Sub-watersheds Prioritization for Watershed Planning and Management, of Nandani Watershed, Western Maharashtra, India using Geospatial Techniques

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Abstract : Drainage morphometric analysis is very important to understand the hydrological and morphological characteristics of any region. Geographic Information system (GIS) technique is appropriate tool for the identification of geomorphological features. GIS and image processing techniques can be used to define morphological characteristics and to investigate the characteristics of the basin. The present study focused on the morphometric analysis of Nandani watershed using RS and GIS techniques. The study area has been classified into seven sub-watersheds, which have ordered SW1–SW7. The very important quantitative watershed aspects such as linear, relief and areal have been taken in consideration for morphometric analysis of watersheds, and eighteen morphometric parameters have been selected and used for ranking and prioritizing of sub-watersheds. In this regard, sub-watersheds (SW2, SW1 and SW4) and (SW6, SW5 and SW3) have categorized into higher and medium priorities, whereas sub-watershed (SW7) has assigned at lower priority. This shows that SW7 is relatively sustainable than other sub-watersheds, on the contrary, SW2 is relatively affected sub-watershed by runoff and soil erosion that needs first priority for management practices. For this study, all the satellite data is obtained from Bhuvan website and analyzed in ArcGIS software. Morphometric analysis of watershed was performed by determining the parameters like Linear Aspects, Basin Geometry, Drainage Texture Analysis, Relief characteristics. The drainage pattern of stream network from the basin have been observed as mainly dendritic type. Watershed boundary, flow direction, flow accumulation, flow volume flow ordering have been prepared using a hydrological tool and the slope aspect has been prepared using a surface tool in ArcGIS. The study is very useful for design and development of soil and water conservation practices such as bunds, check dams, micro-basins and multipurpose tree species planting based on suitable location and design parameters.

***IndexTerms* - Geographic Information system (GIS), Morphometric analysis, Prioritization, watershed.**

I. INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimension of its landforms (Clarke, 1966; Agarwal, 1998; Obi Reddy *et al.*, 2002). Morphometric parameters of a drainage basin describe its form, structure and extension. It is actually quantitative analysis of basin's terrain and drainage network therein which helps us to understand the consequent development of drainage network and thereby enable us to have an idea of the geological and geomorphological processes over time. Thus it gives us a cue of landform evolutionary phase that basin is currently going through as described in various morphometric studies (Horton, 1945; Strahler, 1952; Strahler, 1964; Shreve, 1969; Muller, 1968).

Horton is considered to be the pioneer in application of quantitative techniques in drainage basin analysis. In early days the method was very much manual which was both time taking and laborious (Horton, 1945; Strahler, 1952; Strahler,1964; Shreve, 1969; Muller,1968; Evans IS, 1972; Chorley *et. al.*, 1984; Strahler, 1957; Schumm, 1956; Chorley and Morgan, 1962). Then J.T. Hack's Stream-profile analysis and stream-gradient index proved to be significant in the quantitative description of drainage basins (Hack, 1973). The advent of Remote Sensing and Geographical Information System (GIS) techniques began to make things much easier and computation of results more accurate. Now much advancement in RS, GIS and personal computers has made possible its widespread application in quantitative geomorphology in general and in morphotectonic analysis of drainage basins in particular (Williams, 1972; Mesa,2006; Lyew-Ayee *et al.*, 2007; Altin and Altin, 2011; Buccolini *et al.*, 2012). Here in India too, Quantitative techniques have been applied to study the morphometric analysis of different drainage basins (Vittala *et al.*, 2004; Chopra *et al.*, 2005, Vijith and Sateesh, 2006; Rudraiah *et al.*, 2008; Bagyaraj and Gurugnanam, 2011; Malik *et al.*, 2011; Thomas *et al.*, 2011; Magesh *et al.*, 2012; Singh *et al.*, 2012; Pareta and Pareta, 2012; Rai *et al.*, 2014; Biswas *et al.*, 2014; Chougale and Sapkale, 2017). Various Studies suggests morphometric properties of drainage basins as good indicators of structural influence on drainage development and neotectonic activity (Nag and Chakraborty, 2003; Das *et al.*, 2011; Bali *et al.*, 2012; Demoulin, 2011). There are many studies where morphometric analysis of drainage basins has been used to assess the groundwater potentiality of the basins and to locate suitable sites for construction of check dams and artificial recharge structures (Sreedevi *et al.*, 2005; Narendra and Rao, 2006; Avinash *et al.*, 2011; Mishra *et al.*, 2011; Jasmin and Mallikarjuna, 2013). Watershed prioritisation based on morphometric characteristics has also been carried out and aids in the mapping of high flood potential and erosion prone zones (Javed *et al.*, 2011; Patton and Baker, 1976; Diakakis, 2011; Wakode *et al.*, 2011).

The remote sensing and GIS provides nowadays has become cheap, convenient and gives higher accuracy level results in morphometric analysis of drainage basins. According to (Rao *et al.*, 2010) the fast emerging spatial information technology, remote sensing, GIS, and GPS are effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process. Watershed prioritization is one of the most important processes in natural resource management system especially in areas of sustainable watershed development and planning (Balasubramanian et al. 2017). The present study aims at using the remote sensing and GIS technology to compute various parameters of morphometric characteristics of the Nandani watershed. Prioritization of the 7 subwatersheds of Nandani basin has been attempted with the ranking of the compound parameter.

II. STUDY AREA

The Nandani River is a major tributary of Yerala River. It originates from the hilly regions of Aundh, Maharashtra-India. It flows through rain shadow region of Satara and Sangli districts, which is confluence to Yerala at Shivni near Kadepur, Sangli. The study area is bounded by Latitude 17º 15' to 17º 35' N and Longitude 74º 15' to 74º 25' E (Fig 1). The watershed experiences tropical monsoon climate with normal temperature, humidity and evaporation throughout the year. The study area receives rainfall during South-West monsoon from June to September. The distribution of rainfall is not even all over the area. During July and August it rains more and significant runoff takes place. The rainfall stations are Karad, Kadegaon, Vita, Palus & Vaduj. It has been observed that about 20% rainfall is received during post-monsoon and by thunder showers in the month of May. The temperature may rise up to 44ºC in summer and may fall down to 20ºC during winter. The climate of the region is defined as subtropical with hot and dry weather in the summer.

