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Prioritization of Sub-Watersheds in Ruparel Watershed, Rajasthan Based on Morphometric and Land Use/Land Cover Analysis Using Remote Sensing and GIS

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Abstract

Watershed prioritization is considered as the most significant aspect in watershed resource management and development program. The present work attempts to prioritize seventeen sub-watersheds in Ruparel watershed of Alwar district of Rajasthan, India. For prioritization of sub-watersheds, morphometric and land use/land cover (LULC) analysis were performed using remote sensing and GIS. Base map of the study area has been derived from SOI toposheet on 1:50,000 scale whereas LULC mapping was done using IRS P6 LISS III data. Standard methods for drainage morphometry have been followed for computing morphometric parameters such as linear and shape for seventeen sub-watersheds and allotted ranks based on their relationship with erodibility and a compound value has been calculated for final ranking. Five main LULC categories were computed and were assigned priority ranks and subsequently a compound parameter was determined for final ranking. Integration of both morphometric and LULC results reveal that SBW5, SBW7, SBW12 and SBW16 are the common sub-watersheds that fall under high priority, SBW3 falls under Medium category and SBW11 comes under low priority. The results of the analysis can be used to identify the sub-watersheds which need immediate restoration and will eventually help in watershed resource management for sustainable development.

Keywords

Prioritization, Watershed Resource Management, Morphometry, Land Use/Land Cover Analysis

1. Introduction

Natural resources like land, forest and water are finite, their improper and uncontrolled consumption is posing a serious threat to the precious environment particularly in developing countries like India, hence their conservation and proper management is essential for sustainable development. Watershed is considered as an ideal unit for proper management and effective planning of land, forest and water resources by classifying it into smaller units, *i.e.*, sub-watersheds or milli-watersheds by taking into consideration various terrain conditions such as contour values, drainage network, relief and spot height [1].

Watershed prioritization classifies different watersheds in order of their priority so that management and conservation measures can be implemented. Morphometric analysis with the help of remote sensing and GIS techniques is considered to be the most useful approach for prioritization of watersheds [2]-[10]. Morphometry allows the quantitative analysis of a drainage basin which is an important aspect in the characterization of watersheds [11]. Sub-watersheds can be prioritized on the basis of a number of factors such as drainage basin morphometry, Universal Soil Loss Equation (USLE), Sediment Yield Index (SYI), LULC analysis etc. [1] [3] [12]. LULC mapping is considered as an important component in which other characteristics are combined on the requirement basis to drive various developmental indexes for land and water resources [13]. Drainage basin morphometry together with soil and LULC analysis is very critical for developing a water resource action plan that includes locating recharge and discharge zones as well as for classification and prioritization of the watersheds [6]. A host of workers have attempted watershed prioritization in different parts of India with the help of remote sensing and GIS [1] [3] [4] [5] [8] [13]. The current study prioritizes seventeen sub-watersheds in Ruparel watershed of Alwar district of Rajasthan using techniques such as morphometric and LULC analysis with the help of remote sensing and GIS. The main objectives of this study are to identify and classify sub-watersheds in the Ruparel watershed for conservation of natural resources for ultimate sustainable development and to recommend watershed conservation measures for planning and resource development.

2. Study Area Description

Ruparel watershed is located in Alwar district of Rajasthan, India and occupies an area of 1215.76 km^2. The watershed lies between 27˚10'N to 27˚54'N latitudes and 76˚16'E and 76˚45'E longitudes and the maximum and minimum elevation of the watershed is 732 m and 231 m above mean sea level (MSL), respectively. The study area falls in Alwar, Bansur, Thanghazi, and Rajgarh tehsils of Alwar district. Agriculture is the primary economic activity in the study area and the major crops grown are bajra, wheat, gram, Gaur, groundnut, arhar and mustard. The main Ruparel River also known as Barah or Laswari Nadi originates from Udainath hills in Thanaghazi tehsil of Alwar district, transverses northwards

passing through the Sariska forest and then flows eastwards from Natni ka Bara where from an 8 kms long feeder channel known as Barah Feeding Channel diverts the Alwar share of water to Jaisamand lake. The Ruparel River continues to flow eastwards, passes through the fertile plains of the Alwar district and finally terminates in the adjoining Bharatpur district (Figure 1). The Ruparel watershed is mainly rainfed and experiences semi-arid climate. Watershed shows dendritic to sub-dendritic drainage pattern in general but locally trellis, rectangular and parallel patterns have also developed.

