Bulletin of Pure and Applied Sciences.
Vol.39F, Geology (Geological Science), No.1
January-June 2020: P.66-72

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.5958/2320-3234.2020.00006.2

Original Article

Available online at www.bpasjournals.com

A GIS Based Morphometric Analysis of Watershed (KR 40) Around Sangli, Maharashtra (India)

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(Received on 09.01.2020, Accepted on 29.04.2020)

ABSTRACT

The study area is one of the watershed (KR 40) from Krishna river basin, around Sangli town, Maharashtra, which is drained by two major streams i.e. Sheri and Laxmi streams. The morphometric analysis has been carried out to understand the hydrogeological conditions of the study area. The modern software tool i.e. Geographical Information System (GIS) is used to evaluate linear, aerial and relief aspects. The different quantitative morphological parameters like stream number, stream length, stream frequency, bifurcation ratio, stream density, etc. of the watershed which reflect its hydrogeological behavior and helpful when quantify the hydrogeological response. The geomorphological study of the drainage network of a watershed basin gives idea about the interdependency and relationship between the surface runoff and infiltration of rainwater and relative permeability of the rocks in study area. The GIS analysis provides a relationship between morphometric parameters, lithology and structural characteristics of study area. The present watershed (KR 40) is 5th order stream with dendritic drainage pattern and drainage density (1.08 km/km^2) which indicates moderate runoff causing moderate floods and moderate permeability of the catchments.

KEYWORDS: *Drainage morphometry, GIS, Groundwater, Watershed (KR 40), Sangli, India*

INTRODUCTION

The morphometric analysis of any river basin shows its hydrogeological characteristics and therefore it is useful in evaluating the hydrogeological responses of the basin. The watershed (KR 40) around Sangli of Krishna river basin has been studied to quantify its morphometric characteristic that will reveal its geomorphic behavior. The studied watershed produces moderate flooding condition due to dendritic drainage pattern. The systematic hydrogeological study is essential in order to assess the availability water for utilization. In this contest the systematic geomorphological study of the watershed has been carried out and preliminary results presented and interpreted in this paper. The studied watershed (KR 40) is bounded between latitude 16°48'00'' to 17°05'00'' N and longitude 74°30'00'' to 74° 47'00'' E in Survey of India (SOI) toposheets numbers 47K/12, 47K/16,47L/9 and

47L/13 with area about 359 km^2. The watershed (KR 40) is mainly drained by Sheri and Laxmi streams which are the major tributaries of the river Krishna. The major part of study area covers a Deccan volcanic basaltic terrain of Upper Cretaceous to Lower Eocene age. The study area having black cotton type of soil which can hold good quality water and hence it is highly fertile for agricultural purpose. The study area falls in semiarid climatic condition with average annual rainfall is 637mm.

