Influence of Geomorphometric Parameters on Hydrologic Response of Sangola watershed in Maharashtra, India

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Abstract- Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. Morphometric description of the drainage basins will provide very valuable information on the hydrologic response of the basin, hence, it is very useful in river basin evaluation, watershed prioritization, planning soil and water conservation measures, etc. Salient findings of the study carried out to investigate Geomorphometry and its response on hydrology for Sangola watershed in Solapur district of Maharashtra state with the application of GIS is presented in this paper.

Keywords – Sangola watershed, Geomorphometric Analysis, GIS, Hydrologic Response

I. INTRODUCTION

The drainage basin consists of all the land area that drains water to the outlet during a rainstorm, is the basic unit of all hydrologic analysis and designs. Geomorphometric analysis gives an idea about the basin characteristics in terms of slope, topography, soil condition, runoff, recharge, etc. An American engineer, Robert. E. Horton(1945) investigated the relationship between morphometry, hydrology and landscape. This form of analysis is now often referred to as Horton Morphometry. The basin morphometric characteristics of the various basins have been studied by many scientists using conventional (Horton 1945; Strahler 1952) and remote sensing and GIS methods (Krishnamurthy and Srinivas 1995; Biswas et al., 1999). Morphometric analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope characteristics (Nag and Chakraborty, 2003). Geographical Information System (GIS) techniques are now-a- days used for assessing various morphometric parameters of the drainage basins as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. In this context, the morphometric parameters of Sangola watershed in Solapur district of Maharashtra state have been analyzed in GIS environment. ArcGIS (version 9.3) software is used for study of morphometric parameters.

II. STUDY AREA

The study area constitutes Sangola watershed located in the Solapur district of Maharashtra state.
(Fig. 1). The basin area is bounded between longitudes 75° 7´ East- 75° 14´ East and latitudes 17° 25´ North- 17° 28´ North. It has a catchment area of 33 sq.km. (Fig.2)

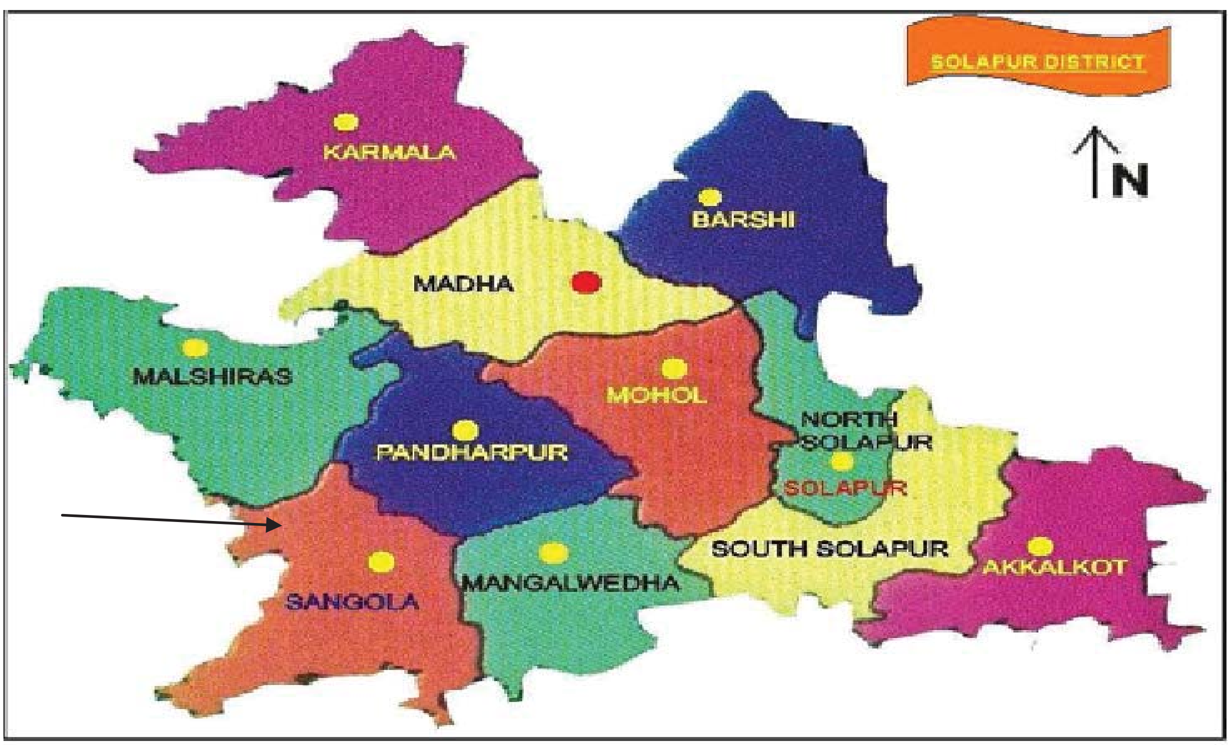

Fig. 1: Location Map of Sangola watershed located in the Solapur district of Maharashtra