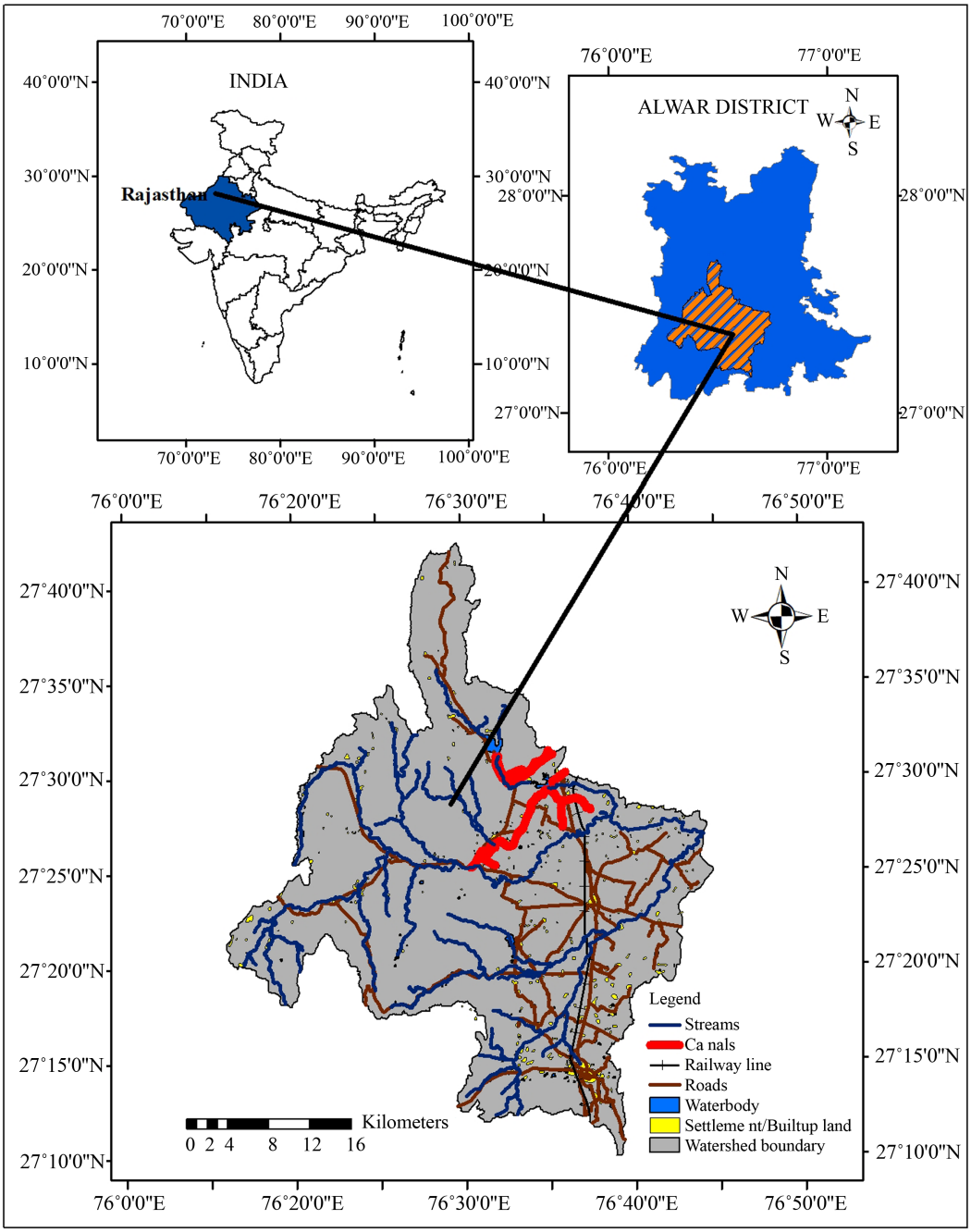

Figure 1. Location map of Ruparel watershed.

3. Data Used and Methodology

The present study has utilised Survey of India (SOI) toposheets 54A/6, 54A/7, 54A/8, 54A/10, 54A/11 and 54A/12 on 1:50,000 scale. The toposheets were scanned, mosaiced and then georeferenced and registered to UTM projection (WGS 84, zone 43) in ARC GIS environment for using as baseline data of the study area. The watershed boundary was delineated by considering first order channels, contour lines, spot height and drainage divide. SOI toposheets have been utilized to generate the drainage network of the study area by on screen digitization using ArcGIS 10.5 software (Figure 2). Elevation map of the study

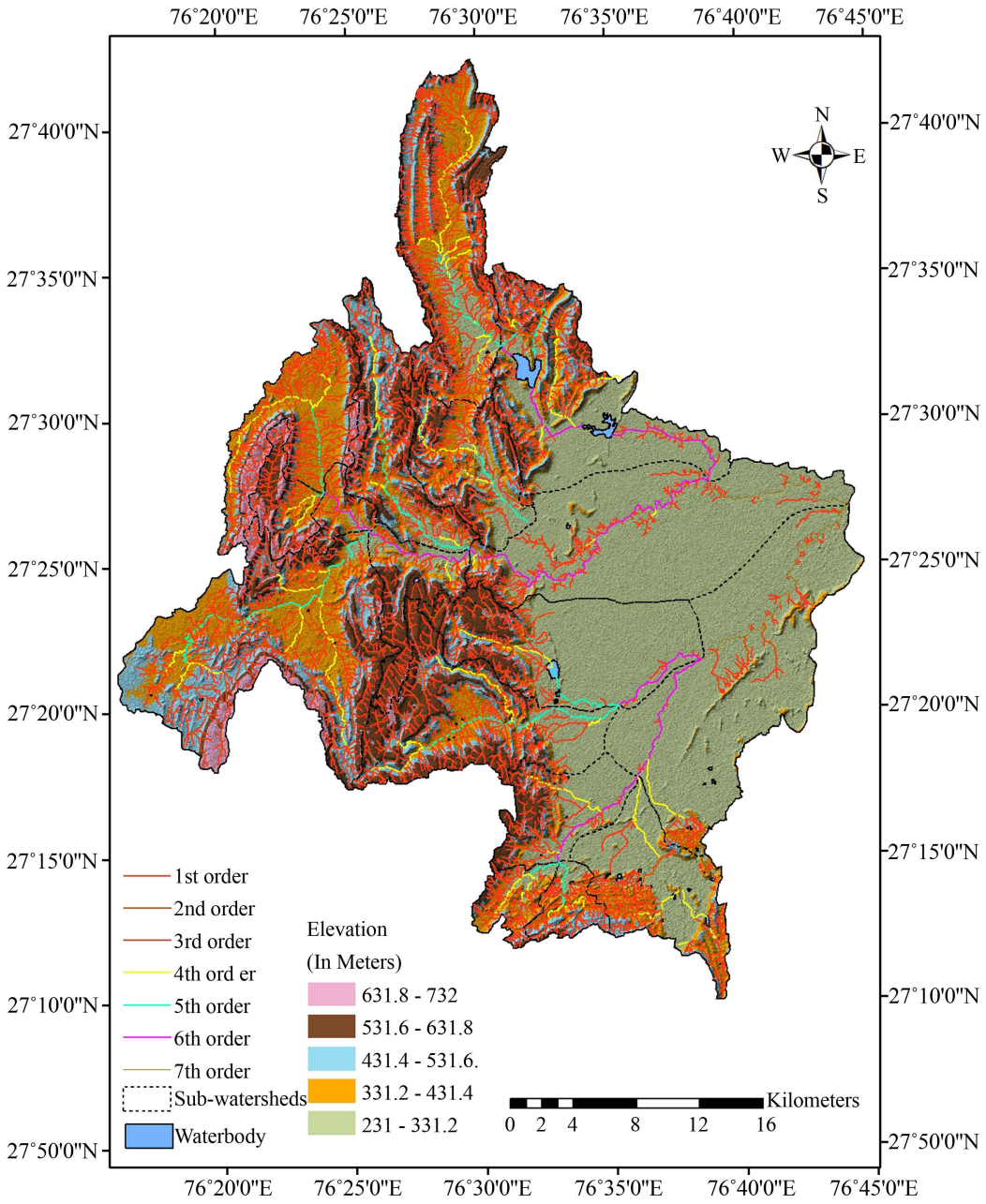

Figure 2. Drainage network superimposed on the elevation map of the study area.

area was produced from Advanced Space borne Thermal Emission Radiometer data of 30 m resolution downloaded from USGS website (https://earthexplorer.usgs.gov/) (**Figure 2**). The Ruparel watershed was classified into 17 sub-watersheds and named as SBW1, SBW2, SBW3, SBW4 and so on. Smallest SBW *i.e.*, SBW3 occupies an area of 12.67 km^2 whereas largest SBW *i.e.*, SBW1 occupies an area of 154.76 km^2. For each sub-watershed quantitative morphometric parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture, length of overland flow, basin shape, form factor, elongation ratio, circularity ratio and length of overland flow were computed using standard formulae and methods [11] [14] [15] [16] [17] [18].

