Morphometric Analysis of Bhima River at Niranarshingpur in Maharashtra: A GIS approach

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Abstract

Morphometry is the measurement of form analysis of its landforms. Morphometric analysis is an important aspect to study characteristics of the river basin. The present study is undertaken to determine the drainage characteristics of Bhima river basin in Maharashtra. The total area of the basin is 29,493.97 km^2. The Morphometric variables are computed by using Geographic Information system (GIS). Order of the stream is 9^{th}. The quantitative analysis of various aspects of river basin drainage network characteristics reveals complex Morphometric attributes. The streams of lower order mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall For the Morphometric analysis Geographic information system techniques has been used and Strahler (1964) stream order method used for stream ordering. The drainage density of the basin is 0.075 per km. Lithology of the basin plays important role on erosional processes of the basin. Nira River is 14424.10 square km.

Introduction:

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms (Clarke, 1966). The morphometry analysis includes the linear aspects and aerial aspects, in the linear aspects the stream ordering, stream length, stream length ratio, and bifurcation ratio and in the aerial aspect the drainage density, stream frequency, form factor, circulatory ratio, and elongated ratio has been calculated. Morphometric analysis is an important aspect of hydrological and hydrogeological studies (Agarwal et al., 2000). Morphometric analysis will help to quantify and understand the hydrological characters and the results will be useful input for a comprehensive water resource management plan (Jawahar raj et al., 1998; Kumaraswami et al., 1998 and Sreedevi et al., 2001). GIS techniques are now a day used for assessing various terrain and Morphometric parameters of the drainage basins, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information.

The Morphometric analysis of the drainage basin and channel network play a vital role in order to understand the hydro-geological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structure etc. The relationship between various drainage parameters and the aforesaid factors are well recognized by Horton, 1945, Strahler, 1957, Melton, 1958, Pakhmode, *et al.*, 2003 and Gangalakunta, *et al.*, 2004. Recently many workers have used remote sensing data and GIS generated more precise data on Morphometric parameters (Srivastava, 1997, Agarwal, 1998, Nag, 1998, Das and Mukherjee, 2005) and concluded that remote sensing has emerged as a powerful tool and useful in analyzing the drainage morphometry. The objective of the present study is to analyze

the Morphometric attributes of Bhima river basin.

Aim and Objectives:

1. The main objective of the present study is to derive the different drainage aspects of Bhima River basin and to understand the relationship of the drainage networking.
2. To study the quantitative analysis of drainage system.
3. To evaluate linear and areal aspects of morphometric characteristics.

Study Area:

The total study area extends from Ujjani Dam up to Man River Confluence extending between 17° 2' 50" N to 18° 4' 26" N latitude and 75° 7' 12"E to 75° 37' 25" E longitude. The River Bhima rises in the Western Ghats at Bhimashankar at an altitude of about 945 m and flows south-eastwards though Maharashtra and Karnataka. It has a total length of 861 km and falls into River Krishna about 26 km North at Raichur at an altitude of 343 m. About 137 km. from its source the Bhima River receives from its right the cabined waters of the River Mula and Mutha from Poona and about 29 km lower the Ghod River joined on its right bank by the Nira River which is also rises in the Western Ghats and then by the run for a length of 74 km. The Bhima River runs along the boundary between Maharashtra and Karnataka. The total catchments area of the River Bhima is 76614 km^2. During this long journey many small rivers join to the main river River Kundali, Bhima, Indrayani, Pawana are the major tributaries around Pune, of these River Indrayani, Mula, Mutha and River Pawana flows through Pune and Pimpari Chinchwad city limits. River Chandani, Thamini, Moshi, Bori, Sina, Man, Bhogwati and Nira are the major tributaries in the Solapur district. River Nira and River Bhima confluence at Niranarsingpur in Malshiras Taluka and River Man confluences at Sarkoli, Manglweda Taluka in Solapur district. Study area is selected from Ujjani Dam to the Niranarshingpur, at the river Nira River confluence in the Solapur district. The total length of the study area is 36.66 km. The major flood affected villages are 23 and pilgrim place Niranarshingpur is western bank side of River Bhima. Select locations are highly affected by flood. Many villages and stretches both the bank side of Bhima River, Major changes have observed.