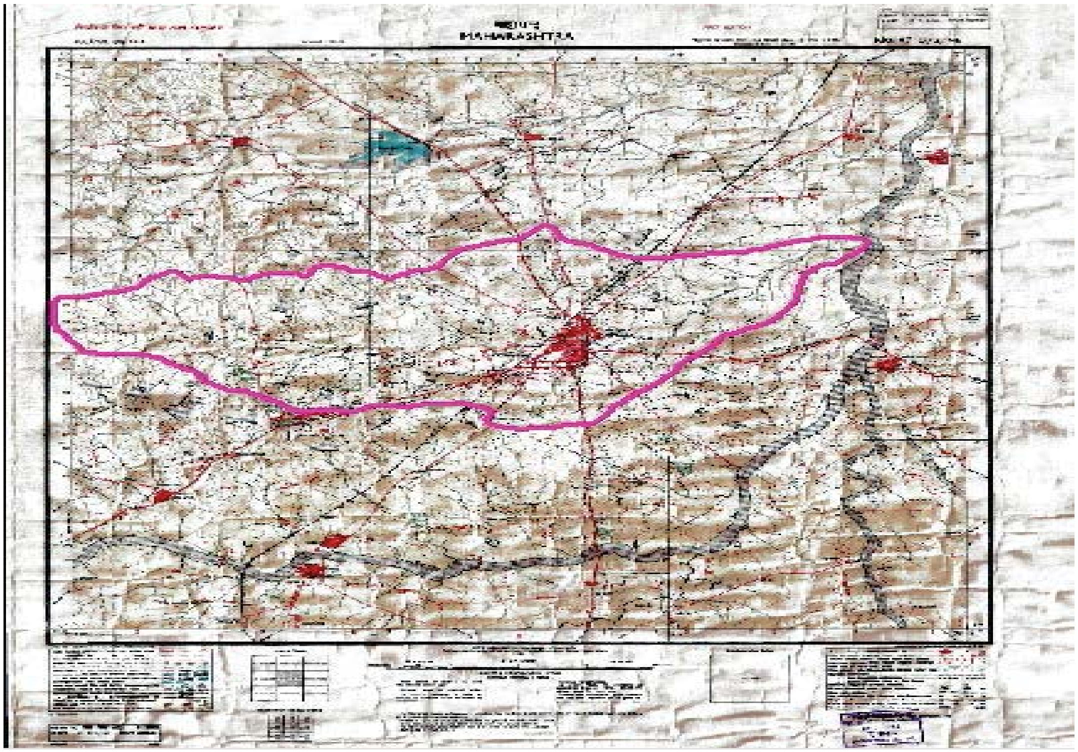

Fig.2 : Sangola watershed boundary in Contour map
(No. 47 0/3/NE First edition , scale 1:25,000)

Materials And Methods

The delineation of the catchment area of Sangola watershed has been carried from the Survey of India Toposheet bearing number 47 O/3/NE on 1:25,000 scale. Drainage map of the basin was prepared by digitization in ArcGIS (version 9.3) software.(fig.3) The toposheets and digital data were geometrically rectified and georeferenced to world space coordinate system using digital image processing software ERDAS Imagine 9.1. Spatial analysis of basin morphometry has been carried out using ArcGIS (version 9.3) software and ERDAS Imagine 9.1. The orders were designated to each stream following Strahler (Strahler AN, 1964) stream ordering technique. The stream numbers of various orders were counted to obtain the stream length, basin length, basin digital data base for drainage layer of the river basin. Various linear, arial, relief morphometric
parameters of Sangola watershed were computed using formulae suggested by Horton (1945), Strahler (1964), Schumn (1956), Miller (1953) and Nookaratnam, et al. (2005).

