Morphometric Analysis for Hydrological Studies using Geographical Information System: A Case Study

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ABSTRACT

Geographical information system (GIS) has proved to be an efficient tool in delineation of drainage pattern and water resources management and its planning. The morphometric analysis of study area has been carried out using Arc GIS software. The basin morphometric parameters such as linear, aerial and relief aspects of the river basin were determined and computed.

Bordi river basin is mainly drained by dendritic drainage which indicates the homogeneity in texture and lack of structural control. The bifurcation ratio (Rb) value is 3.787 indicates that the geological structures are less disturbing the drainage pattern. The basin had medium drainage density (D) 2.627 km/sq. km indicating the moderately permeable subsoil and moderate vegetative cover. The stream frequency (Fs), 3.44 exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density. The texture ratio (T) of the basin is moderate 3.430 while elongation ratio (R_e) is 0.55 indicates that the low relief of the terrain and elongated shape. The circularity ratio (Rc) 0.463 of the basin also indicates that the basin is elongated in shape, have low discharge of runoff and highly permeability of the subsoil condition. The low form factor (Rf) value of the basin, 0.37 represents a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin. Hence from the study it is clear that morphometric analys based on GIS technique is a competent tool hydrological studies.

Keywords*: Bordi river basin, Morphometric analysis, Hydrological studies, GIS applications, Amravati district, Maharashtra.*

1. Introduction

The available surface and ground water resources are inadequate to meet the growing water demands due to rapid urbanization and increasing population. The geomorphic conditions are essential pre-requisites in understanding the water bearing characteristics of hard rocks. The role of rocks types and geologic structure in the development of stream networks can be better understood by quantitative morphometric analysis. The morphometric parameters of a watershed are reflective of its hydrological response to a considerable extent and are helpful in synthesizing its hydrological behavior because it enables us to understand the relationship among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes.

The basin morphometric characteristics of the various basins have been studied by many scientists using conventional (Horton, 1945; Smith, 1950; Strahler, 1957) and Remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999; Narendra and Nageswara Rao, 2006). The rapidly emerging Geoinformatics technology has effective tools to overcome most of the problems of land and water resources planning and management on the account of usage of conventional methods of data process.

2. Study Area

The study area Bordi river basin (BRB) lies in west part of Maharashtra state bounded latitude 20°55'N to 21°18'N and longitude 77°05'E to 77° 18'E, falling in Survey of India (SOI) toposheet nos: 55 G/3, 55 G/4, 55 G/7, 55 G/8, and 55 H/1 (Fig.1). It covers an area of 450 km^2 and lies on eastern margin of Akola district and western part of Amravati district of Maharashtra state. Geologically, the area under study is occupied mostly by alluvium.

