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Original Research Paper

Morphometric Analysis of Sub-basins in and Around Malur Taluk, Kolar District, Karnataka Using Remote Sensing and GIS Techniques

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ABSTRACT

The study reveals that remote sensing and GIS techniques proved to be the competent tool in analysing various morphometric parameters. The drainage network of Kanamanahalli and Devaraguttahalli sub-basins were delineated using false colour composite (FCC) of IRS-1C/1D merged satellite data on 1:50,000 scale. SOI toposheets were used as reference with limited field work. The study area falls in Ponnaiyar river basin covering an area of 686 sq. km comprising two sub-basins namely Kanamanahalli and Devaraguttahalli having an area of 439 sq.km and 247 sq.km respectively in and around Malur taluk of Kolar district. The morphometric analysis of these two sub-basins shows that the terrain exhibits dendritic to sub-dendritic drainage pattern. Stream order ranges from first to sixth order. Drainage density varies between 1.57 and 1.88 km/km^2 and has coarse to fine drainage texture. The relief ratio ranges from 0.0111 to 0.0117. The mean bifurcation ratio varies from 3.51 to 4.86 which fall under normal basin category. The elongation ratio shows that these sub-basins are associated with high relief and steep ground slopes.

INTRODUCTION

Morphometric analysis requires measurement of linear features, gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal 1994). Morphometric analysis provides quantitative description of the basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler 1964). The morphometric analysis of a drainage basin/watershed is of great importance in understanding the hydrologic behaviour as well as hydrogeology and groundwater conditions of the area. A strong mutual relationship exists between morphological variables and hydrological characteristics. Such relation can be applied to both surface and groundwater regime. Even though quantitative measures were proposed for specific areas or for particular problems during the 19th century, methods of stream ordering were conceived by the early 20th century. The description of drainage basins and channel networks, based on the contributions made by Horton (1932, 1945) and supplemented by Chorley (1957), Langbein (1947), Melton (1958), Miller (1953), Schumn (1956), Smith (1950) and Strahler (1964) were transformed from a purely qualitative and deductive study to a rigorous quantitative science providing hydrologists with numerical data of practical values. Remote sensing techniques using satellite images and aerial photographs are convenient tools for morphometric analysis. The satellite remote sensing has the ability to provide synoptic view of large area and is very useful in analysing drainage morphometry. The image interpretation techniques are less time consuming than the ground surveys, which if coupled with limited field checks yield valuable results. Many researchers have proved that remote sensing and GIS techniques are the powerful tools for carrying out the morphometric analysis of drainage basins (Srivastava & Mitra 1995, Srivastava 1997, Singh & Singh 1997, Nag 1998, Vittala et al. 2004, Chopra et al. 2005, Rudraiah et al. 2008).

STUDY AREA

The study area around Malur forms part of Ponnaiyar river basin, which comprises of 2 sub-basins namely Kanamanahalli and Devaraguttahalli sub-basins having an area of 439 and 247 sq.km respectively. The study area is located between N latitude of 12°46’00’ to 13°15’00’ and E longitude of 77°56’00’ to 78°14’00’ (Fig. 1). About 5% of the study area towards southern part belongs to Tamilnadu State. The mean annual rainfall is 722 mm and receives rainfall from both southwest and northeast monsoons. Southwest monsoon contributes 51.97% and northeast monsoon contributes 31.57% of the mean annual rain fall, while remaining 16% is received during summer. The study area enjoys sub-tropical climate with temperature ranging from 25.3 to 39°C. April and May are the hottest months and with onset of southwest monsoon in June temperature drops considerably. December is the coldest month. The relative humidity is high during the southwest monsoon season ranging from 70 to 74% and moderate during rest of the period which ranges from 47 to 64%. Wind speed is generally moderate with some increase in velocity during monsoon months. Physiographically, the area is characterised by undulating terrain interspersed by low ranges of rocky hills and the elevation rages from 860 to 1127 m above M.S.L. The major rock types in the study area are gneisses and granites of Achaeans age. At places these formations are intruded by basic dykes, pegmatites and quartz veins. Recent alluvium occurs along the banks of streams and rivers. Two types of soils namely red soils and laterite soils cover the area. The red soil is dominant all over the study area.