Satellite data IRS LISS III FCC (False colour composite) of 2014 (Path-Row: 95 - 52) was utilized to identify various LULC categories. Seventeen LULC categories were identified and delineated using visual image interpretation methods and include fallow land, cultivated land, dense forest, open forest, degraded forest, open scrub, dense scrub, ravenous land (with open scrub), ravenous land, exposed rock (with open scrub), settlement/build up land, waterbody, dry waterbody, plantation, barren land, barren/rocky/stony waste, and stone quarry. LULC analysis in terms of area and percentage under each LULC category was done sub-watershed wise using ArcGIS. Morphometric and LULC analysis were used as basic elements for carrying out prioritization in Ruparel watershed. Morphometric parameters such as linear and shape parameters were calculated and priority ranking was given based on their relationship with erodibility [4] [5]. For prioritization based on LULC analysis, categories such as cultivated land, dense forest, open forest, open scrub and wasteland were considered. Based on average priority ranking value, the sub-watersheds were given four priority ranks as Very High, High, Medium and Low.

4. Results and Discussion

4.1. Morphometric Analysis

The quantitative morphometric characterization of Ruparel watershed was done through the measurement of linear and shape parameters. The first step in the morphometric analysis of a drainage basin is the designation of stream order (u), using hierarchic ranking method of streams [11]. The whole Watershed has been classified into 17 sub-watersheds (viz. SBW1, SBW2, SBW3 etc.) (**Figure 2**). The mean bifurcation value in the Ruparel watershed ranges from 2.82 to 7 (**Table 1**). The lower mean bifurcation value in SBW11 shows lack of structural control on drainage development whereas higher value in SBW3 suggests that the drainage pattern is structurally controlled. The values of drainage density range between 0.62 (SBW11) and 4.28 (SBW13) km/km^2 (**Table 1**). High drainage density values are recorded in SBW13 and SBW14 which represent impermeable sub-surface material, high mountain relief, increased runoff and decreased infiltration capacity whereas moderate drainage density values are observed in SBW4, SBW5, SBW6, SBW7 and SBW8. Low drainage density values are

Table 1. Morphometric analysis of the Ruparel watershed.

Morphometric Parameters	SBW1	SBW2	SBW3	SBW4	SBW5	SBW6	SBW7	SBW8	SBW9	SBW10	SBW11	SBW12	SBW13	SBW14	SBW15	SBW16	SBW17	Whole Watershed
Area (sq·km)	154.76	31.35	12.67	20.4	60.41	58.17	52.43	105.81	102.66	143.22	154.62	62.17	15.83	16.97	40.12	90.1	94.07	1215.76
Bifurcation ratio (Rb) I/II	3.7	3.52	4	4.16	4.15	3.86	4.34	4.4	4.55	4.39	3.76	3.34	4.26	3.93	4.22	4.05	3.89	4.04
II/III	4.65	3.28	10	4.8	7.11	3.1	4.3	4.38	4.8	4.81	3.71	4.18	4.28	3.75	3.85	4.27	5.57	4.42
III/IV	4.14	7		2.5	4.5	4.75	3.33	3.71	3	3.66	7	2.66	2.33	4	3.5	3.6	3.5	3.67
IV/V	7			2	2	4	3	7	2.5				3	2		5	1	4.23
V/VI									0.66								2	2.16
VI/VII											1							3.0
Mean Bifurcation Ratio (Rbm)	4.87	4.6	7	3.36	4.44	3.92	3.74	4.87	3.1	3.47	2.82	3.39	3.47	3.42	3.85	4.23	3.19	3.58
Stream Length Ratio (SLR) II/I	0.39	0.22	0.4	0.37	0.34	0.28	0.34	0.3	0.34	0.21	0.31	0.3	0.28	0.28	0.32	0.4	0.28	0.32
III/II	0.54	1.15	0.32	0.59	0.33	0.76	0.68	0.66	0.39	0.58	0.47	0.98	0.58	0.58	0.73	0.47	0.84	0.59
IV/III	0.54	0.12		0.52	0.87	0.41	0.49	0.47	0.82	0.29	0.79	0.75	0.63	0.9	0.57	0.62	0.44	0.55
V/IV	0.7			0.14	0.41	1.25	0.54	0.34	0.44				0.77	0.37		0.9	0.81	0.50
VI/V									2.64								1.22	0.88
VII/VI										0.5	1.87							0.37
Perimeter (km)	83.84	39.27	18.26	26.35	57.44	49.55	35.93	62.67	59.78	65.77	69.33	44.61	20.3	24.53	32.82	60.14	49.69	269.28
Basin Length (km)	17.79	9.28	3.76	7.19	13.47	13.16	11.7	18.53	18.21	24.28	21.89	15.13	4.65	6.64	10.66	17.68	18.26	47.9
Drainage Density D (km/km^2)	2.84	2.56	2.85	3.55	3.72	3.3	3.08	3.9	2.11	1.09	0.62	2.03	4.28	4.1	2.33	2.9	1.37	2.32
Stream Frequency (Fs)	4.34	3.6	4.1	6.47	5.66	5.34	4.67	6.14	4.13	2.1	0.86	5.03	10.68	9.36	3.76	4.58	2.15	3.93
Drainage Texture (Rt)	8.01	2.87	2.85	5	5.95	6.27	6.81	10.37	7.1	4.59	1.93	7.01	8.32	6.48	4.6	6.86	4.08	17.75
Form Factor (Rf)	0.48	0.36	0.89	0.38	0.33	0.33	0.38	0.3	0.3	0.24	0.32	0.27	0.73	0.38	0.35	0.28	0.28	0.52
Circularity Ratio (Rc)	0.27	0.25	0.47	0.39	0.23	0.29	0.51	0.33	0.36	0.41	0.4	0.39	0.48	0.35	0.46	0.31	0.47	0.21
Elongation Ratio (Re)	0.78	0.68	1.06	0.7	0.65	0.65	0.7	0.62	0.62	0.55	0.64	0.58	0.97	0.7	0.67	0.6	0.59	0.82

Continued

Basin Shape (Bs)	2.04	2.71	1.11	2.53	2.98	2.97	2.61	3.24	3.23	4.11	3.09	3.68	1.36	2.6	2.83	3.46	3.54	1.88
Compactness Coefficient (Cc)	1.9	1.97	1.44	1.64	2.08	1.83	1.4	1.72	1.66	1.55	1.57	1.6	1.43	1.69	1.47	1.78	1.44	2.17
Length of Overland Flow (Lo)	0.17	0.19	0.17	0.14	0.13	0.15	0.16	0.12	0.23	0.45	0.79	0.24	0.11	0.12	0.21	0.17	0.36	0.21
Constant of Channel Maintenance (C)	0.35	0.39	0.35	0.28	0.26	0.3	0.32	0.25	0.47	0.91	1.59	0.49	0.23	0.24	0.42	0.34	0.72	0.42

reported from SBW1, SBW2, SBW3, SBW9, SBW10, SBW11, SBW12, SBW15, SBW16 and SBW17 indicating permeable sub soil, low relief, decreased runoff and increased infiltration capacity. Drainage texture values of sub-watersheds range from 1.93 (SBW11) to 10.37 (SBW8). SBW2 and SBW3 represent coarse drainage texture, whereas SBW6, SBW7, SBW9, SBW12, SBW14 and SBW16 display a fine drainage texture. SBW8 is the only sub-watershed which shows very fine drainage texture, whereas remaining of sub-watersheds indicate moderate drainage texture (Table 1). Fine drainage texture is generally observed in sub-watersheds which are characterized by soft and impermeable sub soil material with high basin relief and higher susceptibility to erosion.

