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Assessment of Morphometric Parameters in Baitarani Basin using Remote Sensing and GIS

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ABSTRACT

Keywords

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Morphometric analysis is an important and crucial parameter in watershed development and management programme. The present study is conducted on Baitarani basin upto Anandapur covering 8603.7 km² area. The morphometric analysis of the study area is done in GIS platform. Watershed delineation is done from ASTER DEM. In this paper three aspects of morphometric analysis i.e. linear, areal and relief aspects are carried out and pertinent results are discussed. The highest order stream of the area is found to be 5th order. The mean bifurcation ratio and length of overland flow of the study area are 4.4 and 2.28 km, respectively which indicate high surface runoff in the basin and late youth stage of geomorphic development of the basin. The drainage density, stream frequency and drainage texture are calculated as 0.219 km/km², 0.039 km⁻² and 0.409 km⁻¹, respectively. Ruggedness value is 0.258.

Introduction

Morphometric analysis is the process of measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke, 1966). The morphometric analysis could be achieved through measurement of linear, aerial and relief aspects of basin (Horton, 1945). This provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). Morphometric analysis measures the 3 dimensional geometry of landform and has

traditionally been applied to watershed, drainages, hill slopes, and other group of terrain features (Barber, 2005). The morphological 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). Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of watershed, because it enables 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 (Pingale *et al.*, 2012). A drainage basin represents a natural hydrological entity which enables surface runoff to a defined channel, ravine, stream or river at a particular point (Chopra *et al.*, 2005). Drainage network is the system of streams which transport runoff, sediment and other material from a drainage area (Bowlkar *et al.*, 2019).

The morphometric analysis consists of linear, aerial and relief aspects. This is an important tool for understanding the topographic situation and hydrological condition of watershed. Quantitative evaluation of geomorphological parameters of a basin is very much important in modelling runoff (Singh, 1994). Morphological parameters within certain range of values directly indicate the runoff generation and erosion hazard of a watershed. Apart from rainfall, soil, vegetation and slope, the quantitative hydro-morphological characteristics also affect the stream flow hydrograph, run-off volume, run-off intensity and peak flow.

Computation of morphological parameters in GIS environment using remote sensing has proved to be less tedious, fast, most updated and accurate and made best spatial representation of topographic situations (Singh *et al.*, 2013). In recent years, the importance of remote sensing technology for geomorphological studies has increased because, it is not only cost effective, but also reliable and timely (Magesh *et al.*, 2012). Integration of Remote Sensing (RS) and Geographic Information System (GIS) technologies have been utilized worldwide to identify and examine changes in the landscape and the consequential environmental impacts like gully erosion, flooding, etc. RS and GIS techniques have also proven to be capable

tools in the delineation, characterization and morphometric analysis of drainage basins worldwide (Paulinus *et al.*, 2016).

The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the geo-referenced data which is further used. DEMs (Digital Elevation Model) can be used to derive flow networks and then automatically generate watershed boundaries for given outlet points using GIS technology. Therefore, an essential component to watershed delineation is a hydrologically sound DEM of the land area of interest (Julia *et al.*, 2007).

Raju and Kumar (2011) classified micro-watersheds based on morphological characteristics. They used three classification techniques, namely, K-means Cluster Analysis (KCA), Fuzzy Cluster Analysis (FCA) and Kohonen Neural Networks (KNN) to group 25 micro watersheds of Kherthal watershed, Rajasthan. They classified micro-watersheds into homogeneous groups for formulating the basis for suitable conservation and management practices. Choudhari *et al.*, (2014) studied morphometric analysis of Kharlikani watershed in Odisha using spatial information technology. By using GIS techniques, they created the basin model map, watershed network, land slope map, land use map and drainage network map. They also calculated various morphometric parameters of the watershed. The study revealed that the watershed was elongated in nature and had low drainage density.

Satish and Vajrappa (2014) calculated the morphological parameters through ASTER-DEM using GIS and RS techniques. They studied Hosakote watershed of Dakshina Pinakini River Basin, Karnataka, India. They studied the groundwater potential zone and sites for groundwater recharge using morphological analysis.

