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MORPHOMETRIC ANALYSIS OF BORDI RIVER BASIN, AKOLA DISTRICT MAHARASHTRA, INDIA USING REMOTE SENSING AND GIS TECHNIQUES

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Abstract

Detailed morphometric analysis has been carried out for the Bordi River basin, Akola District, Maharashtra to understand and quantify and understand the various hydrological characters for a comprehensive water resource management plan. The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basic unit in morphometric analysis is the most logical choice because all hydrologic and geomorphic processes occur within the watershed. The main objective of the present study is to derive the different drainage aspects of Bordi river basin and to understand the relationship of the drainage networking by utilizing quantitative analysis of drainage system in order to evaluate linear and areal aspects of morphometric characteristics. The area of investigation is characterized by the presence of thick lava flows belonging to upper Cretaceous to lower Eocene age with the mantle of recent alluvium. However, certain portion of the area consists of alluvial zone showing saline nature of groundwater in general. The results of the morphometric analysis has revealed that the total number as well as total length of stream segments is maximum in first order streams and decreases as the stream order increases. Horton's laws of stream numbers and stream lengths also hold good. The bifurcation ratio between different successive orders is almost constant. The drainage density values of the different watersheds exhibit high degree of positive correlation (4.02) with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density and vice versa. The results have demonstrated the possible presence of potential water bearing horizons in the Bordi River basin with good to excellent groundwater resources.

Introduction

Morphometric analysis (Agarwal et al., 2000) is an important aspect of hydrological and hydro geological studies. 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; Kumar swami et al., 1998 and Sreedevi et al., 2001). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Leopold & Maddock, 1953; Abrahams, 1984). Most previous morphometric analyses were based on arbitrary areas or individual channel segments. Using watershed as a basic unit in morphometric analysis is the most logical choice. A watershed is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. In fact, they are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks and quantitative description of drainage texture, pattern and shape (Abrahams, 1984). The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Singh, 1992).

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964; Krishnamurthy et al., 1996). Geographical Information System (GIS) techniques are now days used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. In the present study stream number, order, frequency, density and bifurcation ratio are derived and tabulated on the basis of areal and linear properties of drainage channels using GIS based on drainage lines as represented over the topographical maps

Study Area

The Bordi River basin covers an area of 450 km^2 in the survey of India toposheet numbers on a scale of 1:50,000. The basin area lies between 12 ° 50’ 00’’ to 13 ° 30’00’’ N latitudes and 76 ° 10’ 00’’ to 77 ° 20’ 25’’E longitudes. The maximum elevation is 467 m and is in the western part of the basin, which is a mountainous terrain (Fig.1). Rolling and isolated hills are found in the central parts while the eastern side is practically a flat terrain culminating at sea levels. The general climate of the Bordi River basin is semi arid in nature. The temperature reaches its high in the month of April and low in the month of January.

Methodology

Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation was done

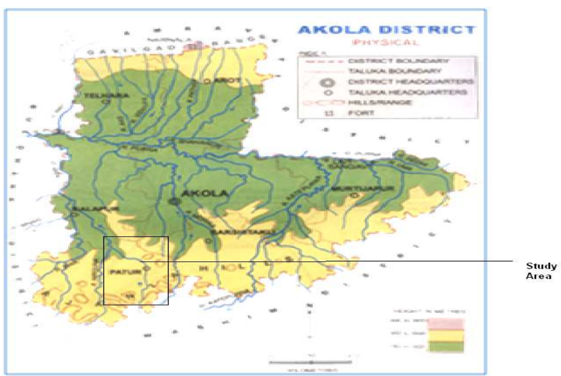

Fig. 1 Location map of the study area

Digitally in GIS (Arc view:3.2a) system. All tributaries of different extents and patterns were digitized from survey of India toposheets 1961 (1:50,000 scale) and the catchment boundary was also determined for Bordi catchment. Similarly, two sub-catchments consisting of 6 watersheds were also delineated and measured for intensive study. Digitization work was carried out for entire analysis of drainage morphometry. The different morphometric parameters have been determined as shown in table 3.