DATA USED AND METHODOLOGY

The data used for the study includes IRS-1C/1D LISS-III + PAN merged data and Survey of India (SOI) toposheets No. 57 G/16, H/13, K/4 and L/1 of 1:50,000 scale as collateral data. The image was geometrically rectified with respect to the Survey of India (SOI) topographical maps on 1:50,000 scale. The drainage pattern was initially derived from SOI toposheets and later updated using linearly stretched False Colour Composite (FCC) of IRS-ID merged satellite data. SOI toposheets have been used as a reference. Field work has been carried out. The detailed drainage map is given in Fig. 1. The morphometric parameters considered for the analysis are summarized in Table 1 and the results are summarized in Table 2. The GIS software like ArcInfo and ArcView have been used for digitization and computational purpose and also for output generation.

RESULTS AND DISCUSSION

Watershed delineation: Watershed is a natural hydrological entity from which surface runoff flows to a defined drain, channel, stream or river at a particular point. The entire study area has been divided in to two sub-basins namely Kanamanahalli and Devaraguttahalli sub-basins having an area of 439 and 247 km^2 respectively (Table 2). The sub-basins have been named based on the villages at the outlet of the streams.

Morphometric analysis: Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms (Clarke 1966). This analysis can be achieved through measurement of linear, aerial and relief aspects of basin and slope contributions (Nag & Chakraborty 2003). In the present study, the morphometric analysis for the parameters namely stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio, etc., has been carried out using the mathematical formulae given in Table 1 and the results are summarized in Table 2.

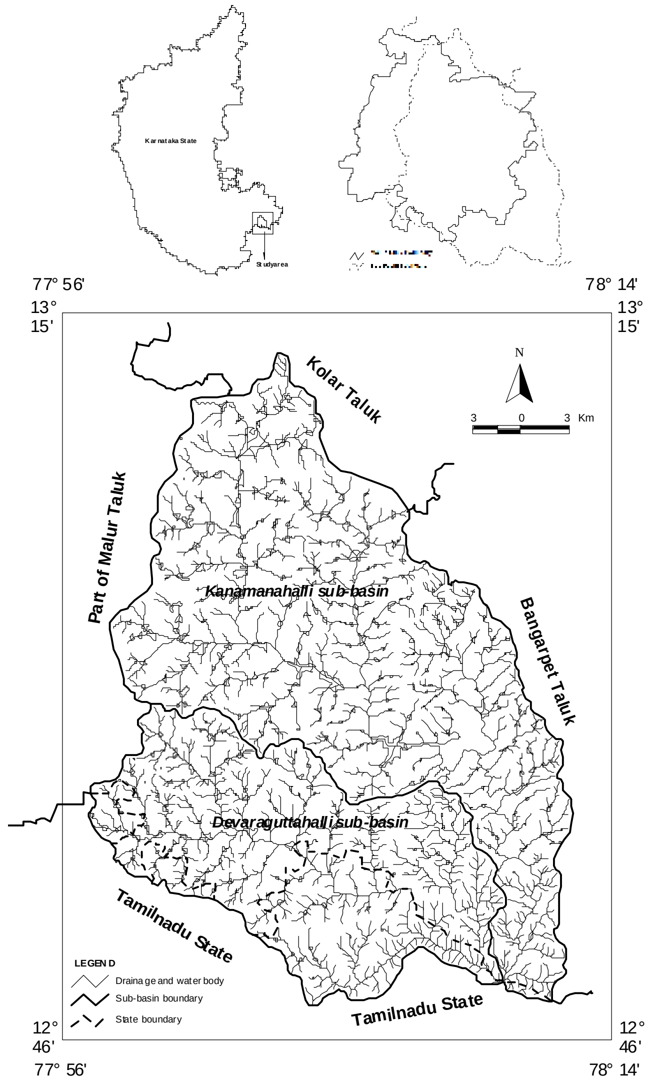

Fig. 1: Drainage map of the study area.

Linear Aspects

Stream order, stream length, mean stream length, stream length ratio and bifurcation ratio are linear aspects that were determined and results have been given in Table 2.