Materials and Methods:

The Morphometric analysis of the Bhima River basin was based on topographical maps on a 1: 50,000 scale, and different Morphometric parameters have been generated in GIS environment. Digitization and the stream order were assigned by layer concept. The quantitative analyses of the basin which include stream orders, stream numbers, stream lengths, bifurcation ratios, basin circularity, drainage density, drainage frequency, drainage texture etc., have been analyzed through use of a GIS using Arc Info, which determines the geomorphic stage of development of the area. The drainage network of the basin is analyzed as per laws of Horton (1945) and stream ordering is made after Strahler (1964).

Morphometric Analysis:

The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps

for a geomorphological survey (Bates and Jackson, 1980). This approach has recently been termed as Morphometry. The area, altitude, volume, slope, profile and texture of landforms comprise principal parameters of investigation. Dury (1952), Christian, Jenning and Tuidale (1957) applied various methods for landform analysis, which could be classified in different ways and their results presented in the form of graphs, maps or statistical indices.

Linear Aspects of the Drainage Basin:

Stream Order:

The streams of the Bhima river basin have been ranked according to the method described by Strahler (1964). According to Strahler, when two first order streams join, a stream segment of second order is formed; When two second order streams join, a segment of third order is formed, and so on. The study area is a ninth order drainage basin.

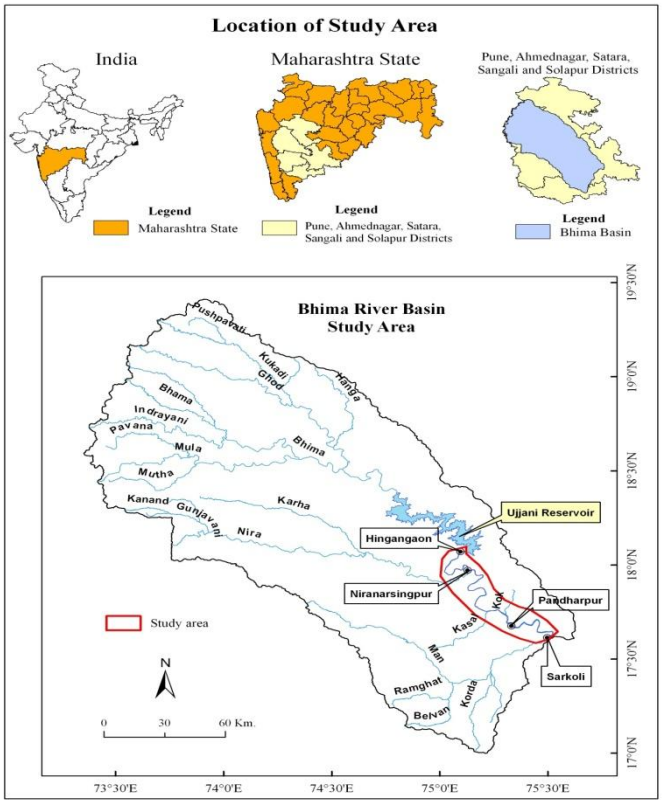

Fig. 1

Stream Number:

After assigning stream orders, the segments of each order are counted to get the number of segments of the given order (u). The stream lengths of the various segments are measured with the help of GIS software. In the study area, the total stream are present 1, 03, 557 of which 75.44 % are first order streams having 78,123 segments (Table 1). The second order stream segments are 19,442 and account for 18.77 %; Third order stream segments are 4,584 and accounted 4.42 %; Fourth order

stream segments are 1,085 and account for 1.04%; Fifth order stream segments are 258 and account for 0.24 %; Sixth order stream segments are 50 and account for 0.048 %; Seventh order stream segment is 10 and account for 0.01 %; eight order stream segments are 4 and account for 0.0038 % and Ninth order stream segment is 1 and account for 0.0009 %.