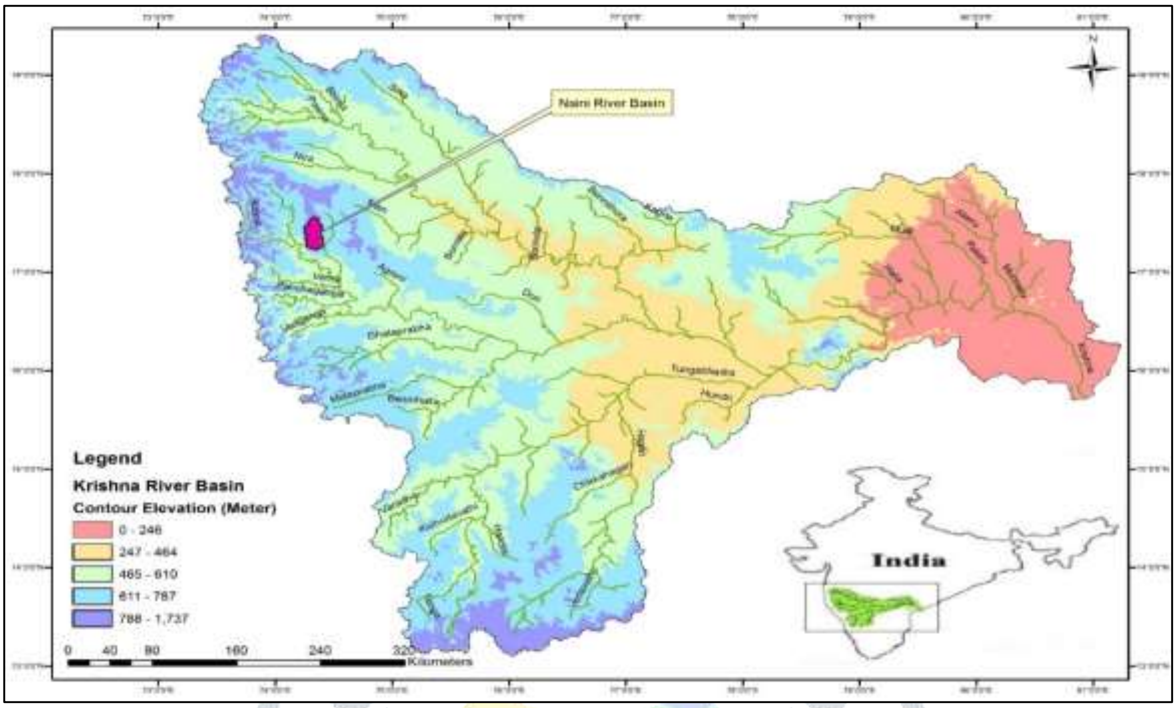

Fig. 1 Location Map of Nandani Watershed

III. METHODOLOGY

In this study Topographic information was digitized and geo-referenced in ArcMap 10.1. The watershed boundary and drainage lines were automatically extracted from the SRTM DEM using Arc hydro tools in ArcGIS 10.1 by collaborating SOI toposheets. DEM and contours maps were also generated for the basin. Spatial analyst tools in ArcGIS 10.1 software were largely used for computation of aspect, relief and slope of the basin. All morphometric parameters such as linear, areal and relief have been calculated with the help of DEM in consultation with SOI topographical maps and Google Earth in GIS environment (ArcMap 10.1). To determine the morphometric parameters of a basin, two extraction techniques have been developed: extraction of the watershed boundary and extraction of the stream network using SRTM DEM from the watershed.

The Nandani watershed is extracted from the Bhuvan Digital Elevation Model (DEM). The contributing basin area was extracted with the help of various geoprocessing techniques in ArcGIS 10 software. The stream network of the study area is extracted from a series of geoprocessing tools in ArcGIS 10. The output of the stream network is smoothened using a smooth line tool in ArcGIS 10. Different parameters such as stream number, stream order, stream length ratio, stream length ratio, bifurcation ratio, basin length, basin area, relief ratio, elongation ratio, overland flow length, drainage density, stream frequency, drainage texture, form factor and circulatory ratio were evaluated using the standard mathematical formulas given in Table 1. Moreover, the aspect and the slope map of the study area were derived from the STRM DEM using the aspect and slope tool in ArcGIS 10 Spatial analyst module.

The Ranking And Prioritizing of Sub-watersheds based on compound parameter (Cp). The compound parameter (Cp) is calculated by taking average of eighteen parameters from Linear, Shape and Areal parameters (Table 4). The subwatershed with the least compound value has assigned at the highest priority and denoted by number 1, the next higher value has denoted by number 2 and so on, then the sub-watershed that got the highest compound value has assigned at the last priority number. Based on the compound factor value, all the 7 subwatersheds of Nandani Watershed were classified into three priority categories as High, Medium and Low priority. The highest priority indicates there is a need to development of sub-watershed.