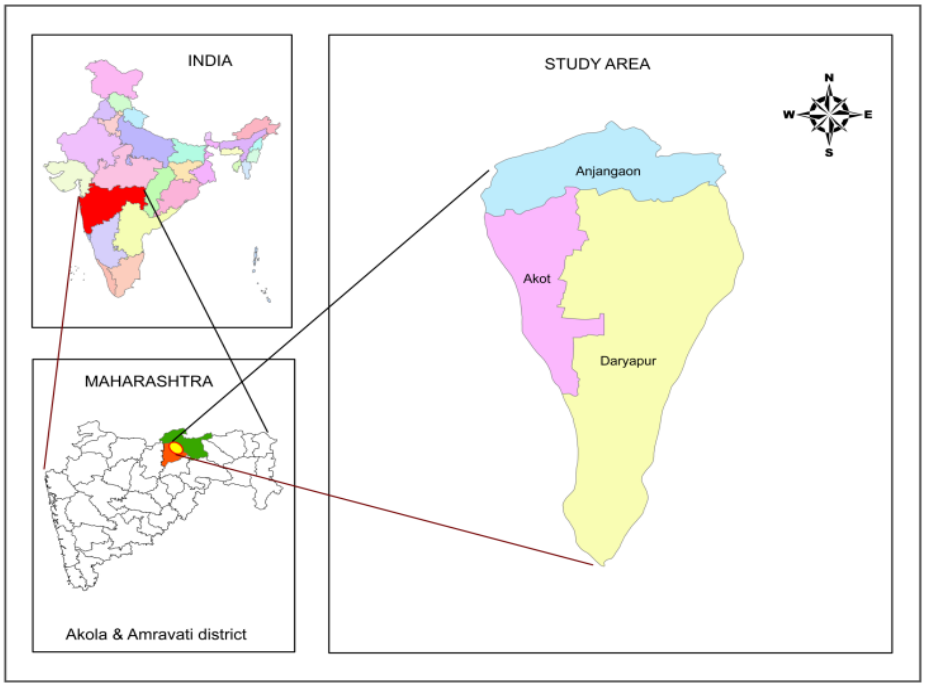

Figure 1: Location map of the study area

3. Materials and Methods

Entire study area is delineated from rectified, mosaiced SOI topographic maps no. 55 G/3, G/4, G/7, G/8, and 55 H/1 on the scale 1:50,000 with the help of Arc-GIS software assigning UTM, WGS 1984, 43N zone projection system. Digitization of the drainage basin was carried out (Figure 2) for morphometric analysis in GIS environment using Arc GIS software. The stream ordering was done following Strahler (1964) technique. The attributes were assigned to create the digital data base for drainage layer of the river basin. Various morphometric parameters such as linear aspects, aerial and relief aspects of the drainage basin were computed.

4. Results and Discussion

The salient features of the various morphometric parameters of the Bordi river basin as determined are summarized in Tables 1and 2.

Linear Aspects of the basin

The linear aspects of drainage network includes stream order (N_u), bifurcation ratio (R_b), stream length (L_u) and the results of the same are presented in Table 1.

Table 1: Salient features of linear aspects of the Bordi river basin

S.No.	Parameters	Stream Order						Mean
		1st	2nd	3rd	4th	5th	6th	
1.	No. of streams	685	150	39	8	3	1	
2.	Stream length (Km)	484.91	214.03	118.4	66.53	42.92	27.97	
3.	Bifurcation ratio (R_b)	1st order/ 2nd order	2nd order/ 3rd order	3rd order/ 4th order	5th order/ 6th order			
		4.57	3.84	4.87	2.66			3.0

Stream Order (N_u)

In the present study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system. The study area is a 6th order drainage basin. Table.1 represents the streams order classification in the Bordi River Basin. Drainage patterns of stream network from the basin have been observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. The properties of the stream networks are very important to study the landform making process (Strahler, 2002).

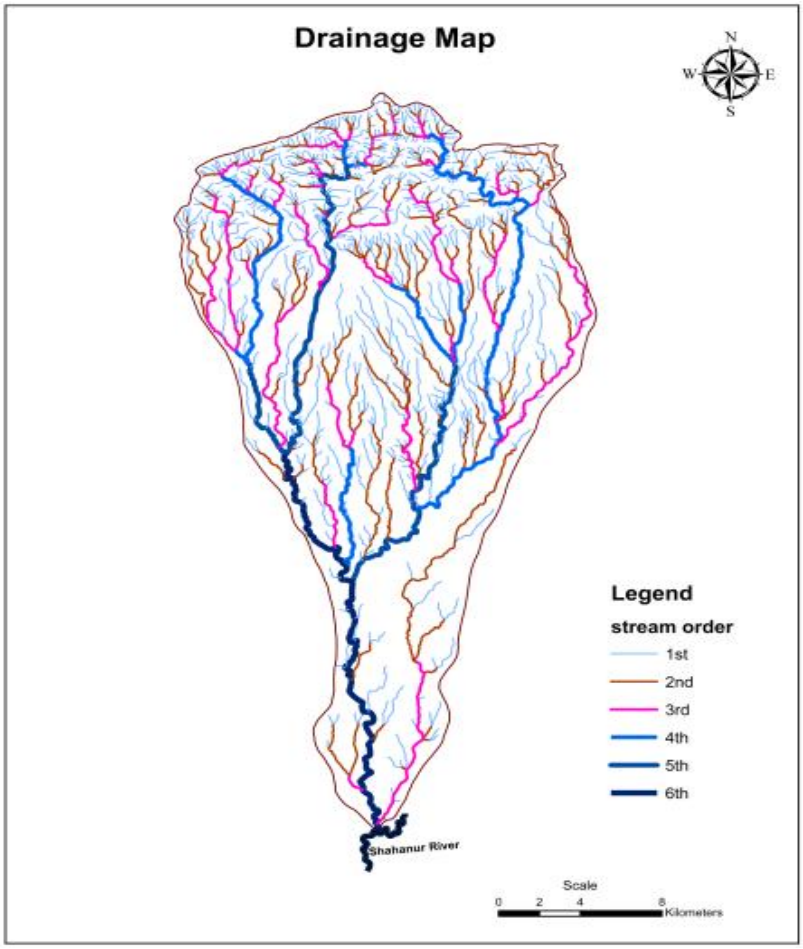

Figure 2: Drainage map of the study area

Bifurcation Ratio (R_b)

The term bifurcation ratio (R_b) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Schumn, 1956). Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964). The bifurcation ratio value is 3.787 for the study area (Table 1) indicates that the geological structures are less disturbing the drainage pattern.

