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Quantitative Morphometric Analysis of Bhadar River Basin, India using ASTER (GDEM) Data and GIS

Vishnu Dayal and Jyoti Sarup

Department of Civil Engineering, MANIT, Bhopal, Madhya Pradesh, India

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Abstract The present study highlights the morphometric parameters of Bhadar River, located in state of Gujarat, India. In this study, ASTER Global Digital Elevation Model (GDEM) and Geographical Information System (GIS) have been taken to evaluate Linear and Areal aspects of different morphometric parameters using ArcGIS software. The study is mainly focused on morphometric analysis which revealed that the Bhadar River Basin is from first to seventh orders with dendritic type of drainage pattern. The results show that the drainage density of the Basin has been obtained low which indicates drainage texture is very coarse in nature. The result of Elongation ratio explore that the Basin is less elongated. Bifurcation ratio values of Bhadar River Basin have experience minimum structural disturbances.
Keywords *Geographical Information System; Morphometric Analysis; ASTER GDEM; Bhadar River Basin*

1. Introduction

According to (Horton, 1945), a large portion in geomorphology over the last many years has been on the event of quantitative physiographic strategies to explain the origin and behavior of drainage networks that are useful in analysis of availability of water resources. There is an urgent need for the evaluation of water resources because of high inhabitant's expansion of urbanization, variation in rainfall intensity and climate change. Due to this, it is necessary to make plan for water management and its storage. The basin analysis is one of the factor on which national development depends and has started to receive recognition by national and state governments in all over the world. Global digital elevation model (GDEM) comes into existence from remote sensing and has been broadly used in the structure and drainage network extraction. Grid GDEMs consist in digital file format and stores terrain elevation values in regular square grid. Hydrological, biological, and geological units are natural investigator to form a basin and it requires an integration approach to modeling and data analysis, this analysis helps in delineating accurate vector layer boundaries of watershed as an input. Basin based natural resource system management in mountain regions are rigorously gaining attention and accepted by government and other community organizations. Watershed management is a typical Morphometry and Geomorphologic activity that utilizes DEM (Subyani et al., 2010). Morphometric analysis of a Basin gives an indication about permeability, storage capability of the rocks (Clarke, 1966; Lee et al., 2008). The present study has been successfully aimed at using GIS technology and to calculate numerous parameters of morphometric characteristics of the Bhadar River Basin.

2. Study Area

The study area lies between latitude 21^{0}12'05" to 22^{0}08'52"N and longitude 69^{0}42'55" to 71^{0}19'11"E with an area of 12385.7852 km^2 and length about 178.5359 km. Bhadar river flows through Rajkot and Porbandar district within Gujarat and it originates from Mandav hills in Rajkot district's Jasdan City and Taluk and drops into Arabian sea (Figure 1).

