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Prioritization of Micro-watersheds in the Balekoppa Sub-watershed based on Morphometric Analysis: A Geospatial Approach

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Abstract : *Conservation and optimum usage of surface and subsurface water can be done by the development of watershed management. GIS and RS are very efficient in quantifying morphometric parameters and giving an idea about the geological and hydrological conditions of the area under consideration. In this regard Balekoppa sub-watershed is chosen for the prioritization of its micro-watersheds and to assess its erodibility and other critical problems and potential threats. The study area is located in the Sirsi taluk of Uttara Kannada district and covers an area of 58.94 sq. km. With the help of GIS the basic morphometric parameters are determined and the applied parameters are derived from the basic parameters. The study area is divided into fourteen micro-watersheds and these are prioritized based on morphometric analysis in a GIS platform. Based on the compound ranking of each micro-watershed prioritization is carried out and its erosional potentiality is analyzed. Based on the results obtained, three micro-watersheds fall under high priority, other three under medium and the remaining eight under low priority.*

Keywords - *Balekoppa, Morphometric Analysis, Erodibility, GIS, RS, Prioritization*

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I. INTRODUCTION

Among the various renewable resources water finds a unique place. It is impossible to substitute for most of its uses. It is essential for sustaining all forms of life, food production, economic development and for general well being. Water is also one of the most manageable of the natural resources as it is capable of diversion, transport, storage, and recycling (Rakesh Kumar et al. 2005). Soil erosion has been accepted as a serious problem arising from agricultural intensification, land degradation and possibly due to global climatic change (Yang et al., 2003). Not only the deposition of sediment transported by river into a reservoir reduces the reservoir capacity, but also sediment deposition on river bed and banks causes widening of flood plains during floods. Soil erosion is the most significant contributor of off-site ground water pollution on a global scale with most of the contaminants originating within an agricultural setting (Marsh WM et al. 1996). Watershed management and development is very important in these aspects. A watershed becomes ideal for the management of natural resources such as land, forest , soil etc.

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms (Clarke et al. 1966). Morphometric characteristic of hydrologic and geomorphic processes gives the information about the watershed formation in different scale (Singh S et al. 1997). Remote Sensing and GIS techniques are the proven efficient tools in the delineation, updating and morphometric analysis of drainage basin. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential and groundwater management (Waikar M.L. et al. 2011). The morphometric analysis of the drainage basin and the channel network plays an important role in understanding the geo-hydrological behaviour of drainage basin and express the prevailing climate, geology, geomorphology, structural antecedents of the catchment.GIS and RS are very important in determining the morphometric parameters and carrying out morphometric analysis of drainage basin.

Watershed prioritization is the ranking of different sub-watersheds of a watershed according to the order in which they have to be taken for treatment for water and soil conservation measures (Javed et al. 2011).Morphometric and land use analysis has been commonly used to prioritize the watersheds. The watersheds are prioritized based on different selection criteria i.e., morphometry, land use/land cover, universal soil loss equation, sediment yield, sediment production rate etc. (Thirumalai et al. 2014).Remote Sensing and GIS has been found to be effective in planning for regional development based on watershed approach. In the present study our approach is to prioritize the micro-watersheds in the Balekoppa sub-watershed.

II. STUDY AREA

The Balekoppa Sub-watershed is derived from the River Aghanashini water basin situated in Sirsi taluk, Uttara Kannada, Karnataka. The geographical extent of the study area stretches from 14^0 31’ 40’’ to 14^0 37’ 20’’ North latitudes and 74^o 34’ 40’’ to 74^o 39’ 45’’ East longitudes and covers an area of 58.94sq. Km. It has a perimeter of 38.09 Km. The drainages of this sub-watershed connects to the River Aghanashini which flows West and joins the Arabian Sea. The mean annual rainfall of the study area is about 2879 mm most of which occurs between the months May and September. The average minimum and maximum temperature are 26^0C and 36^0C respectively. Major land covers in the catchment are forest followed by agriculture. The plantations in the study area mainly are of areca nut, coco nut, paddy, sugarcane, coke, vanilla. Geographically the study area consists of lateritic soil. The location map is shown in the Figure 1.