Gajbhiye (2015) analysed the morphometry of Shakkra River Catchment using RS and GIS. He delineated the catchment and preparation of drainage map from geo-coded Digital Elevation Model (DEM) using Arc view 3.1 power GIS software. He found that basin structure was dendritic covering area of 2220 sq.km that produced high surface runoff with low infiltration rates. He concluded that conventional methods of morphometric analysis was time consuming, tiresome and error prone, while use of GIS technique was more reliable and accurate in estimation of parameters of watersheds. Sutariya *et al.*, (2015) studied the morphometric analysis of Dhadhar River Basin, Gujarat. Development of morphometric techniques was a great advance within the quantitative description of basin in form of the pure mathematics and its network that helps in characterizing the drainage network and examining the impact of variables like lithology, rock structure, rain etc. The morphometric analysis clearly indicated some relations among the attributes of the morphometric parameters of the basin and would help to grasp their role indicating the surface of the region.

Afreeda and Kannan (2018) determined the watershed morphological parameters using Remote Sensing and GIS. They studied the morphological parameters of three sub watersheds of Nilgiris district of Tamil Nadu. Remote Sensing (RS) coupled with Geographical Information System (GIS) technique had proved to be an efficient tool in drainage delineation and their study for morphometric analysis. They used four different DEM sources viz., Toposheet, ASTER, SRTM and Cartosat data for delineating watershed boundary. Geographical information system for evaluation of linear aspects of morphometric parameters was carried out. They concluded that the use of geospatial technologies was more effective in comparison with the conservative approach in terms of time taken and output product.

Materials and Methods

Study area

The study area for this research work is Baitarani basin upto Anandapur. The Baitarani river is one of the major rivers of Odisha. It originates from Guptaganga hills near Gonasika village in Kendujhar district of Odisha. The basin spreads over latitude of $20^{\circ}35'$ to $22^{\circ}15'N$ and longitude of $85^{\circ}10'$ to $87^{\circ}03'$ E. Anadapur gauging station has latitude of $21^{\circ}12'34''$ N and longitude of $86^{\circ}07'23''$ E. The major portion of the river basin lies in the state of Odisha, while a smaller part of the upper reach lies in Jharkhand state. The river travels about 360 km to drain water in the Bay of Bengal. Before draining into the Bay of Bengal, the river flows in a northern direction for about 80 km and then takes an abrupt right turn near Champua and flows in a south easterly direction and joins to the deltaic area of river Brahmani. The total drainage area of the basin is over 14,000 km². The Baitarani basin covers most of area of Kendujhar, Bhadrak, Mayurbhanj and Balasore districts. The river has total 65 tributaries out of which 35 join from the left side and 30 join from the right side. The main tributaries of Baitarani River are Budhi, Kanjori, Ambajhara, Mushal, Kusei, Salandi. Figure 1 shows the location map of study area.

The Baitarani river basin mainly falls within the sub-tropical monsoon climate zone. The annual normal rainfall varies from 1250 mm to 1500 mm over the Baitarani basin. About 80% of the annual normal rainfall occurs during the 4 months of south-west monsoon season (June to September). The coefficient of variation of annual rainfall is about 20%, which indicates that the rainfall in the region is fairly dependable (HP, 1998).

The study area has maximum temperature of

47⁰ C in summer and minimum temperature of 9⁰ C in winter. The maximum relative humidity is 83.08% and it is observed in the month of August. The minimum relative humidity is 39.63% which it is observed in the month of April. The maximum wind speed is 70 km/h and minimum wind speed is 7 km/h. The cloud cover is observed to be maximum in the month of June and July and minimum in the month of December and January (Anonymous, 2011).

The drainage pattern of Baitarani river basin (central plateau) is dendrite type and flash flood is a natural character of such type of drainage pattern. The major part of basin is covered with agricultural land accounting to 52% of the total area and 3% of the basin is covered by water bodies. The upper catchment of Baitarani is full of hillocks (Anonymous, 2011).

A large number of drainage lines are present which allow the run off to rush into the main river with greater force in very short span of time. Baitarani is a highly meandering river. In meandering channels, the flow is highly turbulent and forms eddy currents which very often leads to sudden overflow of the embankments causing inundation of surrounding areas. There is heavy mining activities and practices of shifting cultivation in the upper catchment. Therefore, a large quantity of sediments is added to the river during monsoon seasons. The most flood affected blocks in Baitarani basin are Anandapur, Dasarathpur, Korei, Bari, Jajpur, Binjharpur and Rajkanika.