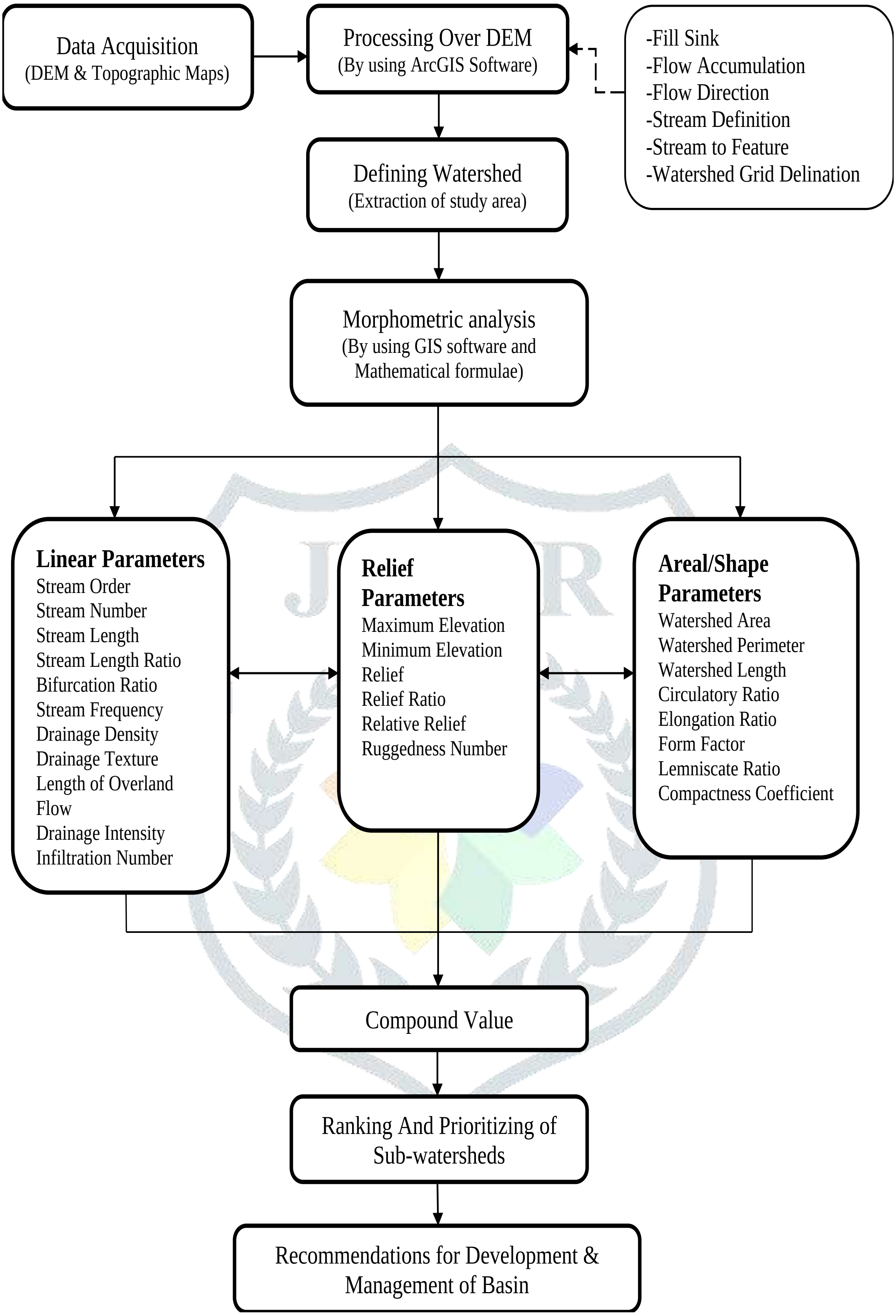

Fig. 2 Methodological flowchart for watershed morphometric analysis

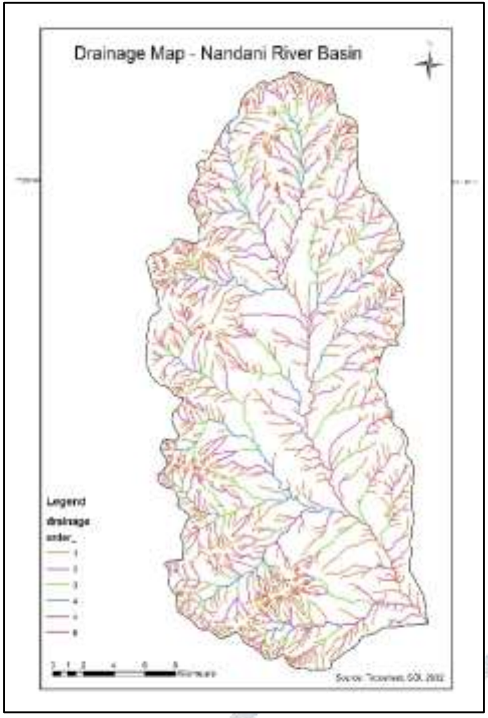

Fig. 3 Drainage Map of Study Area

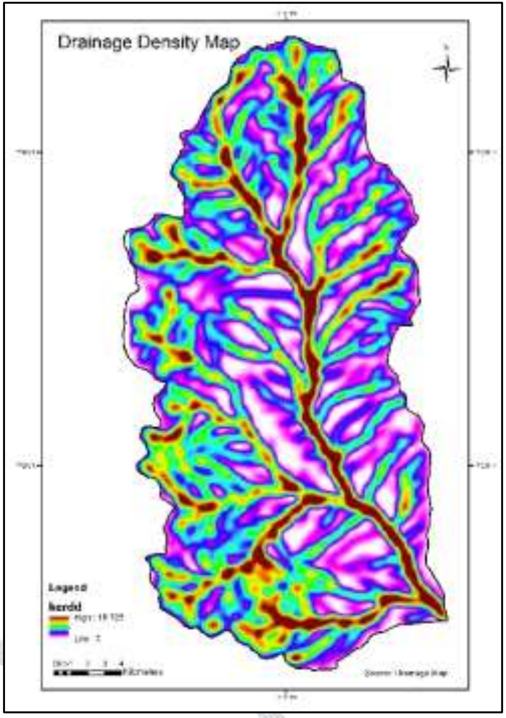

Fig. 4 Drainage Density map of study Area

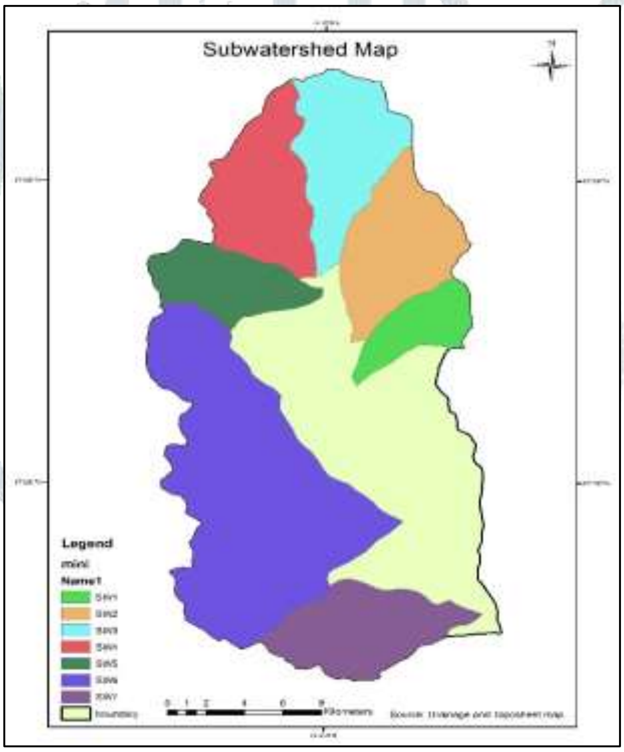

Fig. 5 Map of subwatershed drainage network

IV. RESULT AND DISCUSSION

The morphometric parameters of Nandani watershed have been examined and the results are given below (Table 2). The total drainage area of the Nandani basin is 492 km^2. The drainage pattern is dendritic in nature and it is influenced by the general topography of the area.

Linear Aspects

Stream Order (Su)

There are four different system of ordering streams that are available (Gravelius, 1914; Horton, 1945; Strahler, 1952; Schideggar, 1970). Strahler's system, which is a slightly modified of Hortons system, has been followed because of its simplicity, where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channels segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When the two channels of different order join together then the higher order is maintained. The trunk stream is the highest order stream segment. It is found that Nandani watershed is divided into seven sub basins. The SW1 and SW5 sub basins have 4th order stream, SW2,SW3,SW4,SW7 have 5th order stream and SW6 have 6th order stream (Table 3). Drainage patterns of the stream network from the basin have been observed mainly as dendritic, indicating homogeneity in texture and lack of structural control. The characteristics of the stream networks are very significant for studying the characteristics of the basin (Strahler, 2002).

Stream Length (Lu)

The stream length (Lu) has been calculated on the basis of the Horton’s law. Stream length is one of the most important hydrological characteristics of the area as it provides information on surface runoff characteristics. The river of fairly smaller length is characteristics of regions with steep slopes and better textures. Longer length rivers commonly suggestive of smoother slope. In general, the total length of river section is highest in first order stream and the length is inversely proportional to the stream order. The numbers of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The