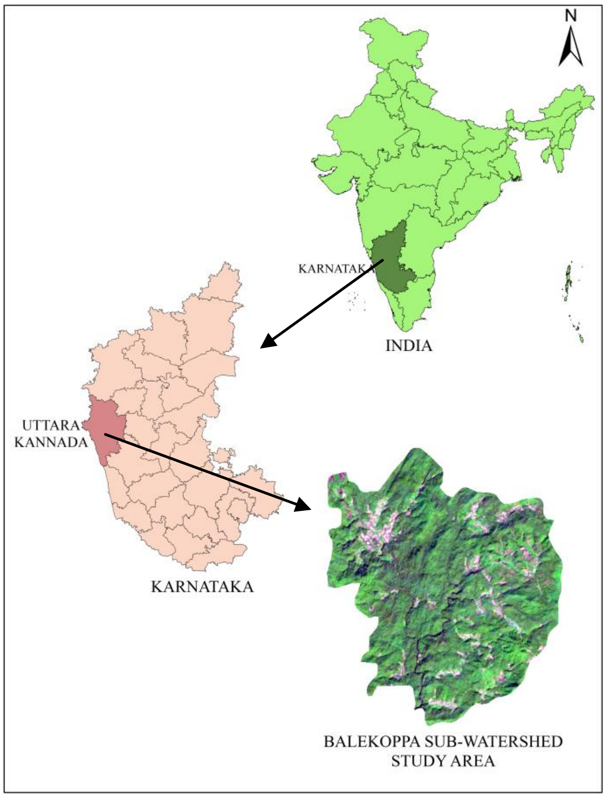

Fig 1: Location Map

III. METHODOLOGY

The base map of the sub-watershed under consideration is demarcated using Survey Of India toposheet 48J10. The drainages of the sub-watershed are delineated with the help of toposheet of scale 1:50,000 and updated using IRS LISS III satellite imagery data. For our analysis the micro-watersheds are derived from the third order streams. The stream ordering by carried out based on Strahler (1964) stream ordering technique. The drainage map is shown in the Figure 2. The standard methods and formulae are employed to determine the morphometric parameters of each micro-watershed. The basic parameter such as the area, perimeter, stream length, stream number and basin length are calculated in the GIS platform. The rest parameters are determined by using the standard formulae. The study area Balekoppa sub-watershed was further divided into fourteen micro-watersheds for our analysis and prioritization. They are designated as MW1, MW2, MW3, MW4, MW5, MW6, MW7, MW8, MW9, MW10, MW11, MW12, MW13 and MW14. The study area with its micro-watershed is shown in the Figure 3. The standard formulae for the calculation of morphometric parameters are shown in the Table 1.

