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Morphometric Analysis and Prioritization of Hebbal Valley in Bangalore

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Abstract : *In this study, morphometric analysis and prioritization of nine sub-watersheds of Hebbal valley, located in Bangalore district of Karnataka state, India is carried out using Remote Sensing and GIS techniques. The morphometric parameters considered for analysis are stream order, stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, relief ratio, length of overland flow and basin shape. The watershed has a dendritic drainage pattern. The bifurcation ratio varies from 1.89 to 3.03 and all sub-watersheds fall under normal basin category. The circularity ratio ranges from 0.42 to 0.78 indicating that all the sub-watersheds except SWD9 are more or less circular. Elongation ration of all the water sheds except SWD3 and SWD9 is above 0.7 indicating that all the sub-watersheds except SWD3 and SWD9 are more or less circular. The compound parameter values are calculated and prioritization rating of nine sub-watersheds in Hebbal valley was carried out. The sub-watershed with lowest compound parameter value is given the highest priority. The sub-watershed SWD3 is likely to be subjected to maximum soil erosion hence it should be provided with immediate soil conservation measures.*

Keywords - *Dendrites', Drainage Patterns, GIS, Morphometric analysis, Sub watershed*

I. INTRODUCTION

The quantitative morphometric analysis of drainage system is an important aspect of characterisation of watersheds [Strahler, 1964][1]. Drainage pattern refers to spatial relationship among streams or rivers, which may be influenced in their erosion by inequalities of slope, soils, rock resistance, structure and geological history of a region. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution [Nag and Chakraborty, 2003][2].

Integrated use of remote sensing and GIS techniques can be used for detailed morphometric analysis and watershed prioritization studies. The input parameters required for morphometric analysis and watershed prioritization studies can be generated by GIS. In the recent past sediment yield and soil erosion studies using GIS and remote sensing technologies have been carried out by many investigators. Amee et. al [2007][3] used a GIS procedure for morphometric analysis and prioritization of watersheds. M.A Khan et. al [2001][4] studied for priority watershed delineation with the objective of selecting watersheds to undertake soil and water conservation measures using remote sensing and Geographical Information System (GIS) techniques. In the present study, morphometric analysis and prioritization of sub-watersheds are carried out for nine sub-watersheds of Hebbal valley of Bangalore, Karnataka, India by using remote Sensing and GIS techniques.

II. DESCRIPTION OF THE STUDY AREA

The study area is located between 12°50' to 13°5'N Latitude and 77°30' to 77°40'E Longitude forming a part of Cauvery river basin. The study area covers an area of 305.217 km^2 and comprises of nine sub-watersheds draining into river Pinakini in Bangalore district of Karnataka. Physiographically the area is characterized by undulating topography with plains and shallow valleys. The study area is located at the north east part of Bangalore. Bangalore is the capital of Karnataka state. However the district does not have any major river flowing. The district falls in Cauvery River basin. The study area attains maximum elevation of 940 m and a minimum of 880 m above mean sea level. The district is well connected by highways and other main roads. The average depth of annual rainfall in the study area (Hebbal valley watershed) is 820 mm. The location map of the study area is shown in fig.1

