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RESEARCH ARTICLE

GIS BASED MORPHOMETRIC ANALYSIS OF GADILAM RIVER BASIN, TAMIL NADU, INDIA

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Abstract

Geographical Information System (GIS) have proved to be an efficient tool in the delineation of drainage pattern for water resources management and its planning. In this study, GIS and image processing techniques have been adopted for the identification of morphological features and analyzing the properties of the of Gadilam river basin, Cuddalore District, Tamil Nadu. The morphometric parameters considered for analysis includes the linear, areal aspects of the basin. The Means basin covers an area of 1628 km^2 and is a drainage basin with mainly parallel to sub-parallel drainage pattern. The mean bifurcation ratio is 4.46 indicating the basin is largely controlled by structure. The basin has medium drainage density of 0.82 per km^2 and is elongated in shape. The study has strengthened in understanding the hydrological, geological characteristics of the Means drainage basin.

Introduction

Quantitative measurements of drainage basins and its parameters were assessed earlier using conventional methods. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; ObiReddy et al., 2002). Evaluation of the morphometric parameters necessitates preparation of drainage map, ordering of the various streams, measurement of the catchment area and perimeter, length of drainage channels, drainage density and frequency, bifurcation ratio, texture ratio, circulatory ratio and constant channel maintenance, which helps to understand the nature of drainage basins (Krishnamurthy et al., 1996; Kumar et al., 2000; ObiReddy et al., 2002; Nag and Chakraborty, 2003; Nooka Ratnam et al., 2005). Geographical Information System (GIS) techniques have already been 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 particularly for the feature identification and the extraction of information for better understanding. In the present study, the GIS analysis techniques were used to evaluate linear, relief and aerial morphometric parameters of the sub-watersheds for the future developmental planning of the watersheds.

Morphometric studies in the field of hydrology were first initiated by Horton (1940) and Strahler (1950). The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural, etc. The relationship between various drainage parameters and the aforesaid factors are well recognized by many workers (Horton, 1945, Strahler, 1957, Melton, 1958, Pakhmode et. al., 2003 and Gangalakunta, 2004). The drainage basin analysis is important in any hydrogeological investigation as assessment of groundwater potential, groundwater management, pedology and environmental assessment. Varies important hydrogeological phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories etc. (Rastogi et. al., 1976).

The objective of the present study was to analyze the linear and areal morphometric attributes of Gadilam river drainage basin in Cuddalore district by using geo-spatial technology. This study is attempted to use the morphometric technique using GIS to give an insight of the different geo-hydrological characteristics of the drainage basin to help in the identification of ground water potential zones and overall management of the basin with focus on groundwater.

2. Study Area

Gadilam river basin is located in parts of Cuddalore and Villupuram districts of Tamil Nadu, India. It lies in between 79° 0' E to 79° 47' E longitudes and 11° 30' N to 11° 55' N latitudes (Fig. 1). It occurs within the Survey of India toposheets of 58M/1, 2, 5, 6, 9, 13, 10, and 14, covering a total area of about 1,628 km2. The Gadilam river basin is bounded by Ponnaiyar river basin in the North and the Vellar river basin in the south. The total length of the river is about 1333.94 km with a catchment area extending about 900 km^2. The average annual rainfall of the basin is about1, 643 mm. The water level ranges from 3.10 mbgl to 98.85 mbgl (below ground level) with an average of 62.37 bgl. The river basin has different rock types along its flow path. The lithological setup of the basin shows that hard basement rocks are exposed in the western part of the study area and sedimentary formation in the east with a faulted contact between both (Aravindan et al. 2004). River originates in the hard rock region and flows through the sedimentary terrain. The basin covers different stratigraphic units viz. Archaean, Cretaceous, and Tertiary to Recent alluvium. The charnockites, granites, syenites, and gneiss of Archaean complex constitute the upstream area. The younger Cretaceous and Tertiary formations are found in the midstream and recent alluvium in the downstream of the Gadilam river basin. Lithologically, hard rock's constitute the western part of the basin. In the sedimentary region, the northern part essentially comprises of recent alluvium and the rest by sandstone (Prasannaet, al., 2010).