The values of Basin shape in sub-watersheds lie between 1.11 (SBW3) and 4.11 (SBW10) (Table 1), which suggest that SBW3 and SBW13 have sharply peaked flood discharge whereas the other 15 sub-watersheds show low flood discharge periods. Circularity ratio values within Ruparel watershed range from 0.23 for (SBW5) to 0.51 (SBW7), indicating overall elongated shape of the sub-watersheds with low runoff and high infiltration due to presence of permeable subsoil material. Lower (Rc) values indicate that the basin is less circular and the discharge rate will be slow and hence the possibility of erosion will be less [6]. Elongation ratio values range from 0.55 (SBW10) to 1.06 (SBW3). Only two sub-watersheds *i.e.*, SBW3 and SBW13 are found to be circular in shape whereas the remaining 15 sub-watersheds fall into elongated to less elongated category. Higher Re values in SBW3 and SBW13 suggest increased infiltration and decreased runoff; whereas, lower Re values in remaining 15 sub-watersheds indicate strong erosive and sediment-load susceptibility.

4.2. Land Use and Land Cover Analysis

Seventeen land use/land cover classes (LULC) were identified in Ruparel watershed by visual image interpretation of IRS P6 LISS III FCC imagery of 2014 using various image interpretation elements such as tone, texture, pattern, size, association etc., [19]. LULC categories within the Ruparel watershed include Cultivated land, fallow land, dense forest, open forest, degraded forest, open

scrub, dense scrub, ravenous land (with open scrub), ravenous land, exposed rock (with open scrub), settlement/build up land, waterbody, dry waterbody, plantation, barren land, barren/rocky/stony waste, and stone quarry (Figure 3). LULC statistics has been derived from LULC map by computing area and percentage under each category of LULC (Table 2).

Five main LULC categories such as Cultivated land, Dense Forest, Open Forest, Open scrub and wasteland were taken for the prioritization of sub-watersheds as adopted by [5]. The most dominant land cover category in the Ruparel watershed is Dense Forest, which occupies an area of 373.6 km^2 (30.73%). Cultivated land is the second most dominant category comprising 342.67 km^2 (28.19%) of the watershed area. Wasteland covers 143.48 km^2 (11.8%) of the total watershed area and comprises ravenous land, ravenous land (with open scrub), barren land, barren/rocky/stony waste and degraded forestland [20]. Open forest covers an area of 33.66 km^2 *i.e.* (2.77%). Open scrub is covering an area of 70.13 km^2 *i.e.*, (5.77%).

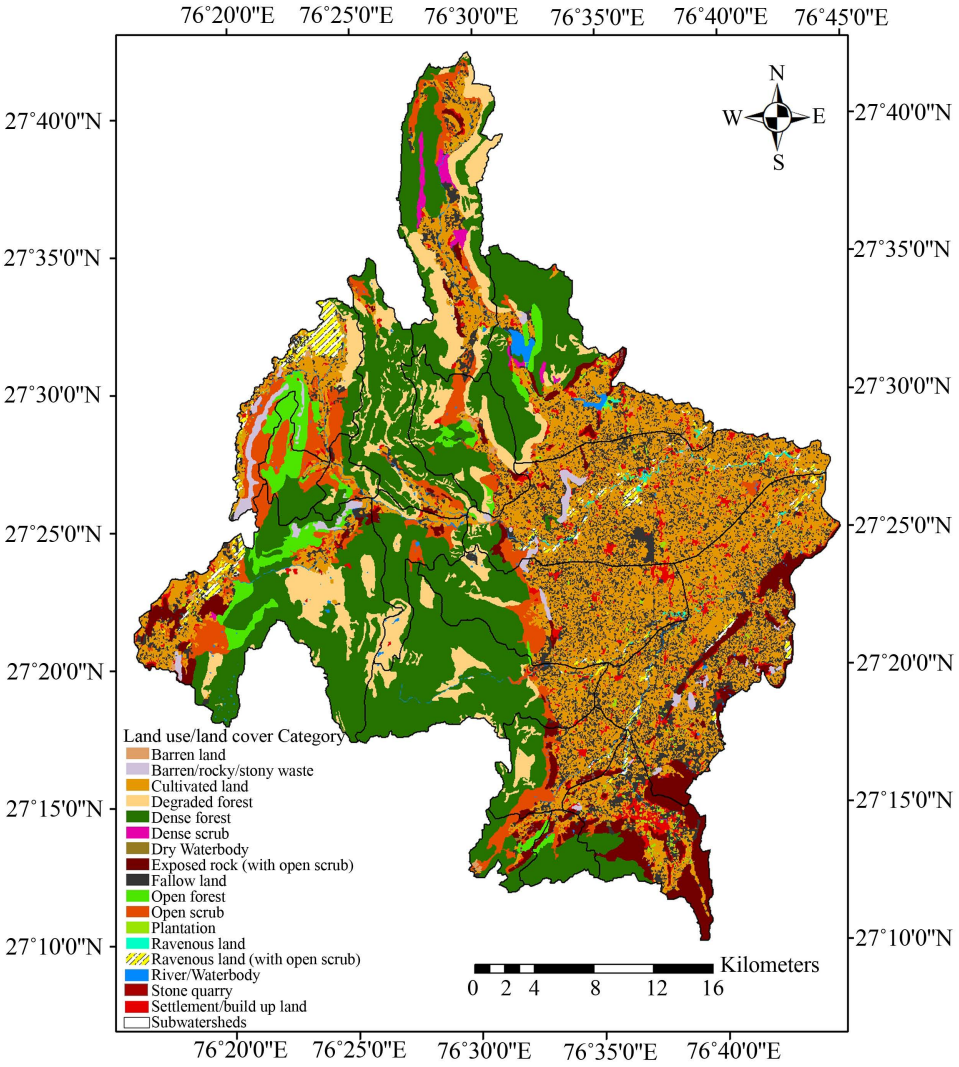

Figure 3. LULC map of Ruparel watershed based on IRS P6 LISS III data of 2014.

Table 2. Sub-watershed wise LULC analysis of Ruparel watershed.