Stream Length (L_u)

Stream length reveals surface runoff characteristics in the basin for hydrological interpretation. Basins with relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the maximum length of stream segments is in first order and decreases as the stream order increases. The stream lengths of various orders in the basin were measured with the help of GIS software and represented in table 1.

Areal Aspects of the Drainage Basin

Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. The area

of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. Perimeter is the length of the boundary of the basin which can be drawn with the help of GIS software. Basin area directly affects the size of the storm hydrograph, the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size (Chorley, et al., 1957). The aerial aspects of the drainage basin such as drainage density (D), stream frequency (F_s), texture ratio (T), elongation ratio (R_e), circularity ratio (R_c) and form factor ratio (R_f) were calculated and results have been given in Table 2.

Table 2: Salient features of aerial aspects of the Bordi river basin

S.No.	**Parameters**	**Formula**	**Stream Order**			
			3rd	**4th**	**5th**	**6th**
1	Drainage density	$\mathbf{D_d = L_u/A}$	3.067	2.87	2.449	2.123
2	Stream frequency	$\mathbf{F_s = N_u/A}$	4.866	3.872	3.053	1.970
3	Texture ratio	$\mathbf{T = N_1/P}$	1.219	2.226	3.690	6.586
4	Elongation ratio	$\mathbf{R_e = 2/L_m*(A/\pi)^{\wedge 0.5}}$	0.579	0.537	0.512	0.592
5	Circularity ratio (Rc)	$\mathbf{R_c = 4\pi A/p^2}$	0.506	0.416	0.406	0.522
6	Form factor ratio	$\mathbf{R_f = A/(L_b)^2}$	0.040	0.033	0.032	0.042

Where,

L_u = Total stream length of each order
N_u = Total number of streams of each order
N_1 = Total number of 1st order streams
L_m = Maximum length of basin parallel to the principal drainage
P = Perimeter (km)
L_b = Basin length

Drainage Density (D)

The drainage density indicates the closeness of spacing of channels in the basin and provides a quantitative measure of the average length of stream channel. Low drainage density is observed in regions of highly permeable subsoil material, dense vegetative cover, and under low relief. High drainage density is the resultant of 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 (Strahaler, 1964).

The drainage density (D) of the study area is 2.627 km/sq. km indicating medium drainage density and indicates the basin to have moderately permeable subsoil and moderate vegetative cover (Nag, 1998). The type of rock also corroborates with the moderate drainage density observed in the basin.

Stream Frequency (F_s)

Stream frequency (F_s) is the total number of stream segments per unit area (Horton, 1932). The stream frequency in the basin was found to be 3.44. The stream frequency (Fs) for the basin exhibit positive correlation with the drainage density indicating the increase in stream population with respect to increase in drainage density.

Texture Ratio (T)

The texture ratio (T) is dependent on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio in the basin was found to be 3.43 and can be described as moderate in nature.

Elongation Ratio (R_e)

Schumm (1956) defined elongation ratio (R_e) as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. Values near to 1.0 are typical of regions of very low relief (Strahler, 1964). The value R_e in the study area was found to be 0.55 indicating low relief of the terrain and elongated shape.

Circularity Ratio (R_c)

Miller (1953) defined a dimensionless circularity ratio (R_c) as the ratio of basin area to the area of circle having the same perimeter as the basin. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (0.463) of the basin corroborates the Miller's range which indicating that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition.

Form Factor Ratio (R_f)

Quantitative expression of drainage basin outline form was made by Horton (1932) through a form factor ratio (R_f), 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 low, 0.37 which represents elongated 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.

Relief Aspect of the Drainage Basin

Relief aspect of the watershed play an important role in drainage development, surface and subsurface water flow, permeability, landform development and associated features of the terrain. The Bordi river basin shows low relief indicating high infiltration and low runoff.