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 & 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. The morphometric analysis of the Bordi watershed was carried out on the Survey of India topographical maps No. 55D/14, and 55D/15 on the scale 1:50,000 .The lengths of the streams, areas of the watershed were measured by using Rotometer & Planimeter, and stream ordering has been generated using Strahler (1953) system. The linear aspects were studied using the methods of Horton (1945), Strahler (1953), Chorley (1957), the areal aspects using those of Schumm (1956), Strahler (1956, 1968), Miller (1953), and Horton (1932), and the relief aspects employing the techniques of Horton (1945), Broscoe (1959), Melton (1957), Schumm (1954), Strahler (1952), and Pareta (2004).

Results and Discussion

The drainage characteristics of Bordi catchment have been examined with particular reference to following:

Drainage Network

Stream Order (Su):

Stream ordering is the first step of quantitative analysis of the watershed. The stream ordering systems has first advocated by Horton (1945), but Strahler (1952) has proposed this ordering system with some modifications. Author has been carried out the stream ordering based on the method proposed by Strahler, 1 to 5. It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases.

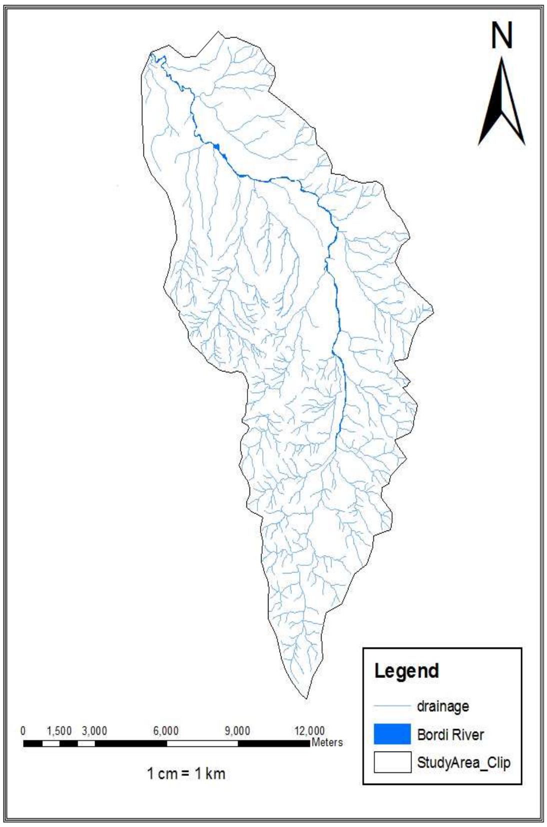

Fig. 2 Drainage map of the study area based on topographic data and remote sensing analysis

Stream Number (Nu)

The total of order wise stream segments is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number, i.e. 561.

Stream Length (Lu)

The total stream lengths of the Bordi watershed have various orders,i.e.14.61 which have computed with the help of Planimeter. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order (Strahler, 1964). The stream length has been computed based on the low proposed by Horton (1945) (Table 2).

Mean Stream Length (Lum)

Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces (Strahler, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order, Bordi Mean Stream Length is 0.82

Stream Length Ratio (Lurm)

Horton (1945, p.291) states that the length ratio is the ratio of the mean (Lu) of segments of order (So) to mean length of segments of the next lower order (Lu-1), which tends to be constant throughout the successive orders of a basin. His law of stream lengths refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the first term (stream length) is the average length of segments of the first order (Table 2). Changes of stream length ratio from one order to another order indicating their late youth stage of geomorphic development (Singh and Singh, 1997).i.e. 3.65

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1), Table 1. Horton (1945) considered the bifurcation ratio as index of relief and dissertation. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed from 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 bifurcation ratio is dimensionless property and generally ranges from 4.0 to 8.0. The lower values of Rb are characteristics of the 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 indicates strong structural control on the drainage pattern, while the lower values indicative of watershed that are not affect by structural disturbances.