Stream order: The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964) (Table 1). The order-wise stream numbers, area and stream lengths of the 2 sub-basins are given in Table 2. Out of these two sub-basins, Kanamanahalli sub-basin possesses fifth order while Devaraguttahalli sub-basin is sixth order. It is observed from the Table 2 that the maximum frequency is in case of first order streams. It is also noticed that there is a decrease in stream frequency as the stream order increases.

Stream length: The number of streams of various orders in a sub-basin are counted and their lengths from mouth to drainage divide are measured (Table 2) with the help of GIS software. The stream length (Lu) has been computed based on the law proposed by Horton (1945) for both sub-basins (Table 1). It is observed in both sub-basins that the total length of stream segments is maximum in first order streams and decreases as the stream order increases.

Mean stream length: The mean stream length is a characteristic property related to the drainage network and its associated surfaces. The mean stream length (Lsm) has been calculated by dividing the total stream length of order 'u' and number of streams of segment of order 'u' (Table 1). It is noted from Table 2 that Lsm in both sub-basins varies from 0.62 to 45.00. The Lsm of any given order is greater than that of the lower order and lesser than that of its next higher order in Kamanaanahalli sub-basin but it is not so in Devaraguttahalli sub-basin which might be due to variations in slope and topography.

Stream length ratio: Stream length ratio (RL) may be defined as the ratio of the mean length of the one order to the next lower order of stream segment (Table 1). Horton's law (Horton 1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams. The RL between streams of different order in the study area reveals that there is a variation in RL in each sub-basin (Table 2). This variation might be due to changes in slope and topography. In both the sub-basins, there is a change from one order to another order indicating their late youth stage of geomorphic development (Singh & Singh 1997).

Bifurcation ratio: Bifurcation ratio (Rb) may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher order (Schumn 1956) (Table 1). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environments except where the powerful geological control dominates. It is observed from the Table 2, that the Rb is not same from one order to its next order. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler 1964). The lower values of Rb are characteristics of the sub-watersheds which have suffered less structural disturbances (Strahler 1964) and the drainage pattern has not been distorted because of the structural disturbances (Nag 1998). In the present study, the higher values of Rb indicate strong structural control on the drainage pattern while the lower values are indicative of sub-basins that are not affected by structural disturbances. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all orders (Table 1). In the present study, Rbm varies from 3.51 to 4.86 (Table 2) and all sub-watersheds fall under normal basin category (Strahler 1957).

Relief Aspect

The relief measurements like relief ratio, basin length and total relief are given in Table 2.

The elevation difference between the highest on the ridge and lowest point on the valley floor of a sub-basin is known as the total relief of that sub-basin. The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm 1956) (Table 1). According to him, there is direct relationship between the relief and channel gradient. There is also a correlation between hydrological characteristics and the relief ratio of a drainage basin. The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin (Gottschalk 1964).

The values of Rh are given in Table 2 and range from 0.011 (Devaraguttahalli) to 0.0117 (Kanamanahalli). It is noticed that the high values of Rh indicate steep slope and high relief (490 m), while the lower values (300 m) may indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (GSI 1981).

Aerial Aspect

Different morphometric parameters like drainage density, texture ratio, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow have been discussed in detail and are presented in Table 2.

Drainage density: Horton (1932) has introduced drainage density (D) into American hydrologic literature as an expression to indicate the closeness of spacing of channels. It is defined as the total length of streams of all orders per drainage area (Table 1). Langbein (1947) recognized the significance of D as a factor determining the time of travel by water and he also suggested a drainage density varying between 0.55 and 2.09 km/km^2 in humid region with an average density of 1.03 km/km^2. Density factor is related to climate, type of rocks, relief, infiltration capacity, vegetation cover, surface roughness and run-off intensity index. Of these only surface roughness has no significant correlation with drainage density. The amount and type of precipitation influences directly the quantity and character of surface run-off. An area with high precipitation such as thundershowers loses greater percentage of rainfall as run-off resulting in more surface drainage lines. Amount of vegetation and rainfall absorption capacity of soils, which influences the rate of surface run-off affects the drainage texture of an area. Under similar condition of lithology and geologic structures, semi-arid regions have finer drainage density texture than humid regions. According to Nag (1998), low drainage density generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. In the present study, the drainage density varies between 1.57 and 1.88 km/km^2. Low drainage density suggests that the region has highly permeable subsoil and dense vegetative cover.