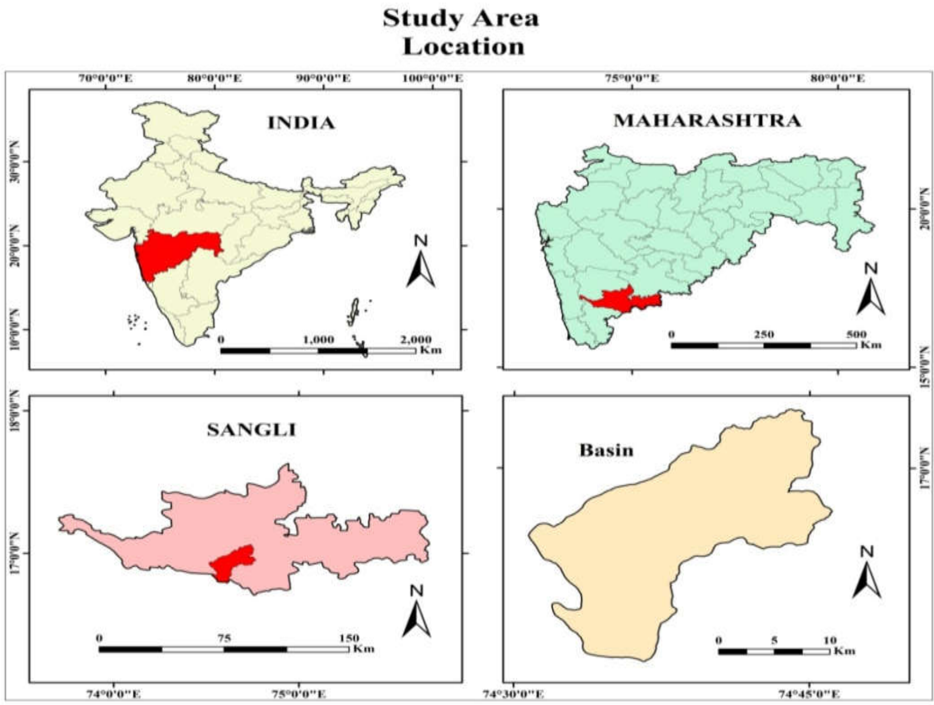

Figure 1: Location map of the study area

GEOLOGY OF STUDY AREA

The only geological formation in the study area is the deccan traps (*Cretaceous-Eocene*). The deccan lava flows are found usually in the form of horizontally bedded sheets. At places a gentle dip of about 5^0 to the west is noticed. The flows usually form flat-topped hills so characteristic of the trappean country. The traps belong to the type called 'plateau basalt'. They are more or less uniform in composition corresponding to dolerite or basalt. These are dark grey or greenish grey in colour. These traps are distinguished into vesicular and non-vesicular varieties. The non-vesicular types are hard, tough, compact and medium to fine-grained, and break with a conchoidal fracture. The vesicular types are comparatively soft and friable and break more easily. The amygdaloidal types are characterised by vesicles filled with quartz, chalcedony, calcite and zeolite.

The inter-trappean beds generally form aquifers. In the study area which is composed of deccan trap flows, the main aquifers are either the inter-trappean beds or the decomposed zones in the traps. The depth of the water-table is variable, generally being more than 6 metres. In general the deccan traps are unreliable sources of ground-water because of the sporadic distribution of their inter-trappean beds.

METHODOLOGY AND DATA COLLECTION

The morphometric analysis and preparation of different types of maps like location map, drainage map, etc. of watershed (KR 40) around Sangli is carried out by using digital data source Carto DEM and Arc GIS software 10.2 versions. Stream order method of Strahler (1957) has been employed. The standard formulae were used for calculations for different morphometric parameters. The topological information of the studied watershed (KR 40) was digitized and geo referenced using the capabilities of GIS tools. The contours were digitized to generate the line feature class in GIS Software which was further processed using the spatial analyst module to generate the digital elevation model (DEM) representing the watershed terrain topology. Further, the developed DEM was processed to generate the delineated watershed and sub watershed regions and the natural drainage pattern of the watershed using the Watershed Morphology Estimation Tool (WMET) interface (Sarangi et al. 2004).

RESULT AND DISCUSSION

Morphometric analysis has been carried out to understand the geometry of the drainage basin, drainage network, drainage texture and relief characteristics. Many authors have emphasized the controls of lithological, structural and tectonic features on drainage network development (Horton, 1945; Chorley, 1962; Leopold et. .al., 1964 and Morisawa, 1968). The details results of morphometric parameters were presented in Table1, 2 and 3.

Drainage Pattern

The studied watershed (KR 40) exhibits dendritic pattern of drainage (Fig. 2), which is typically present in the hard rock terrains. The basin exhibits 5^{th} order of drainage network, bifurcation ratio is 4.05, which is normal according to Horton (1945) and it indicates the basin is at mature stage and also elongated in shape. According to Strahler (1952), the value of bifurcation ratio is higher than 05 it indicates the structural control over the drainage network. In the present study, the bifurcation ratio value of 4.05 which showed that it does not reflect any structural control of the lineament zones on the drainage. But as the value of 4.05 is nearer to 05, it indicates that some portions of the major streams are controlled by the lineaments. Most of the lineaments in the studied area fallow the stream flow direction. Drainage analysis is also known as fluvial morphometry, which provides information regarding the factors which control in the development of the drainage. Morphometric analysis means measurements of shape of the watershed, area of the watershed and the length of the stream. On the basis of projection of the system to horizontal plane, the linear properties such as length, area arrangement, etc. were calculated. This type of study is known as 'planimetric' which meaning measurements in a single plane.