Table 1 Stream Order, Streams Number, and Bifurcation Ratios in Bordi River basin

SN	SU	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
1	I	409				
2	II	102	4	511	2044	
3	III	41	2.48	143	354.6	4.9
4	IV	8	5.12	49	250	
5	V	1	8	9	72	
6	Total		19.6			
7	Mean		4.9			

Su: Stream order, Nu: Number of streams, Rb: Bifurcation ratios, Rbm: Mean bifurcation Ratio*, Nu-r: Number of stream used in the ratio, Rbwm: Weighted mean bifurcation ratios

Weighted Mean Bifurcation Ratio (Rbwm)

To arrive at a more representative bifurcation number Strahler (1953) used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. Schumm (1956, pp 603) has used this method to determine the mean bifurcation ratio of the value of 4.9 of the drainage of Perth Amboy, N.J. The values of the weighted mean bifurcation ratio this determined are very close to each other.

Length of Main Channel (Cl)

This is the length along the longest watercourse from the outflow point of designated sun watershed to the upper limit to the watershed boundary. Length of Main Channel of Bordi Watershed 25Km

Rho Coefficient (ρ)

The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton Drainage map of Bordi Water Basin1945). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho values of the Bordi watershed is 0.74. This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

Basin Geometry

Length of the Basin (Lb)

Several people defined basin length in different ways, such as Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gregory and Walling (1973) defined the basin length as the longest in the basin in which are end being the mouth. Gardiner (1975) defined the basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter. The author has determined length of the Bordi watershed in accordance with the definition of Schumm (1956) that is 22.5 Kms.

Basin Area (A)

The area of the watershed is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas, which is 450Sq Kms, 900cm (Table 3).

Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. The author has computed the basin perimeter by using Rotometer, which is 55 Kms,110cm.

Lemniscate's (k)

Chorely (1957), express the lemniscate's value to determine the slope of the basin. In the formula k = Lb2 / 4 * A. Where, Lb is the basin length (Km) and A is the area of the basin (km2). The lemniscate (k) value for the watershed is 2.25 (Table 3), which shows that the watershed occupies the maximum area in its regions of inception with large number of streams of higher order.

Form Factor (Ff)

According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.44 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watersheds with high form factors have high peak flows of shorter duration.

Elongation Ratio (Re)

According to Schumm (1965, p. 612), 'elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). The elongation ration of Bordi watershed is 0.28, which is represented the watershed is less elongated.

Texture Ratio (Rt)

According to Schumm (1965), texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin (Rt = Nl / P) and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of the watershed is 3.71 and categorized as moderate in nature, Table 3.

Drainage Texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of stream segments of all orders per perimeter of that area (Horton, 1945). (Smith, 1950) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of the watershed is 5.1(Table 3). It indicates that category is very fine drainage texture.

Compactness Coefficient (Cc)

According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The Cc is independent of size of watershed and dependent only on the slope.

The author has computed the compactness coefficient of Bordi watershed, which is 0.12,

Fitness Ratio (Rf)

As per Melton (1957), the ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness. The fitness ratio for Bordi watershed is 0.45,

Wandering Ratio (Rw)

According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the mainstream length to the valley length. Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the watershed is 1.11, Table 3.

Sinuosity Index (Si)

Sinuosity deals with the pattern of channel of a drainage basin. Sinuosity has been defined as the ratio of channel length to down valley distance. In general, its value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman and Miller,1964). It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes. For the measurement of sinuosity index Mueller (1968,) has suggested some important computations that deal various types of sinuosity indices. He also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively. Sinuosity Index of Bordi Watershed is 1.11.

Table 2: Stream Length, and Stream Length Ratio in Bordi Watershed

Su: Stream order, Lu: Stream length, Lur: Stream length ratio, Lurm: Mean stream length ratio*, Lur-r: Stream length used in the ratio, Luwm: Weighted mean stream length ratio

Drainage Texture Analysis

Stream Frequency (Fs)

The drainage frequency introduced by Horton (1932) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area. In the present study, the stream frequency of the Bordi watershed is 0.62.

Drainage Density (Dd)

Drainage density is the stream length per unit area in region of watershed (Horton, 1945, p.243 and 1932, p. 357; Strahler, 1952, and

1958; Melton 1958) is another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform. Drainage Density is calculated by Dd=Lu/A, Drainage density of Bordi Watershed is 4.02 km.