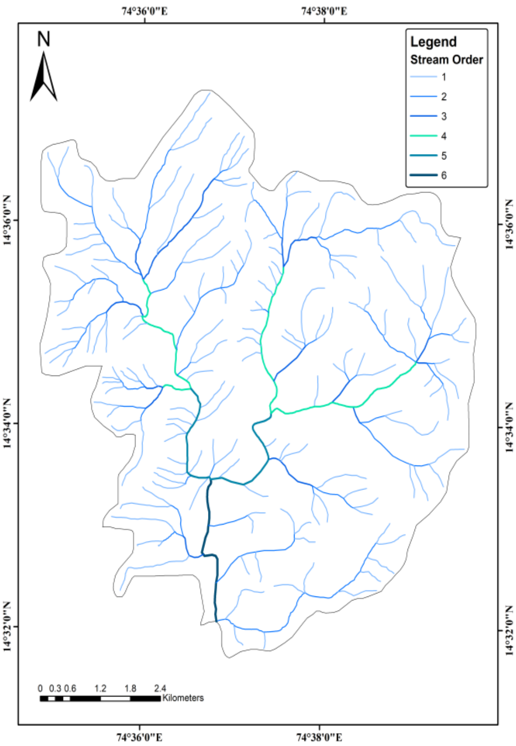

Fig 2: Drainage Map

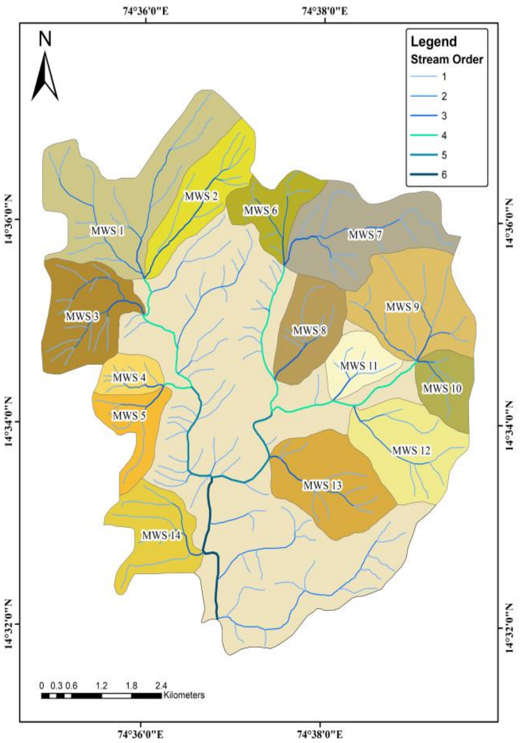

Fig 3: Micro-watershed Map

Table 1: Formulae for Calculation of Morphometric Parameters

Sl. No.	Morphometric Parameter	Formula	References
1	Stream Order (Nu)	Hierarchical rank	Strahler (1964)
2	Stream Length (Lu)	Length of the stream	Horton (1945)
3	Bifurcation Ratio (Rb)	Rb = Nu/(Nu+1) Nu = Total no. of stream segments of order ‘u’	Schumn (1956)
4	Drainage Density (Dd)	Dd = ΣLu/A ΣLu = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932)
5	Stream Frequency (Fs)	Fs = ΣNu/A ΣNu = Total no. Of streams of all orders.	Horton (1932)
6	Texture Ratio (T)	T = ΣNu/P P = Perimeter of the basin	Horton (1945)
7	Circularity Ratio (Rc)	$Rc = 4\pi A/P^2$	Miller (1953)
8	Form Factor (Rf)	$Rf = A/Lb^2$ Lb = Basin length	Horton (1932)
9	Elongation Ratio (Re)	$Re = 2(A/\pi)^{0.5}/Lb$	Schumn (1956)
10	Compactness Coefficient (Cc)	$Cc = 0.2841P/A^{0.5}$	Gravelius (1914)

IV. RESULTS AND DISCUSSIONS

Morphometric characteristic of hydrologic and geomorphic processes gives the information about the watershed formation in different scale (Singh S et al. 1997). Morphometric analysis is the quantitative analysis of the configuration of Earth’s surface, shape and dimension of its landform. The morphometric analysis of the drainage basin and the channel network plays an important role in understanding the geo-hydrological behaviour of drainage basin and express the prevailing climate, geology, geomorphology, structural antecedents of the catchment. The watersheds are prioritized based on different selection criteria i.e., morphometry, land use/land cover, universal soil loss equation, sediment yield, sediment production rate etc (Thirumalai et al. 2014). Watershed prioritization is the ranking of different sub-watersheds or micro-watersheds of a watershed according to the order in which they have to be taken for treatment for water and soil conservation measures, etc., (Javed et al. 2011).

4.1 Basic Morphometric Parameters:

The basic morphometric parameters are computed from the vector data extracted from the topographic maps. The main basic morphometric parameters are maximum order of the streams, number of streams in each order, length, area, perimeter, relief for each of the basins. These can be easily and accurately quantified using the GIS software. The values of the basic morphometric parameters are shown in the Table 2.