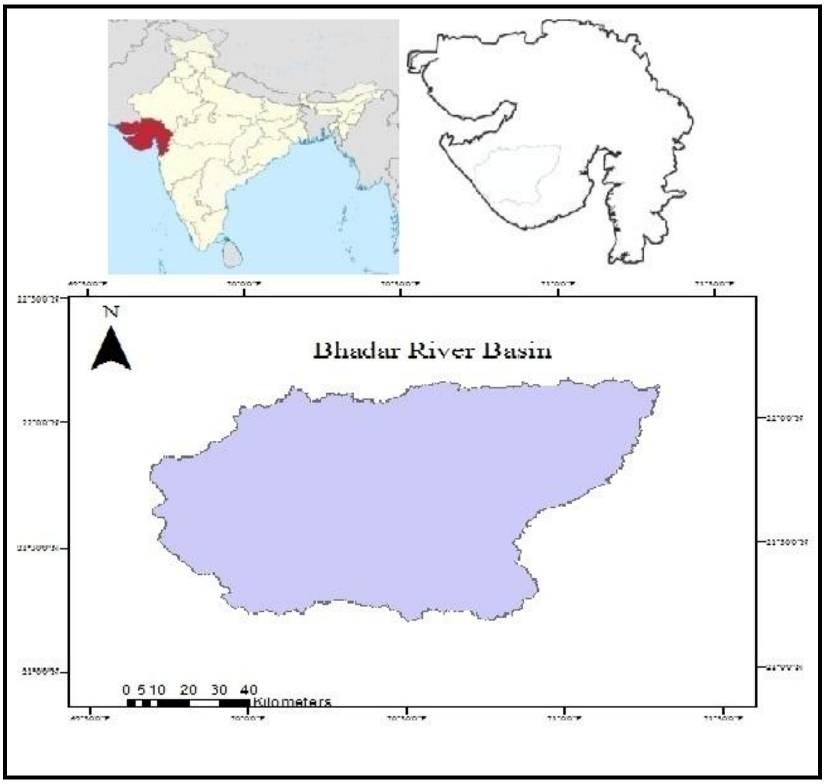

Figure 1: *Location of the Study Area*

Topographically, the region has a semi-arid climate, but the places near the sea are wetter than the interiors. Dams on the Bhadar River have significant irrigation and conservation of water importance. There are two dams on Bhadar River Bhadar 1 and Bhadar 2 which are at the distance of 68 km and 106 km respectively from the origin of river. There are 9 major tributaries having lengths more than 25 km, 6 tributaries of them are feeding from right which are Gandali, Chapparwadi, Phopal, Moj, Utawali and Venu and remaining feeds from left which are Vasavadi, Surwa and Galolio. The average rainfall in Bhadar Basin is 625 mm. Temperature varies between 4^{0}C and 15^{0}C in different parts of the region in winter season. May is the hottest month and maximum temperature varies between 40^{0}C and 45^{0}C.

2. Data and Methodology

The morphometric parameters of drainage basin such as stream order, drainage pattern, perimeter and area have been delineated from the ASTER GDEM (30m) data using ArcGIS software. There are some conventional techniques of surveying but they are time consuming and chances to give more errors due to manual operation. Nowadays, GIS technique is used to determine the various parameters of drainage basins, by spatial analyst tool it has been done in very flexible environment.

The results are more accurate than conventional techniques. It is possible to update the data and do computation using GIS. In the present study, an integrated global digital elevation model (GDEM), has been used to generation and extraction of various parameters. The following procedure is adopted for Basin analysis.

Table 1: *Methodology for Computation of Morphometric Parameters*

S. No.	Parameters	Formulae	References
1.	Stream order(U)	Hierarchical rank	Strahler (1964)
2.	Stream length(L_u)	Length of the stream	Horton (1945)
3.	Mean stream length(L_{sm})	Lsm= Lu/Nu Where Nu is no. of streams	Strahler (1964)
4.	Stream length ratio(R_l)	$R_l=L_u/(L_u-1)$	Horton (1945)
5.	Bifurcation ratio(R_b)	$R_b=N_u/(N_u+1)$	Schumm (1956)
6.	Mean Bifurcation ratio(R_{bm})	R_{bm}=Average of all bifurcation ratios	Strahler (1957)
7.	Drainage density(D_d)	$D_d=L_u/A$	Horton (1932)
8.	Drainage intensity(D_i)	$D_i= F_s/D_d$	Faniran (1968)
9.	Infiltration Number I_f	$I_f=F_s*D_d$	Faniran (1968)
10.	Drainage texture(T)	$T=N_u/P$	Horton (1945)
11.	Texture ratio	$R_t=N_1/P$	Schumm(1965)
12.	Stream frequency(F_s)	$F_s=N_u/A$	Horton (1932)
13.	Elongation ratio(R_e)	$R_e = (2 / L_b) * (A / \pi)^{0.5}$	Schumm (1956)
14.	Circularity ratio(R_c)	R_c=4pA/ P2	Miller (1953)
15.	Form factor(F_f)	$F_f=A/L_b^2$	Horton (1932)
16.	Length of overland flow(L_g)	$L_g = A/(2*L_u)$	Horton, 1945
17.	Shape factor ratio(R_s)	$R_s=L_b^2/A$	Horton, 1956
18.	Relative perimeter (P_r)	$P_r = A / P$	Schumm (1956)

A. Catchment area of watershed delineation from ASTER GDEM, it is the instrument of Terra satellite and freely available.

B. Global digital elevation model (GDEM) was extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer data obtained during October 2011 with resolution of 30 meter (downloaded from USGS website). ASTER GDEMs were mosaiced and were used to prepare slope and delineation of drainage map of the basin using Spatial Analyst tool of ArcGIS 10.2.

