Crossref: 10.23953/cloud.ijarsg.471

Research Article

Morphometric Analysis and Prioritization of Sub-watersheds for Management of Natural Resources using GIS: A Case Study of Rajasthan, India

S. Sangita Mishra, Krutarth Patel, Srinivas Pendem, and Neel Shrivatra

Department of Civil Engineering, Amity School of Engineering and Technology, Amity University Mumbai, Panvel-410206, Maharashtra, India

Correspondence should be addressed to S. Sangita Mishra, *dr.sushreemishra80@gmail.com*

Publication Date: 2 July 2020

DOI: https://doi.org/10.23953/cloud.ijarsg.471

Abstract Natural resources management is crucial in water scarce semi-arid regions because of scanty rainfall and over exploitation of ground water resources. The watershed chosen in this study is drained by Bandi River having area of 2162.7 km^2 and located in Pali district of Rajasthan, India. Incessant rainfall, continuous exploitation of ground water results in the reduction of ground water level and recurrent drought conditions in this area. Hence, the watershed had been further divided into 5 sub-watersheds represented as SWS-1 to SWS-5 with geographical area ranging from 98 km^2 to 265 km^2 and perimeter ranging from 47 km to 79 km. These sub watersheds were then prioritized based on morphometric analysis considering the linear, areal and relief aspects of the drainage system in GIS environment using ArcGIS 10.5.5. The analysis showed that the drainage density of sub-watersheds varies between 1.351 km/km^2 to 2.513 km/km^2 and the lowest drainage density was found in SWS-4 that indicated the presence of impermeable sub-soil system with dense vegetation cover and low relief in the sub-watershed. The sub-watershed, SWS-2 has high circularity ratio of 0.6 that indicated the topography at the late maturity stage. Similarly, the Elongation Ratio varied from 0.4007 to 0.9340 in the sub-watersheds indicated comparatively steep ground slope and high relief. After the computation of all morphometric parameters of the sub watersheds, the compound parameter values were calculated and the sub-watershed having the lowest compound parameter value was given the highest priority for conservation measures. In this study, the sub-watershed SWS-1 was found to have the lowest compound value of 1.875 and hence considered for immediate soil conservation and water management measures.

Keywords *Bandi River; Soil Conservation; Drainage density; Elongation ratio; Circularity ratio*

1. Introduction

Natural Resources i.e. water and soils are scanty and their optimum usage is imperative, especially in developing countries like India, wherein the population density has been increasing alarmingly. The catchment areas, watersheds, sub watersheds, mini and micro watersheds are the hydrological units considered to conserve natural resources. The river basin management concept recognizes the interrelationships among the hydrological response units like low lands, highlands, land use and land cover, slope, aspect, geomorphology, and soil. However, it may not be feasible to consider the entire watershed or river basin area at once for management of land and water resources. Hence the river basin is usually divided into numerous smaller units, as sub watersheds, mini watersheds or micro watersheds, by considering its drainage system. Geo morphological analysis or morphometric analysis of the watersheds is very important in this regard.

Morphometric analysis requires measurement of the linear, areal and relief features, slope of the drainage network, ground slopes and aspect of the drainage basin. Many researchers have carried out studies on the morphometric analysis of watersheds or sub watersheds using GIS and remote sensing techniques (Ahmed and Rao, 2015; Nag et al., 1998; Thakkar and Dhiman, 2007). Mishra and Nagarajan (2010) had researched on the management of natural resources in Tel River Basin of Odisha, India using morphometric analysis and prioritization of 12 sub-watersheds. They had concluded that the sub watershed having the highest priority based on compound parameters should be provided with soil conservation measures. Srinivasa et al., (2004) had carried out a study on morphometric analysis of sub watersheds of Pawagada area, Tumkur district, Karnataka using GIS software. Shrimali et al., (2001) had studied on the 42km^2 Sukhana lake catchment in the Shiwalik hills to prioritize the regions facing soil erosion of soil using remote sensing and GIS. Chopra et al., (2005) had conducted a study on morphometric analysis of Bhagra Phungotri and Hara maja sub watersheds of Gurdaspur district, Panjab. Khan et al., (2001) had used remote sensing and GIS for prioritization of watershed in the Guhiya basin, India. Nookaratnam et al., (2005) had conducted a study on the positioning of check dams by prioritization of micro watersheds using a sediment yield index (SYI) model and morphometric analysis in GIS environment. Mundetia et al., (2018) had analyzed morphometric parameters of the Khari River basin and prioritized the sub-watersheds on the basis of ground water potential using GIS approach. In this study, a part of the Bandi River Basin had been taken up as the study area and morphometric analysis and prioritization of sub watersheds were carried out.

