Quantitative Analysis of Morphometric and Hypsometric using RS and GIS Techniques

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***Abstract*— Morphometric analysis is significant in any hydrological investigation and it is needed for development and management of watersheds. A critical evaluation of morphometric parameters have been achieved through measurement of linear, areal and relief aspects of basins. Integration of RS and GIS techniques are useful for morphometric analysis as compare to conventional methods. The study area chosen is Kabini command area which spreads in Chamarajanagar and Mysore districts. In the present study, an attempt has been made to analyse the Command area at the watershed. Based on the drainage pattern and topography, seven watersheds have been delineated. The study area geographically lies between 76' 12" 0" E and 77' 0" 12" E longitude and 11' 58" 0" N and 12' 16" 0" N latitude with an area of 713.70 km^2. Horton's and strahler method of stream ordering has been applied for the analysis. The analysis reveals that the stream order varies from 1st to 5thorder and the total number of stream segments of all orders found to be 782. It is observed that the drainage density is 0.945km/km^2, which indicates that the study area has highly permeable subsoil and thick vegetative cover. The circularity ratio value reveals there is strongly elongated and highly permeable homogenous geologic material. The hypsometric analysis carried out and value of hypsometric integral (HI) is found to be 0.5 based on integrating method and 0.49 from Elevation-Relief ratio method, which indicates the watershed is at equilibrium or mature stage. The study concludes that morphometric and hypsometric analysis using RS and GIS technique proves to be very helpful to identify the geo-hydrological, geomorphological characteristics of basin for planning, sustainable development, management and conservation of soil for kabini command area.**

Keywords*— Remote Sensing, GIS, DEM, Drainage, Morphometric parameters, Hypsometric integral value.

I.INTRODUCTION

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface, shape and size of its landforms (Agarwal, 1998). Morphometric analysis was initiated in the field of hydrology to ascertain complete stream characteristics from the quantification of various stream attributes (Horton, 1940). Horton was the first person to explain the formation of streams, stream ordering technique and basins quantitatively and it is then revised by Strahler (1952).

Morphometric analysis is significant for characterization of watersheds and gives information about quantitative description of the streams network and useful for hydrological investigation. The influence of stream network is significant in understanding the landform process, soil physical properties and land degradation status (Schumm, 1956). Morphometric analysis can be analyzed through measurement of linear, areal and relief aspects of basins by using Remote sensing (RS) and Geographic Information System (GIS) technique. Integration of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques are more convenient for morphometric analysis as compare to conventional method. Various thematic layers required for the morphometric analysis can be prepared by using RS and ArcGIS tools (Sharma, 2018).

RS and GIS is a proven technique for delineating, updating and analyzing the morphometric parameters of drainage basin. Delineation of drainage network and its parameter analysis generally emphasis the climate, geology, geomorphology and relief aspects of a basin. The morphometric analysis of a basin thus provides the first hand information to understand the geomorphology and watershed characteristics (Pareta,2011). The quantitative analysis of morphometric parameters is very much useful for prioritization of watershed, planning for site specific soil, water management and soil conservation measures at watershed.

Hypsometric analysis was first time introduced by Langbein(1947), to convey the overall slope and the forms of drainage basin. Hypsometry describes the measurement and analysis of relationships between the distribution of elevations across an area of land surface and basin area. Hypsometric analysis has been used to make difference between erosional landforms at different stages during their evolution at watershed. The numerical characteristic in the hypsometric analysis includes the hypsometric integral, hypsometric curve, hypsometric skewness (Pike and Wilson, 1971).