3. Materials and Methods

The present study is based on Survey of India (SOI) topographic maps of 1971 with no. 58M/1, 2, 5, 6, 9, 13, 10, and 14, on the scale 1, 50,000. Topographical maps were rectified/ referenced geographically and mosaiced and entire study area was delineated in GIS environment with the help of Arc-GIS 10.1 software assigning Universal Transverse Mercator (UTM), World Geodetic System (WGS dating from 1984 and last revised in 2004) and 44N Zone Projection System. Since, morphometric analysis of a drainage basin requires the delineation of all the existing streams, digitization of the drainage basin was carried out for morphometric analysis in GIS environment using Arc GIS 10.1 software. The attributes were assigned to create the digital data base for drainage layer of the basin. Various morphometric parameters such as linear, aerial and relief aspects of the basin were computed. The different morphometric parameters were determined by using the standard methodologies as shown in Table 1. Moreover, GIS technology was used to generate several other layers of maps such as map of elevation zones of the basin, map of the geological setup of the area and map showing distribution and concentration of the natural springs irrespective of the size and discharge in different geological zones to validate the results and inferences drawn through morphometric analysis. Finally, by assembling the whole data generated, groundwater potential zones were identified.

4. Results and Discussions

The total drainage area of Gadilam River basin is 1628 km^2. The drainage noticed in the area is mainly parallel to sub-parallel drainage pattern and also some relict pattern is also seen (Fig.3). 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.

4.1. Linear Aspects of the Drainage Basin

4.1.1. Stream Order

The streams of the Gadilam 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 "Five" order drainage basin.

4.1.2 Stream Number (Nu)

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 streams segments present are 1894 of which 67.42 % are first order streams having 1277 segments (Table.1). The second order stream segments are 485 and account for 25.61 %; Third order stream segments are 117 and accounted 6.18 %; Fourth order stream segments are 13 and account for 0.68 %; fifth order stream segments are 2 and account for 0.11. Fig. 2(a).

4.1.3 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 Gadilam River basin bifurcation ratio ranges from 2.63 to 9.00 (Table 1). The average bifurcation ratio of area is 4.46. This means that on an average, there are 4.46 times as many channel segments to any given order as of the next higher order. According to Strahler (1957), the bifurcation ratio (Rb) greater than 4 is an indication of structural control on the drainage; therefore, the bifurcation of this basin indicates the predominance of structural control over this basin. A lower Rb range between 2 to 4 suggests that structure does not exercise a dominance 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).

4.1.4 Stream Length (Lu)

The stream length of various orders has been measured from 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 Fig. 2(b).

4.2. Aerial Aspects of Drainage Basin

4.2.1 Basin Area (A)

The area of Gadilam River basin is 1628 km^2. If the basin 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. 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).

4.2.2 Basin Length (Lb)

According to Schumm (1956), the basin length (Lb) is the longest dimension of the basin parallel to the principle drainage line. The length of the Gadilam River basin is 133.94 km.

4.2.3 Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divide between watersheds and may be used as an indicator of watershed size and shape. The perimeter (P) of the study basin is 242.17 km.

4.2.4 Drainage Density (Dd)

The Drainage Density (Dd) is defined as the length of streams per unit area. It is obtained by dividing the accumutive stream length by the basin area (Horton, 1932). For the Gadilam River basin the overall drainage density is 0.82 km/sq.km.

4.2.5 Stream Frequency (Fs)

Stream frequency of the basin may be defined as the ratio of the total numbers of segments accumulated for all orders with a basin to the basin area (Horton, 1945). The Fs of the whole basin is 1.16 sq km. High drainage density and stream frequency indicate larger run off from a basin.

4.2.6 Form Factor (Rf)

It is the ratio of a basin area (A) (Horton, 1932) to the square of the basin length (Lb). For Gadilam River basin, the form factor is 18.33. 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 Gadilam River basin, being elongated in shape, has an Rf of 18.33.

4.2.7 Circularity Ratio (Rc)

Circularity Ratio is defined as the ratio of basin area (A) to the area of circle having the same perimeter (P) 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 Gadilam River basin, the ratio is 2.59.

4.2.8 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). 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. The value of Elongation ration (Re) of the study area is 11.67 indicates that the low relief of the terrain and elongated in shape.

4.2.9 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 Cc computed of the study area is 0.02.