Basin Area (A) is the areas of different micro-watersheds; here it varies from 0.85 to 5.68 sq. km. Based on the areas it is clear that all micro-watersheds are comparatively smaller in size. The area of each micro-watershed can easily be determined in the GIS platform. **Basin Perimeter (P)** is the total length of boundary of the drainage basin. In this study the perimeter of the micro-watershed varies from 3.64 to 13.88 km. **Basin Length (L)** is the longest part of the basin parallel to the principal drainage line (Schumn 1956). The basin length of the micro-watersheds under consideration varies in between 1.21 to 3.65 km. Seven out of fourteen micro-watersheds have basin lengths less than 2 km and the remaining seven in the range above 2 km. **Stream Order (Nu)**, Strahler (1964) stream ordering technique was used to order the streams. The stream order is based on hierarchical ranking. In our study area we obtained the highest stream order of sixth order stream. Seven out of fourteen micro-watersheds have total number of streams orders less than 10 whereas the remaining seven have above 10. In our study we can find that the stream order is proportional to the area of the micro-watersheds. **Stream Length (Lu)** is a significant hydrological feature of the basin and it shows surface runoff characteristics (Swatantra Kumar Dubey et al. 2015). The total length of the streams of each order within the micro-watersheds was calculated in the GIS platform. Here eight out of fourteen micro-watersheds have total stream length less than 7 km whereas remaining six have stream lengths above 7 km.

Table 2: Basic Morphometric Parameters

Micro Water shed	Basin Area (Km^2)	Perimeter (Km)	Basin Length (Km)	Nu			Σ Nu	Lu			ΣLu
				I	II	III		I	II	III	
1	5.68	13.88	3.65	12	3	1	16	9.06	4.74	0.79	14.59
2	2.41	7.95	3.3	7	2	1	10	5.42	0.48	2.38	8.28
3	2.99	7.5	2.06	12	3	1	16	6.22	2.56	0.94	9.72
4	0.85	3.64	1.21	7	2	1	10	2.78	0.73	0.38	3.89
5	1.4	6.6	1.96	4	2	1	7	2.88	0.77	0.52	4.17
6	1.61	6.39	1.76	6	2	1	9	2.5	1.69	0.52	4.71
7	4.11	9.75	3.45	8	2	1	11	6.17	2.32	0.98	9.47
8	2.02	5.62	1.97	5	2	1	8	3.47	0.3	0.9	4.67
9	3.85	8.18	2.04	9	3	1	13	6.24	2.55	0.49	9.28
10	1.33	4.55	1.23	5	2	1	8	2.5	0.65	0.22	3.37
11	1.22	4.42	1.45	4	2	1	7	2.07	0.34	0.53	2.94
12	3.09	7.09	2.35	6	2	1	9	4.25	2.19	0.32	6.76
13	3.27	7.13	2.3	8	2	1	11	4.8	1.06	1.08	6.94
14	2.31	7.52	1.96	6	2	1	9	5.53	1.15	0.67	7.35

4.2 Derived Morphometric Parameters:

The derived morphometric parameters are derived from the basic parameters by using the standard formulae and methods. These parameters give a brief description of the sub-watershed. It tells us about the nature and the behaviour of the area under consideration. Based on the values of the derived parameters the compound ranking is done and with the help of the compound ranking the prioritization of the micro-watersheds can be performed. The values of the derived parameters are discussed in the Table 3.

Bifurcation Ratio (Rbm): It is defined as the ratio of the number of the stream segments of given order to the number of the next higher order segments (Schumn 1956). The bifurcation ratio is an index of relief and dissection (Horton 1945). The lower values of bifurcation ratio are characteristics of the sub-watershed which have suffered less structural disturbances (Strahler 1964). Higher values of bifurcation ratio indicate potential flooding. The lowest bifurcation ratio value of 2 was obtained in two micro-watersheds (MW5 and MW11) and the highest of 3.5 in MW1 and MW3. Bifurcation ratio characteristically ranges from 3.0 to 5.0 for basins in which the geological structures do not distort the drainage pattern (Strahler 1964). All the fourteen micro-watersheds have mean bifurcation ratio less than 5. Therefore, based on the values obtained it indicates that the drainage pattern is not affected by the geological structures of the area (Md. Zakaria et al. 2016). The mean bifurcation ratios of the micro-watersheds is shown in Figure 4-A.