2. Study Area

The area selected in this study is one of the watersheds of Bandi River covering 2162 km^2 and lies between 25° 15′ and 25° 49′ N latitude and 73° 17′ and 73° 54′ E longitude in Marwar area of Pali District, Rajasthan (Figure 1). It is a sixth order watershed having nearly dendritic to sub-dendritic drainage pattern with non-perennial streams of Someshar river, Mithri river, Khari river and Sukri river (Tributaries of Bandi River). Besides natural streams, the watershed area is also occupied by many surface canals namely Jawai canal, Mandiya canal, Betwa canal, Sumer Samand canal and large number of lakes which are almost dry in all the seasons. Rainfall at Pali is very less all year long and average temperature is 26.6 ºC. The rainfall throughout a year is around 462 mm, due to less rainfall most of the part of year there is water scarcity and very less forest area (Figure 2). In order to cope with the surface water scarcity, the ground water resource is over exploited resulting in the reduction of ground water level as shown in Figure 3. Incessant rainfall, continuous exploitation of ground water is the main reasons of recurrent drought conditions in this area.

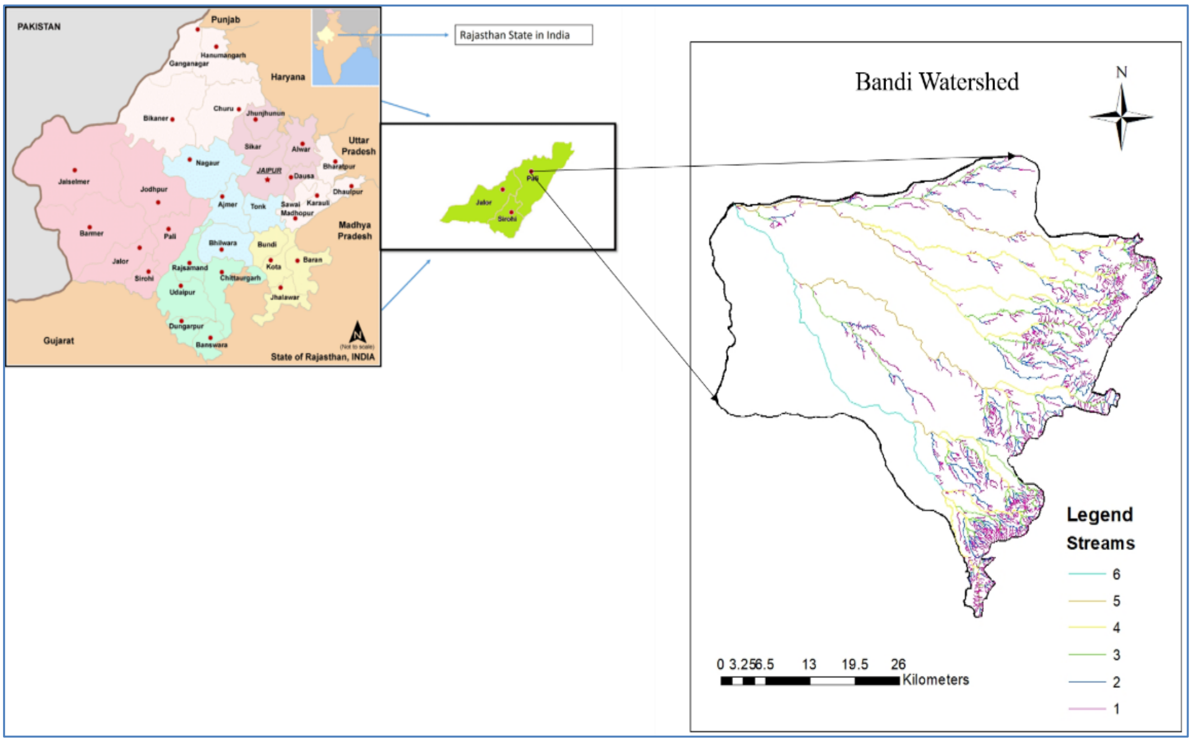

Figure 1: *Index map of Bandi watershed*

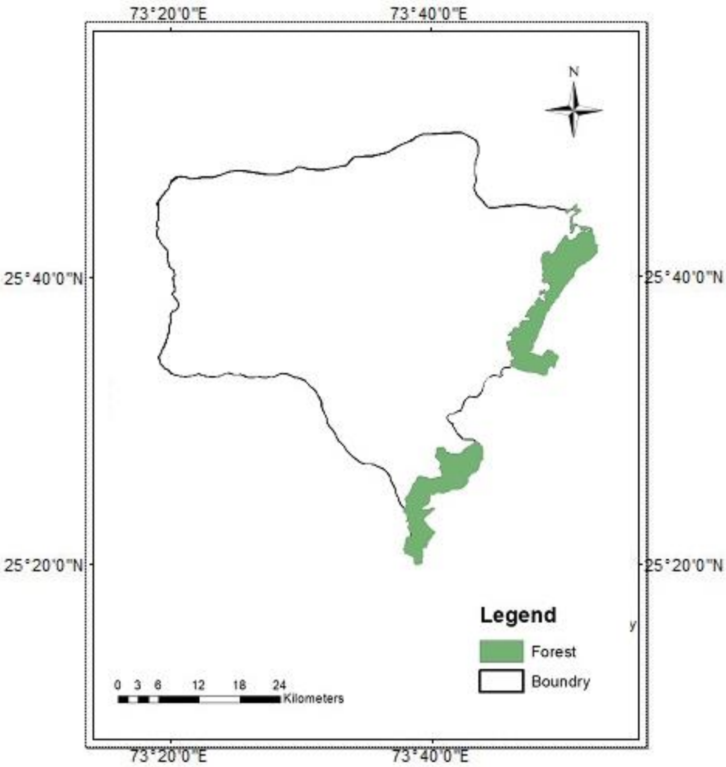