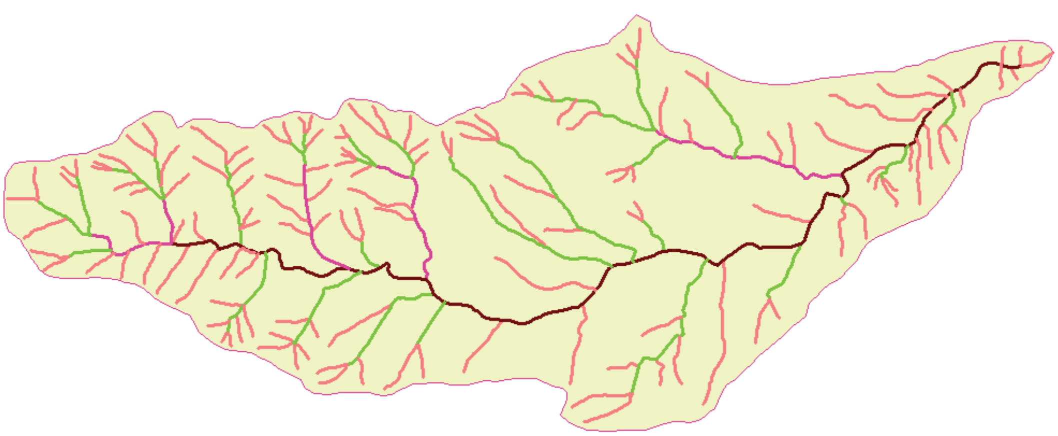

Fig. 3: Drainage Map of Sangola watershed located in the Solapur district

III. DISCUSSIONS AND RESULTS

The morphometric parameters of Sangola watershed have been analyzed and their hydrologic responses over the basin were examined. Based on Strahler's (Strahler, A.N., 1964) system of classification, the drainage pattern of the basin shows dendritic pattern with general stream flow direction from Northwest, Southwest to Northeast.

Linear Aspects:

Linear morphoemetric aspects of Sangola watershed are presented in Table 1.

Table 1: Linear Aspects of the Drainage Network of Sangola watershed

Stream order(u)	No. of streams(Nu)	Total length of streams in km(Lu)	Mean stream length (Lsm) =(Lu/Nu)	Log Nu	Log Lu
1	138	59.442	0.43	2.14	1.77
2	32	24.132	0.75	1.5	1.38
3	10	7.340	0.734	1.0	0.87
4	2	12.287	6.1435	0.3	1.089

Stream order (u): Stream order expresses the hierarchical relationship between stream segments. The channel segment of the drainage basin has been ranked according to Strahler stream ordering system using ArcGIS10. Sangola watershed is found to be a fourth order river basin. The lower order streams mostly dominate the basin. Number of stream lines is maximum for first order stream. It decreases as the order increases.

Stream Number (Nu): Sangola watershed has 182 stream segments (lines) of various orders. The logarithm of stream number of each order as a function of order is plotted. The points generally pass through a straight line (fig.4) which indicates very minimal structural disturbances in Sangola watershed. Refer fig.4

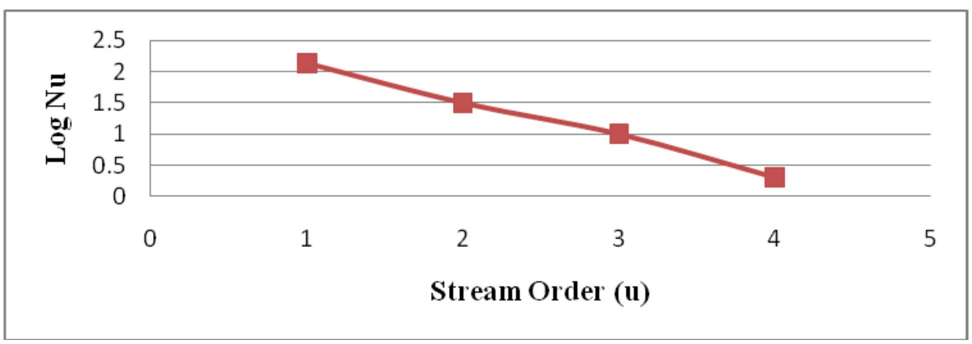

Fig.4: Relationship between logarithm of number of streams versus stream order

Stream Length (Lu): The length of the stream channel is a dimensional property, which reveals the size of the component of drainage lines. It is the total length of stream in a particular order. It is the most significant hydrological feature of the basin as it reveals surface runoff characteristics. Stream of relatively smaller length are characteristics of areas with larger slopes and finer texture. The total length of stream segment is maximum for first order (59.442 km) and decreases as order increases. Longer lengths of stream indicate flatter gradient. Relationship between logarithm of length of stream Vs stream order is shown in fig.4. Relationship between logarithm of number of streams versus stream order and logarithm of length of stream versus stream order (Figures 4 and 5) showed the linear pattern which indicates the basin is of homogenous rock material subjected to weathering and erosion.