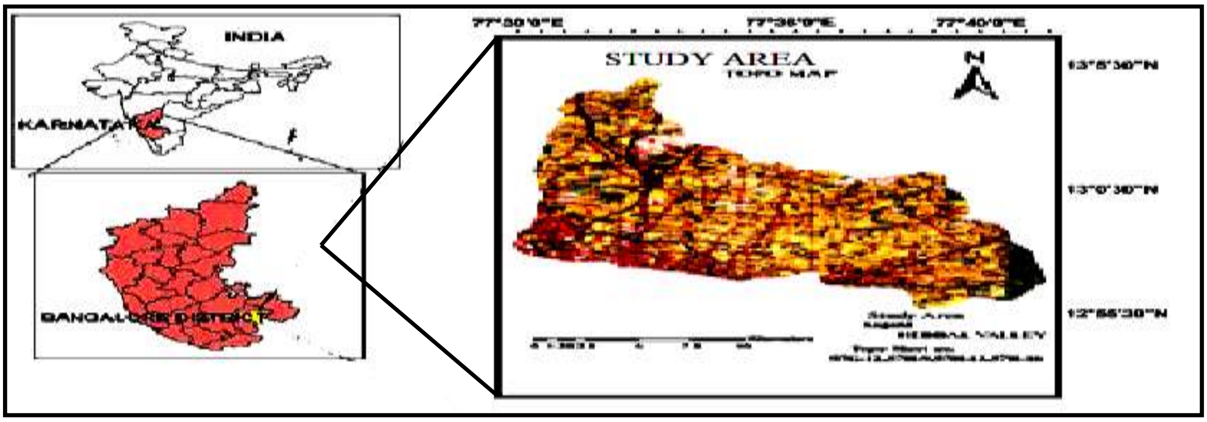
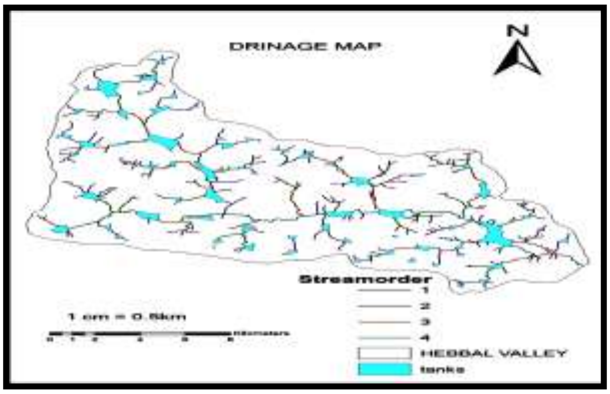


Fig. 1 Location map of the study area

III. METHODOLOGY

Survey of India (SOI) top maps, Indian Remote Sensing satellite data and collateral data were used for the present study. The various topographic maps that were used for the analysis of the area of interest that covers the Hebbal valley catchment are 57G/12, H/9, H/13 and H/16 topomaps on 1:50000 scale. The digitization of dendritic drainage pattern was carried out in GIS environment. The stream ordering was carried out using the Horton's law. The fundamental parameters namely; stream length, area, perimeter, number of streams and basin length were derived from the drainage layer. The morphometric parameters for the delineated watershed area were calculated based on the formula suggested by Horton [1945]5, Strahler [1964][1], Hardly [1961][6], Schumn [1956][7], Nookaratanm et. al. [2005][8] and Miller [1953][9] and are given in Table 1. The morphometric parameters i.e., Mean bifurcation ratio (Rbm), drainage density (Dd), mean stream length (Lsm), compactness coefficient (Cc), basin shape (Bs), stream frequency (Fs), texture ratio (Rt), length of overland flow (Lg), form factor (Rf), circularity ratio (Rc) and elongation ratio (Re) are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility, higher the value, more is erodibility. Hence prioritization of sub-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility [Akram Javed et al., 2009][10] lower the value more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Hence, the ranking of the sub-watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters (Table 3). After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each sub-watersheds were added up for each of the nine sub-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the sub-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on.