Figure 2: *Forest area Cover in Bandi Watershed*

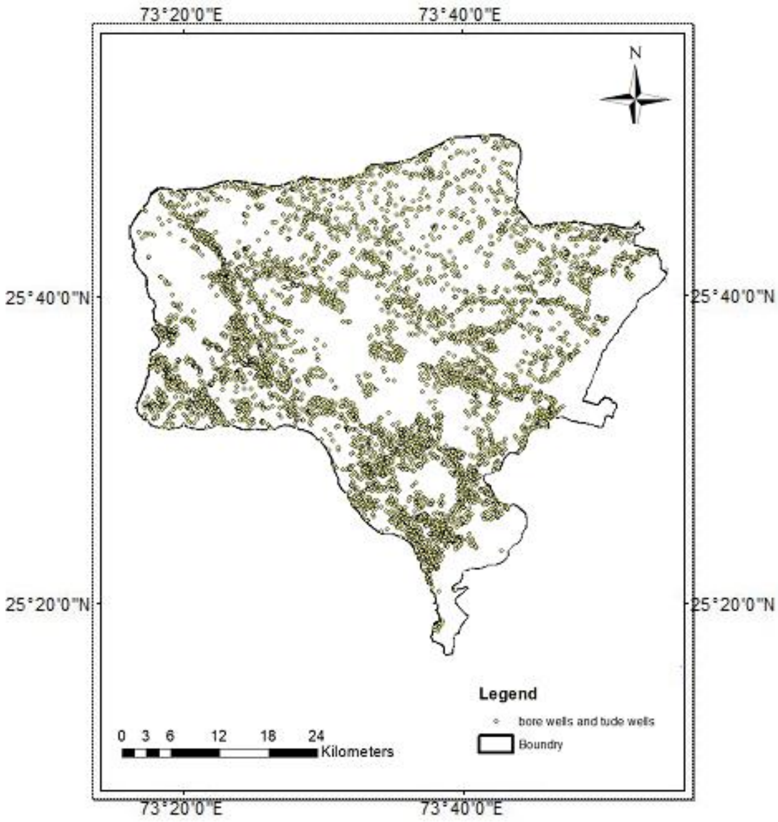

Figure 3: *Groundwater resources in Bandi Watershed*

3. Methodology

The study area i.e. a part of Bandi watershed was divided into 5 sub-watersheds for Morphometric analysis. The main watershed and sub watersheds were delineated using the toposheet from the survey of India in GIS environment. For digitization of the drainage pattern of the watershed and sub-watersheds, ArcGIS 10.5.5 was used and all the fundamental parameters like perimeter, area, basin length, stream length and number of streams were extracted from the drainage map. The morphometric parameters were computed using the formulae given by (Horton, 1945), (Schumm, 1956) and (Miller, 1953). Several other morphometric parameters viz. circularity ratio, bifurcation ratio, stream order, elongation ratio, drainage frequency, stream length, drainage density and compactness constants were calculated using the formulae mentioned in Table 1. Rank was provided to each sub watershed based on these parameters. At last the compound parameter value of all sub-watersheds was computed and the sub watershed having the least compound parameter value was given the highest priority. The detailed procedure adopted in this study is explained in the methodology flow chart (Figure 4).