Watershed morphometric characteristics

Watershed morphometric characteristics contains linear aspects, areal aspects and relief aspects. The watershed delineation and stream network preparation were done in GIS platform from ASTER DEM having resolution 30 m.

Other morphometric parameters were calculated manually.

Linear aspects of morphometric parameters

In this study, various linear aspects of the basin such as stream number, stream order, stream length, mean stream length, bifurcation ratio, and stream length ratio were calculated. These parameters and the formula to calculate them are described in Table 1.

Areal aspects of morphometric parameters

The areal aspects of the watershed like drainage density, stream frequency, drainage intensity, drainage texture, infiltration number, texture ratio, elongation ratio, circulatory ratio, form factor, length of overland flow and channel maintenance factor were calculated as described in Table 2.

Relief aspects of morphometric parameters

Relief aspects of a drainage basin replicate the topographical gradient characteristics of the basin and give a bird's eye view of the whole area (Pophare and Balpande, 2014).

The relief aspects of watershed such as total relief, relief ratio, relative relief and ruggedness number were computed by the method as described in Table 3.

Results and Discussions

The different morphometric parameters of the study basin were calculated as described in materials and method section and are presented in Table 4.

Linear aspects

Stream order (u)

A stream segment with no tributaries is called first order stream (Strahler, 1964). When two

first orders come together they form a second order stream and so forth. When a higher order stream joins with a lower order stream, the order of resulting stream is the same as that of the higher order stream. In the study area, highest order stream is found to be 5th order. The stream network of the study area is shown in figure 2. In the highest order stream segment, all discharge of runoff and sediment pass.

Stream length (L_u)

Stream length of different order streams are shown in Table 4. The length of the streams of 1st, 2nd, 3rd, 4th and 5th order stream are 908.5, 464.3, 300.3, 108.3 and 106.5 km, respectively. It is observed that length of stream segments is highest in first order streams and decreases as the stream order increases. So, it is assumed that the basin is subjected to erosion and some areas of the basin are characterized by variation in lithology and topography (Singh and Singh, 1997).

Stream number (N_u)

From Table 4 and Figure 2, it is seen that the number of streams for 1st order, 2nd order, 3rd order, 4th order and 5th order were 270, 58, 13, 2 and 1, respectively. The number of stream is highest for 1st order stream and lowest for 5th order stream. It is observed that the number of stream decreases as the order of stream increases.

Stream length ratio (R_L)

From Table 4, it is observed that the stream length ratios are 0.51, 0.64, 0.36 and 0.98 for 2nd, 3rd, 4th and 5th order streams, respectively. If there is a change of stream length ratio from one order to another order, it indicates their late youth stage of geomorphic development

(Singh and Singh, 1997). The variation in stream length ratio is due to change in slope and topography (Moharir and Pande, 2014).

Bifurcation ratio (R_b)

As shown in Table 4, the bifurcation ratio for 1st, 2nd, 3rd and 4th order streams are 4.65, 4.46, 6.5 and 2, respectively. The mean bifurcation ratio of the study area is 4.4, which indicates that geological structures are less disturbing the drainage pattern and also the watershed is less elongated and may result in high peak of runoff rate (Strahler, 1964). Strahler (1957) confirmed that, bifurcation ratio shows only a small variation for different regions with different environments, except where powerful geological control dominates.

Areal aspects

Drainage density (D)

The drainage density is calculated as 0.219 km/km². Drainage densities range from less than 5 km/km² in areas, where the slopes are gentle and have permeable bedrock. Similarly larger values i.e., more than 500 km/km² are found in upland areas where rocks are impermeable and steep slopes. (Sharma, 2014). The drainage density of the study area indicate that areas are highly permeable subsoil material, dense vegetation, low relief and coarse drainage texture (Sethupathi *et al.*, 2011).

Stream Frequency (F_s)

Stream frequency is calculated as 0.039 km⁻². Stream frequency exhibits positive correlation with drainage density in the watershed, which indicates an increase in stream population with respect to increase in drainage density (Sharma, 2014).