LULC CLASSES	Area		Area		Area		Area		Area		Area		Area		Area		Area	
	Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)	
	SBW1		SBW2		SBW3		SBW4		SBW5		SBW6		SBW7		SBW8		SBW9	
Cultivated land	18.65	12.05	2.29	7.31	1.38	10.9	0.69	3.38	11.6	19.2	4.04	6.95	4.39	8.37	19.18	18.13	30.91	30.11
Fallow land	6.41	4.14	0.27	0.86	0.35	2.76	0.09	0.44	3.99	6.6	1.19	2.05	1.75	3.34	8.41	7.95	8.85	8.62
Dense forest	71.46	46.17	17.02	54.31	5.72	45.15	6.36	31.18	4.50	7.45	37.34	64.19	26.3	50.16	36.38	34.38	39.50	38.48
Open forest	10.56	6.82			0.67	5.29	6.89	33.77	6.89	11.41	0.04	0.07	2.66	5.07			3.61	3.52
Degraded forest	20.23	13.07	7.32	23.36	1.54	12.15			4.93	8.16	11.28	19.39	10.08	19.23	25.88	24.46	5.53	5.38
Open scrub	10.03	6.48	2.51	8.0	2.58	20.36	6.11	29.95	13.38	22.15	2.88	4.95	5.06	9.65	7.48	7.07	0.91	0.89
Dense scrub	0.15	0.09													4.26	4.03	0.95	0.93
Exposed rock with open scrub	7.69	4.97	0.97	3.09	0.13	1.03	0.01	0.05	0.03	0.05	0.63	1.08	0.82	1.56	2.06	1.95	3.52	3.43
Ravenous land with open scrub	3.35	2.16							8.29	13.72							0.23	0.22
Ravenous land																	0.33	0.32
Waterbody	0.86	0.56	0.61	1.95	0.15	1.18	0.08	0.40	0.51	0.84	0.36	0.62	0.05	0.10	0.77	0.72	2.99	2.91
Dry waterbody	0.07	0.05																
Settlement/ Build up Land	2.29	1.48	0.34	1.09	0.05	0.39	0.16	0.78	0.69	1.14	0.41	0.7	0.68	1.30	1.26	1.19	3.50	3.41
Barren/ Rocky/Stony waste	2.53	1.63			0.09	0.71			5.19	8.60			0.04	0.08			0.34	0.33
Barren land	0.29	0.19							0.19	0.31			0.60	1.14			0.17	0.16
Stone quarry					0.01	0.08											0.11	0.11
Plantation	0.19	0.12	0.01	0.03			0.01	0.05	0.22	0.36					0.13	0.12	1.21	1.18
Total	154.76	100	31.35	100	12.67	100	20.40	100	60.41	100	58.17	100	52.43	100	105.81	100	102.66	100

LULC CLASSES	Area		Area		Area		Area		Area		Area		Area		Area	
	Sq·Km (%)		Sq·km (%)		Sq·Km (%)		Sq·Km (%)		Sq·km (%)		Sq·Km (%)		Sq·Km (%)		Sq·Km (%)	
	SBW10		SBW11		SBW12		SBW13		SBW14		SBW15		SBW16		SBW17	
Cultivated land	84.52	59.01	86.06	55.66	16.05	25.82	1.13	7.14	1.54	9.07	11.23	27.99	8.78	9.74	40.23	42.77
Fallow land	30.89	21.57	37.69	24.38	9.57	15.39	0.26	1.64	0.46	2.71	4.90	12.21	3.8	4.22	15.32	16.29
Dense forest	4.85	3.39			6.72	10.81	10.37	65.55	7.81	46.02	11.66	29.06	63.8	70.81	23.81	25.31

Continued

Open forest	0.13	0.09					0.84	5.31	1.09	6.42			0.08	0.09	0.20	0.21
Degraded forest	2.14	1.50									3.39	8.45	9.82	10.9	3.51	3.73
Open scrub	2.84	1.98	0.38	0.25	0.47	0.76	0.72	4.55	3.51	20.68	4.19	10.44	1.9	2.11	5.18	5.51
Dense scrub																
Exposed rock with open scrub	1.62	1.13	17.04	11.02	21.33	34.31	2.29	14.47	1.86	10.96	2.97	7.40	0.46	0.51	0.39	0.41
Ravenous land with open scrub	3.96	2.76	2.65	1.71	0.52	0.84					0.24	0.60	0.14	0.16	0.46	0.49
Ravenous land	1.06	0.74	0.16	0.1											0.18	0.20
Waterbody	1.04	0.73	0.92	0.6	0.26	0.42	0.08	0.51	0.04	0.24	0.31	0.80	0.46	0.51	0.28	0.30
Dry waterbody	0.07	0.05	0.28	0.18	0.23	0.37			0.09	0.53	0.06	0.15	0.04	0.04	0.07	0.07
Settlement/ Build up Land	5.95	4.15	6.03	3.89	5.13	8.25	0.12	0.76	0.17	1.00	1.07	2.66	0.61	0.68	3.08	3.27
Barren/ Rocky/Stony waste	2.89	2.02	1.90	1.23	0.32	0.51									1.01	1.07
Barren land	0.37	0.26	0.04	0.03	0.02	0.03			0.26	1.53	0.01	0.02				
Stone quarry			0.14	0.09	0.03	0.05	0.01	0.06	0.11	0.65	0.04	0.1				
Plantation	0.89	0.62	1.33	0.86	1.52	2.44			0.03	0.18	0.05	0.12	0.21	0.23	0.35	0.37
Total	**143.22**	**100**	**154.62**	**100**	**62.17**	**100**	**15.83**	**100**	**16.97**	**100**	**40.12**	**100**	**90.1**	**100**	**94.07**	**100**

4.3. Prioritization of Sub-Watersheds Based on Morphometric Parameters

The morphometric parameters like linear and shape are also termed as Erosion risk assessment parameters [3] and have been taken for the prioritization of sub-watersheds. The linear parameters with direct relationship with erodibility like drainage density, stream frequency, mean bifurcation ratio, and length of overland flow were used for priority ranking. Shape parameters show an inverse relationship with the erodibility *i.e.* circularity ratio, elongation ratio, form factor and compactness coefficient and were also considered in the ranking process [4].

Hence highest priority ranking was given to the linear parameters with the highest values whereas lowest ranking to the shape parameters with the lowest values.

A compound parameter (Cp) was computed by averaging the rankings for each linear and shape parameters. The sub-watersheds with lowest (Cp) value were given highest piority, next lowest value was assigned second priority and so on and the sub-watersheds were categorized into Very High, High, Medium and

Low priority classes (Table 3). The results of the analysis show SBW8 and SBW13 fall in the Very High priority category, SBW1, SBW4, SBW5, SBW6, SBW7, SBW12, SBW14 and SBW16 in High priority, SBW2, SBW3, SBW9, SBW10 and SBW15 fall in medium priority whereas SBW11 and SBW17 fall under low priority category (Figure 4).

Table 3. Sub-watershed wise priority ranking based on Morphometric analysis.