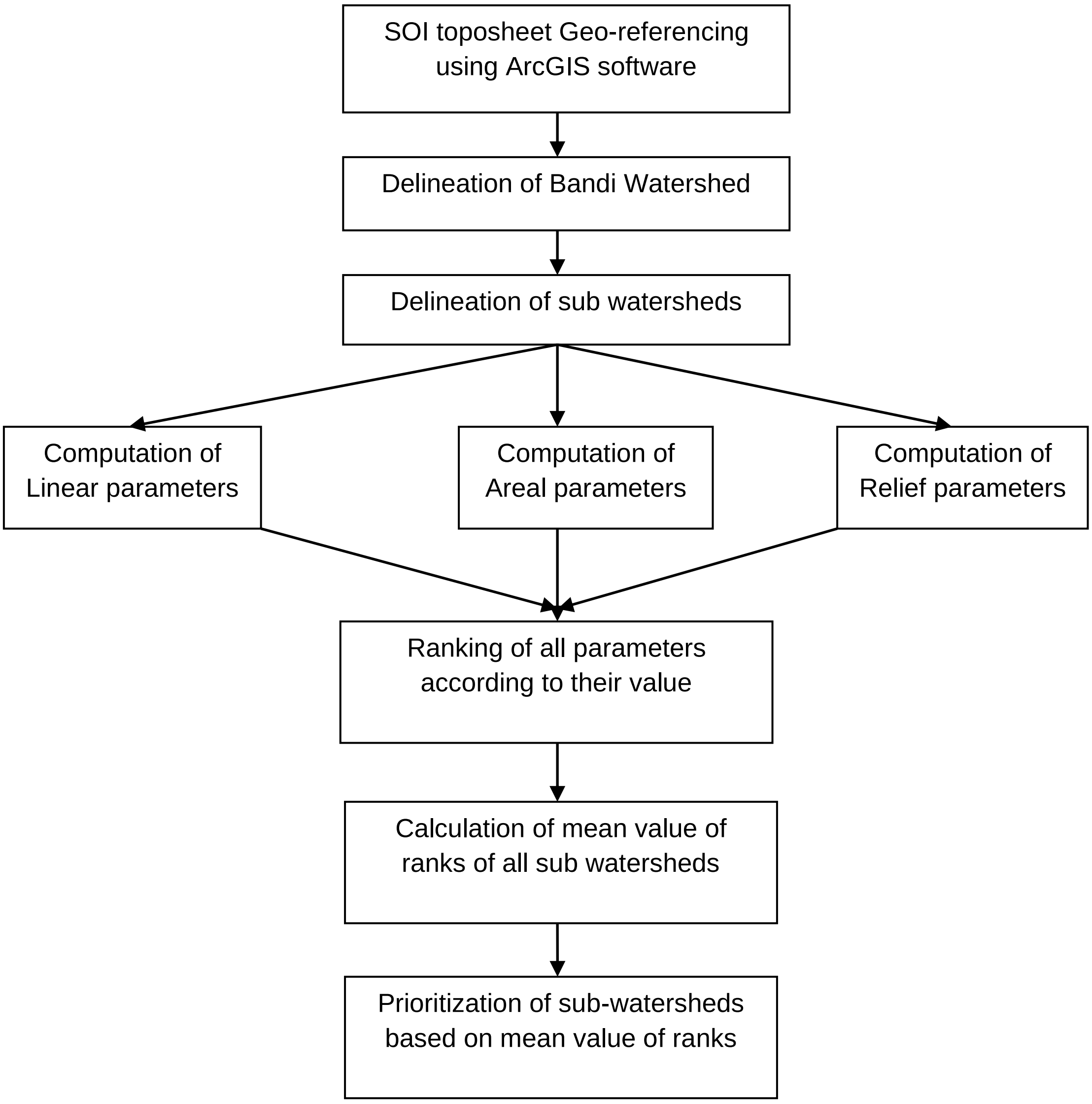

Figure 4: *Methodology flow chart*

Table 1: *Formula for computation of Morphometric parameters*

Morphometric Parameters	Formula	Reference
Stream order	Hierarchical rank	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$ where L_u = Total stream length of order 'u' N_u = Total number of stream segments of order 'u'	Strahler (1964)
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	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ where N_u = Total no. of stream segments of order 'u' N_{u+1} = Number of segments of the next higher order	Schumm (1956)

Drainage density (D_d)	$D_d = L_u / A$ where D_d = drainage density L_u = total stream length of all orders A = area of the basin(km^2)	Horton (1945)
Stream frequency (F_s)	$F_s = N_u / A$ where F_s = stream frequency N_u = total number of streams of streams of all orders A = area of the basin, km^2	Horton (1945)
Circulatory ratio (R_c)	$R_c = 4 * \pi * A/P^2$ where R_c = circularity ratio π = π value i.e., 3.141 A = area of the basin, km^2 P^2 = square of the perimeter, km	Miller (1953)
Elongation ratio (R_e)	$R_e = (4*A/\pi)^{0.5} / L_b$ where R_e = elongation ratio A = area of the basin, km^2 π = π value i.e., 3.141 L_b = basin length, m	Miller (1953)
Form factor (F_f)	$F_f = A/L_b^2$ where, F_f = form factor A = area of the basin, km^2 L_b = basin length	Schumm (1956)
Drainage texture (T)	$T = N_u/P$ where N_u = total no. of streams of all orders P = basin perimeter, km	Horton (1945)
Compactness constant (C_c)	$C_c = 0.2821\ P/A^{0.5}$ where C_c = Compactness Ratio A = Area of the basin, km^2 P = basin perimeter, km	Horton (1945)