Table.1 Formula to calculate linear aspects of morphometric parameters

Linear aspects	Formula	Reference
Stream order,U	Hierarchical rank	Strahler (1964)
Stream length (km), L_u	Length of the stream segment	Horton (1945)
Stream number, N_u	Number of stream segments	Strahler (1964)
Mean stream length, L_{sm}	$L = \frac{L_u}{N_u}$ <p>Where L_u = Total stream length of order 'u' N_u= Total no. of stream segments of order 'u'</p>	Strahler (1964)
Bifurcation ratio, R_b	$R_b = \frac{N_u}{N_{u+1}}$ <p>Where N_u = Total no. of stream segments of order 'u' N_{u+1} = Number of segments of the next higher order</p>	Schumm (1956)
Mean bifurcation ratio, R_{bm}	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
Stream length ratio, R_L	$R_L = \frac{L_u}{L_{u-1}}$ <p>L_u = Total stream length of order 'u' L_{u-1} = Total stream length of its next lower order</p>	Horton (1945)

Table.2 Formula to calculate areal aspects of morphometric parameters

Areal aspects	Formula	Reference
Drainage density(km/km²), D	$D = \frac{L_u}{A}$ <p>Where Lu = Total stream length of order(km) A = Area of the basin (km²)</p>	Horton (1945)
Stream frequency, F_s	$F_s = \frac{N_u}{A}$ <p>Where Nu = Total no. of streams of all orders A = Area of the basin (Km²)</p>	Horton (1945)
Drainage texture, R_t	$R_t = \frac{N_u}{P}$ <p>Where Nu = Total no. of streams of all orders P =Basin Perimeter (km)</p>	Horton (1945)
Elongation ratio, R_e	$R_e = \frac{\sqrt{\left(\frac{4 \times A}{\pi}\right)}}{L_b}$ <p>Where A = Area of the Basin(km²) L_b = Basin length (km)</p>	Schumm (1956)
Circularity ratio, R_c	$R_c = \frac{(4 \times \pi \times A)}{P^2}$ <p>Pi = 'Pi' value i.e. 3.14 A = Area of the Basin (km²) P = Perimeter (km)</p>	Miller (1953)
Form Factor, F_f	$F_f = \frac{A}{(L_b)^2}$ <p>Where A = Area of the Basin(km²) L_b² = Square of Basin Length (km)</p>	Horton (1945)
Length of overland flow, L_g	$L_g = \frac{1}{2D}$	Horton (1945)
Channel maintenance factor, C_m	$C_m = \frac{1}{D}$ <p>Where D = Drainage density</p>	Schumm (1956)

Table.3 Formula to calculate relief aspects of morphometric parameters

Relief aspects	Formula	Reference
Total relief, H	Maximum vertical distance between the lowest (outlet) and highest (divide) points on the valley floor of a watershed	
Relief ratio, R_h	$R_h = \frac{H}{L_b}$ Where H = Total relief of the basin (km) L _b = Basin length (km)	Schumm (1956)
Relative relief, R_p	$R_p = \frac{H}{P}$ Where H = Total relief P = Basin perimeter	Melton (1958)
Ruggedness number, R_n	$R_n = H \cdot D$ Where D = Drainage density H = Total relief of the basin, km	Strahler (1964)