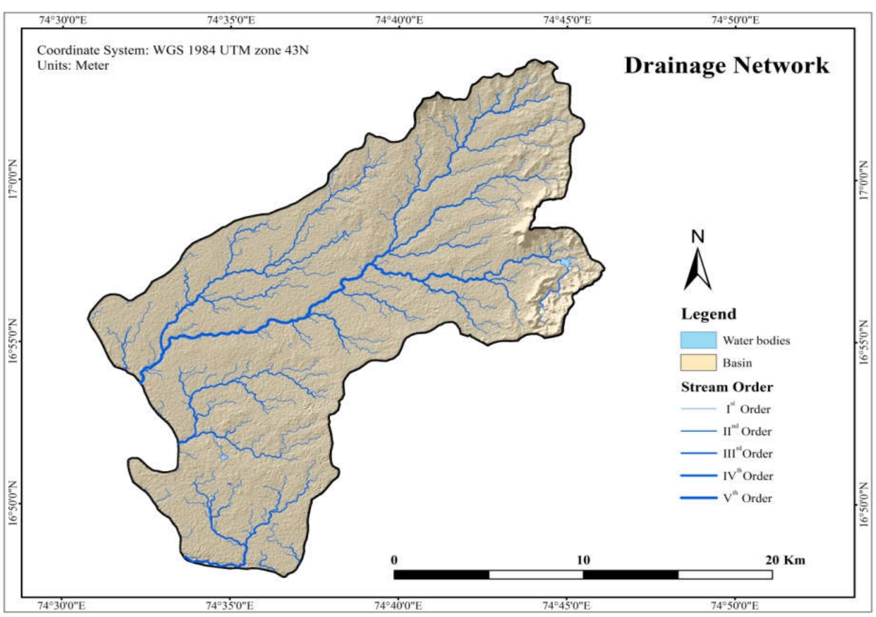

Figure 2: Drainage network map of the watershed (KR 40)

Linear parameters

The linear parameters of morphometric analysis of the studied watershed (KR 40) include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio were calculated and presented in Table 1.

Table 1: Linear parameters of watershed (KR 40)

Stream order (U)	No. of streams (Nu)	Bifurcation Ratio (Rb)	Total Stream length (Lu)	Mean stream length (kms) (Lu)	Cumulative mean length (kms) (Lu)	Stream Length Ratio R_L
I	223	5.31	199	0.89	0.89	
II	42	3.50	106	2.52	3.42	2.83
III	12	2.40	47	3.92	7.33	1.55
IV	5	5.00	18	3.60	10.93	0.92
V	1		17	17.00	27.93	4.72
Total	283	16.21	387			2.5

Stream Order: The designation of stream orders is the first step in drainage watershed analysis and is based on the method proposed by Strahler (1964). The order wise stream numbers, area and stream lengths shown in Table 1. It is observed in the present study that the maximum number of streams were in lower order. It is also noticed that there is a decrease in stream frequency as the stream order increases. Horton (1945) stated that the number of streams of each order forms an inverse geometric sequence with the other higher order number.

Stream length: Stream length is one of the most significant hydrogeological features of the watershed as it reveals surface runoff characteristics. Streams of relatively smaller lengths have characteristic areas with larger slopes and linear textures. The average stream length has been determined using random sampling technique. The length of first order stream is 199Km, second order stream is 106 Km, third order stream is 47 Km, fourth order stream is 18 Km and fifth order is 17 Km. This change may be indicates the flowing of streams from high altitude, lithological variation and moderately steep slopes (Singh 1997).

Mean stream length (Lsm): The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964), Horton (1945) defined a length ratio (RL) as the ratio of mean length of channel segment of a given order to that of lower order. The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of stream (Table 1).

Stream length ratio (R_L): The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The RL values between streams of different order in the basin reveal that there are variations in slope and topography.

Bifurcation ratio (Rb): Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). It is observed that Rb is not the same from one order to its next order. In the study area mean Rb varies from 5.31 to 5.00; the mean Rb of the entire basin is 4.05. Usually these values are common in the areas where geological structures do not exercise a dominant influence on the drainage pattern.

Relief parameters

The relief parameters of the studied watershed (KR 40) were determined includes relief ratio, relative relief and ruggedness number (Table 2).

Basin relief (Bh): The vertical distance between the lowest and highest points of elevation of basin is called as basin relief. The basin relief of study area is 302 mts.

Relief ratio (Rh): Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The relief ratio, (Rh) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The Rh normally increases with decreasing drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). The value of Rh in basin is 8.84 indicating moderate relief and moderate slope.

Ruggedness number (Rn): It is the product of maximum basin relief (H) and drainage density (Dd), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Strahler, 1957). The value of ruggedness number in present basin is 0.326.

Table 2: Relief parameters of watershed (KR 40)

Morphometric parameters	Formula	Calculated values
Basin relief (H)	H = (Maximum Elevation) – (Minimum Elevation)	302 meter
Relief ratio (Rh)	Rh = H/ Lb	8.84
Ruggedness number (Rn)	Rn = Dd × (H/1000)	0.326

Aerial parameters

Drainage Density (Dd): Horton (1932) has introduced drainage density (D) into American hydrologic literature as an expression to indicate the closeness of spacing of stream. It is defined as the total length of streams of all orders per drainage area. Drainage density of any basin reveals the terrain configuration that is properties of rock of the area. The drainage density of the study basin is found to be 1.08 km/km^2; it indicates the basin is medium to coarse texture and of moderate permeability and moderate relief. The low value of drainage density of the basin is mainly due to the presence of hard resistant lithological units. Since, drainage density value of the study basin is 1.08 km/km^2; it is classed as average catchment.