C. All the extracted parameters such as the number and lengths of the streams of each different order, basin perimeter, basin area, and total length and width have been calculated using ArcGIS 10.2 software. Other parameters like drainage density, drainage frequency, circulatory ratio, elongation ratio, form factor etc. were calculated from these parameters. There are some given methodologies which are adopted for the computation of quantitative morphometric parameters (Table 1).

3. Results and Discussions

Quantitative assessment of morphometric analysis of Basin can explore the information about the nature of the rocks exposed near and within the river basin and it will give a reliable semi permeable index of rocks and provides a sign of the chance of the basin. Some researchers have revealed that the activity and analysis of the configuration of the surface, form and dimensions of its landform give the primary investigation of maps for a morphologic survey (Babu et al., 2012). The ASTER GDEM has been obtained with 30 m resolution and further used to calculate slope, aspect maps of the watershed. Linear, areal and relief aspects of the watershed were used to be evaluated in GIS environment using ArcGIS 10.2

Software. Both Satellite data and GIS (Geographical Information System) plays important role to trigger data on the basis of geographical deviations in drainage attributes that provide interior hydro geologic mandatory conditions for developing watershed management policies. Hydro geologic observations and its synthesis with drainage analysis, give helpful data concerning relation between the geological attributes of the basin (Das et al., 2005). Therefore, the results reveal different levels of agreement using morphometric analysis, which are supposed to be different from one region to another. Factors influencing groundwater storage are different and these factors are depends on the following parameters: (1) rainfall availability as the source of water; (2) characteristic of drainage network has a wide role in indicating the runoff distribution within the basin and also it indicate towards an infiltration behavior of flow of water on terrain surface horizontally and vertically; (3) lithological character of different rock governs flow and storage management; (4) slope is another factor, that controls water flow energy. The morphometric analysis can be obtained by measuring the linear and areal aspects of basin.

4. Linear Aspects of the Channel System

4.1. Stream Order (S_u)

Initial step of quantitative analysis is stream ordering of the watershed. Some researchers proposed methods for stream ordering and those methods have been used in this study and streams were automatically extracted from satellite images. The stream ordering system comes into existence in year 1945 and first advocated by (Horton, 1945), but (Strahler, 1957) has made some changes in ordering system with some modifications. It was found that, as the stream order increases, number of streams decreases. This shows that Horton's law is satisfied. The result of positive correlation between stream order and stream number (Figure 2).

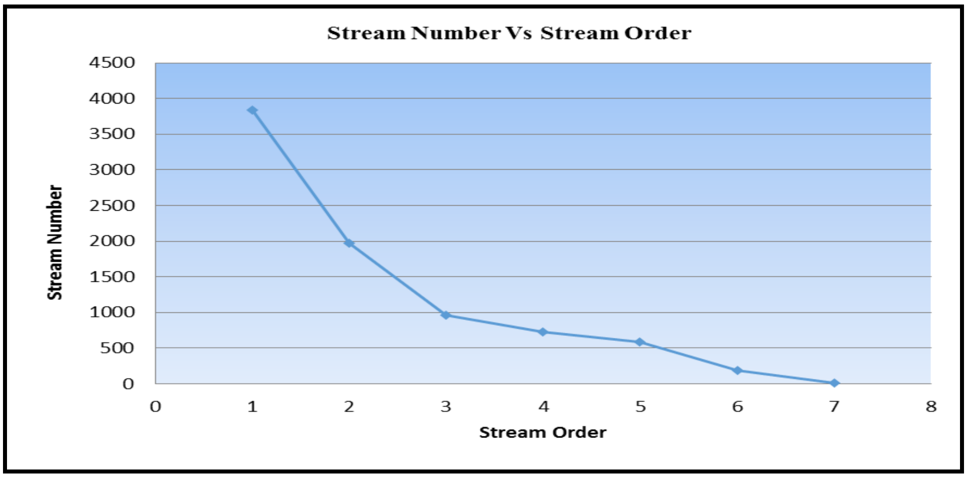

Figure 2: *Graph Showing Relation between Stream Number [Nu] and Stream Order [U]*

4.2. Stream Number (N_u)

The total number of streams in different order is known as stream number. Some researchers have found that the numbers of stream segments are in inverse geometric sequence of each order with order number (Figure 3)