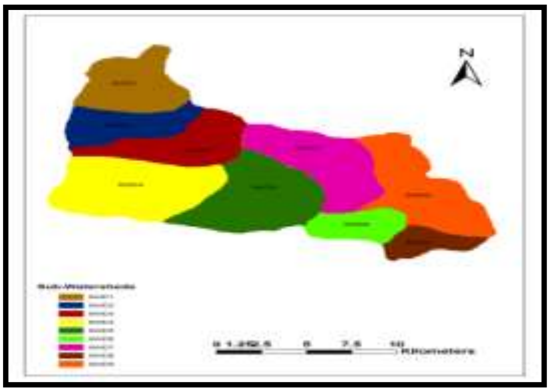


Fig. 2 Drainage Map of Hebbal valley

Fig.3 Sub watersheds

Table 1.Formulae adopted for computation of morphometric parameters

Morphometric Parameters	Formula	Reference
Stream Order (Nu)	Hierarchical rank	Strahler [1964][1]
Stream Length (Lu)	Length of the stream	Horton [1945][5]
Mean Stream Length (Lsm)	Lsm = Lu/Nu	Strahler [1964][1]
Bifurcation Ratio (Rb)	$Rb = Nu/N_{u+1}$	Schumn [1956][7]
Mean Bifurcation Ratio (Rbm)	Rbm=Average of bifurcation ratio	Strahler (1964)[1]
Basin Length (Lb)	$Lb=1.312 \text{ X } A^{0.568}$	Nookartnam et. al [2005][8]
Drainage Density (Dd)	Dd=Lu/A	Horton [1945][5]
Stream frequency (Fs)	Fs= Nu/P	Horton [1945][5]
Texture Ratio (Rt)	Rt= Nu/P	Horton [1945][5]
Form factor (Rf)	$Rf=A/Lb^2$	Horton [1945][5]
Circularity Ratio (Rc)	$Rc=4\pi A/P^2$	Miller [1953][9]
Elongation Ratio(Re)	$Re=(2/Lb)X(A/\pi)^{0.5}$	Schumn [1956][7]
Compactness Constant(Cc)	$Cc=0.2821\ P/A^{0.5}$	Horton [1945][5]
Basin Shape (Bs)	$Bs=Lb^2/A$	Horton [1945][5]
Length of over Land flow (Lg)	Lg=1/Dd*2	Horton [1945][5]
Relief (R)	R=H-h	Hardley and Schumn [1961][6]
Relief Ratio (Rh)	Rh=R/Lb	Schumn [1956][7]

Where, A = Area of the Basin (km^2), Bs = Form Factor, Cc = Compactness Ratio, Dd = Drainage density, Lb = Length of Basin (km), Lb^2=Square of the basin length, Lg=Length of overland flow, Lsm = mean Stream Length, Lu=Total Stream length of order u, Nu = Total number of stream segment of order u, N_{u+1}= Number of stream segment of next higher order, P=Perimeter (Km), R= Relief, Rb = Bifurcation Ratio, Rc= Circularity Ratio, Re= Elongation Ratio, Rh= Relief Ratio.

Table 2. Sub- watershed parameters

SWSD No	Basin Area (km^2)	Stream Order				Stream Length in km (Lu)				Perimeter (P) (km)	Basin Length (Lb)(km)
		I	II	III	IV	I	II	III	IV		
SWD1	32.53	18	7	2	-	11.27	6.1	2.4	-	24.30	7.7
SWD2	24.28	11	7	2	-	7.88	2.96	1.63	-	23.61	6.04
SWD3	31.65	24	10	6	2	11.6	5.52	4.17	1.61	27.8	6.34
SWD4	52.99	28	9	4	2	16.4	10.17	3.41	1.72	29.23	8.87
SWD5	48.39	23	8	4	5	13.63	5.42	5.02	5.12	29.83	5.88
SWD6	16.62	12	4	4	-	4.32	1.81	2.95	-	16.49	5.93
SWD7	41.02	27	10	3	4	15.32	8.51	5.35	3.32	30.19	10.18
SWD8	12.96	9	3	1	-	3.35	2.67	0.77	-	16.44	4.28
SWD9	44.75	47	18	8	4	21.6	11.12	7.85	6.55	36.45	13.2

SWSD No	Mean Stream Length in km (Lsm)				Stream Length Ratio (RL)			Total Relief (R)	Relief Ratio (Rh)	Elongation Ratio (Re)	Compactness Coefficient (Cc)
	I	II	III	IV	II/I	III/II	IV/III				
SWD1	0.63	0.87	1.20	-	1.38	1.38	-	26	0.0011	0.84	1.2
SWD2	0.72	0.42	0.81	-	0.58	1.93	-	13	0.0006	0.70	1.35
SWD3	0.48	0.55	0.69	0.81	1.15	1.25	1.17	20	0.0007	0.64	1.39
SWD4	0.59	1.13	0.85	0.86	1.92	0.75	1.01	40	0.0014	0.79	1.13
SWD5	0.59	0.68	1.26	1.12	1.15	1.85	0.89	20	0.0007	0.96	1.2
SWD6	0.36	0.45	0.74	-	1.25	1.64	-	10	0.0006	0.78	1.14
SWD7	0.57	0.85	1.78	0.83	1.49	2.09	0.47	10	0.0003	0.71	1.33
SWD8	0.37	0.89	0.77	-	2.41	0.87	-	13	0.0008	0.73	1.28
SWD9	0.46	0.62	0.98	1.64	1.35	1.58	-	30	0.0008	0.57	1.53