Drainage Density (Dd): It is the ratio of total stream length to the total area of the basin. It is an important indicator of the linear scale of land form elements in stream eroded topography (Horton 1932). The Lower drainage density of any watershed indicates that it has permeable subsurface material, good vegetation covers and low relief and vice versa (Nag et al. 1998). Density factor is related to climate, type of rocks, relief, infiltration capacity, vegetation cover, surface roughness and runoff intensity index (Rudraiah et al. 2008). The two micro-watersheds (MW13 and MW12) has the lowest drainage density of 2.12 and MW4 has 4.58 which is the highest. Ten micro-watersheds out of fourteen have drainage density less than 3. From the drainage density values we can say with reference to Gajul M. D. et al. (2016) that the drainage density is predominantly low and moderate and the area under consideration has permeable subsoil, low relief and is having a rich vegetation cover (Nag S. K. 1998 and Waikar M.L. et al. 2014). Drainage densities of the micro-watersheds is shown in Figure 4-B.

Stream Frequency (Fs): The total number of drainages of all orders per unit area is called stream frequency. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream frequency with respect to increase in drainage density (Horton 1932). Stream frequency is inversely proportional to permeability, infiltration capacity and directly proportional to the relief of watersheds. The MW7 has the lowest stream frequency of 2.68 and MW4 has the highest of 11.76. Based on the study of Gajul M. D. et al. (2016) the stream frequency value below 6 is low and above 6 can be termed high. Twelve of the micro-watershed have stream frequency lesser than 6 and the remaining two micro-watersheds with stream frequency more than 6 ranging up to 11.76. Based on the results obtained majority micro-watersheds have lesser stream frequency indicates runoff is slower and flooding is less likely to occur (Charles W Carlston 1963 and Rafiq Ahmad Hajam et al. 2013). The stream frequencies of the micro-watersheds are shown in the Figure 4-C.

Texture Ratio (T): The drainage texture ratio is the total number of drainages of all orders per perimeter of that watershed (Horton 1945). The drainage texture depends on climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of basin. The drainage density can be classified into five different categories i.e. very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8) (Smith 1950). The MW4 records texture ratio of 2.75 which is the highest and MW5 records 1.06 which is the lowest. Twelve out of fourteen micro-watersheds have very coarse texture and remaining two have coarse texture. Therefore, the area under consideration has texture predominately of very coarse ranging to coarse texture. The texture ratios of the micro-watersheds is shown in the Figure 4-D.

Circularity Ratio (Rc): The circularity ratio is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin (Miller 1953). Higher circularity ratio is indicative of circular shape of the watershed and of the moderate to high relief and permeable surface (Sadaf et al. 2014). In our study the circularity ratio varies from 0.37 of the MW1 to 0.81 of three micro-watersheds (MW4, MW10 and MW13). Only six out of fourteen micro-watersheds have circularity ratio greater than 0.75, this indicates that the micro-watersheds MW4, MW8, MW10, MW11, MW12 and MW13 are circular whereas the remaining micro-watersheds are elongated in shape (Nageshwara Rao K et al. 2010). The circularity ratios of the micro-watersheds is shown in the Figure 4-E.

Form Factor (Rf): Form factor is the ratio between basin area and the square of basin length. It indicates the flow intensity of a basin of a defined area (Horton 1945). The smaller value of the form factor indicates basin will be more elongated. Basins with higher form factor experiences larger peak flows of shorter duration, whereas elongated watersheds with low form factor experiences lower peak flow of longer duration (Waikar M.L. et al. 2014). The lowest form factor observed in our study was 0.22 of the MW2 and the highest being 0.93 of the MW9. Only five out of fourteen micro-watersheds have form factor greater than 0.6 where the remaining nine have a smaller form factor and hence can conclude saying that the micro-watersheds have elongated basins with lower peak flow of longer duration (Gursewak Singh Brar 2014). The form factors of the micro-watersheds is shown in the Figure 4-F.