Morphometric Parameters												
	Linear parameters						Shape parameters					
Sub-watersheds	D	Fs	Rbm	Lo	Rt	Re	Rc	Rf	Bs	Cc	Cp	Priority value
SBW1 [154.76]	2.84 *[10]*	4.34 *[10]*	4.87 *[2]*	0.17 *[8]*	8.01 *[3]*	0.78 *[11]*	0.27 *[3]*	0.48 *[10]*	2.04 *[3]*	1.9 *[14]*	**7.4**	**High**
SBW2 [31.35]	2.56 *[11]*	3.6 *[14]*	4.6 *[3]*	0.19 *[7]*	2.87 *[15]*	0.68 *[9]*	0.25 *[2]*	0.36 *[8]*	2.71 *[7]*	1.97 *[15]*	**9.1**	**Medium**
SBW3 [12.67]	2.85 *[9]*	4.1 *[12]*	7.0 *[1]*	0.17 *[8]*	2.84 *[16]*	1.06 *[13]*	0.47 *[13]*	0.89 *[12]*	1.11 *[1]*	1.44 *[3]*	**8.8**	**Medium**
SBW4 [20.4]	3.55 *[5]*	6.47 *[3]*	3.36 *[12]*	0.14 *[11]*	5.0 *[11]*	0.7 *[10]*	0.39 *[9]*	0.38 *[9]*	2.53 *[4]*	1.64 *[8]*	**8.2**	**High**
SBW5 [60.41]	3.72 *[4]*	5.66 *[5]*	4.44 *[4]*	0.13 *[12]*	5.95 *[10]*	0.65 *[7]*	0.23 *[1]*	0.33 *[6]*	2.98 *[10]*	2.08 *[16]*	**7.5**	**High**
SBW6 [58.17]	3.3 *[6]*	5.34 *[6]*	3.92 *[6]*	0.15 *[10]*	6.27 *[9]*	0.65 *[7]*	0.29 *[4]*	0.33 *[6]*	2.97 *[9]*	1.83 *[13]*	**7.6**	**High**
SBW7 [52.43]	3.08 *[7]*	4.67 *[8]*	3.74 *[8]*	0.16 *[9]*	6.81 *[7]*	0.7 *[10]*	0.51 *[15]*	0.38 *[9]*	2.61 *[6]*	1.4 *[1]*	**8.0**	**High**
SBW8 [105.81]	3.9 *[3]*	6.14 *[4]*	4.87 *[2]*	0.12 *[13]*	10.37 *[1]*	0.62 *[5]*	0.33 *[6]*	0.3 *[4]*	3.24 *[12]*	1.72 *[11]*	**6.1**	**Very High**
SBW9 [102.66]	2.11 *[13]*	4.13 *[11]*	3.1 *[14]*	0.23 *[5]*	7.1 *[4]*	0.62 *[5]*	0.36 *[8]*	0.3 *[4]*	3.24 *[12]*	1.66 *[9]*	**8.5**	**Medium**
SBW10 [143.22]	1.09 *[16]*	2.1 *[16]*	3.47 *[9]*	0.45 *[2]*	4.59 *[13]*	0.55 *[1]*	0.41 *[11]*	0.24 *[1]*	4.11 *[16]*	1.55 *[5]*	**9.0**	**Medium**
SBW11 [154.62]	0.62 *[17]*	0.86 *[17]*	2.82 *[15]*	0.79 *[1]*	1.93 *[17]*	0.64 *[6]*	0.4 *[10]*	0.32 *[5]*	3.09 *[11]*	1.57 *[6]*	**10.5**	**Low**
SBW12 [62.17]	2.03 *[14]*	5.03 *[7]*	3.39 *[11]*	0.24 *[4]*	7.01 *[5]*	0.58 *[2]*	0.39 *[9]*	0.27 *[2]*	3.68 *[15]*	1.6 *[7]*	**7.6**	**High**
SBW13 [15.83]	4.28 *[1]*	10.68 *[1]*	3.47 *[9]*	0.11 *[14]*	8.32 *[2]*	0.97 *[12]*	0.48 *[14]*	0.73 *[11]*	1.36 *[2]*	1.43 *[2]*	**6.8**	**Very High**
SBW14 [16.97]	4.1 *[2]*	9.36 *[2]*	3.42 *[10]*	0.12 *[13]*	6.48 *[8]*	0.7 *[10]*	0.35 *[7]*	0.38 *[9]*	2.6 *[5]*	1.69 *[10]*	**7.6**	**High**
SBW15 [40.12]	2.33 *[12]*	3.76 *[13]*	3.85 *[7]*	0.21 *[6]*	4.6 *[12]*	0.67 *[8]*	0.46 *[12]*	0.35 *[7]*	2.83 *[8]*	1.47 *[4]*	**8.9**	**Medium**
SBW16 [90.1]	2.9 *[8]*	4.58 *[9]*	4.23 *[5]*	0.17 *[8]*	6.86 *[6]*	0.6 *[4]*	**0.31** *[5]*	0.28 *[3]*	3.46 *[13]*	1.78 *[12]*	**7.3**	**High**
SBW17 [94.07]	1.37 *[15]*	2.15 *[15]*	3.19 *[13]*	0.36 *[3]*	4.08 *[14]*	0.59 *[3]*	**0.47** *[13]*	0.28 *[3]*	3.54 *[14]*	1.44 *[3]*	**9.6**	**Low**