SWSD No	Bifurcation Ratio (Rb)			Mean Bifurcation Ratio (Rbm)	Drainage Density(Dd) (km/km^2)	Stream Frequency (Fs)	Form Factor (Rf)
	I/II	II/III	III/IV				
SWD1	0.63	0.87	1.20	3.03	0.60	0.83	0.55
SWD2	0.72	0.42	0.81	2.53	0.51	0.82	0.39
SWD3	0.48	0.55	0.69	2.3	0.72	1.32	0.32
SWD4	0.59	1.13	0.85	2.45	0.59	0.81	0.48
SWD5	0.59	0.68	1.26	1.89	0.61	0.82	0.72
SWD6	0.36	0.45	0.74	2	0.54	1.21	0.48
SWD7	0.57	0.85	1.78	2.26	0.79	1.07	0.40
SWD8	0.37	0.89	0.77	3	0.52	1.00	0.42
SWD9	0.46	0.62	0.98	2.28	1.05	1.72	0.26

SWSD No	Texture Ratio (Rt)	Circularity Ratio (Rc)	Length of over land flow (Lg)	Basin Shape (Bs)
SWD1	1.11	0.69	0.83	1.82
SWD2	0.85	0.55	0.98	1.50
SWD3	1.51	0.51	0.69	1.27
SWD4	1.47	0.78	0.85	1.48
SWD5	1.34	0.68	0.82	0.73
SWD6	1.21	0.77	0.93	2.08
SWD7	1.46	0.57	0.63	2.53
SWD8	0.79	0.60	0.96	1.41
SWD9	2.11	0.42	0.48	3.89

IV. RESULTS AND DISCUSSIONS

In the present study, morphometric analysis of the parameters, namely stream order, stream length, bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circulatory ratio, elongation ratio, area, perimeter, length and width of all the sub-watersheds has been carried out using the mathematical formulae given in the Table 1 and their results are summarized in Table 2.

4.1 Stream Order (Nu)

The designation of stream orders is the first step in drainage basin analysis. It is based on hierarchic ranking of streams proposed by Strahler [1964][1]. The first order streams have no tributaries. The second order streams have only first order streams as tributaries. Similarly, third order streams have first and second order streams as tributaries and so on. A perusal of the Table 2 indicates that the total number of 326 streams were identified of which 199 are first order streams, 76 are 2nd order, 34 are 3rd order and 17 are of 4th order. The streams up to forth order can be seen in SWD3, SWD4, SWD5, SWD7 and SWD9. Drainage patterns of stream network from the basin have been observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control.

4.2 Stream Length (Lu)

It is the total length of streams in a particular order. The numbers of streams of various orders in a sub-watershed were counted and their lengths measured. Generally, the total length of stream segments decrease with stream order. Deviation from its general behavior indicate that the terrain is characterised by high relief and/or moderately steep slopes, underlain by varying lithology and probable uplift across the basin [Singh and Singh 1997][11]. In general logarithms of the number of streams of a given order, when plotted against the stream order, the points lie on a straight line [Horton, 1945][5]. In the present study, SWD5 and SWD6 sub-watersheds (Fig.4) show deviation from a straight line at order III which may be due to regional upliftment.

4.3 Mean Stream Length (Lsm)

The mean stream length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces [Strahler, 1964][1]. The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of streams. Table 2 indicates that Lsm in these sub-watersheds ranges from 0.36 to 1.78 km. It is observed that Lsm values of SWD1, SWD3, SWD6 and SWD9 sub-water sheds indicate that Lsm of the given order is greater than that of the lower order and less than that of the next order, whereas in case of SWD2, SWD4, SWD5, SWD7 and SWD8 there is a deviation from this general observation. This deviation might be due to variation in slope and topography.