SW6 (352.752 Km) has highest stream length and SW1 (45.73 Km) has lowest stream length (Table 3). The change may indicate the flow of high altitude streams, lithological variations and moderately steep slopes (Singh, 1997). The examination of stream order validates the Horton’s law of stream number i.e. The number of the stream segments of each order forms an inverse geometric series with the order number.

Table 1 : Formulae and methods adopted to compute watershed morphometric parameters

Sr.No.	Parameters	Formulae	References
	A) Basic Parameters		
1	Area (A) (Km^2)	GIS software analysis	
2	Perimeter (P) (Km)	GIS software analysis	
3	Maximum elevation (H) (m)	GIS software analysis	
4	Minimum elevation (h) (m)	GIS software analysis	
5	Length of Basin (Km)	GIS software analysis	Nookaratnam et al. (2005)
6	Stream order (U)	Hierarchical rank	Strahler (1964)
7	Stream number (Nu)	Nu = Nu1 + Nu2 + ⋯ + Nun	Horton (1945)
8	Stream length (Km)	Lu = Lu1 + Lu2 + ⋯ + Lun	Horton (1945)
	B) Derived parameters		
	a) Linear aspects		
1	Mean stream length (Km)	Lsm = Average of stream length of all orders	Horton (1945)
2	Bifurcation ratio	$Rb = N_u/N_{u+1}$	Schumm (1956)
3	Stream length ratio	$Rl = L_u/L_{u-1}$	Horton (1945)
4	Mean bifurcation ratio	Rbm = Average of bifurcation ratios of all orders	Schumm (1956)
5	Mean stream length ratio	Rlm = Average of stream length ratios of all orders	Schumm (1956)
6	Stream frequency (Km^{-2})	Fs = Nu/A	Schumm (1956)
7	Drainage density (Km/Km^2)	Dd = Lu/A	Schumm (1956)
8	Drainage texture (Km^{-1})	Dt = Nu/P	Schumm (1956)
9	Length of overland flow (Km)	Lo = 1/(2Dd)	Schumm (1956)
10	Drainage intensity (Km^{-1})	Di = Fs/Dd	Faniran (1968)
11	RHO coefficient (ρ)	$\rho = Rlm/Rb$	Horton (1945)
12	Infiltration number (Km^{-3})	If = Fs × Dd	Faniran (1968)
	b) Relief aspects		

1	Relief (Km)	Bh = H–h	Strahler (1952)
2	Relief ratio	Rh = Bh/Lb	Schumm (1956)
3	Relative relief	Rhp = H × 100/P	Melton (1957)
4	Ruggedness number	Rn = Bh × Dd	Strahler (1952)
	c) Areal/shape aspects		
1	Circulatory ratio	Rc = 4πA/P2; π = 3.14	Miller (1953)
2	Elongation ratio	$Re = (2/Lb) \times (A/\pi)^{0.5}$	Schumm (1956)
3	Form factor	$Ff = A/Lb^2$	Horton (1945)
4	Lemniscates ratio	$K = Lb^2/4A$	Chorley et al. (1957)
5	Compactness coefficient	$Cc = P/2(\pi A)^{0.5}$	Horton (1945)