Hypsometric analysis is a useful method to identify the stage reached by a drainage basin in the present cycle of erosion and evaluate the erosional status of a basin and also expresses the denudation processes over a region. Hypsometric curve is the graphical representation of area Vs elevation. Strahler (1952) evaluated different shapes of hypsometric curves through the comparison of different drainage basins and classified as youth stage, where the watershed undergoes erosion and land sliding, equilibrium or mature stage, less erosion and land slide than youth stage and lastly old stage, very less erosion and land slide. Hypsometric integral is the area under hypsometric curve which shows percentage of landmass eroded from the watershed based and on this the watershed is divided into three stages as old (HI $<$ 0.3), equilibrium or mature stage (HI 0.3 $<$ 0.6) in which watershed is highly susceptible to erosion (Strahler 1952).The hypsometric integral is expressed as a percentage and is an indicator of the residue of the present volume as compared to the original volume of the basin. The hypsometric integral thus helps in explaining the erosion that had taken place in the watershed during the geological time scale due to hydrologic processes and land degradation factors (Strahler, 1964).

II. STUDY AREA

Study area chosen is Kabini command area which spreads in Chamrajnagar and Mysore districts. The study area geographically lies between 76^0 12” 0” E and $77^{\,0}$ 12” 0” E longitude and 11^0 58” 0” N and 12^0 16” 0” N latitude with an area of 713.70 km^2 .The maximum length and width of the command is 91.137 km and 25.68 km respectively. Kabini river is one of the major rivers in Cauvery basin and constitutes C-2 subbasin. The river originates in Western Ghats at an altitude of 2134 m in Wynadtauk, Kerala state and flows for a length of 212 km before joining the river Cauvery at TirumakudaluNarasipura, Karnataka state. Fig.1 shows the location map of Kabini command area.

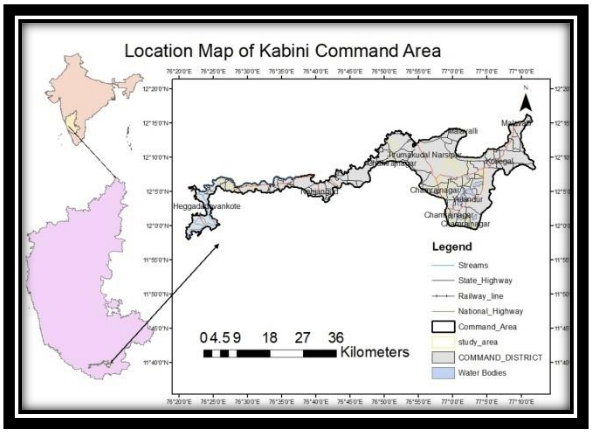

Fig 1. Location Map of Study Area.

III.METHODOLOGY

The methodology adopted for the study is to ,

1. Extraction of study area from Toposheets of 1:50000 scale.
2. SRTM DEM images of the study area as shown in fig.2,were downloaded using earthexplorer.usgs.gov website.
3. Delineating drainage network of the study area using Arc GIS 10.4 software.
4. Evaluation of morphometric parameters as shown in table.1 based on linear, areal and relief aspects respectively, by using various tools in ArcGIS10.4 software.
5. Using 3D analyst tool, the watershed is reclassified into different elevations and using these reclassified elevations and their surface area the hypsometric analysis is carried out and hypsometric curve is generated.
6. The hypsometric integral value is found out using two methods, Integrating of Hypsometric curve within limits 0 to 1 and Elevation-relief ratio (E) relationship.

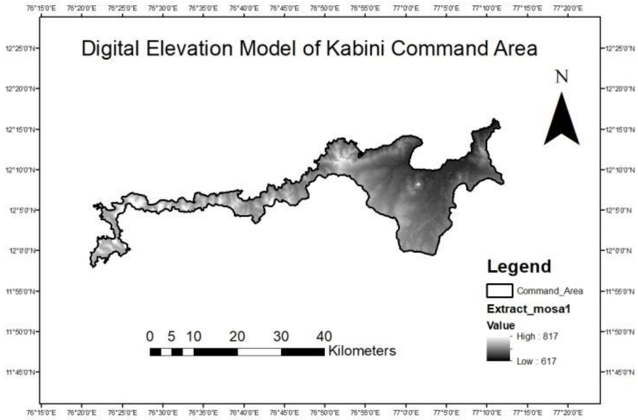

Fig.2 DEM of Kabini Command Area

TABLE 1. Morphometric parameters with formula.