4.2.10 Drainage Texture (Dt)

It is the total number of stream segment of all orders per perimeter of that area. Horton recognized infiltration capacity as the single important factor which influences drainage texture (Dt) and considered the drainage texture to include drainage density and stream frequency. In the present study, the Rd is 7.82 which according to Smith's classification has fine drainage ratio.

4.2.11 Texture Ratio (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),
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 l and topography)

For Gadilam River basin, the texture ratio is 0.95 indicating the coarse texture.

4.2.12 Drainage Intensity (Di)

Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. Gadilam Basin shows a low drainage intensity of 1.42 for the watershed. This low value of drainage intensity implies that drainage density and stream frequency have little effect 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 gully erosion.

4.2.13 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 study area shows 0.95 infiltration Number which shows that the run-off is moderate in Gadilam River Basin.

Table 1. Linear aspects of the drainage network of the study area

Basin	**Stream Order(u)**	**Number Of Streams (Nu)**	**Total length of Streams (Lu) kms**	**Log Nu**	**Log Lu**
Gadilam Basin	1	1277	764.60	3.11	2.88
	2	485	306.10	2.69	2.49
	3	117	112.78	2.07	2.05
	4	13	96.03	1.11	1.98
	5	2	54.43	0.30	1.74
Bifurcation Ratio (Rb)				**Mean Rb (Rbm)**	
1st/2nd Order	2nd /3rd Order	3rd /4th Order	4th /5th Order		
2.63	4.15	9.00	6.50	4.46	

Table 2. Aerial aspects of the drainage network of the study area

S.N.	Morphometric Parameters	Symbols/ Formulas	Values	References
2.1	Area (sq. km)	A	1628	Schumm (1956)
2.2	Basin length (km)	Lb	1333.94	Schumm (1956)
2.3	Perimeter (km)	P	242.17	Schumm (1956)
2.4	Drainage density (km/sq. km)	Dd = Lu / A	0.82	Horton (1932)
2.5	Stream frequency	Fs = Nu / A	1.16	Horton (1932)
2.6	Form factor ratio	Rf = A / Lb2	18.33	Horton (1932)
2.7	Circularity ratio	Rc = 12.57 * (A / P2)	2.59	Miller (1953)
2.8	Elongation ratio	$Re = 2 / Lb * (A / \pi)^{0.5}$	11.67	Schumm (1956)
2.9	Compactness coefficient	Cc = 0.2841 * P/A *0.5	0.02	Gravelius (1914)
2.10	Drainage texture	Dt = Nu / P	7.82	Horton (1945)
2.11	Texture ratio	T = Dd*Fs	0.95	Smith(1950)
2.12	Drainage Intensity (Di)	Di = Fs / Dd	1.42	Faniran (1968)
2.13	Infiltration Number (If)	If = Fs * Dd	0.95	Faniran (1968)