Table 2 : Computed results of watershed morphometric parameters

Sr.No.	Parameters	Computed results for sub-watersheds						
		SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	SW 7
1	Area (A) (Km^2)	19	44	44	43	28	136	40
2	Perimeter (P) (Km)	20	30	33	32	24	61	29
3	Maximum elevation (H) (m)	729	799	938	832	882	779	815
4	Minimum elevation (h) (m)	672	687	703	711	706	635	608
5	Length of Basin (Lb) (Km)	9.25	13.67	17.38	16.32	11.85	23.46	14.1
6	Highest stream order (U)	4th	5th	5th	5th	4th	6th	5th
7	Stream number (Nu)	58	112	204	167	114	566	206
8	Stream length (Lu) (Km)	45.730	95.238	155.785	115.840	82.787	352.752	127.806
9	Mean stream length (Lsm) (Km)	11.433	19.048	31.157	23.168	20.697	58.792	25.561
10	Bifurcation ratio (Rb)	11.500	13.250	14.465	13.838	14.449	17.414	15.008
11	Stream length ratio(Rl)	13.389	1.461	2.274	2.307	2.348	2.047	4.212
12	Mean bifurcation ratio (Rbm)	2.875	2.650	2.893	2.768	3.612	2.902	3.002
13	Mean stream length ratio (Rlm)	3.347	0.292	0.455	0.461	0.587	0.341	0.842
14	Stream frequency (Fs) (Km^{-2})	3.053	2.545	4.636	3.884	4.071	4.162	5.150
15	Drainage density (Dd) (Km/Km^2)	2.407	2.165	3.541	2.694	2.957	2.594	3.195
16	Drainage texture (Dt) (Km^{-1})	2.900	3.733	6.182	5.219	4.750	9.279	7.103
17	Length of overland flow (Lo) (Km)	0.208	0.231	0.141	0.186	0.169	0.193	0.156
18	Drainage intensity (Di) (Km^{-1})	1.268	1.176	1.309	1.442	1.377	1.605	1.612
19	RHO coefficient (ρ)	0.291	0.022	0.031	0.033	0.041	0.020	0.056

20	Infiltration number (If) (Km^{-3})	7.347	5.510	16.415	10.463	12.038	10.795	16.455
21	Relief (Bh) (m)	57.000	112.000	235.000	121.000	176.000	144.000	207.000
22	Relief ratio (Rh)	6.162	8.193	13.521	7.414	14.852	6.138	14.681
23	Relative relief (Rhp)	3.645	2.663	2.842	2.600	3.675	1.277	2.810
24	Ruggedness number (Rn)	137.190	242.424	832.034	325.968	520.375	373.502	661.396
25	Circulatory ratio (Rc)	0.597	0.614	0.507	0.527	0.611	0.459	0.597
26	Elongation ratio (Re)	0.534	0.547	0.430	0.453	0.503	0.560	0.506
27	Form factor (Ff)	0.222	0.235	0.146	0.161	0.199	0.247	0.201
28	Lemniscate ratio (K)	1.126	1.062	1.716	1.549	1.254	1.012	1.243
29	Compactness coefficient (Cc)	1.294	1.275	1.403	1.376	1.279	1.475	1.293

Table 3 : Stream orders and numbers

Sr.No.	Stream orders	Code of watersheds						
		SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	SW 7
1	Number of stream (Nu)	58	112	204	167	114	566	206
	1st order (Nu1)	45	85	153	122	87	404	147
	2nd order (Nu2)	10	20	39	34	23	122	44
	3rd order (Nu3)	2	4	8	8	3	31	12
	4th order (Nu4)	1	2	3	2	1	6	2
	5th order (Nu5)	-	1	1	1	-	2	1
	6th order (Nu6)	-	-	-	-	-	1	-
2	Length of stream (Lu)	45.721	95.238	155.785	115.84	82.787	352.752	127.806
	1st order (Lu1)	27.614	50.468	73.178	57.468	49.213	187.539	73.777
	2nd order (Lu2)	9.906	23.363	41.06	32.353	18.912	84.647	22.626
	3rd order (Lu3)	0.587	13.122	26.149	10.899	5.483	57.105	19.074
	4th order (Lu4)	7.614	5.732	8.863	10.414	9.179	15.109	3.164
	5th order (Lu5)	-	2.553	6.535	4.706	-	6.998	9.165
	6th order (Lu6)	-	-	-	-	-	1.354	-
3	Bifurcation ratio (Rb)	11.5	13.25	14.4647	13.8382	14.4493	17.4136	15.0076
	Nu1/Nu2(Rb1)	4.5	4.25	3.92308	3.58824	3.78261	3.31148	3.34091
	Nu2/Nu3(Rb2)	5	5	4.875	4.25	7.66667	3.93548	3.66667
	Nu3/Nu4(Rb3)	2	2	2.66667	4	3	5.16667	6
	Nu4/Nu5(Rb4)	-	2	3	2	-	3	2

	Nu5/Nu6(Rb5)	-	-	-	-	-	2	-
4	Stream length ratio (Rl)	13.389	1.461	2.274	2.307	2.348	2.047	4.212
	Lu2/Lu1(Rl1)	0.359	0.463	0.561	0.563	0.384	0.451	0.307
	Lu3/Lu2(Rl2)	0.059	0.562	0.637	0.337	0.290	0.675	0.843
	Lu4/Lu3(Rl3)	12.971	0.437	0.339	0.956	1.674	0.265	0.166
	Lu5/Lu4(Rl4)	-	-	0.737	0.452	-	0.463	2.897
	Lu6/Lu5(Rl5)	-	-	-	-	-	0.193	-

Mean Stream Length (Lsm)

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). The mean stream length (Lsm) is the ratio of the total stream length of order to the number of stream. The mean stream length of SW1 is 11.433 Km, SW2 is 19.048 Km, SW3 is 31.157 Km, SW4 is 23.168 Km, SW5 is 20.697 Km, SW6 is 58.792 Km and SW7 is 25.561 Km (Table 2). The sub watershed 6 have maximum mean stream length and sub watershed 1 have minimum mean stream length.

Stream Length Ratio (RL)

Horton (1945, 291) states that the length ratio is the ratio of the mean (Lu) of segments of order (So) to mean length of segments of the next lower order (Lu-1), which tends to be constant throughout the successive orders of a basin (Table 3). Horton’s law of stream lengths refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the stream length is the average length of segments of the first order. Changes of stream length ratio from one order to the another order indicating their late youth stage of geomorphic development (Singhand Singh, 1997).