Constant of Channel Maintenance (1/D)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of Kms2 of basin surface required to develop and sustain a channel 1 Km long. The constant of channel **maintenance** indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the watershed is 0.24 Kms2/Km (Table 5).

Drainage Intensity (Di)

Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This study shows a low drainage intensity of 0.15 for the watershed, This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not quickly removed from the watershed, making it highly susceptible to flooding, gully erosion and landslides.

SU	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	240	0.58				
II	110	1.07	2.8	350	980	
III	65	1.58	1.69	175	295.75	3.65
IV	43	5.37	1.51	108	163.08	
V	5	5	8.6	48	48	
TOTAL	463		14.61			
Mean	92.6		3.65			

Infiltration Number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher ran-off. (Table 3).

Drainage Pattern (Dp)

In the watershed, the drainage pattern reflects the influence of slope, lithology and structure. Finally, the study of drainage pattern helps in identifying the stage in the cycle of erosion. Drainage pattern presents some characteristics of drainage basins through drainage pattern and drainage texture. It is possible to deduce the geology of the basin, the strike and dip of depositional rocks, existence of faults and other information about geological structure from drainage patterns. Drainage texture reflects climate, permeability of rocks, vegetation, and relief ratio, etc. Howard (1967) related drainage patterns to geological information. Author has identified the dendritic and radial pattern in the study area. Dendritic pattern is most common pattern is formed in a drainage basin composed of fairly homogeneous rock without control by the underlying geologic structure. The longer the time of formation of a drainage basin is, the more easily the dendritic pattern is formed.

Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. In this study, the length of overland flow of the Bordi watershed is 2.42 Kms, which shows low surface runoff of the study area.

Relief Characterizes

Relief Ratio (Rhl)

Difference in the elevation between the highest point of a watershed 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. In the study area, the value of relief ratio is 169. It has been observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope.

Relative Relief (Rhp)

The maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Using the basin relief (174 m), a relief ratio was computed as suggested by Schumm (1956), which is 0.006. Melton's (1957) relative relief was also calculated using the formula: Rhp = (H*100) / P, where P is perimeter in meters. This comes to 169 for Bordi watershed.

Absolute Relief (Ra)

The difference in elevation between a given location and sea level .i.e. for Bordi Basin is 298 m.

Ruggedness Number (Rn)

Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. Calculated accordingly, the Bordi watershed has a ruggedness number of 0.67. The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

Melton Ruggedness Number (MRn)

The MRn is a slope index that provides specialized representation of relief ruggedness within the watershed (Melton 1965). Bordi watershed has an MRn of 7.51(Table 3). According to the classification of Wilfordet al. (2004), this watershed is debris flood watersheds, where bed load component dominates sediment under transport.

Dissection Index (Dis)

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh and Dubey 1994). On average, the values of Dis vary between'0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and'1' (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). Dis value of Bordi watershed is 0.56 (Table 3), which indicate the watershed is a moderate dissected.

Gradient Ratio (Rg)

Gradient ratio is an indicator of channel slope, which enables assessment of the runoff volume (Sreedevi, 2004). Watershed has an Rg of 3.75 (Table 3), which reflects the mountainous nature of the terrain.

Comparison of Drainage Basin Characteristics

The details of the morphometric analysis and comparison of drainage basin characteristics of Bordi watershed are presented in the following table 3.