4. Results and Discussion

As mentioned in the methodology section, the Bandi watershed was divided into five sub-watersheds named as SWS-1 to SWS-5. It was found from the analysis that the drainage pattern is irregular in all the sub watersheds.

Linear aspects

Stream Length (L_u): The stream length was calculated using Horton's law (Horton, 1945), for all five sub-watersheds. Usually, the total length of all the stream segments decreases as the stream order increase (Table 2). Sub-watershed SWS-2, SWS-3 and SWS-4 follows Horton's law, but SWS-1 and SWS-5 has variation in stream segments. This might have happened due to moderately steep slopes, and lithological variations.

Stream Length ratio (R_l): According to Horton's law of stream length, the 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. All the five Sub-watersheds SWS-1 to SWS-5 has irregular pattern from one order to another order indicating the late geomorphic development.

Stream order (U): The Bandi river is a long River having many streams and this river is a 6th order stream covering an area of 2162.7 km^2. The Bandi River is further divided into Sub-watersheds SWS-1, SWS-2, SWS-3, SWS-4, and SWS-5 covering an area of 115.427 km^2, 106.704 km^2, 160.153 km^2, 264.422 km^2 and 98.643 km^2 respectively. The SWS-1 is having 6th order streams while the SWS-2, SWS-3, SWS-4, and SWS-5 are 5th order streams. Geomorphologic pattern for Bandi Basin is observed as dendritic to semi-dendritic pattern that exhibits homogeneous underlain material.