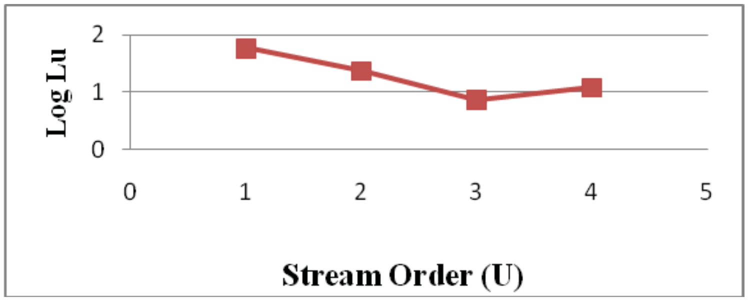

Fig. 5: Relationship between Logarithm of Length of Stream versus Stream Order

Mean Stream Length (Lsm): The mean stream length is a dimensionless property, characterizing the size aspects of drainage network and its associated surface (Strahler, 1964). The mean stream length of fourth order stream of Sangola watershed is 6.1435. Mean stream length(Lsm) generally increases as the stream order increases. It is mainly concerned with drainage network and its contributing watershed surface. Lsm value fluctuates from 0.43-6.1435 for Sangola watershed.

Stream Length Ratio (Lur): It is the ratio between the mean lengths of streams of any two consecutive orders. Horton's law (1945) of stream length states that the mean length of stream segments of each of the successive orders of a basin tends to approximate a direct geometric Sangola watershed. The Stream length ratio between streams of different orders in the basin area reveals that there are variations in Stream length ratio. The variation is due to change in slope and topography. Sangola watershed shows an increasing trend in stream length ratio from lower to higher order, which indicates their mature geographic stage of development.

Bifurcation Ratio (Rb): Horton's (1945) and Strahler (1952) have defined the Bifurcation ratio as the ratio of the number of streams of one order to the number of the next higher order. Strahler (1952) demonstrated that Bifurcation ratio shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. The bifurcation ratio varies significantly ranging from 4.22 to 4.68 values indicates that the basin has suffered less structural disturbances. Rb varies from 3.2 to 5 for Sangola watershed.

Aerial Aspects:
Aerial morphometric aspects of Sangola watershed are presented in Table 2.

Table 2: Aerial Aspects of the Drainage Network of Sangola watershed

Morphometric Parameters	Symbol/Formula	Abbreviations	Calculated Value
Basin Area, sq.km	A	A= Area of the Basin (km2)	33
Perimeter (km)	P	P= Perimeter of the basin (km)	30
Basin Length (km)	L_b	L_b= Maximum Basin length (km)	14.615
Drainage Density	$D_d = (\Sigma Lu/A)$ (km/km2)	Lu= Total Stream length	3.1273
Stream Frequency	Fs = ΣNu/A	Nu= Area of the Basin (km2)Stream Number	5.515
Elongation Ratio	Re = √A/π/Lb	A= Area of the Basin (km2) L_b = Maximum Basin length (km)	0.4433
Circularity Ratio	Rc = 4πA/P2	A= Area of the Basin (km2) P= Perimeter of the basin (km)	0.4609

Form Factor	R_f = A/Lb2	A= Area of the Basin (km2) L_b= Maximum Basin length (km)	0.15
Length of Over Land flow	Lg = 1/ Dd ×2	D_d = Drainage density (km/km2)	0.1598
Infiltration No.	I_f = Dd *Fs	D_d = Drainage density Fs = Stream Frequency	17.25
Compactness Coefficient	Cc = 0.2841 * P/A ^0.5	P= Perimeter of the basin (km) A= Area of the Basin (km2)	1.48
Lemniscate's slope	k = L_b^2/A	L_b= Maximum Basin length (km) A= Area of the basin (km2)	6.4726

Basin Area (A): Basin area is the direct outcome of the drainage development in a particular basin. The basin area of Sangola watershed is 33 sq. km. Since, the basin size is small, the lag time will be shorter, hence the rainwater will reach the main channel very fast.

Drainage Density (D_d): The drainage density is an important indicator of the linear scale of landform element in stream eroded topography and defines as the total length of stream of all
orders divided by drainage area and is an expression of the closeness of spacing of channels. The significance of drainage density is recognized as a factor determining the time due to its relation with surface runoff and permeability. The drainage density below 12 indicates Low, between 12 and 16 indicates Medium and above 16 indicates high density. Low drainage density indicates highly resistant of highly permeable subsoil material with dense vegetative cover. High drainage density indicates the area with fine texture and less vegetative cover. The low drainage density of Sangola watershed (3.1273 km/sq.km) indicates that the drainage area is highly resistant of highly permeable subsoil material with dense vegetative cover. Hence, the groundwater potential will be relatively low.