Bifurcation Ratio (Rb)

Bifurcation ratio (Rb) is the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn, 1956). Horton (1945) considered that the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. It is noted that Rb is not the same from one order to the next. In the study area total Rb varies from 11.5 to 17.41 (Table 3). Usually these values of Bifurcation Ratio common in the areas where geologic structures less disturbing the drainage pattern.

Stream Frequency (Fs)

The drainage frequency introduced by Horton (1932, 357 and 1945, 285) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area. In the present study, the stream frequency of SW1 and SW2 lies between 2.5/km^2 to 3.5/km^2 which classified as moderate stream frequency. The moderate stream frequency value indicate moderate slope and moderate permeability. SW3, SW4, SW5, SW6 and SW7 have stream frequency more than 3.5/km^2 (Table 2) which is classified as high stream frequency which indicates high slope and high permeability.

Drainage Density (Dd)

Drainage density (Dd) is the ratio of stream length per unit area in region of watershed (Horton, 1945, 243 and 1932, 357; Strahler, 1952 and 1958; Melton, 1958) is another element of drainage analysis. Drainage density (Dd) is the expression of the closeness of spacing of channel within a basin as per Horton (1945). It is the important indicator of landform element and important parameter to determine the travel time of water in the basin. Here all the sun watersheds have drainage density less than 2 Km/Km^2 (Table 2) indicating low drainage densities (Table 2). Low drainage density is indicative of low relief, low slope, high infiltration capacity and low water regimes throughout the basin.

Drainage texture (Dt)

Drainage texture (Dt) is the total number of streams per perimeter of a watershed (Horton 1945). It shows the relative spacing of drainage lines. The Dt values of <2 indicate very coarse, 2–4 coarse, 4–6 moderate, 6–8 fine, >8 very fine drainage texture (Smith 1950). The SW1 and SW2 have drainage texture between 2-4 which indicates course drainage texture, SW4 and SW5 have drainage texture between 4-6 which indicates moderate drainage texture, SW3 and SW7 have drainage texture between 6-8 which indicates Fine drainage texture and SW6 having drainage texture more than 8 which indicates very fine drainage texture (Table 2).

Drainage Intensity (Di)

Faniran (1968) defines that the drainage intensity is the ratio of the stream frequency to the drainage density. This study area shows drainage intensity between 1.2-1.7(Table 2) which is low. This low value of the drainage intensity concludes that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, the surface runoff isn't removed quickly from the watershed, making it highly possible to flooding, gully erosion and landslides may takes place.

Rho Coefficient (ρ)

The Rho coefficient is the ratio of Mean stream length ratio to the bifurcation ratio. The Rho coefficient depends upon the climatic, geologic, biologic, geomorphologic, and anthropogenic factors. Here, Rho coefficient is higher at SW1, while lower at remaining sub watersheds (Table 2). Lower values of Rho coefficient have lover water storage during flood periods and as such a results into the erosion effect during elevated discharge (Mesa, 2006).

Infiltration Number (If)

The infiltration number of a watershed is the multiplication of drainage density and stream frequency and gives an idea about the infiltration related characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher runoff. In the present study, SW3, SW4 and SW5, SW6 and SW7 are higher, and SW1 and SW2 are lower values in infiltration number (Table 2). This indicates that SW3, SW4, SW5 , SW6 and SW7 are relatively dominating higher runoff while SW1 and SW2 having lower runoff.

Drainage Pattern (Dp)

In the watershed, the drainage pattern represents the influence of slope, lithology and structure of the basin. Finally, the study of the drainage pattern helps in identifying the stage in the cycle of erosion. Drainage pattern represents some characteristics of drainage basins through drainage intensity and drainage texture. The geology of the basin, the strike and dip of depositional rocks, the presence of faults and other geological structure details can be derived from drainage patterns. Nandani watershed has dendritic pattern. Dendritic pattern is the most common pattern formed in a drainage basin composed of fairly homogeneous rock with no or little control over the underlying geological structure.

Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is reach into definite channels. Over land area is defined as half of the reciprocal of drainage density. It is one of the most important variable, affecting both the hydrological and physiographical developments of the drainage basin (Horton 1945). Length overland flow value for this sub watershed is in between 0.141 to 0.208 (Table 2). This low Lg value indicates that the rainwater had to travel relatively lower distance before getting concentrated into stream channels (Chitra et al. 2011). The rainwater will enter the stream quickly.

Basin Geometry
Length of the Basin (Lb)

Several people defined the basin length in different ways, such as Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gregory and Walling (1973) defined the basin length as the longest length in the basin in which are end being the mouth. Gardiner (1975) defined the basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in any direction around the perimeter. The total length of Nandani watershed in accordance with the definition of Schumm (1956) that is 106.03 Kms. The length of basin for SW1,SW2,SW3,SW4,SW5,SW6,SW7 is 9.25, 13.67, 17.38, 16.32, 11.85, 23.46, 14.1 Kms respectively (Table 2).

Basin Area (A)

The area of the watershed is another important parameter such as length of the stream drainage. Schumm (1956) established an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas in watershed. In present study, the area ranges 19–136 km2, the smallest at SW1 and the largest at SW6 (Table 2).

Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. The basin perimeter is computed by using ArcGIS-10 software, The perimeter ranges 20–61.00 km; the shortest at SW1 and the longest at SW6 (Table 2).

Length Area Relation (Lar)

Hack (1957) found that for a large number of basins, the stream length and basin area are related by a simple power function as follows: $Lar = 1.4 \times A^{0.6}$.

Areal/ Shape Aspects
Circulatory ratio (Rc)

Circulatory ratio (Rc) is ratio of watershed area to area of a circle having the same circumference as perimeter of the watershed (Miller 1953). A circular watershed is the most susceptible to peak discharge because it will yield the shortest time of concentration. Lower, medium and higher values of Rc indicate young, mature and old stages of watershed development. SW1, SW2, SW5, SW7 are higher, while SW3, SW4, SW6 show lower values in circulatory ratio at the study area (Table 2).