Stream frequency (F_s): Mostly low stream frequency indicates less slope and high permeability of the subsurface material, which may result in less runoff. Whereas high frequency indicates high slope and low permeability of subsurface material, which may result in more runoff. Sub-watersheds SWS-1, SWS-2, SWS-3 and SWS-5 has high stream frequency which shows that there is less slope, high permeability and less runoff, whereas SWS-4 has less frequency which shows that there is high slope, less permeability and more runoff. These result shows that this area has more dense forest.

***Table 2**: Stream analysis*

Sub-watersheds	Stream numbers in different orders						Order wise total stream lengths (km)						Stream 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	201	39	17	7	1	1	167.69	51.17	29.34	36.74	1.26	3.92	0.31	0.57	1.25	0.03	3.10
SWS-2	0	0	0	0	0	0	86.44	45.66	33.98	19.64	5.15	0.00	0.53	0.74	0.58	0.26	0.00
SWS-3	133	40	14	4	2	0	129.87	65.28	25.97	19.40	17.76	0.00	0.50	0.40	0.75	0.92	0.00
SWS-4	156	51	27	9	1	0	162.28	77.02	63.44	50.58	3.84	0.00	0.47	0.82	0.80	0.08	0.00
SWS-5	104	27	19	11	1	0	87.25	21.68	16.62	26.20	2.92	0.00	0.25	0.77	1.58	0.11	0.00

Dimensionless factors

Circularity Ratio (R_e): The high, medium and low value of circularity ratio usually indicates young, mature and old stage of basin respectively. Values close to 0 indicates elongated basin and values close to 1 indicates circular basin. All the sub-watersheds have circularity ratio values ranging from 0.32 to 0.7 which indicated that all basins come under young to medium stage (Table 3). It was also observed that SWS-1 and SWS-3 are more elongated than SWS-2, SWS-4 and SWS-5. Based on these results, it can be assumed that the SWS-2, SWS-4 and SWS-5 have more diversity of slope, less permeable subsoil and high runoff.

Form Factor (F_f): All sub-watersheds have form factor varies from 0.12 to 0.69. This parameter defines basin shape and its value always varies from 0 to 1. Its indication is almost same as Circularity ratio but has different parameter of analysis. So values indicate that SWS-4 is more circular than others which has highest value 0.685. Flood flow is difficult to manage in circular shape basin than elongated shape basin.

Elongation Ratio (R_e): Elongation ratio value usually varies from 0 to 1 and it indicates the shape of the basin. Depending on the elongation ratio, the sub watersheds can be classified as elongated (<0.7), Oval (0.8 - 0.9) and circular (>0.9). Elongation ratio of all sub-watersheds varies from 0.4 to 0.94, in which SWS-4 has value 0.934 indicate circular shape basin, and all others has value less than 0.7 indicates elongated shaped basins.

***Table 3:** Morphometric parameters of sub watersheds Bandi watershed*

Sub-watersheds	Area (Km^2)	Stream frequency (F_s) (km/km^2)	Basin Length (Km)	Form Factor (F_f)	Elongation Ratio (R_e)	Circularity Ratio (R_c)	Compactness constant (C_c)
SWS-1	115.427	2.304	18.416	0.340	0.658	0.321	1.764
SWS-2	106.704	1.415	29.090	0.126	0.401	0.603	1.288
SWS-3	160.153	1.205	27.813	0.207	0.513	0.323	1.758
SWS-4	264.422	0.923	19.648	0.685	0.934	0.594	1.298
SWS-5	98.6431	1.642	20.160	0.243	0.556	0.527	1.377

Measurement of intensity of dissection

Drainage density (D_d): Drainage density indicates how loosely the channels are spaced in the watershed/sub-watersheds. It is a ratio between total length of streams and total area of the basin (Horton, 1945). It also gives physiographic classifications, runoff potential, land cover, rock type, and climate and basin shape. Drainage density can be characterized as low (<2km^{-1}), moderate (2-4km^{-1}), high (4-6km^{-1}) and very high. All Sub-watersheds has drainage density varies from 1.35 to 2.52 (Table 4). SWS-1 has D_d (2.513km^{-1}) which indicates moderate and other sub-watersheds has D_d less than 2. As per the analysis, it can be determined that all the watersheds had relatively low Drainage density which indicates that subsoil material of all sub-watersheds is highly permeable, having good vegetation cover and low slope because of that runoff is less and soil has coarse drainage texture which improves infiltration.