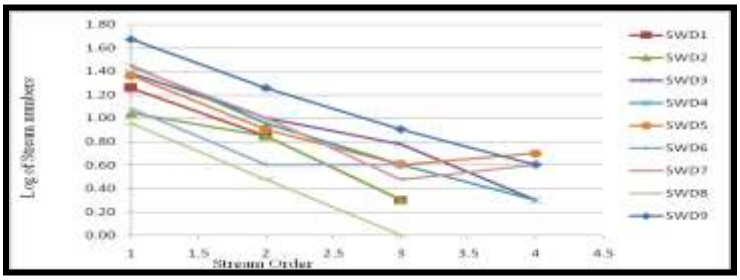


Fig.4 Relationship between Log (Stream Numbers) and stream Order

4.4 Bifurcation Ratio (Rb)

It is the ratio of the number of streams of a given order to the number of streams of the next higher order [Schumn, 1956][7]. Horton[1945][5] considered bifurcation ratio (Rb) as an index of relief and dissections. Strahler [1957][12] demonstrated that Rb shows only a small variation for different regions on different environment except where powerful geological control dominates. Lower Rb values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern [Nag, 1998][13]. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all order (Table 2). In the present study, Rbm varies from 1.89 to 3.03 and all sub-watersheds fall under normal basin category.

4.5 Relief Ratio (Rh)

The elevation difference between the highest and lowest points on the valley floor of a sub-watershed is its total relief, whereas the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is Relief Ratio (Rh) [Schunm, 1956][7]. It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. The areas with high relief and steep slope are characterized by high value of relief ratios. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope [Mahadevaswamy G. et. al][14]. The Rh normally increases with decreasing drainage area and size of a given drainage basin [Gottschalk, 1964][15]. In the present study, Rh ranges from 0.0003 (SWD7) to 0.00144 (SWD4).

4.6 Drainage Density (Dd)

Horton [1932][16] introduced the drainage density (Dd) is an important indicator of the linear scale of land-form elements in stream –eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of km/sq.km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. High drainage density is the result of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to course drainage texture while high drainage density leads to fine drainage texture [Strahaler, 1964][1].

The drainage density (Dd) of the study area is varying between 0.51and 1.05 km/km^2 indicating low drainage densities. It is suggested that the low drainage density indicated the basin is highly permeable subsoil, thick vegetation cover, low relief and course drainage texture [Nag 1998][13].

4.7 Stream Frequency (Fs)

Stream frequency/channel frequency (Fs) is the total number of stream segments of all orders per unit area [Horton, 1932][16]. Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of stream frequency differing in drainage density.

Table 2 shows Fs for all sub-watersheds of the study area. It is noted that the Fs exhibits positive correlation with the drainage density values of the sub-watersheds indicating the increase in stream population with respect to increase in drainage density.

4.8 Texture Ratio (Rt)

It is the total number of stream segment of all orders per perimeter of that area [Horton, 1945][5]. Horton recognized infiltration capacity as the single important factor which influences drainage texture (Rt) and considered the drainage texture to include drainage density and stream frequency. Smith [1950][17] has classified drainage density into five different texture i.e. very coarse (<2), Coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the present study all the sub watersheds have very course drainage texture as their drainage densities are vary from 0.79 to 2.11. The lower values of texture ratio indicate that the basin is plain with lower degree of slopes.

4.9 Form Factor (Rf)

It is defined as the ratio of basin area to square of the basin length [Horton, 1932][16]. The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated sub-watershed with low form factors have lower peak flow of longer duration. Rf values of the study area are presented in Table 2. It is noted that the Rf values vary from 0.26 to 0.72 indicate that they are to be elongated circular shape and suggesting flatter peak flow for longer duration. Flood flows of such elongated circular basins are easier to manage than those of the circular basin.

4.10 Circulatory Ratio (Rc)

It is ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin [Miller, 1953][9]. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. In the present case Rc ranges from 0.42 to 0.78 indicating that all the sub-watersheds except SWD9 are more or less circular and are characterized by high to moderate relief and drainage system is structurally controlled. The sub-watershed SWD9 having an Rc value of 0.42 indicating that it is elongated.

4.11 Elongation Ratio (Re)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. A circular basin is more efficient in run-off discharge than an elongated basin [Singh and Singh, 1997][11]. The value of elongation ratio (Re) generally varies from 0.6 to 1.0 associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope [Strahler, 1964][1]. These values can be grouped into three categories, namely circular (>0.9), oval (09-0.8) and elongated (<0.7). Elongation ration of all the water sheds except SWD3 and SWD9 is above 0.7 indicating that all the sub-watersheds except SWD3 and SWD9 are more or less circular or oval. The elongation ratio of SWD3 and SWD9 are 0.64 and 0.57 respectively and indicating that it is elongated.