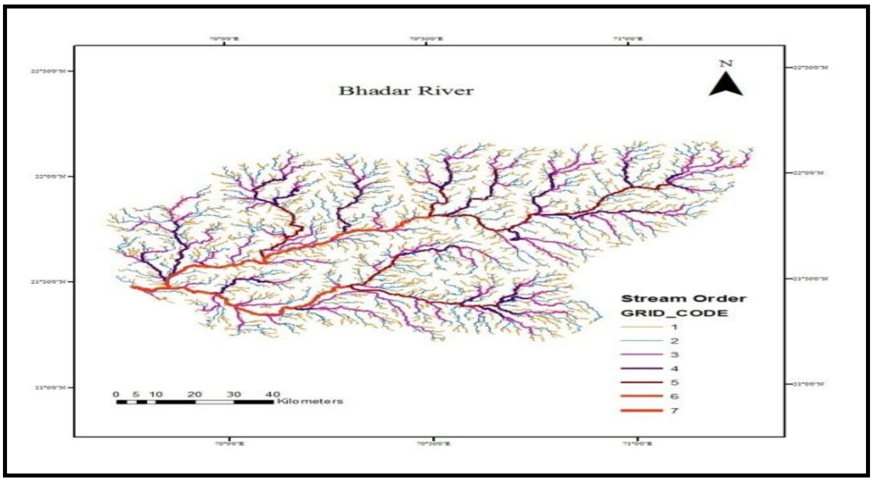

Figure 3: *Drainage Map Showing Stream Orders Bhadar River Basin*

4.3. Bifurcation Ratio (R_b)

The ratio of the total number of streams of a given order to the total number of streams of the next higher i.e. $R_b = N_u/N_u + 1$ is known as Bifurcation ratio (R_b). Bifurcation ratio values of Bhadar River Basin existing between 3 to 5, which shows minimum structural disturbances. The mean Bifurcation ratio of the basin is observed 4.4876. Bifurcation ratio indicates good structural control within the drainage basin whereas the lower value confirms that the Bhadar river basin is less influenced by structural disturbances (Table 2).

Table 2: *Linear Aspect of the Watershed*

Stream Order	No. of Streams (N_u)	Bifurcation Ratio(R_b)	Mean Bifurcation Ratio	Total Length of Streams(Km)	Mean Stream Length (Km)	Length Ratio	Mean Length Ratio(R_l)
1.	3842			3951.2131			
2.	1966	1.9542		2098.7221		0.5312	
3.	961	2.0458		977.3975		0.4657	
4.	727	1.3219	4.4876	436.2155	0.9516	0.4463	0.4665
5.	588	1.2364		231.6872		0.5311	
6.	190	3.0947		179.3952		0.7743	
7.	11	17.2727		9.0942		0.0507	
Total	31036			7883.724725			

4.4. Stream Length (Lu)

Stream lengths have various orders of the Bhadar river watershed, and computed with the help of ArcGIS software. The relationship between the bifurcation ratio and the stream length ratio is determined by hydrogeologic, physiographic and geological characteristics (Smith, 1950). According to (Subyani et al., 2010), Horton's law theory of stream lengths supports and preserves geometrical similarity of watershed with increasing order. Relation between stream order and stream length has been drawn (Figure 4).

4.5. Mean Stream Length (L_{sm})

Drainage networks were distributed among whole basin and the components of drainage network were obtained by its dimensional property is known as Mean Stream length (Subyani et al., 2010). The mean stream length obtained by ArcGIS 10.2 software automatically is 0.9516 km of the given basin.