Sl No	Parameters	Symbol	Formula	Reference
1	**Linear aspects**			
1.1	Stream order	Nu	Hierarchical rank	Strahler (1952)
1.2	Bifurcation ratio	R_b	$R_b = \frac{N_u}{N_{(u+1)}}$	Schumn (1956)
1.3	Stream length	L_u	Length of stream (km)	Horton (1945)
1.4	Mean Stream length	Lsm	Lsm $= \frac{\sum_{i=1}^{N} L_u}{N_u}$ km	Strahler and Chow (1964)
1.5	Stream length ratio	R_l	$R_l = \frac{L_u}{L_{(u-1)}}$	Horton (1945)
2	**Areal aspects**			
2.1	Form factor	R_f	$R_f = \frac{A}{L^2}$	Horton (1945)
2.2	Circularity ratio	R_c	$R_c = \frac{4\pi A}{P^2}$	Sarma et al. (2013)
2.3	Elongation ratio	R_e	$R_e = \frac{2\sqrt{A/\pi}}{L}$	Schumn (1956)
2.4	Drainage density	D_d	$D_d = \frac{\sum L_u}{A} \boldsymbol{Km/Km^2}$	Horton (1945)
2.5	Stream frequency	S_f	$S_f = \frac{N_s}{A}$	Horton (1945)
2.6	Constant of channel maintenance	C	$C = \frac{1}{D_d}$	Schumm (1956)
3	**Relief aspects**			
3.1	Watershed relief	R	$R = H - h$	Hadley and Schumm (1961)
3.2	Relief ratio	R_f	$R_f = \frac{H}{L}$	Schumn (1956)
3.3	Relative relief	R_r	$R_r = \frac{H}{P}$	Schumn (1956)
3.4	Ruggedness number	R_n	$R_n = \frac{HD_d}{1000}$	Schumn (1956)

IV.RESULT AND DISCUSSION

In the present study morphometric analysis has been carried out for the study area using stream order map as shown in fig.3, based on three major aspects which are linear, areal and relief aspects.

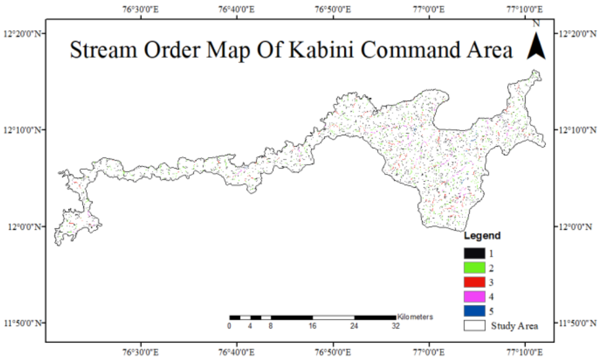

Fig .3.Stream Order Map of Kabini Command Area.

Linear aspect: The morphometric analysis for linear aspects of the study area were calculated and tabulated in Table 2.From the graph it is observed that as the stream order increases the number of streams and length of streams gradually decreases as shown in fig. 4 and fig.4respectively.

Table 2. Linear aspects of the Kabini Command Area.

Stream Order	Stream Number (N)	Bifurcation Ratio (Rb)	Stream Length (Lμ) Km	Mean Stream Length (Ls m) Km	Stream Length Ratio R_l	Mean Bifurcation Ratio R_b	Length Of Overland Flow (L_G) Km	Basin Perimeter (P) Km	Basin Length (L) Km
1st	446		392.86			2.57	0.4725	387.36	91.14
		2.23		0.444	0.443				
2nd	200		174.32						
		2.02		0.439	1.703				
3rd	99		76.44						
		3.96		0.255	0.336				
4th	25		19.52						
		2.08		0.563	0.6				
5th	12		10.99						
Total	782	10.29	674.13	1.701	3.082				