Table 3 Comparison of drainage basin Characteristics of Bordi River Basin

	Morphometric Parameter	Formula	Reference	Results
A	**Drainage Network**			
1	Stream Order (Su)	Hierarchical Rank	Strahler(1952)	**1 to5**
2	1st Order Stream (Suf)	Suf=N1	Strahler(1952)	**409**
3	Stream Number (Nu)	Nu=N1+N2+Nn	Horton (1945)	**561**
4	Stream Length (Lu) Kms	Lu=L1+L2--Ln		**463**
5	Stream Length Ratio (Lur)	see Table 2	Strahler 1964)	**14.61**
6	Mean Stream Length Ratio (Lurm)	see Table 2	Horton (1945)	**3.65**
7	Weighted Mean Stream Length Ratio(Luwm)	see Table 2	Horton (1945)	**3.65**
8	Bifurcation Ratio (Rb)	see Table 1	Strahler(1964)	
9	Mean Bifurcation Ratio (Rbm)	see Table 1	Strahler(1964)	**4.9**
10	Weighted Mean Bifurcation Ratio (Rbwm)	see Table 1	Strahler(1964)	**4.9**
11	Main Channel Length (Cl) Kms			**50cm**
12	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	**0.74**
	Basin Geometry			
13	Basin Length (Lb)		Schumm(1956	**45cm**
14	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)	**20cm**
15	Basin Area (A) Sq Kms		Schumm(1956)	**900cm-450km**
16	Basin Perimeter (P) Kms		Schumm(1956)	**110cm-55km**
17	Relative Perimeter (Pr)	Pr = A / P	Schumm(1956)	**8.18**
18	Length Area Relation (Lar)	Lar = 1.4 *	Hack (1957)	**1260**

		A0.6		
19	Lemniscate's (k)	k = Lb2 / A	Chorley (1957)	**2.25**
20	Form Factor Ratio (Rf)	Ff = A / Lb2	Horton (1932)	**0.44**
21	Shape Factor Ratio (Rs)	Sf = Lb2 / A	Horton (1932	**2.25**
22	Elongation Ratio (Re)	Re = 2 / Lb * (A/π)	Schumm(1956)	**0.28**
23	Texture Ratio (Rt)	Rt = N1 / P	Schumm(1965)	**3.71**
24	Circularity Ratio (Rc)	Rc = 12.57 * (A /P2)	Miller (1953)	**51.41**
25	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)	**4.09**
26	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	**5.1**
27	Compactness Coefficient (Cc)	Cc = 0.2841 * P /A 0.5	Gravelius(1914)	**0.12**
28	Fitness Ratio (Rf)	Rf = Cl / P	Melton (1957)	**0.45**
29	Wandering Ratio (Rw)	Rw = Cl / Lb	Smart &Surkan (1967)	**1.11**
30	**Drainage Texture Analysis**			
31	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	**0.62**
32	Drainage Density (Dd) Km / Kms	Dd = Lu / A	Horton (1932)	**4.02**
33	Constant of Channel Maintenance(Kms2 / Km)	C = 1 / Dd	Schumm(1956)	**0.24**
34	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	**0.15**
35	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	**2.49**
36	Drainage Pattern (Dp)		Horton (1932)	**DD**
37	Length of Overland Flow (Lg) Kms	Lg = A / 2 * Lu	Horton (1945)	**2.42**
38	Height of Basin Mouth (z) m	-	-	**298**
39	Maximum Height of the Basin (Z) m	-	-	**467M**
40	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	**169**

41	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm(1956)	**169**
42	Absolute Relief (Ra) m	-	-	**298M**
43	Relative Relief Ratio (Rhp)	Rhp = H * 100 /P	Melton (1957)	**153.6**
44	Dissection Index (Dis)	Dis = H / Ra	Singh &Dubey (1994)	**0.56**
45	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	Sreedevi(2004)	**3.75**
46	Watershed Slope (Sw)	Sw = H / Lb	-	**3.75**
47	Ruggedness Number (Rn)	Rn = Dd * (H /1000)	Patton &Baker (1976)	**0.67**
48	Melton Ruggedness Number (MRn)	MRn = H / A0.5	Melton (1965)	**7.51**
49	Contour Interval (Cin) m			
50	Average Slope Width of Contour (Swc)	Swc = A /{(L1+L2) / 2}	Strahler (1952)	**2.57**

Summary:

The drainage basin is being frequently selected as an ideal geomorphological unit. Watershed as a basic unit of morphometric analysis has gained importance because of its topographic and hydrological unity. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. Drainage density and stream frequency are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The Drainage density appears significantly higher in watershed implying the existence of impermeable rocks and high relief. It is observed that there is a decrease in stream frequency as the stream order increases. The law of lower the order higher the number of streams is implied throughout

the catchment. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The study has shown that the catchment is in conformity with the Hoton's law of stream numbers and law of stream lengths. The same geological and lithological development of the catchment has resulted into more or less constant bifurcation ratio between different successive orders in Bordi catchment.

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