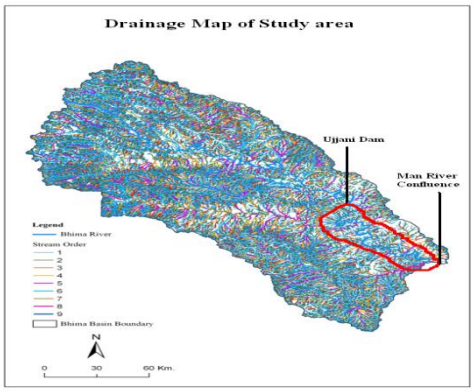

Fig. 2

Bifurcation Ratio (Rb):

Bifurcation Ratio is the ratio of the number of streams of an order to the number streams of the next higher order (Horton, 1945, Strahler, 1964). In the Bhima basin bifurcation ratio ranges from 2.5 to 5.16 (Table 1). The average bifurcation ratio of area is 4.16. This means that on an average, there are 4.16 times as many channel segments to any given order as of the next higher order. Bifurcation ratios are related to the structural control on the drainage (Nautiyal, 1994; Strahler, 1964; Chow, 1964). A lower Rb range suggests that structure does not exercise a dominant influence on the drainage pattern. Higher Rb indicates some sort of geological control (Agarwal, 1998). If the Rb is low, the basin produces a sharp peak in discharge and if it is high, the basin yields low, but extended peak flow (Agarwal, 1998). In well developed drainage network the bifurcation ratio is generally between 2 to 5 (Horton, 1945; Strahler, 1964).

$$Rb = \frac{Nu}{Nu + 1}$$

Stream Length (Lu):

The stream length of various orders has been measured form topographical map. Horton's law (Horton, 1932) of stream length supports the theory that geometrical similarity is preserved generally in the basins of increasing order (Strahler, 1964). The mean length of channel Lu of order U is the ratio of the total length to the number of streams of a given order. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order. The logarithm of stream length of each order as a function of order is plotted and yields a set of points lying generally along a straight line.

Table 1: Morphometric parameters of Bhima River basin

Stream Order	No of Streams	No of streams %	Total Length km	Mean Stream Length km	Bifurcation Ratio	Log of No of Streams	Log of total Length
1	78123	75.44	44538.23	0.57	-	4.89	4.65
2	19442	18.77	14460.31	0.74	4.01	4.28	4.16
3	4584	4.42	7542.96	1.65	4.24	3.66	3.87
4	1085	1.04	3990.00	3.68	4.22	3.03	3.60
5	258	0.24	1774.93	6.88	4.20	2.41	3.24
6	50	0.048	952.52	19.05	5.16	1.69	2.97
7	10	0.01	451.33	45.13	5.00	1.00	2.65
8	4	0.0038	231.17	57.79	2.50	0.60	2.36
9	1	0.0009	292.09	292.09	4.00	0.00	2.46
Total	**1,03,557**						

Here,

$$\text{MSL} = \frac{\text{Total Length of streams}}{\text{Number of streams in this order}}$$

Aerial Aspects of Drainage Basin:

Basin Watershed area in study area:

Sr. No	Name of Watershed	Area of Watershed (km^2)	Length of Basin (km)
1	Ghod	4,546.17	407.12
2	Mula-Mutha	3,897.16	363.15
3	Nira	6,531.10	496.71
4	Man	4,756.85	421.27
5	Bhima	9,696.83	836.54
	Total	**29,428.11**	**2524.79**

Basin Area (Au):

The area of watershed is 29,493.97 km^2. If the basin size is small, it is likely that rainwater will reach the main channel more rapidly than in a larger basin, where the water has much further to travel. Lag time will therefore be shorter in the smaller basin. According to Gregery and Walking (1973), the 'L' is the longest length of the basin from the catchment to the point confluence. The length of the River Bhima basin is 142.18 km. Basin area is the direct outcome of the drainage development in a particular basin. It is usually seen that the basin are pear shaped in early stages, but as the cycle advances, the shape tends to become more elongated (Padmaja Rao, 1978). The shape of the basin is significant since it affects the stream discharge characteristics (Strahler, 1969). It has long been accepted that a circular area is more likely to have a shorter lag time and a higher peak flow than an elongated basin. Three

dimensionless ratios viz., form factor, circularity ratio and elongation ratio, reflect the basin shapes.