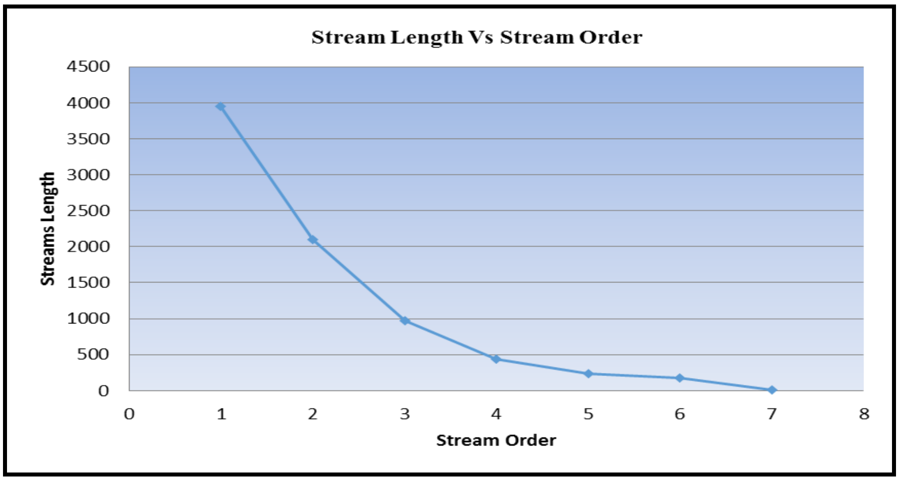

Figure 4: *Graph Showing Relation between Stream Length and Stream Order [U]*

5. Areal Aspects of the Basin

5.1. Drainage Density (D_d) and Drainage Texture (D_t)

Some researchers have indicated that the spacing of channels and its compactness is an expression that is known as Drainage density (Horton, 1932). Drainage density is the ratio of the total stream lengths to the total orders per unit area and the Slope gradient is the main factor that control it and relative relief of the basin. The drainage density of the watershed has been obtained is 0.6365 km^2 (Figure 5a). According to (Strahler, 1957), Drainage density has been categorized into five categories (Table 3). In this study drainage density observed very low and drainage texture is about very coarse. On the basis of the categories of drainage density we categorize again in six categories between 0 to 2: 0 - 0.2380, 0.2381 - 0.4760, 0.4761 - 0.7141, 0.7142 - 0.9521, 0.9522 - 1.5552, >2, (Figure 5b).

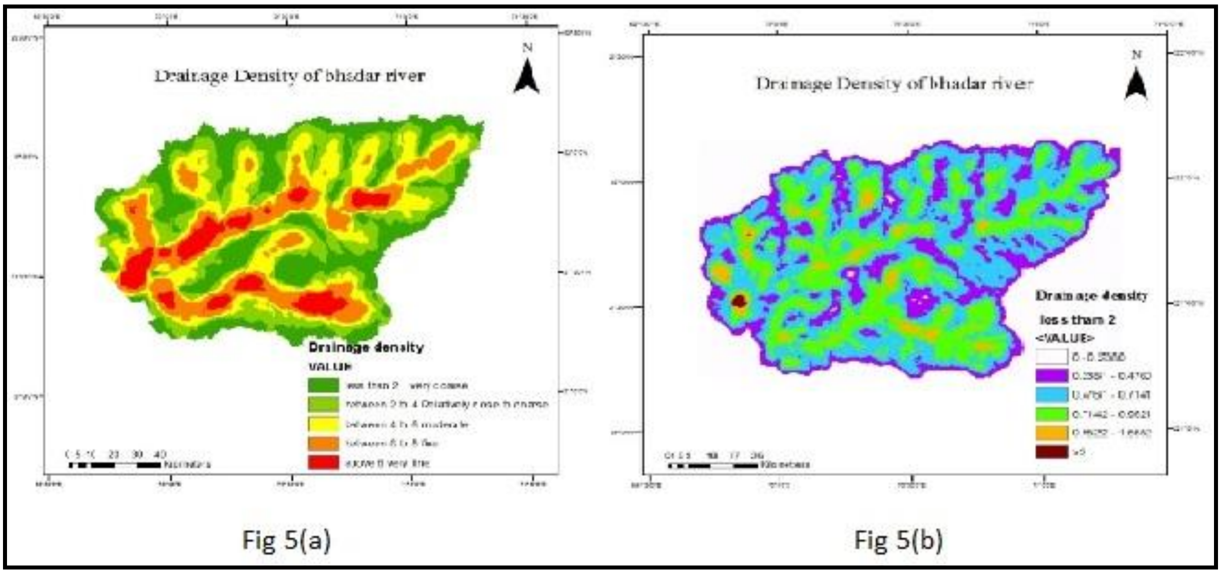

Figure 5 (a) and Figure 5 (b): *Are the Drainage Density Map and Drainage Density Map Less than 2 of Bhadar River Basin*

Table 3: *Different Categories of Drainage Densities*

Categories	Drainage Texture
less than 2	very coarse
between 2 to 4	Relatively close to coarse
between 4 to 6	moderate
between 6 to 8	fine
above 8	very fine

5.2. Stream Frequency (Fs)

Horton proposed that the Stream frequency (Fs) is the total number of streams segments of all orders per unit area (Horton, 1932). The average stream frequency of Bhadar river basin is 2.505776 (Table 4). Stream frequency of Bhadar basin indicating towards the correlation between drainage density and stream population that is increase in stream segments occurs when drainage density increases.