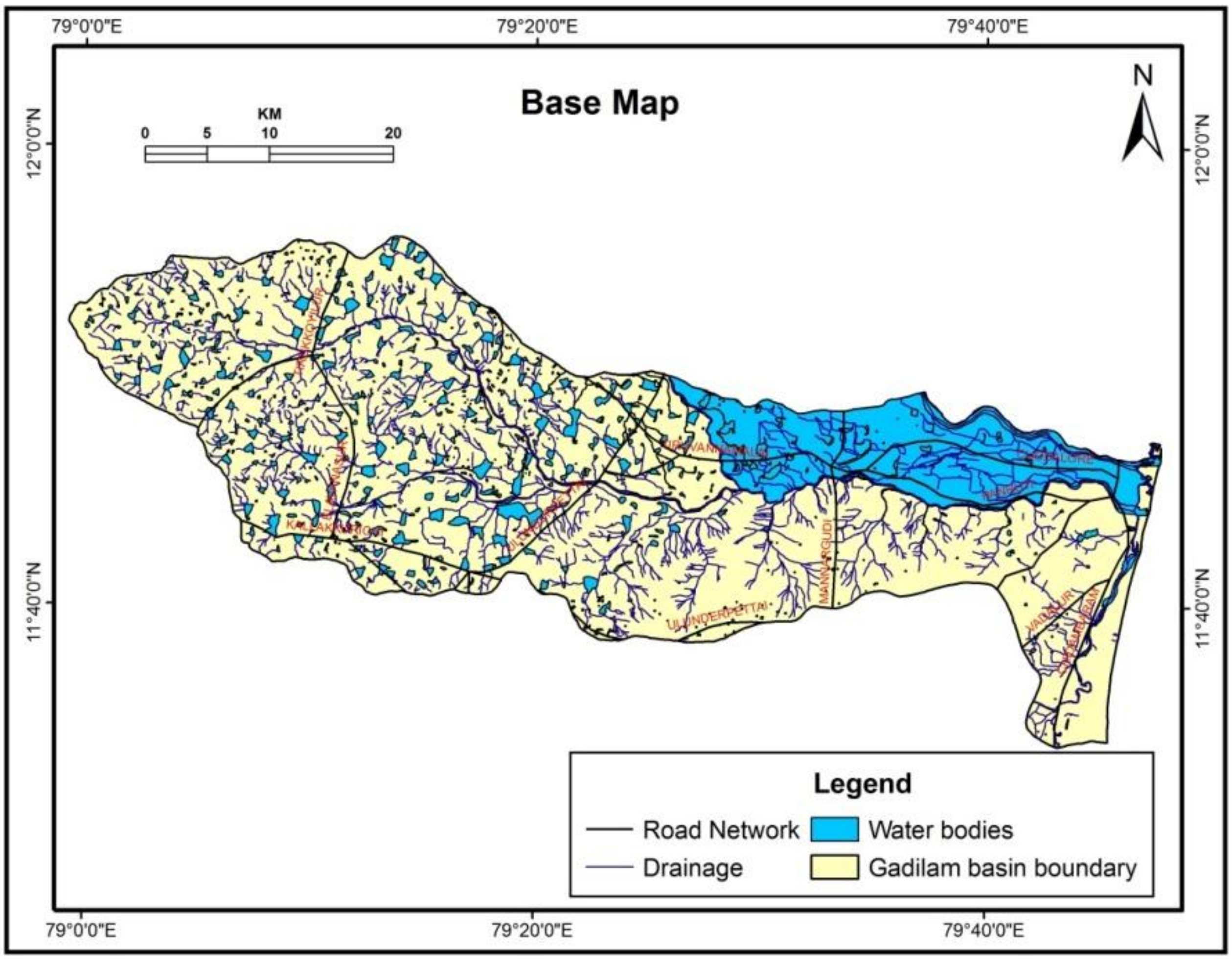

Fig.1. Location map of Gadilam River Basin.