Stream frequency: Stream frequency (Fs) or channel frequency is the total number of stream segments of all orders per unit area (Table 1). Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of same 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-basins indicating the increase in stream population with respect to increase in drainage density.

Drainage texture: Drainage texture (Rt) is one of the important concepts of geomorphology which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. According to Horton (1945), Rt is the total number of stream segments of

Table 1: Methodology adopted for computations of morphometric parameters.

Aspects	Morphometric parameters	Formula	Reference
Linear Aspect	Stream Order	Hierarchial rank	Strahler (1964)
	Stream Length (Lu)	Length of the Stream	Horton (1945)
	Mean Stream Length(Lsm)	Lsm = Lu/Nu, Where Lsm = Mean Stream Length, Lu = Total stream length of order ‘u’ Nu = Total no. of stream segments of order ‘u’	Strahler (1964)
	Stream Length Ratio (RL)	RL = Lu/Lu – 1, Where RL = Stream Length Ratio Lu = The total stream length of the order ‘u’Lu – 1 = The total stream length of its next lower order	Horton (1945)
	Bifurcation Ratio (Rb)	Rb = Nu/Nu + 1, Where, Rb = Bifurcation Ratio, Nu = Total no. of stream segments of order ‘u’ Nu + 1 = Number of segments of the next higher order	Schumn (1956)
	Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
Relief Aspect	Relief Ratio (Rh)	Rh = H/Lb, Where Rh = Relief Ratio, H = Total relief (Relative relief) of the basin in kilometers Lb = Basin length	Schumm (1956)
Aerial Aspect	Drainage Density (D)	D = Lu/A, Where D = Drainage Density, Lu = Total stream length of all orders, A = Area of the basin (km^2)	Horton (1932)
	Stream Frequency (Fs)	Fs = Nu/A, Where Fs = Stream Frequency, Nu = Total no. of streams of all orders, A = Area of the basin (km^2)	Horton (1932)
	Drainage Texture (Rt)	Rt = Nu/P, Where, Rt = Drainage Texture, Nu = Total No. of streams of all orders, P = Perimeter (km)	Horton (1945)
	Form Factor (Rf)	$Rf = A/Lb^2$, Where Rf = Form Factor, A = Area of the basin (km^2), Lb^2 = Square of basin length	Horton (1932)
	Circularity Ratio (Rc)	$Rc = 4 \times Pi \times A/P^2$, Where Rc = Circularity Ratio, Pi = ‘Pi’ value i.e., 3.14, A = Area of the basin (km^2), P^2 = Square of the perimeter (km)	Miller (1953)
	Elongation Ratio (Re)	$Re = 2 \times Sqrt (A/Pi)/Lb$, Where Re = Elongation Ratio A = Area of the basin (km^2)Pi = ‘Pi’ value i.e., 3.14 Lb = Basin length	Schumn (1956)
	Length of Overland Flow (Lg)	$Lg = 1/D \times 2$, Where Lg = Length of overland flow D = Drainage Density	Horton (1945)

Table 2: Results of morphometric analysis.

Sl.No.	Parameters	Kanamanahalli sub-basin						Devaraguttahalli sub-basin					
1	Area (km^2)	439						247					
2	Perimeter (km)	119						81					
3	Basin Length (km)	42						27					
4	Stream Order	V						VI					
5	No. of streams in each order	I	II	III	IV	V	VI	I	II	III	IV	V	VI
		505	124	33	5	1	-	431	92	25	6	2	1
6	Total number of streams of all orders	668						557					
7	Stream length in each order (Lu)	I	II	III	IV	V	VI	I	II	III	IV	V	VI
		373	155	80	37	45	-	266	97	52	21	27	2
8	Total length of streams of all orders	690						465					
9	Bifurcation Ratio (Rb)	I/II	II/III	III/IV	IV/V	V/VI		I/II	II/III	III/IV	IV/V	V/VI	
		4.07	3.76	6.60	5.00	-		4.68	3.68	4.17	3.00	2.00	
10	Mean Bifurcation Ratio (Rbm)	4.86						3.51					
11	Mean Stream Length (Lsm)	I	II	III	IV	V	VI	I	II	III	IV	V	VI
		0.74	1.25	2.42	7.40	45.00	-	0.62	1.05	2.08	3.50	13.50	2.00
12	Stream Length Ratio (RL)	I/II	II/III	III/IV	IV/V	V/VI		I/II	II/III	III/IV	IV/V	V/VI	
		0.42	0.52	0.46	1.22	-		0.36	0.54	0.40	1.29	0.07	
13	Total Relief (km)	0.49						0.30					
14	Relief Ratio (Rh)	0.0117						0.0111					
15	Drainage Density (D) (km/km^2)	1.57						1.88					
16	Stream Frequency (Fs)	1.52						2.26					
17	Drainage Texture (Rt)	5.61						6.88					
18	Form Factor (Rf)	0.25						0.34					
19	Circularity Ratio (Rc)	0.39						0.47					
20	Elongation Ratio (Re)	0.56						0.66					
21	Length of Overland Flow (Lg)	1.27						1.06					