On the basis of all these parameters, ranks are given to all watersheds from 1 to 5. Then a compound parameter is computed taking the average of the ranks for prioritization shown in Table 5. The Sub-watershed SWS-1 with compound parameter value 1.875 was given the highest priority followed by SWS-5. Basin with highest priority shows greater degree of erosion and becomes important unit for soil conservation measures. The prioritized map of the sub watersheds are represented in Figure 5.

Table 4: *Values of Perimeter, drainage density, texture and bifurcation ratios*

Sub-watersheds	Perimeter	Drainage Density	Drainage Texture (T)	Bifurcation ratios					Mean R_b
				R_{b1}	R_{b2}	R_{b3}	R_{b4}	R_{b5}	
SWS-1	67.163	2.513	3.960	5.153	2.294	2.429	7	1	3.575
SWS-2	47.170	1.788	3.201	3.413	1.933	2.143	7	0	2.898
SWS-3	78.883	1.612	2.446	3.325	2.857	3.500	2	0	2.336
SWS-4	74.801	1.350	3.261	3.058	1.889	3.000	9	0	3.389
SWS-5	48.491	1.567	3.340	3.851	1.421	1.727	11	0	3.600

Table 5: *Estimation of compound parameters of Sub watersheds*

Sub- watersheds	R_b	D_d	F_s	T	F_f	R_c	C_c	R_e	Compound parameter	Final priority
SWS-1	2	1	1	1	2	5	1	2	1.875	1
SWS-2	4	2	3	4	5	1	5	5	3.625	4
SWS-3	5	3	4	5	4	4	2	4	3.875	5
SWS-4	3	5	5	3	1	2	4	1	3	3
SWS-5	1	4	2	2	3	3	3	3	2.625	2