Elongation Ratio (Re): It is defined as the ratio of diameter of a circle having the same area as the drainage basin and the maximum length of the basin (Schumn 1956). The value of elongation ratio generally varies from 0.6 to 1.0 over a wide variety of climatic and geologic conditions. The micro-watersheds show lower elongation ratio values which are high susceptible to erosion and higher values are indicative of high infiltration capacity and low runoff (Prajnesh Kumar J et al. 2017). The elongation ratio close to unity corresponds typically to regions of low relief, whereas values in the range of 0.6-0.8 are usually associated with high relief and steep ground slope (Strahler 1964). These values can be grouped into three categories namely circular (>0.9), oval (0.9-0.8) and elongated (<0.7). In the area under consideration the elongation ratio varies from 0.53 of MW2 to 1.09 of MW9. Four of the fourteen micro-watersheds are elongated, whereas seven are oval and the remaining three are circular. Based on the results, it indicates that the micro-watersheds are prominently elongated and oval in nature. The elongation ratios of the micro-watersheds is shown in the Figure 4-G.

Compactness Coefficient (Cc): It is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed (Gravelius 1914). A circular basin is the most susceptible from drainage point of view because it will yield shortest time of concentration before peak flow occurs in the basin (Nooka Ratnam et al. 2005). Compactness coefficient is indirectly related with the elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion and vice versa (Waikar M.L. et al. 2014 and Md. Zakaria et al. 2016). The micro-watershed compactness coefficient varies from 1.12 of four micro-watersheds (MW4, MW8, MW10 and MW13) to 1.65 of MW1. Here all the micro-watersheds have compactness coefficient less than 2, hence it indicates that the micro-watersheds are more elongated than circular (Md. Zakaria et al. 2016). The compactness coefficients of the micro-watersheds are shown in the Figure 4-H.

Table 3: Derived Morphometric Parameters

Micro Watershed	Rb		Rbm	Dd	Fs	T	Rc	Rf	Re	Cc
	I/II	II/III								
1	4	3	3.5	2.57	2.82	1.15	0.37	0.43	0.74	1.65
2	3.5	2	2.75	3.41	4.15	1.26	0.48	0.22	0.53	1.45
3	4	3	3.5	3.25	5.35	2.13	0.67	0.7	0.95	1.23
4	3.5	2	2.75	4.58	11.76	2.75	0.81	0.58	0.86	1.12
5	2	2	2	2.98	5	1.06	0.4	0.36	0.68	1.58
6	3	2	2.5	2.93	5.59	1.41	0.5	0.52	0.81	1.43
7	4	2	3	2.3	2.68	1.13	0.54	0.35	0.66	1.37
8	2.5	2	2.25	2.31	3.96	1.42	0.8	0.52	0.81	1.12
9	3	3	3	2.41	3.38	1.59	0.72	0.93	1.09	1.18
10	2.5	2	2.25	2.53	6.02	1.76	0.81	0.88	1.06	1.12
11	2	2	2	2.41	5.74	1.58	0.78	0.58	0.86	1.14
12	3	2	2.5	2.19	2.91	1.27	0.77	0.56	0.84	1.15
13	4	2	3	2.12	3.36	1.54	0.81	0.62	0.89	1.12
14	3	2	2.5	3.18	3.90	1.2	0.51	0.6	0.87	1.41