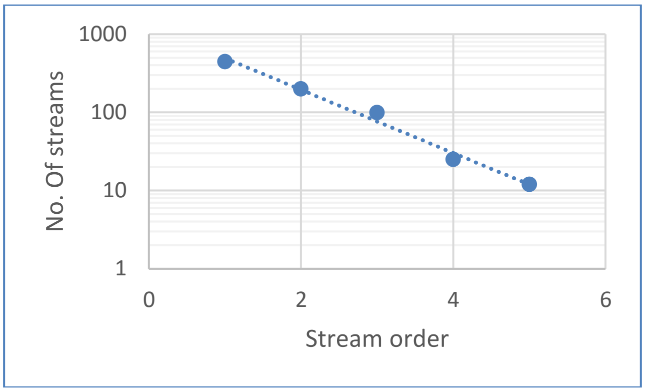

Fig.4. Regression Graph of Stream Order Vs No. of streams

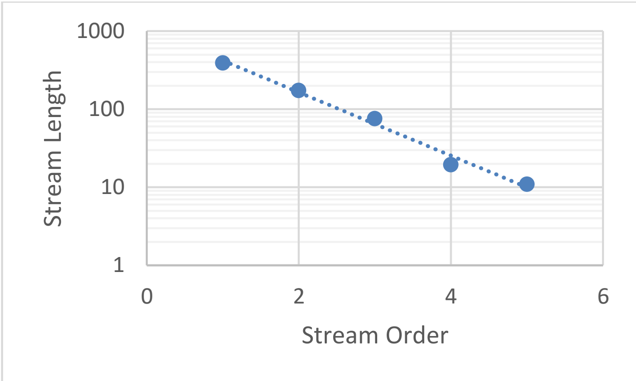

Fig.5. Regression Graph of Stream Order Vs Stream length (km).

According to Strahler (1964), the study area is observed as fifth order stream.The numerous 1st order streams are said to be formed by the continuous erosion of the river banks. Drainage pattern of stream network from the basin have been observed as mainly of dendritic type, which indicates the homogeneity in texture.

Areal aspects: The morphometric analysis for areal aspects of Kabini Command Area were found out and results are tabulated in table 3.

Table 3. Areal Morphometric Parameters of Kabini Command Area.

Sl.No.	Parameter	Results
1	Drainage area (a)	713.70 km^2
2	Drainage density(D_d	0.945km/km^2
3	Drainage frequency (S_f)	1.095 $No./Km^2$
4	Drainage texture (D_t)	2.019
5	Form factor ratio (R_f)	0.086
6	Elongation ratio (R_e)	0.115
7	Circularity ratio (R_c)	0.06

Relief aspects: The morphometric analysis for relief aspects of Kabini Command Area were found out and results are tabulated in table 4.

Table 4. Relief aspects of Kabini Command Area.

Sl.no.	Parameter	Results
1	Highest relief in the watershed	817.0 m
2	Lowest relief in the watershed	617.0 m
3	Watershed relief	0.1
4	Relief ratio	0.1

Hypsometric analysis

A. Integration of Hypsometric curve: The hypsometric curves were fitted with a trend line to represent an equation of the curve. The equation was further integrated within the limits 0–1 (due to non-dimensional nature of the graph) for estimating the area under the curve. Thus, estimated area gives the hypsometric integral value of the hypsometric curve.

B. Elevation-Relief ratio (E) relationship: Integration of the hypsometric curve gives the hypsometric integral (HI), which is equivalent to the elevation-relief ratio (E) as proposed by Pike and Wilson (1971).

The relationship is expressed as $\boldsymbol{E} = \frac{[\boldsymbol{E_{mean}} - \boldsymbol{E_{min.}}]}{[\boldsymbol{E_{max}} - \boldsymbol{E_{min.}}]}$

where E is the elevation-relief ratio which is equivalent to hypsometric integral(HI) .E_{mean} is the weighted mean elevation of the watershed, E_{max} and $E_{min.}$are the minimum and maximum elevations within the watersheds.