4.12 Length of Overland Flow (Lg)

Length of Overland Flow It is the length of water over the ground before it gets concentrated into definite stream channels, [Horton, 1945][5]. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density [Horton, 1945][5]. Table 2 reveals that the computed value of Lg for all sub-watersheds varies from 0.48 and 0.98. The value of Lg higher in case of SWD2 and SWD8 indicating low relief whereas the values of Lg are low in case of SWD7 and SWD9 indicating high relief.

4.13 Basin Shape (Bs)

Basin shape is the ratio of the square of basin length (Lb) to the area of the basin (A). The Bs values of sub-watersheds (table 2) indicates that SWD6 and SWD9 have weaker flood discharge periods, whereas SWD1, SWD2, SWD3, SWD4, SWD5, SWD7 and SWD8 have sharp peak flood discharge.

4.14 Prioritization of Sub-watersheds

The compound parameter values of nine sub-watersheds of Hebbal valley were calculated and prioritization rating is shown in Table 3. Watershed SWD3 with a compound parameter value of 3.5 receives the highest priority (one) with next in the priority list is watershed SWD9 having the compound parameter value of 3.9. Highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes potential area for applying soil conservative measure. The final prioritized map of the study area is shown in fig.5 thus soil conservation measures can first be applied to sub-watersheds area SWD3 and then to the other sub-watersheds depending upon their priority.

Table 3. Priorities of sub-watersheds and their ranks

SWSD No	Rbm	Dd	Fs	Rt	Lg	Rc	Cc	Re	Bs	Rf	Compound Parameter (Cp)	Final Priority
SWD1	1	5	6	7	5	7	3	8	6	8	5.6	7
SWD2	3	9	7	8	1	3	7	3	5	3	4.9	3
SWD3	5	3	2	2	7	2	8	2	2	2	3.5	1
SWD4	4	6	9	3	4	9	1	7	4	6	5.3	6
SWD5	9	4	8	5	6	6	4	9	1	9	6.1	9
SWD6	8	7	3	6	3	8	2	6	7	7	5.7	8
SWD7	7	2	4	4	8	4	6	4	8	4	5.1	5
SWD8	2	8	5	9	2	5	5	5	3	5	4.9	4
SWD9	6	1	1	1	9	1	9	1	9	1	3.9	2

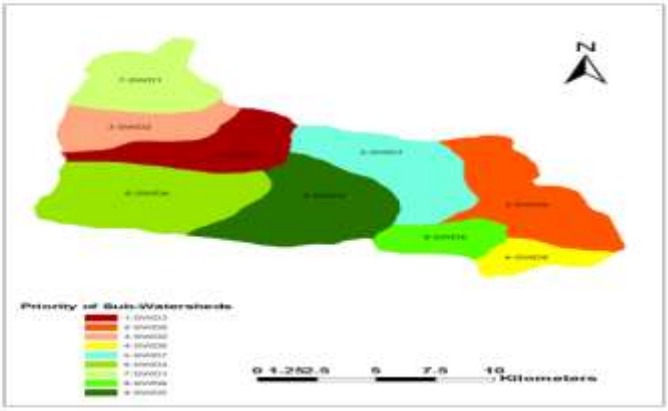


Fig.5 Prioritized Sub watersheds

V. CONCLUSION

The present study demonstrates the utility of remote sensing and GIS techniques in prioritizing sub-watersheds based on morphometric analysis. All the sub- watersheds show dendritic to sub dendritic drainage pattern with course drainage texture. Low bifurcation ratios indicate normal basin category. A plot of logarithm of number of stream vs. stream order shows deviation from straight line indicating regional upliftment. The low drainage density indicates the basin is highly permeable subsoil, thick vegetation cover, low relief and course drainage texture. Circulatory and elongation ratios show that most of the sub-watersheds are more or less circular or oval. Further, the remote sensing techniques have been found to be suitable for the preparation of updated drainage map in a timely and cost-effective manner and should be preferred in soil erosion studies for deriving input data. Results of morphometric analysis show that sub-watersheds SWD3 and SWD9 are possibly having high erosion. Hence, suitable soil erosion control measures are required in these watersheds to preserve the land from further erosion.

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