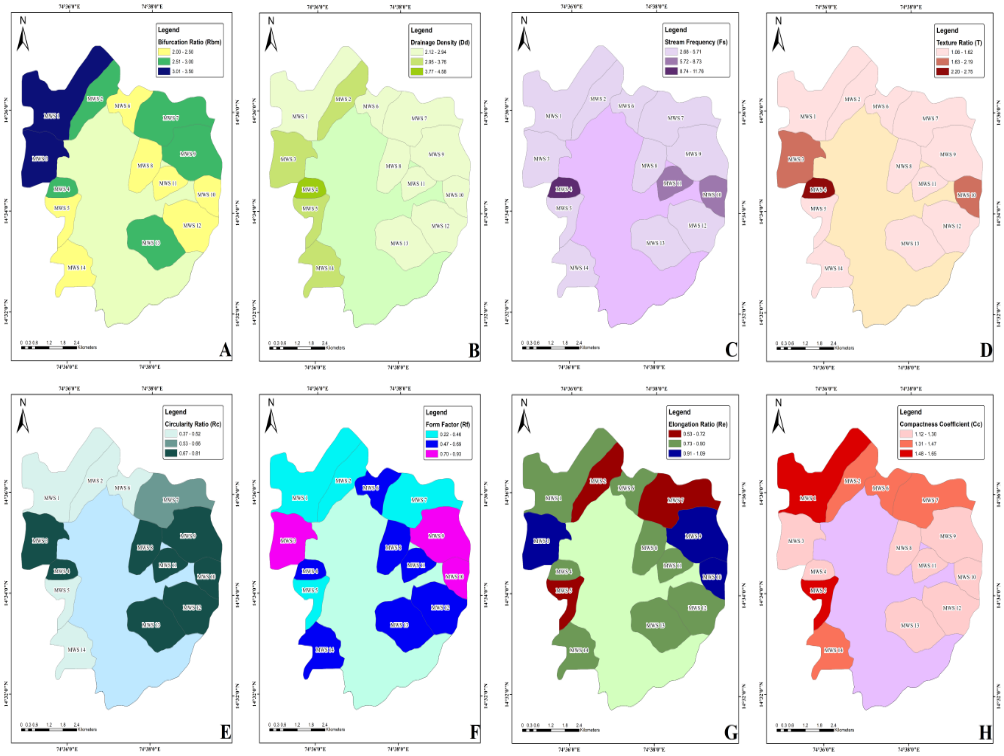

Fig 4: Derived Morphometric Parameters (A-Bifurcation Ratio Map, B-Drainage Density Map, C-Stream Frequency Map, D-Texture Ratio Map, E-Circularity Ratio Map, F-Form Factor Map, G-Elongation Ratio Map, H-Compactness Coefficient Map)

4.3 Prioritization of Micro-watersheds

Morphometric analysis is used for prioritization of watersheds for soil and water conservation at different scales: sub-watersheds, mini-watersheds and micro-watersheds (Biswas et al, 1999). Erosion risk parameters pertained to linear and shape morphometric variables are employed for prioritizing watersheds (Patel D. P et al. 2013). Linear morphometric parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture, length of overland flow etc. have direct relationship with erodibility, whereas the shape morphometric parameters such as circularity ratio, elongation ratio, form factor, basin shape, compactness coefficient etc. show inverse relationship with erodibility (Nooka Ratnam et al. 2005).

The ranking of the micro-watersheds has been carried out for assigning highest rank based on highest value in case of linear parameters and lowest value in case of shape parameters (Biswas et al, 1999). For the prioritization of micro-watersheds in case of linear parameters the highest ranking was given to the greatest values and as the value decreased the ranks reduce correspondingly. In the case of shape parameters, the ranking was the other way round. Based on the ranking the compound ranking value was determined and the priority range for the micro-watershed was assigned. The prioritization is based on the erosion criteria of the micro-watersheds.

In this study the micro-watersheds are classified into three priority range of high, medium and low. High priority indicates high erosion activities taking place in those areas and is of major concern whereas the medium priority indicates erosion but in manageable terms and the low priority means the regions which do not have any serious erosion problems. The compound ranking within the range of 5.25 - 6.46 are prioritized as high, 6.46 - 7.67 are prioritized as medium and 7.67 - 8.88 are prioritized as low. Based on the results the micro-watersheds MW5, MW12 and MW13 falls under high priority, whereas the micro-watersheds MW4, MW11 and MW14 comes under medium priority and the micro-watersheds MW1, MW2, MW3, MW6, MW7, MW8, MW9 and MW10 will be in the low priority range. The prioritization of micro-watersheds based on compound ranking is shown in Table 4. The prioritization map of the micro-watersheds is shown in the Figure 5.