Form Factor (Rf):

It is the ratio of a basin area Au (Horton, 1932) to the square of the basin length Lb. For Bhima basin, the form factor is 0.0046.

$$Rf = \frac{Au}{Lb^2} \qquad Rf = \frac{29428.11}{(2524.79)^2} \qquad Rf = \frac{29428.11}{6374564.54} \qquad Rf = 0.0046$$

A form factor nearer to zero indicates a highly elongated shape and the value that is closer to 1 indicates circular shape. The basins with high form factor value have high peak flow for short duration whereas elongated basin with low form factor will have a flatter peak flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basins (Nautiyal, 1994). The Bhima basin, being elongated in shape, has an Rf of 0.0046.

Circularity Ratio (Rc):

Circularity Ratio is defined as the ratio of basin area (Au) to the area of circle (Ac) having the same perimeter (Pr) as the basin (Miller, 1953). It is influenced more by the length, frequency and gradient of streams of various orders rather than slope conditions and drainage pattern of the basins. For Bhima basin, the ratio is 3.51.

Elongation Ratio (Re)

It is the ratio of the diameter of a circle of the same area as the basin to the maximum length of the basin (Schumm's, 1956). For the study area, the elongation ratio is 0.032. Values range from 0.6 to 0.8 is generally associated with strong relief and steep ground slopes. There is no strong relief.

Drainage Density (Dd):

The Drainage Density (Dd) is defined as the length of streams per unit area. It is obtained by dividing the cumulative stream length by the basin area (Horton, 1932). For the Bhima basin the overall drainage density is 0.075 per km. In general, high Dd is characteristic of regions having nonresistant or impermeable subsurface materials, sparse vegetation and mountainous relief; Whereas low Dd indicates regions of highly resistant rock or highly permeable subsoil materials under dense vegetative cover, where the relief is low. In the study area, the hilly region to west shows high Dd, while it is very low in the area close to the coastal plain.

Stream Frequency (Fs):

Stream frequency of the basin may be defined as the ratio of the total numbers of segments cumulated for all orders with a basin to the basin area (Horton, 1945). The Fs of the whole basin is 3.51streams/km^2. High drainage density and stream frequency indicate larger run off from a basin.

Drainage Texture (T):

The drainage texture may be defined as the relative spacing of drainage lines. The drainage density and drainage frequency have been collectively defined as drainage texture.

It can be expressed by the equation (Smith, 1950),

T = **D**d X **F**s.

Based on the values of T it is classified as (Smith, 1950)

0-4 – Coarse
4-10 – Intermediate
10-15 – Fine
>15 – Ultra Fine (bad land topography)

For Bhima basin the drainage texture is 0.263 indicating the massive and resistant rocks cause coarse texture.

Results and Discussion:

The total drainage area of Bhima river basin is 29,428.11 km^2. The details of stream characteristics confirm with Horton's (1932) "law of stream numbers" which states that the number of streams of different orders in a given drainage basin tends closely to approximately an inverse geometric ratio. It also confirms with Horton's (1932) the "law of stream length" which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.

Conclusion:

The study reveals that drainage area of the basin is passing through an early mature stage to old age stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The development of the stream segments in the basin area is more or less affected by rainfall. It is noticed that stream segments up to third order traverse part of the high altitudinal zones which are characterized by steep slopes while the fourth, fifth and sixth stream segments occur in comparatively flat lands. The average bifurcation ratio of 4.16 reveal that drainage network in study area is well developed stage. The drainage basin size analysis reveals that the flooding may be lesser.

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