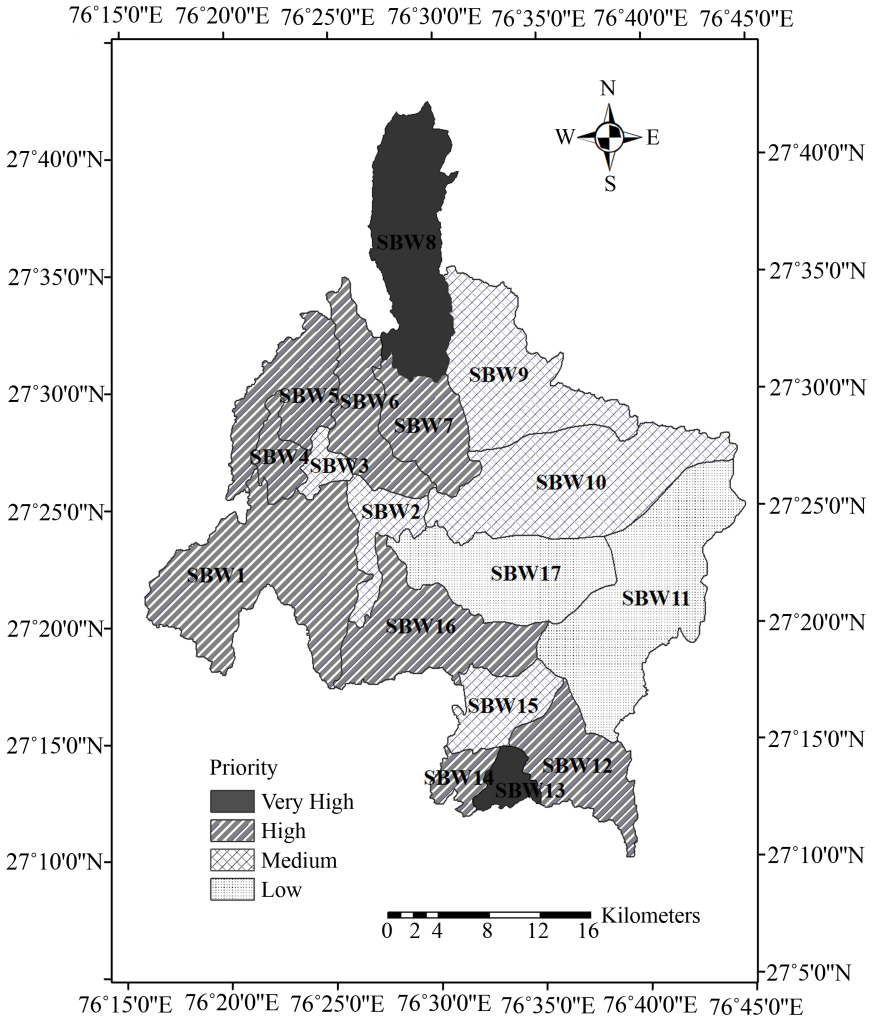

Figure 4. Sub-watershed priority ranking map based on Morphometric analysis.

4.4. Prioritization of Sub-Watersheds Based on LULC Analysis

Five LULC categories namely cultivated land, dense forest, open forest, open scrub and wasteland were considered for sub-watershed prioritization in Ruparel watershed. Sub-watersheds with a higher percentage of wasteland or a lower percentage of cultivated land, dense forest, open forest, and open scrub were given high priority, whereas those with a lower percentage of wasteland or a higher percentage of cultivated land, dense forest, open forest, and open scrub were given low priority [8]. Based on the (Cp) value, sub-watersheds were categorized into Very High, High, Medium and Low priority classes. Results show SBW6 and SBW10 fall under Very High priority category, SBW2, SBW5, SBW7, SBW8, SBW9, SBW12, SBW13 and SBW16 fall under High priority, SBW1, SBW3, SBW4 and SBW17 under Medium priority, whereas SBW11, SBW14 and SBW15 fall under low priority category (Table 4 and Figure 5).

The findings of both the morphometric and LULC analysis were then compared to identify the common sub-watersheds that fall within each priority class

Table 4. Sub-watershed wise priority ranking based on LULC analysis.

Sub-watersheds	Land use and Land cover Analysis					Cp value	Priority
	Wasteland [%]	Cultivated land [%]	Dense forest [%]	Open forest [%]	Open Scrub [%]		
SBW1 **[154.76]**	17.05 *[6]*	12.05 *[9]*	46.17 *[11]*	6.82 *[9]*	6.48 *[9]*	**8.8**	**Medium**
SBW2 **[31.35]**	23.36 *[3]*	7.31 *[4]*	54.31 *[13]*	-	8.0 *[11]*	**7.75**	**High**
SBW3 **[12.67]**	12.86 *[7]*	10.9 *[8]*	45.15 *[9]*	5.29 *[6]*	20.36 *[14]*	**8.8**	**Medium**
SBW4 **[20.4]**	-	3.38 *[1]*	31.18 *[6]*	33.77 *[11]*	29.95 *[17]*	**8.75**	**Medium**
SBW5 **[60.41]**	30.79 *[1]*	19.2 *[11]*	7.45 *[2]*	11.41 *[10]*	22.15 *[16]*	**8.0**	**High**
SBW6 **[58.17]**	19.39 *[5]*	6.95 *[2]*	64.19 *[14]*	0.07 *[1]*	4.95 *[7]*	**5.8**	**Very High**
SBW7 **[52.43]**	20.45 *[4]*	8.37 *[5]*	50.16 *[12]*	5.07 *[5]*	9.65 *[12]*	**7.6**	**High**
SBW8 **[105.81]**	24.46 *[2]*	18.13 *[10]*	34.38 *[7]*	-	7.07 *[10]*	**7.25**	**High**
SBW9 **[102.66]**	6.41 *[11]*	30.11 *[14]*	38.48 *[8]*	3.52 *[4]*	0.89 *[3]*	**8.0**	**High**
SBW10 **[143.22]**	7.28 *[10]*	59.01 *[17]*	3.39 *[1]*	0.09 *[2]*	1.98 *[4]*	**6.8**	**Very High**
SBW11 **[154.62]**	3.07 *[13]*	55.66 *[16]*	-	-	0.25 *[1]*	**10.0**	**Low**
SBW12 [62.17]	1.38 *[15]*	25.82 *[12]*	10.81 *[3]*	-	0.76 *[2]*	**8.0**	**High**
SBW13 **[15.83]**	-	7.14 *[3]*	65.55 *[15]*	5.31 *[7]*	4.55 *[6]*	**7.75**	**High**
SBW14 **[16.97]**	1.53 *[14]*	9.07 *[6]*	46.02 *[10]*	6.42 *[8]*	20.68 *[15]*	**10.6**	**Low**
SBW15 **[40.12]**	9.07 *[9]*	27.99 *[13]*	29.06 *[5]*	-	10.44 *[13]*	**10.0**	**Low**
SBW16 **[90.1]**	11.06 *[8]*	9.74 *[7]*	70.81 *[16]*	0.09 *[2]*	2.11 *[5]*	**7.6**	**High**
SBW17 **[94.07]**	5.49 *[12]*	42.77 *[15]*	25.31 *[4]*	0.21 *[3]*	5.51 *[8]*	**8.4**	**Medium**

(Table 5). It was concluded that SBW5, SBW7, SBW12 and SBW16 are the common sub-watersheds that fall under High priority, SBW3 falls under Medium priority whereas SBW11 falls under Low priority, based on morphometric and LULC analysis. The remaining eleven sub-watersheds show very less or no co-relation under morphometric and LULC analysis. Figure 6 presents the