Fig.1 Location map of study area

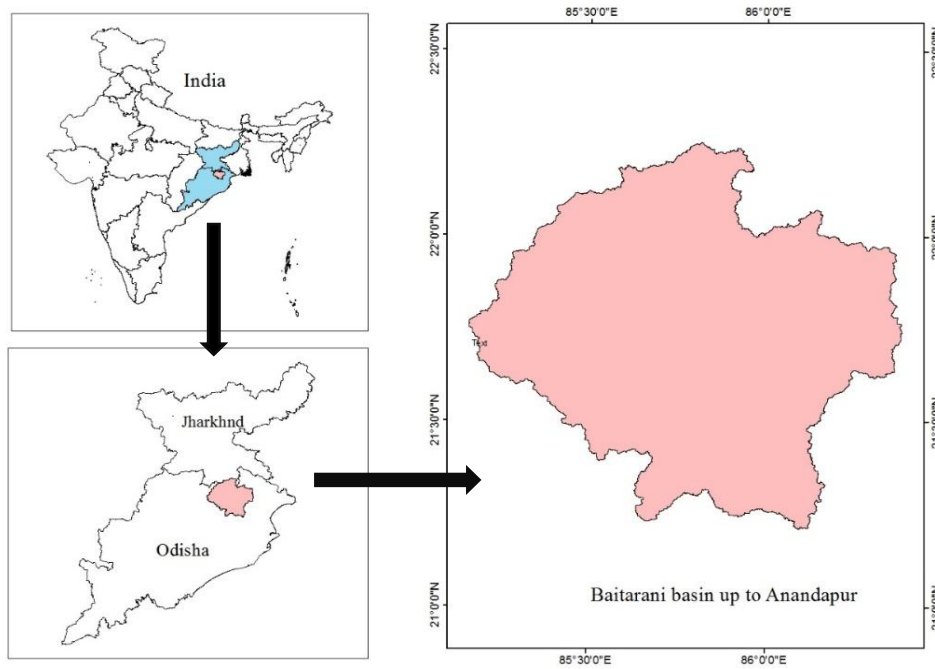
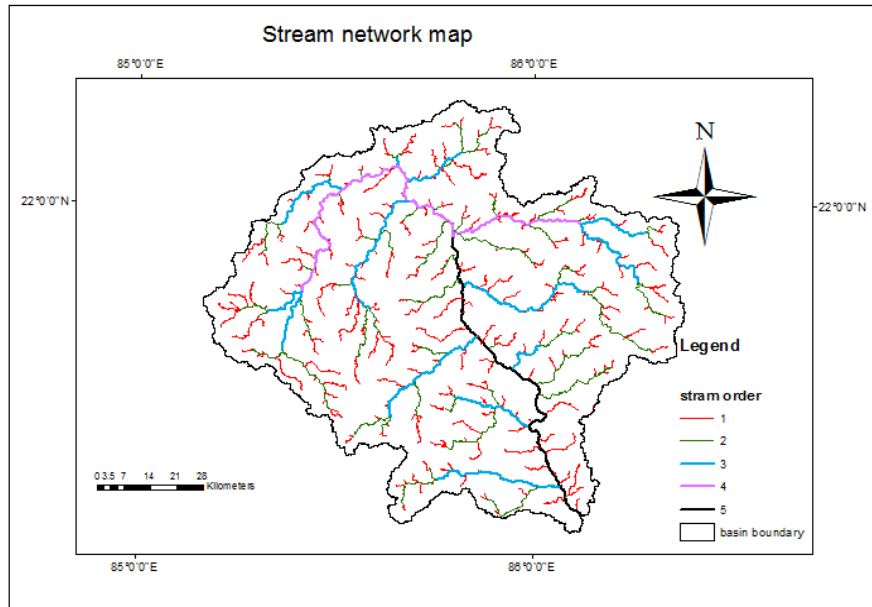


Table.4 Morphometric parameters of study area

Morphometric parameters	Values
Linear aspects	
Stream order, u	The highest order of this Basin is 5th order
Stream length, L_u	$L_1=908.5$ km $L_2=464.3$ km $L_3=300.3$ km $L_4=108.3$ km $L_5=106.5$ km
Stream number, N_u	$N_1=270$ $N_2=58$ $N_3=13$ $N_4=2$ $N_5=1$
Bifurcation Ratio, R_b	$R_{b1}=4.65$ $R_{b2}=4.46$ $R_{b3}=6.5$ $R_{b4}=2$
Mean bifurcation Ratio, R_{bm}	$R_{bm}=4.4$
Stream length ratio, R_L	$R_{L2}=0.51$ $R_{L3}=0.64$ $R_{L4}=0.36$ $R_{L5}=0.98$
Areal aspects	
Drainage density, D	$D=0.219$ km/km ²
Stream Frequency, F_s	$F_s=0.039$ km ⁻²
Drainage Texture, R_t	$R_t=0.409$ km ⁻¹
Elongation Ratio, R_e	$R_e=0.465$
Circularity ratio, R_c	$R_c=0.152$
Form factor, F_f	$F_f=0.17$
Length of overland flow, L_g	$L_g=2.28$ km
Channel Maintenance Factor, C_m	$C_m=4.56$ km
Relief aspects	
Basin relief, H	$H=1.18$ km
Relief ratio, R_h	$R_h=0.0052$
Relative relief, R_p	$R_p=0.0014$
Ruggedness Number, R_n	$R_n=0.258$

Fig.2 Stream network map of the study area



Drainage texture (R_t)

Drainage texture of the study area is 0.409km^{-1} as shown in Table 4. It indicates the closeness of the spacing of channels (Horton, 1932). According to Smith, (1950), the drainage texture depends upon a number of natural factors such as climate, rainfall, infiltration capacity, rock and soil type, relief, vegetation and stage of development. Based on the classification by Smith (1950) drainage texture value 0-4 indicate coarse, 4-10 indicate intermediate, 10-15 indicate fine and >15 indicate ultra-fine. So the study area has coarse drainage structure since the value of drainage structure is 0.409 km^{-1} .