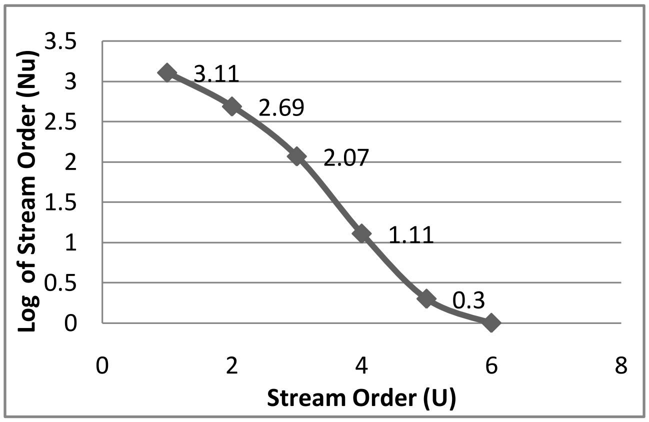

Fig.2(a). Line curve of Logarithm of Stream Number versus stream order

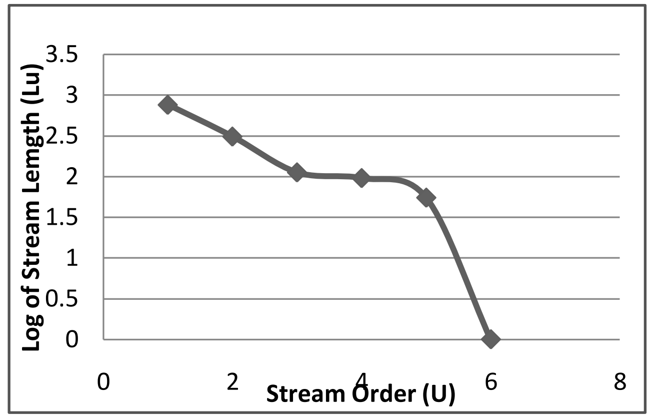

Fig. 2(b). Line curve of Logarithm of stream length versus stream order

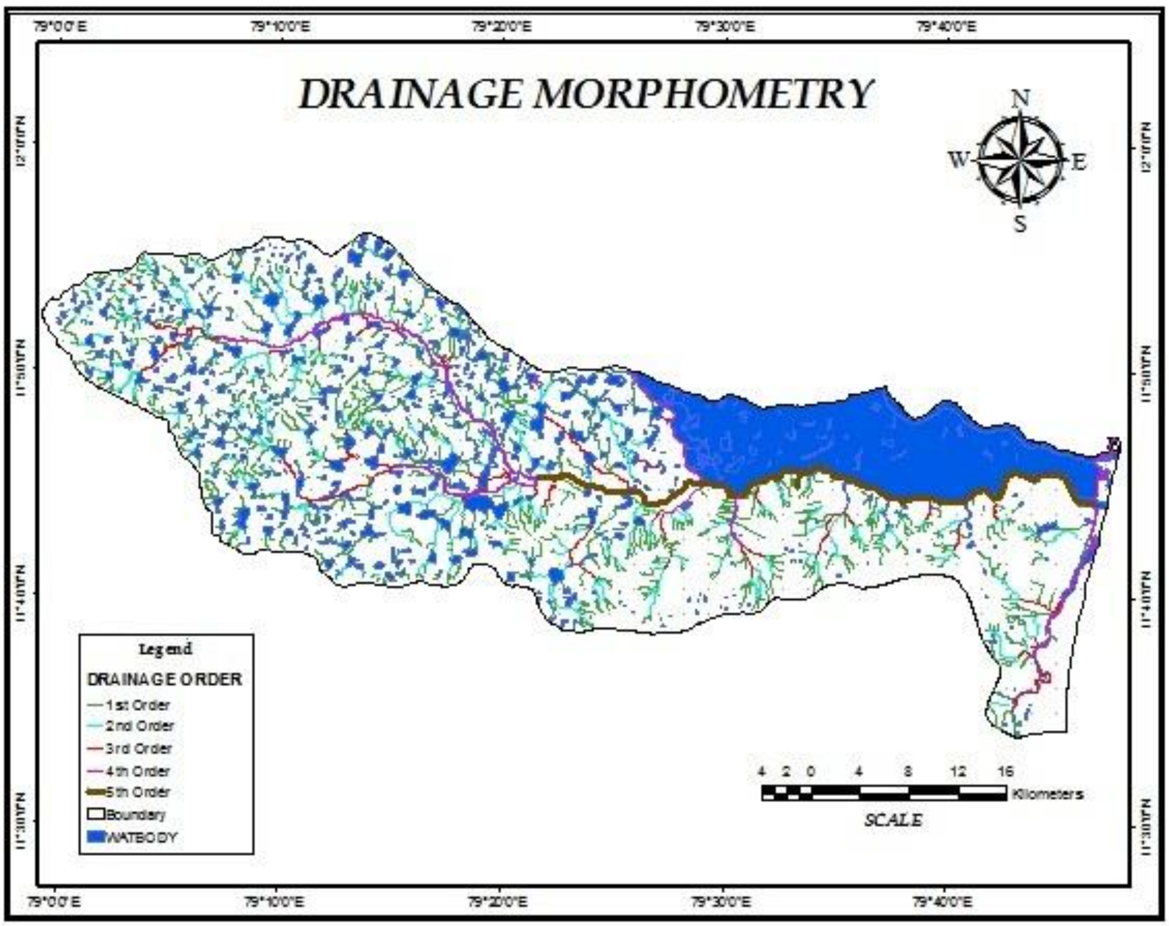

Fig.3. Drainage Pattern of the Study Area

4.3. Conclusion

Quantitative analysis of drainage network found the parallel to sub-parallel drainage pattern. Stream frequency of all sub-watersheds shows positive correlation with drainage density it has been observed that the total number of streams gradually increases as the stream order decreases and vice versa. Gadilam River basin shows coarse drainage texture results in higher value of drainage density, stream order, elongation ratio and less length of overland flow. 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 and fifth stream segments occur in comparatively flat lands. The average bifurcation ratio of 4.46 reveal that drainage network in study area is well developed stage. A bifurcation ratio greater than 4 is an indication of structural control. The drainage basin size analysis reveals that the flooding may be lesser.

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