Table 4: Prioritization of Micro-watersheds using Morphological Parameters

Micro Watershed	Linear Parameters				Shape Parameters				Compound Rank	Final Priority
	Rb	Dd	Fs	T	Rc	Rf	Re	Cc		
1	1	7	13	12	1	4	4	14	7	Medium
2	6	2	7	10	3	1	1	12	5.25	High
3	2	3	5	2	7	12	12	8	6.38	High
4	7	1	1	1	14	8	8	2	5.25	High
5	13	5	6	14	2	3	3	13	7.38	Medium
6	10	6	4	8	4	6	6	11	6.88	Low
7	3	12	14	13	6	2	2	9	7.63	Medium
8	11	11	8	7	11	5	5	4	7.75	Low
9	4	10	10	4	8	14	14	7	8.88	Low
10	12	8	2	3	13	13	13	3	8.38	Low
11	14	9	3	5	10	9	9	5	8	Low
12	8	13	12	9	9	7	7	6	8.88	Low
13	5	14	11	6	12	11	11	1	8.88	Low
14	9	4	9	11	5	10	10	10	8.5	Low

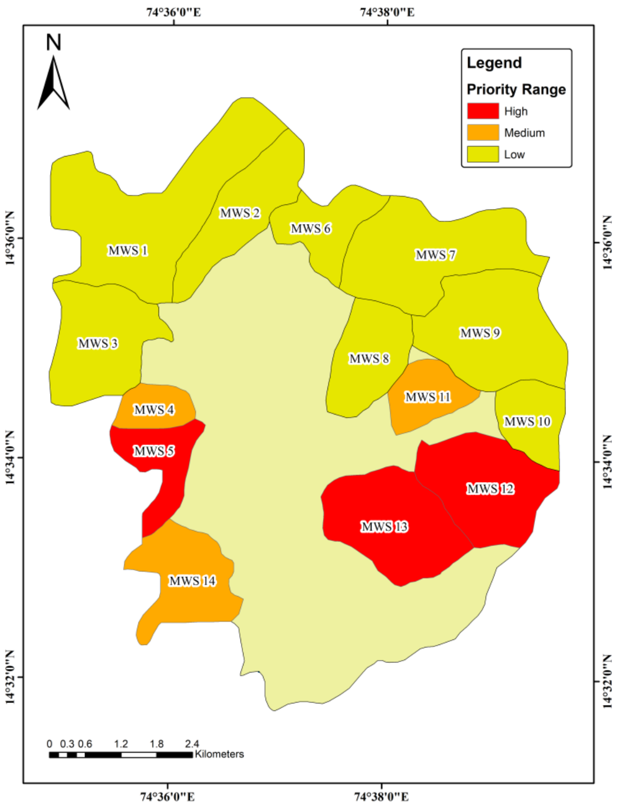

Fig 5: Prioritization of Micro-watersheds of the Study Area

V. CONCLUSION

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms (Clarke et al. 1966). The morphometric analysis of the drainage basin and the channel network plays an important role in understanding the geo-hydrological behavior of drainage basin and express the prevailing climate, geology, geomorphology, structural antecedents of the catchment.GIS and RS are very important in determining the morphometric parameters and carrying out morphometric analysis of drainage basin.GIS and Remote Sensing have proved to be very efficient and accurate in the delineation of the drainage and in the quantification of the morphometric parameters. The stream ordering was carried out based on Strahler (1964) stream ordering technique and the maximum stream order obtained was sixth order stream which is the part of the river itself. Based on our study and the results obtained it is evident that the Balekoppa sub-watershed has dendritic drainage pattern. The development of the drainage pattern is not affected by the geological structures. It has permeable subsoil, low relief and is having a rich vegetation cover and very less runoff from the basin. The texture of the sub-watershed is very coarse and the sub-watershed is more elongated than circular. The majority of the micro-watersheds have elongated basins with lower peak flow of longer duration. Prioritization of any watershed, sub-watershed or micro-watershed is an very important step for watershed management. Based on the prioritization it is possible to know the areas that require conservative measures to be undertaken to avoid further distress. From our study we found that two micro-watersheds from the Balekoppa sub-watershed fall under high erosion category and are in need of immediate preventive control measures whereas other three are in moderate erosion category and the erosion is in manageable terms and remaining eight are in low erosion category and are of no erosion concern. This study is very much helpful for the local administration and also in deciding the construction of erosion preventing structures.

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