Stream Frequency (Fs): Horton (1932) introduced stream frequency as the number of streams
segment per unit area. It is obtained by dividing the total number of stream to the total drainage basin area. The stream frequency is found to be high (5.515) for the basin. Hence, the runoff is faster, and therefore, flooding is more likely to occur in the basin.

Elongation Ratio (Re): Elongation ratio is defined as the ratio of diameter of the circle of the
circle of the same area in the basin to the maximum basin length (Schumm, 1956). The Re values generally ranges between 0.6 and 1.0 over a wide variety of climate and geologic types. Values near to 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6–0.8 usually occur in the areas of high relief and steep ground slope. Hence, the Elongation ratio 0.4433 indicates that the shape of Sangola watershed is elongated, and it has very low relief.

Circulatory Ratio (Rc): Circulatory ratio is the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin (Miller,1953). The value of circularity ratio varies from 0 (in a line) to 1.0 (in a circle). Higher the value of Circulatory ratio more circular shape of the basin and vice-versa. The value of Circulatory ratio is influenced by length and frequency of streams, geological structure, landuse/land cover, climate, relief and slope of the basin.

Rc = (Watershed Area)/(Area of circle of watershed perimeter) = (12.57 A)/P^2

= (12.57*A)/ 〖30〗 ^2 = 0.4609 ≤ 1

(The smaller values result in smaller picks at outlet.)

The circulatory ratio 0.4609 of Sangola watershed indicates that the basin is elongated in shape characterized by moderate relief and drainage system is structurally controlled. The elongation ratio (0.4433) & Circulatory Ratio (0.4609) reveals that Sangola watershed is elongated and flood flows are comparatively easier to manage.

Form Factor (R_f): Quantitative expression of drainage basin outline form was made by Horton (1932) through a Form factor ratio (Rf), which is the dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh, 1998). The form factor value of the basin is 0.15 which indicate lower value of form factor and thus represents elongated in shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin.

Infiltration Number (I_f): Infiltration number of a drainage basin is the product of drainage density and stream frequency of a basin. It is the number by virtue of which an idea of the infiltration characteristics of the basin is obtained. Infiltration number of this drainage basin is 17.25. The higher value of the Infiltration number indicates low infiltration and high runoff.

Relief Aspects:
Relief morphometric aspects of Sangola watershed are presented in Table 3.

Table 3: Relief aspects of the Drainage Network of Sangola watershed

Morphometric Parameters	Symbols/formula	Abbreviations	Calculated value
Basin Relief (H)	H=Hmax-Hmin	Hmax= Max. Elevation Hmin= Min. Elevation	87m = 0.087km
Relief Ratio (Rh)	Rh= H/L_b	H= Maximum basin relief (km) L_b=Maximum basin length(km)	0.0059
Ruggedness Number (Rn)	Rn = $H \times D_d$	H= Maximum basin relief (km) D_d= Drainage density (km/km2)	0.2720
Relative Relief	Rhp= H × (100)/P	H= Maximum basin relief (km) P= Perimeter of watershed(km)	0.29

Basin Relief (H): The difference between point of maximum elevation and minimum elevation is the relief of basin. The basin relief of Sangola watershed is 87 m.

Relief ratio (Rh): Difference in the elevation between the highest point of a basin (on the main divide) and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm who found that sediments loose per unit area is closely correlated with relief ratios. The relief ratio of Sangola watershed is 0.0059, which indicates that the basin has weak relief and gentle slope.

IV.CONCLUSION

The Geomorphometric parameters were calculated for Sangola watershed through measurement of linear, areal and relief aspects of the basin with the help of Arc GIS software. The drainage network of Sangola watershed exhibits dendritic pattern with general stream flow direction from Northwest, Southwest to Northeast. The morphemtric analysis shows that the basin has flatter gradients, suffered less structural disturbances. Sangola watershed is elongated in shape, resulting in less peak discharge for long duration, indicates that, the flood flows are comparatively easier to manage. The basin has high runoff, low infiltration and permeable subsoil; hence groundwater potential is relatively low. The study introduces an imperial approach of morphometric analysis that can be utilized in characterizing the hydrological response of the basin, which is needed for planning, development and management of water resources in the basin. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at watershed level is more appropriate than the conventional methods.

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