Table 5:Hypsometric Integral values of Kabini Command Area

Sl. No.	Elevation Reclassified in GIS (m)	Elevation (m)	Surface Area (km^2)	Cumulative Area	E	E /Emax	a/A	Hypsometric Integral	Geological Stage
		817	0.00	0.00	200	1	0.00E+00	0.5	Equilibrium or Mature stage
1	817 - 797	797	0.03	0.03	180	0.9	4.27E-05		
2	798 - 777	777	0.06	0.09	160	0.8	1.27E-04		
3	778 - 757	757	0.14	0.23	140	0.7	3.24E-04		
4	758 - 737	737	0.48	0.71	120	0.6	9.94E-04		
5	738 - 717	717	1.20	1.91	100	0.5	2.67E-03		
6	718 - 697	697	11.74	13.65	80	0.4	1.91E-02		
7	698 - 677	677	93.21	106.86	60	0.3	1.50E-01		
8	678 - 657	657	302.07	408.93	40	0.2	5.73E-01		
9	658 - 637	637	260.23	669.16	20	0.1	9.38E-01		
10	638 - 617	617	44.27	713.43	0	0	1.00E+00		
	$\boldsymbol{E_{min.}}$	617							
	$\boldsymbol{E_{max} - E_{min.}}$	200							
	$\boldsymbol{E_{mean}}$	717							

Hypsometric analysis is carried out and hypsometric curve was plotted as shown in fig.6 and the results obtained are tabulated in table 5.

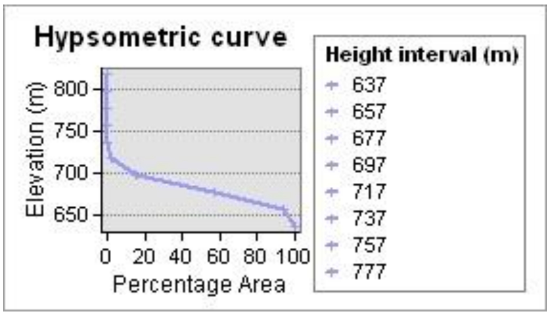

Fig 6. The Percentage Hypsometric Curve

The shape of a hypsometric curve indicates the major geomorphic processes that taken place in a watershed. A convex curve indicates more of the watershed area and soil mass is held relatively high in the watershed. A concave curve indicates the bulk of the watershed area and soil mass resides at relatively low elevation. More material has been removed from elevated areas and deposit that material in downward areas or taken out of the watershed completely. It is observed that head and toe of the curve has convex upward and body of the curve has concave upward which means the watersheds is in equilibrium or mature stage.

IV.CONCLUSION

1. From the analysis it is revealed that the delineation technique of drainage network of the basin and stream ordering from SRTM DEM data with Arc GIS environment is more convenient, time saving and accurate way than the manual delineation technique of drainage network.
2. It is observed that 24 morphometric parameters were carried out through linear, areal and relief aspect of theKabini Command Area and found out that drainage network of this basin shows dendritic pattern, which indicates the homogeneity in texture and the bifurcation ratio of the study area is not same from one order to its next order.
3. It is found out that drainage density of 0.945 km/km^2 was indicated that the basin is not much affected by structural disturbances and indicates the very coarse texture of the watershed.
4. The drainage frequency for the basin was indicated low relief and permeable sub surface material, while very coarse drainage texture indicates good permeability of sub-surface rocks and soils with high infiltration.
5. The form factor, circularity ratio and elongated ratio suggest the basin shape as elongated and lesser relief and slope are characterized by moderate value of relief ratios.
6. Hypsometric curve obtained from hypsometric analysis clearly shows that the watershed is in equilibrium or mature stage.
7. The Hypsometric integral value works out to be 0.5 from Integrating method and 0.49 from Elevation-Relief ratio method.

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