Elongation Ratio (Re)

According to Schumm (1965, 612), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio lies between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed area can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). The SW1, SW2, SW5, SW6, SW7 having elongation ratio in between 0.5-0.7 which indicate that this sub watersheds are elongated and SW3 and SW 4 having elongation ratio below 0.5 which indicates that SW3 and SW4 are more elongated (Table 2).

Form Factor (Ff)

According to Horton (1932), form factor is defined as the ratio of basin area to square of the basin length. The form factor value is always be less than 0.754 (for a perfectly circular watershed). The watershed will be more stretched because the value of form factor reduces. The watershed with excessive form factors have elevated crest flows of lesser period, but lengthened watershed having minimal form factor. Here, value of Ff is lower at SW3, SW4 and SW5 while SW1, SW2, SW6 and SW7 (Table 2) are higher in form factor in the study area. Smaller the value of the form factor, more elongated will be the watershed.

Lemniscates (k)

Chorely (1957), express the Lemniscate's value to determine the slope of the basin. In the formula $k = Lb^2 / 4 X A$. Where, Lb is the basin length (Km) and A is the area of the basin (km2). In the present study, SW1, SW2, SW5, SW6 and SW7 have lower *K* values, whereas SW3 and SW4 have the higher values (Table 2).

Compactness coefficient (Cc)

Compactness coefficient (Cc) is the ratio of perimeter of watershed to circumference of equivalent circular area of the watershed (Horton 1945). It is an independent of watershed size, but it depends on the slope. independent of watershed size, but it depends on the slope. In the present study, value of Cc is lower at SW1, SW2, SW5 and SW6 whereas SW3, SW4 and SW6 are relatively higher in compactness coefficient (Table 2). Lower values of this parameter indicate the more elongation of the basin and less erosion and vice-versa.

Relief Characterizes

Relief Ratio (Rr)

The difference in elevation between the highest point of the watershed and the lowest point of the valley floor is known as the total relief of the watershed. The relief ratio can be defined as the ratio of the total basin relief to the longest basin dimension parallel to the main drainage line (Schumm, 1956). The probability of a close connection between the relief ratio and the hydrological characteristics of the basin suggested by Schumm, who found that sediments loose per unit area are closely associated with relief ratios. In the study area, the value of relief ratio for sub watershed in between 0.0061 to 0.0049 (Table 2), which is low. It has been found that areas with low to moderate relief and slope are distinguished by a moderate relief ratio. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope.

Relative Relief (Rhp)

Maximum basin relief was obtained from the highest point on the perimeter of the watershed to the mouth of the stream. Using the basin relief (340m), a relief ratio was calculated as suggested by Schumm (1956), which is 0.00615 Melton's (1957) relative relief was also calculated using the formula: $Rhp = (H*100) / P$, where P is perimeter in meters'. In the present study, SW1, and SW5 have higher while SW2, SW3, SW4, SW6 and SW7 (Table 2) have lower values in relative relief.

Ruggedness Number (Rn)

Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. In present study, ruggedness number is in between 0.137 and 0.832 (Table 2), which is low. The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

Ranking and prioritization of sub-watersheds

Linear and relief parameters have direct relationship with soil erodibility (Nookaratnam et al. 2005; Singh and Singh 2014; Sujatha et al. 2015), the highest their value shows the most erodible soil in a watershed. Therefore, a sub-watershed showed the highest value in linear and relief parameters has rated at first rank, second higher value has rated as second rank and so on; and the least value has rated at last the rank. In the contrary, areal/ shape parameters have inverse relationship with soil erodibility (Javed et al. 2009; Raja et al. 2017); the lowest their value the most erodible soil in a watershed. Thus, a sub-watershed showed the lowest value in areal/shape parameters has rated at first rank, the next lower value has rated at second rank and so on, then the highest value has rated at the last rank. Compound method of averaging value was used in this study, because it has expected all morphometric parameters have equal importance for final ranking (Ajay et al. 2014; Farhan 2017). After ranking of all (seven) sub-watersheds based on every single parameter, the ranking values for all parameters of each sub-watershed have added and divided by the number of all parameters, in this case it has divided by eighteen; and then to arrive at compound value. The subwatershed with the least compound value has assigned at the highest priority and denoted by number 1, the next higher value has denoted by number 2 and so on, then the sub-watershed that got the highest compound value has assigned at the last priority number (Ayele et al. 2017; Sheikh et al. 2017; Thapliyal et al. 2017; Kumar and Lal 2017). Based on the compound factor value, all the 7 subwatersheds of Nandani Watershed were classified into three priority categories (Aher et al. 2014) such as (i) high (upto 2), (ii) medium (2 to 2.5) and (iii) low (more than 2.5), as given in Table 4. It was observed from Table 4 that the three sub-watersheds (SW1, SW2 and SW4) were under high category, three sub-watersheds (SW3, SW5 and SW6) under medium category and one sub-watershed (SW7) was under low category. This implies that, the highest priority indicates the greatest degree of runoff, peak discharge and soil erosion risks in that sub-watershed. Thus, it is important to plan proper land and water management practices for each sub-watersheds as per their sensitivity ranks. Eighteen morphometric parameters were selected and used for ranking and prioritizing of sub-watersheds based on their values obtained from the calculation (Table 4). Figure 6 shows the final priority map of sub-watersheds. SW2, SW1 and SW4 are relatively the most susceptible to land degradation being prone to soil erosion, respectively. This is due to their inherent geomorphometric characteristics. Hence, they need immediate attention for soil and water conservation measures or practices according to the final priority.