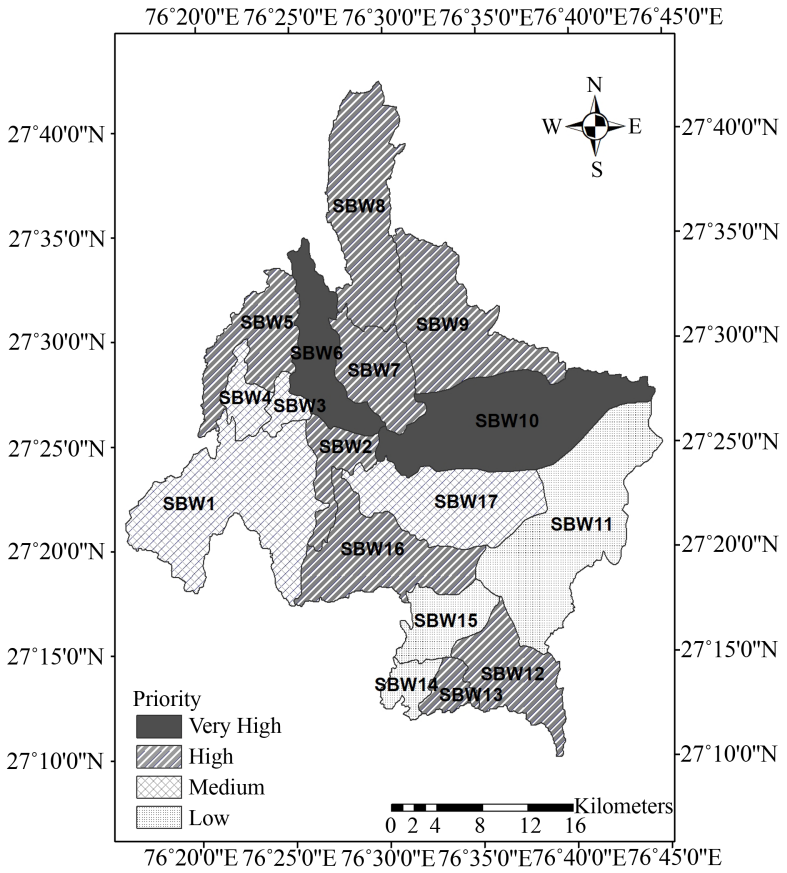

Figure 5. Sub-watershed priority ranking map based on LULC analysis.

Table 5. Sub-watershed wise common priority ranking in Ruparel watershed.

Sub-watersheds	(Cp) value for Morphometric Parameters	Final Priority	(Cp) value for LU/LC parameters	Final Priority	Common Priority
SBW1	7.4	High	8.8	Medium	
SBW2	9.1	Medium	7.75	High	
SBW3	8.8	Medium	8.8	Medium	Medium
SBW4	8.2	High	8.75	Medium	
SBW5	7.5	High	8.0	High	High
SBW6	7.6	High	5.8	Very High	
SBW7	8.0	High	7.6	High	High
SBW8	6.1	Very High	7.25	High	
SBW9	8.5	Medium	8.0	High	
SBW10	9.0	Medium	6.8	Very High	
SBW11	10.5	Low	10.0	Low	Low
SBW12	7.6	High	8.0	High	High
SBW13	6.8	Very High	7.75	High	
SBW14	7.6	High	10.6	Low	
SBW15	8.9	Medium	10.0	Low	
SBW16	7.3	High	7.6	High	High
SBW17	9.6	Low	8.4	Medium	

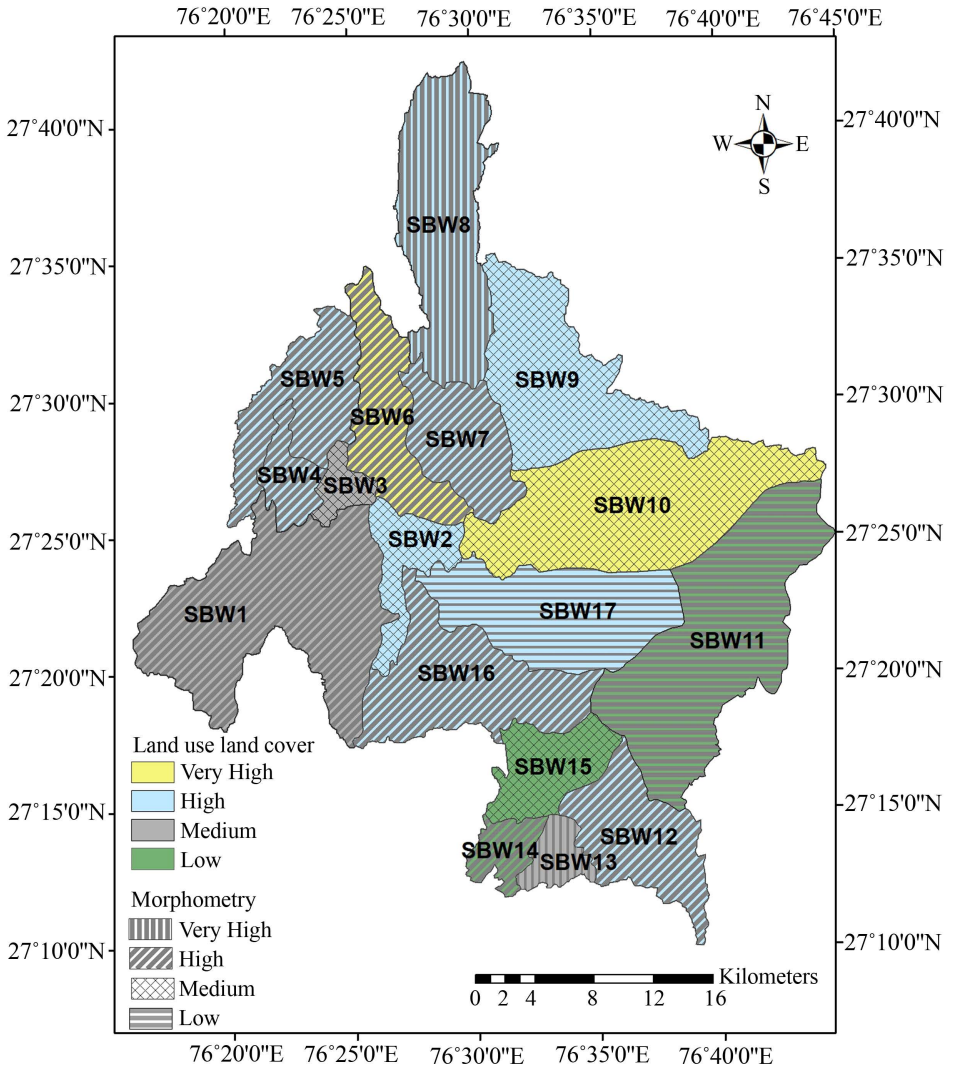

Figure 6. Sub-watershed wise final prioritiy ranking map based on superimposition of Morphometric and LULC parameters.

composite sub-watershed prioritization, on the basis of integration of both morphometric and LULC parameters after their superimpostion in GIS.

5. Conclusion

The current study illustrates the holistic approach of remote sensing and GIS techniques for the prioritization of sub-watersheds in Ruparel watershed based on drainage morphometry and LULC analysis. Basin morphometry in integration with LULC analysis enables prioritization and characterization at sub-watershed level giving a measure of risk potential of sub-watersheds. The present study indicates the stress of the sub-watersheds within the rainfed Ruparel watershed. Correlation of results based on morphometric and LULC analysis show SBW5, SBW7, SBW12 and SBW16 fall under High priority and demand prompt attention from planners and decision makers for conservation measures. The sub-watersheds, SBW3 falls under Medium priority, whereas SBW11 falls under

Low priority category. The remaining sub-watersheds show little or no correlation and therefore differ in their priority. Sub-watersheds with High priority ranking need to be taken up for immediate conservation measures for sustainable development under watershed development programme of the state/central governments.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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