The DEM for Bordi river basin was obtained from the interpolation of the digitized contour. The elevation range of Bordi river basin varies from **270 m** to **1000 m**. The DEM indicates that substantial portion of area was found within an elevation range of **320** to **400 m** comprising **42%** of the total study area. This area is categorized as medium elevation region as shown in (Figure 3)

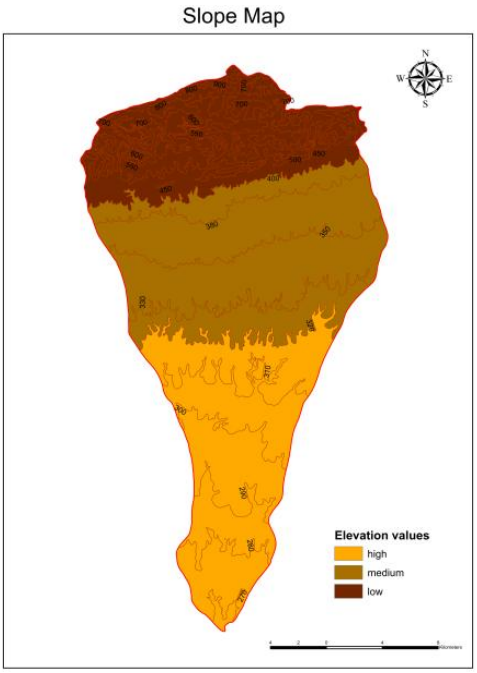

Figure 3: Slope map of the study area

The presence of substantial area at elevation range **320 - 400 m** elevation indicates that the variation within the elevation range is not much and most of the developmental activities can be planned within it. The information on the elevation ranges and their area sharing would be useful in planning and management of the Bordi river basin.

5. Conclusions

The Linear, Areal and Relief aspects of morphometric of the Bordi river basin, using GIS software was found to be immense utility in hydrogeological studies. Bifurcation ratio indicates that the geological structures are less disturbing the drainage pattern. Texture ratio gives idea about infiltration capacity and relief aspect of terrain. Circulatory ratio, Elongation ratio shows watershed have low discharge of runoff and low relief of the terrain. The study area shows that terrain is made up of mainly alluvium and exhibits dendritic drainage pattern which indicates the homogeneity in texture and lack of structural control. The morphometric basin is having low relief of the terrain and elongated in shape.

References

[1] Agarwal, C.S., (1998). “Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P.”, Jour. Indian Soc. Remote Sensing, vol. 26, pp 169-175.

[2] Biswas, S.; Sudhakar, S; and Desai, V.R., (1999). “Prioritisation of sub-watersheds based on morphometric analysis of drainage basin- a remote sensing and GIS approach”, Jour. Indian Soc. Remote Sensing, vol. 27,pp 155-166.

[3] Chorley, R.J.; Donald, E.G.; Malm, and Pogorzelski, H.A., (1957). “A new standard for estimating drainage basin shape”, Amer. Jour. Sci., vol. 255, pp 138-141.

[4] Horton, R.E., (1932). “Drainage basin characteristics”, Trans. Amer. Geophys. Union.,vol. 13, pp 350-361.

[5] Horton, R.E., (1945). “Erosional development of streams and their drainage basins: hydrophysical

approach to quantitative morphology", Bull. Geol. Soc. Amer. Vol. 5, pp 275-370.

[6] Krishnamurthy, J. and Srinivas, G., (1995). "Role of geological and geo-morphological factors in groundwater exploration: a study using IRS LISS data", Int. Jour. Remote Sensing, vol. 16, pp 2595-2618.

[7] Nag, S.K., (1998). "Morphometric analysis using remote sensing techniques in the Chaka sub-basin Purulia district, West Bengal", Jour. Indian Soc. Remote Sensing, vol. 26, pp 69-76.

[8] Narendra, K.; and Nageswara Rao, K., (2006). "Morphometry of the Mehadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and Resourcesat data", Jour. Indian Soc. Remote Sensing, vol. 34, pp 101-110.

[9] Schumn, S.A., (1956). "Evaluation of drainage systems and slopes in badlands at Perth Amboy, New Jersy", Bull. Geol. Soc. Amer, vol. 67, pp 597-646.

[10] Singh, S. A., (1998). Text Book of Physical Geography, Prayag Pustak Bhawan, Allahabad, India.

[11] Smith K.G., (1950). "Standards for grading texture of erosional topography", Amer. Jour. Sci, vol. 248, pp 655-668.

[12] Srivastava V.K.; and Mitra, D., (1995). "Study of drainage pattern of Raniganj Coalfield (Burdwan District) as observed on Landsat-TM/IRS LISS II imagery, Jour. Indian Soc. Remote Sensing, vol. 23, pp 225-235.

[13] Strahler, A.N., (1957). "Quantitative analysis of watershed geomorphology", Trans. Amer. Geophys. Union, vol. 38, pp 913-920.

[14] Strahler, A.N.; and Strahler, A.H., (2002). A Text Book of Physical Geography, John Wiley & Sons, New York.

[15] Strahler, A.N., (1964). Quantitative geomorphology of drainage basins and channel networks In. Handbook of Applied Hydrology, McGraw Hill Book Company, New York, Section 4-II.