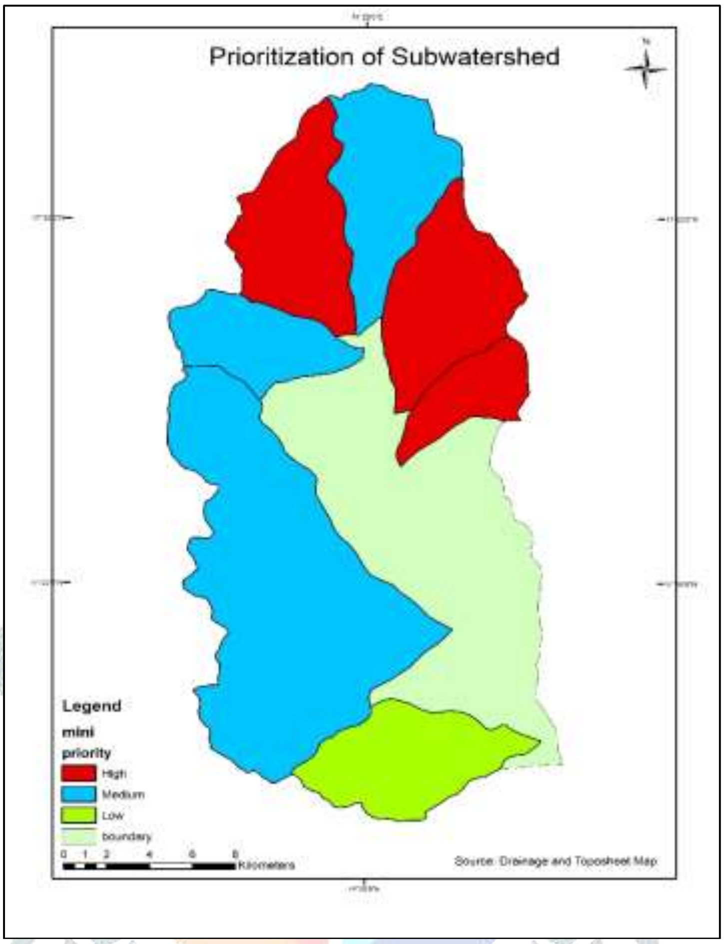

Fig. 6 Map of prioritized sub-watersheds through morphometric parameters

Table 4 : Computed parameters used for ranking and prioritization of sub-watersheds

Sr.No.	Parameters	Computed parametric values and ranks						
		SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	SW 7
1	Rbm	2.875 [5]	2.650 [7]	2.893 [4]	2.768 [6]	3.612 [1]	2.902 [3]	3.002 [2]
2	Rlm	3.347 [1]	0.292 [7]	0.455 [5]	0.461 [4]	0.587 [3]	0.341 [6]	0.842 [2]
3	Fs	3.053 [6]	2.545 [7]	4.636 [2]	3.884 [5]	4.071 [4]	4.162 [3]	5.150 [1]
4	Dd	2.407 [6]	2.165 [7]	3.541 [1]	2.694 [4]	2.957 [3]	2.594 [5]	3.195 [2]
5	Dt	2.900 [7]	3.733 [6]	6.182 [3]	5.219 [4]	4.750 [5]	9.279 [1]	7.103 [2]
6	Lo	0.208 [2]	0.231 [1]	0.141 [7]	0.186 [4]	0.169 [5]	0.193 [3]	0.156 [6]
7	Di	1.268 [6]	1.176 [7]	1.309 [4]	1.442 [5]	1.377 [3]	1.605 [2]	1.612 [1]
8	ρ	0.291 [1]	0.022 [6]	0.031 [5]	0.033 [4]	0.041 [3]	0.020 [7]	0.056 [2]
9	If	7.347 [6]	5.510 [7]	16.415 [2]	10.463 [5]	12.038 [3]	10.795 [4]	16.455 [1]
10	Bh	0.057 [7]	0.112 [6]	0.235 [1]	0.121 [5]	0.176 [3]	0.144 [4]	0.207 [2]
11	Rh	0.0062 [6]	0.008 [4]	0.0135 [3]	0.007 [5]	0.0149 [1]	0.0061 [7]	0.0147 [2]
12	Rhp	3.645 [2]	2.663 [5]	2.842 [3]	2.600 [6]	3.675 [1]	1.277 [7]	2.810 [4]
13	Rn	0.137 [7]	0.242 [6]	0.832 [1]	0.326 [5]	0.520 [3]	0.374 [4]	0.661 [2]

14	Rc	0.5966 [4]	0.614 [1]	0.507 [6]	0.52 [5]	0.611 [2]	0.459 [7]	0.5974 [3]
15	Re	0.534 [3]	0.547 [2]	0.430 [7]	0.453 [6]	0.503 [5]	0.560 [1]	0.506 [4]
16	Ff	0.222 [3]	0.235 [2]	0.146 [7]	0.161 [6]	0.199 [5]	0.247 [1]	0.201 [4]
17	K	1.126 [5]	1.062 [6]	1.716 [1]	1.549 [2]	1.254 [3]	1.012 [7]	1.243 [4]
18	Cc	1.294 [4]	1.275 [7]	1.403 [2]	1.376 [3]	1.279 [6]	1.475 [1]	1.293 [5]
Compound parameter (Cp)		1.740	1.394	2.429	1.904	2.102	2.080	2.506
Ranking		2nd	1st	6th	3rd	5th	4th	7th
Final priority		High	High	Med	High	Med	Med	Low

V. CONCLUSION

Morphometric analysis is very important to illustrate physical and quantitative characteristics of a watershed. Also Morphometric analysis is used to prioritize the sub watershed for effective management of watershed. The present study has proved that the Remote Sensing and GIS is an effective and reliable tool for the analysis of various morphometric parameters of the basin and helps to understand various terrain parameters. The RS data provide recent and accurate information of various landforms and update the existing data. The morphometric parameters evaluated using GIS help to understand various hydrogeological characteristics of the basin. GIS in conjunction with high resolution satellite data helps in better understanding the landforms and drainage pattern demarcations for basin planning and management. Morphometric parameters were evaluated by measurement of linear, areal and relief aspects. It was observed that the three sub-watersheds (SW1, SW2 and SW4) were under high category, three sub-watersheds (SW3, SW5 and SW6) under medium category and one sub-watershed (SW7) was under low category. The approach of this study is helpful for assessment and management of water resources too and can be applied to any drainage basin elsewhere.

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