Elongation ratio (R_e)

Elongation ratio is a very significant index in the analysis of watershed shape which helps to give information about the hydrological character of a basin (Vinoth *et al.*, 2014). The values of elongation ratios can be grouped into four categories namely (a) circular (>0.9), (b) oval (0.9 to 0.8), (c) elongated (0.8 to 0.7) and (d) less elongated (<0.7)

(Choudhari *et al.*, 2014). The study area had elongation ratio 0.465 which is considered as less elongated type.

Circularity ratio (R_c)

It indicates the stage of dissection in the study area. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary of watershed, respectively (Aravinda and Balakrishna, 2013). The circularity ratio is found to be 0.152.

Form factor (F_f)

It is the numerical index normally used to represent different basin shapes, with values to range from (0.1 to 0.8) (Thronbury, 1966) and it indicates the flow intensity of a basin. If the form factor value is 0.7854 then it represents a perfectly circular basin (Choudhari *et al.*, 2014), if it is nearer to 0 indicates a highly elongated shape and the value that is closer to 1 indicates circular shape. Form factor of the basin is 0.17 which is shown in Table 4.

Length of overland flow (L_g)

Generally higher value of length of overland flow is indicative of low relief, whereas low value is an indicative of high relief (Kanth and Hassan, 2012).

The watershed having length of overland flow greater than 0.25 km are under very less structural disturbance because of low runoff and higher overland flow (Patil *et al.*, 2015). The study area has length of overland flow as 2.28 km.

Channel maintenance factor, C_m

Channel maintenance factor depends on climatic regime, vegetation, rock type, permeability, relief, duration of erosion and climatic history. As shown in table the channel Maintenance Factor of the basin is found to be 4.56 km.

Relief aspects

Basin relief (H)

According to Patil *et al.*, (2015) area is of low relief region if the relief is less than 0.3 km and high relief region if it is greater than 0.3km. The high relief value indicates high gravity of water flow as well as infiltration into the ground and high runoff conditions (Patil *et al.*, 2015). In the present study the basin relief is calculated to be 1.18 km which shows the basin has high relief region.

Relief ratio (R_h)

Relief ratio is not only the indicator of overall steepness of the watershed but also it is the indicator of the intensity of erosion process operating at the watershed slopes (Suresh, 2012). The relief ratio of the basin is calculated to be 0.0052 which is shown in Table 4.

Relative relief (R_p)

Relative relief shows the terrain characteristics of the watershed. It is related to basin relief. Relative relief of the drainage basin is found to be 0.0014

Ruggedness number (R_n)

The ruggedness number of the study area is calculated to be 0.258. Low ruggedness value i.e. 0.258 of basin implies that area is less prone to soil erosion and have intrinsic structural complexity with relief and drainage density (Pareta and Pareta, 2012)

The highest order stream of the area is found to be 5th order. The stream numbers of 1st, 2nd, 3rd, 4th and 5th order streams are found to be 270, 58, 13, 2 and 1, respectively. Stream length for 1st, 2nd, 3rd, 4th and 5th order streams are found to be 908.5, 464.3, 300.3, 108.3 and 106.5km, respectively. The stream length ratios are found to be 0.51, 0.64, 0.36 and 0.98 for 2nd, 3rd, 4th and 5th order streams, respectively. The mean bifurcation ratio and length of overland flow of the study area are found to be 4.4 and 2.28, respectively which indicates a high surface runoff in the basin and late youth stage of geomorphic development of the basin. The drainage density, stream frequency and drainage texture are calculated as 0.219 km/km², 0.039 km⁻² and 0.409 km⁻¹, respectively. The study area has elongation ratio 0.465 which is considered as less elongated type. The circulatory ratio and form factor are found to be 0.152 and 0.17, respectively. Ruggedness value is observed to be 0.258. From this analysis it is concluded that the watershed is less elongated which result in high peak of runoff.

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