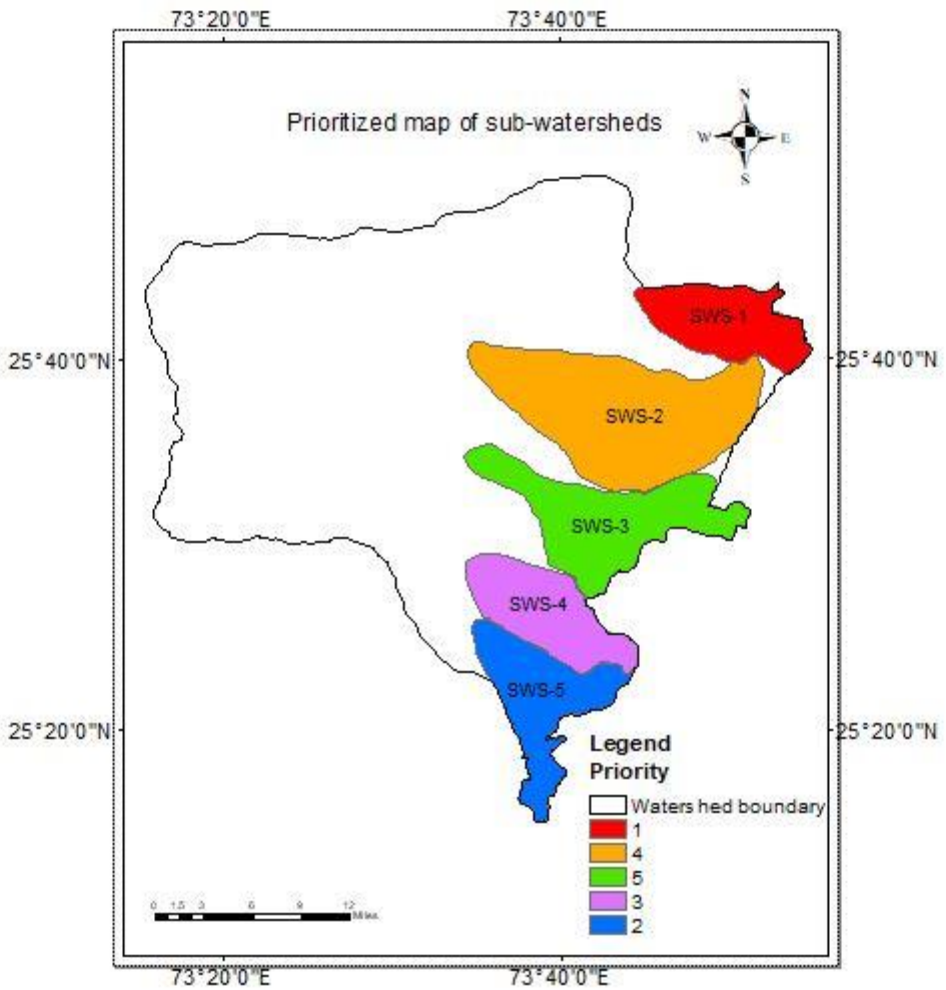

Figure 5: *Prioritization map of Sub Watershed*

5. Conclusion

Management of water resources is given utmost importance now days; hence study of prioritization of watersheds is an important aspect of planning for conservation and management of natural resources. The present study demonstrates the applicability of GIS techniques for prioritization of watershed based on Morphometric analysis which helps in management of water resources. For region like Pali, water management is most important because it was found that most of the underground water of these areas was exploited by bore wells or tube wells. So, analysis of different Morphometric parameters like drainage density, elongation ratio, stream length, stream frequency, land use etc. can help in decision making process for water resource management. From the results of prioritization of sub-watersheds, it can be determined that the sub-watersheds SWS-1 and SWS-5 should be given immediate attention to reduce soil erosion and sedimentation in these sub watersheds.

References

Ahmed, F. and Rao, K.S. 2015. Prioritization of Sub-watersheds based on Morphometric Analysis using Remote Sensing and Geographic Information System Techniques. *International Journal of Remote Sensing and GIS*, 4(2), pp. 51-65.

Chopra, R., Dhiman, R., and Sharma, P.K. 2005. Morphometric analysis of sub-watersheds in Gurdaspur District, Punjab using Remote Sensing and GIS techniques. *Journal of Indian Society of Remote Sensing*, 33(4), pp. 531-539.

Horton, R.E. 1945. Erosional development of streams and their drainage basins; Hydrological approach to quantitative morphology. *Geological Society of American Bulletin*, 56, pp. 275-370.

Khan, M. A., Gupta V.P., and Moharana P.C. 2001. Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya, India. *Journal of Arid Environments,* 49, pp. 465-475.

Miller, V.C. 1953. A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area. *Technical report-3*, Department of Geology, Columbia University.

Mishra. S.S., and Nagarajan, R. 2010. Morphometric analysis and prioritization of sub-watersheds using GIS and Remote Sensing techniques: a case study of Odisha, India. *International Journal of Geomatics and Geosciences*, 1(3), pp. 501-510.

Mundetia, N. 2018. Morphometric assessment and sub-watershed prioritization of Khari River basin in semi-arid region of Rajasthan, India. *Arabian Journal of Geosciences*, 11(18), pp. 530.

Nag, S.K. 1998. Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *Journal of Indian Society of Remote Sensing*, 26(1-2), pp. 69-76.

Nookaratnam, K., Srivastava, Y.K., Venkateswarao, V., Amminedu, E. and Murthy, K.S.R. 2005. Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis – Remote sensing and GIS perspective. *Journal of the Indian Society of Remote Sensing*, 33(1), pp. 25-28.

Schumm, S.A. 1956. Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin,* 67, pp. 597-646.

Shrimali, S.S., Aggarwal S.P., and Samra, J.S. 2001. Prioritizing erosion-prone areas in hills using remote sensing and GIS – a case study of the Sukhna Lake catchment, Northern India. *Journal of Agricultural engineering,* 3(1), pp. 54-60.

Srinivasa, V.S., Govindaonah, S. and Home Gowda, H., 2004. Morphometric analysis of sub-watersheds in the Pawagada area of Tumkur district South India using remote sensing and GIS techniques. *Journal of Indian Society of Remote Sensing,* 32(4), pp. 351-362.

Strahler, A N. 1964. Quantitative geomorphology of drainage basins and channel networks. Section 4-II, In: Handbook of Applied Hydrology (Ed.: VT Chow). McGraw-Hill, pp. 4-39.

Thakkar, A.K. and Dhiman, S.D. 2007. Morphometric analysis and prioritization on miniwatersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. *Journal of Indian Society of Remote Sensing,* 35(4), pp. 313-321.