Drainage frequency (Fs)*:* Stream frequency (Fs), is expressed as the total number of stream segments of all orders per unit area. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density (Horton, 1932). The Fs for the basin is 0.79.

Circulatory Ratio (Rc): Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The Rc value of basin is 0.39 and it indicates that the basin is characterized by moderate to low relief, strongly elongated and drainage system seems to be less influenced by structural disturbances. The high value of circularity ratio shows the late maturity stage of topography.

Elongation Ratio (Re): Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin. Values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. Re values close to unity correspond typically to regions of low relief, whereas values in the range 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 (a) circular (>0.9), (b) oval (0.9-0.8), (c) less elongated (<0.7). The Re values in the study area is 0.62 indicating moderate to slightly steep ground slope and area when collaborated with Strahlers range seem to suggest an elongated shape.

Length of overland flow (Lg): The length of the overland flow approximately equals to half of the reciprocal of drainage density (Horton 1945). Lg = 1/ 2Dd. The length of overland flow of the study basin is 0.86 km. and drainage density of the basin is 1.08 Km /km^2. The length of overland flow of the study basin is 0.86 km, this value indicates a quick surface runoff. The length of overland flow is an important independent variable in both hydrogeological and physiographic development of a drainage basin.

***Form factor (Ff)**:* Form factor (Ff) is defined as the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a basin of a defined area (Horton, 1945). The form factor value should be always less than 0.7854the smaller the value of the form factor, the more elongated will be the basin. The Ff value for study area is 0.307 indicates the elongated basin with lower peak flows of longer duration than the average. Flood flows in elongated basin are easier to manage than that of circular basin.

Texture Ratio (T): Drainage texture ratio (T) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It is depending upon the underlying lithology, infiltration capacity and relief aspect of the terrain (Nageswara 2010). The present study having the texture ratio of the basin is 2.08 and categorized as coarse texture in the nature.

***Constant of Channel Maintenance (C)**:* The constant of channel maintenance (C) is the inverse of drainage density (Schumm, 1956) and is a measure of the area, needed to support a given length of stream channel. The unit 'C' is expressed as km2/km. It indicates the number of sq.km of watershed required to sustain one linear km of channel. The 'C' value for the study basin is 0.92 km^2/km. The value C of basin is 0.92.It means that on an average 0.92 sq.ft. surface is needed in basin for creation of one linear foot of the stream channel.

Table 3: Aerial parameters of the watershed (KR 40)

Morphometric parameters	**Formula**	**Calculated values**
Drainage Density (Dd)	Dd = Lu / A	1.08 km/km2
Stream frequency (Fs)	Fs = Nu /A	0.79
Circulatory Ratio (Rc)	$Rc = 4\pi A / P^2$	0.39
Elongation Ratio (Re)	$Re = 2\sqrt{(A / \pi)} / Lb$	0.62
Length of overland flow (Lg)	Lf = ½ Dd	0.86 km
Form factor (Rf)	$Ff = A / Lb^2$	0.307
Texture Ratio (T)	$T = N_1 / P$	2.08
Constant of Channel Maintenance (C)	C = 1 / Dd	0.92

CONCLUSION

GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their analysis. Bifurcation ratio, length ratio and stream order of basin indicates that the watershed (KR 40) is fifth order having dendritic type of drainage pattern with homogeneous nature and there is no structural or tectonic control. Relief ratio, Ruggedness number and visual interpretation of DEM of study area indicate low relief, low run off and high infiltrations with early mature stage of erosion development. Drainage density, texture ratio, circulatory ratio and elongation ratio shows that texture of basin is coarse and shape of basin almost elongated. The ruggedness number of this basins show low value (0.326) due to the occurrence of hard resistant basalts. The complete morphometric analysis of drainage basin indicates that the studied watershed (KR 40) area is having good groundwater prospect.

ACKNOWLEDGEMENTS

The authors would like to thanks Dr. Vijay Kumar and Dr. P.B. Panaskar of School of Earth Sciences, SRTMU, Nanded for help during the research work of this manuscript. The authors also acknowledge the officials of Swami Ramanand Teerth Marathwada University, Nanded (India).

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