all orders per perimeter of that area (Table 1). He recognized infiltration capacity as the single important factor which influences Rt and considered drainage texture which includes drainage density and stream frequency. Smith (1950) has classified drainage density into five different textures. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. In the present study, the drainage density (Table 2) is of very coarse drainage texture.

Form factor: According to Horton (1932), form factor (Rf) may be defined as the ratio of basin area to square of the basin length (Table 1). From Table 2 it is observed that the Rf varies between 0.25 and 0.34 and thus indicates that the Devaraguttahalli sub-basin is comparatively more circular in shape with higher value (0.34), and Kanamanahalli sub-basin is elongated with lower value (0.25) of form factor.

Circularity ratio: It is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin (Miller 1953) (Table 1). The circularity ratio (Rc) 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 study, the Rc ranges from 0.39 to 0.47 (Table 2). The high Rc of 0.47 in Devaraguttahalli sub-basin indicates that the sub-basin is more or less circular and is characterized by high to moderate relief, and drainage system is structurally controlled, while Kanamanahalli sub-basin has Rc of 0.39, indicating that it is elongated.

Elongation ratio: Schumm (1956) defined elongation ratio (Re) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Table 1). A circular basin is more efficient in the discharge of run-off than an elongated basin (Singh & Singh 1997). The values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. Values close to 1.0 are typical of regions of very 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 four categories namely (a) circular (>0.9), (b) oval (0.9 to 0.8) and (c) less elongated (<0.7). The Re of sub-watersheds of the study area varies from 0.56 to 0.66 (Table 2). These values indicate that the sub-basins are associated with high relief and steep ground slope.

Length of overland flow: It is the length of water over the ground before it gets concentrated into definite stream channels (Horton 1945) (Table 1). This factor basically relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. The length of overland flow (Lg) approximately equals to half of the reciprocal of drainage density (Horton 1945). The computed value of Lg in both sub-basins varies from 1.0 to 1.27. From the Table 2, it is revealed that the Lg is less in Devaraguttahalli sub-basin as drainage density is high.

Morphometric analysis of the two sub-basins around Malur taluk is helpful in understanding the geomorphology and drainage pattern of the area. It also plays very important role in identifying and locating lineaments which have structural control over the movement of groundwater. The lineaments act as pathways for movement of groundwater, and are potential aquifers in the area. As the area around Malur is part of hard rock terrain, devoid of any permanent source of surface water bodies to cater to the need of domestic water supply of the area, morphometric analysis will act as a guiding tool in locating potential aquifers in the area.

CONCLUSION

The study reveals that remote sensing and GIS techniques proved to be the potential tool in drainage delineation and analysing various morphometric parameters. The morphometric analysis of the drainage networks in the study area exhibits the dendritic to sub-dendritic drainage pattern and the variation in stream length ratio might be due to changes in slope and topography. The variation in values of bifurcation ratio among the sub-watersheds is ascribed to the difference in topography and geometric development. The stream frequencies in each sub-basin of the study exhibits positive correlation with the drainage density values indicating the increase in stream population with respect to increase in drainage density. The low drainage density indicates that the region has highly permeable subsoil and dense vegetative cover. The elongation ratio in the study area varies from 0.56 to 0.66 which indicates that the sub-basins are associated with high relief and steep ground slope. The length of overland flow revealed that it is less in Devaraguttahalli sub-basin as drainage density is high.

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