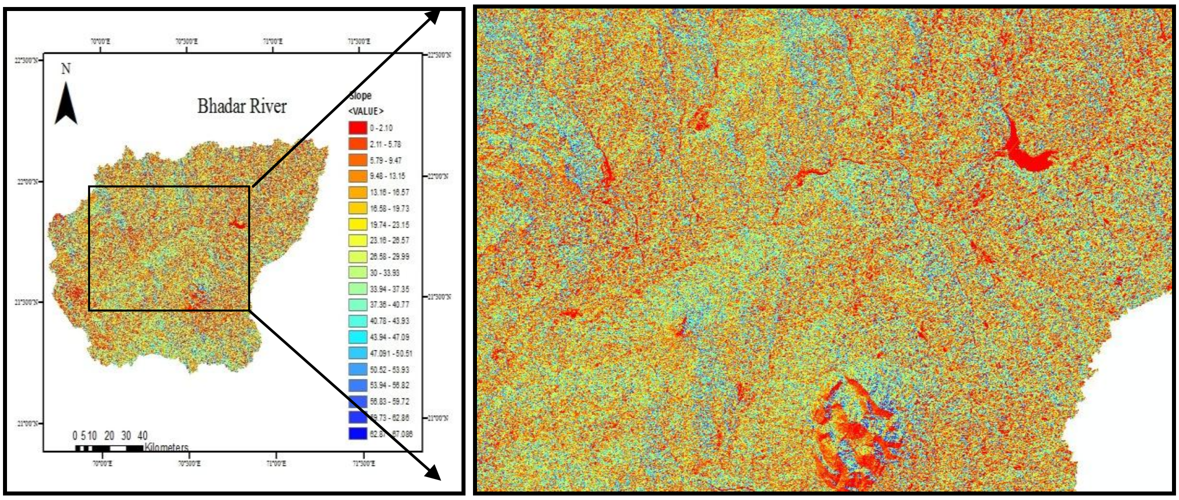

Figure 6: *Slope Map of the Bhadar River Basin*

5.3. Drainage Intensity (D_i)

Some researchers have proposed that the ratio of the stream frequency to the drainage density is known as Drainage intensity (Subyani et al., 2010). The study shows a low drainage intensity of 3.9368 of the Bhadar basin (Table 4). The Lower value of drainage intensity has some little consequences, on behalf of which the surface has been obtained lower denudation.

5.4. Circularity Ratio (R_c)

Circularity ratio (R_c) is the ratio of area occupied by basin to the area of circle, that the basin must have the same perimeter (Miller, 1953). Some of the factors are there that influence the Circulatory ratio which is geological structure, stream frequency length of the stream, climate is also one of the main factors, slop and relief both can have their own importance (Singh et al., 2013). If the basin is having circulatory ratios in between 0.4–0.5, then the permeability of geologic material will be more and it would be strongly elongated. The Circulatory ratio of the basin is 0.2565, it indicate low discharge of runoff and highly permeability of soil.

5.5. Texture Ratio (T)

According to some researchers the texture ratio is depend on the terrain features such as infiltration capacity, relief, aspect and lithology are most important factors of the drainage morphometric analysis (Schumm, 1963). It is defined as the ratio of first order stream to the basin area perimeter ($R_t = N_1/P$). Texture ratio of the present study of watershed is 4.9306 (Table 4).

5.6. Elongation Ratio (R_e)

According to (Schumm, 1963), it is the ratio of maximum diameter of circle of the basin to the maximum length of the basin. Elongation ratio can divide the slope into different categories, i.e. circular, oval, less elongated, elongated and more elongated such as (0.9-0.10) (0.8-0.9), (0.7-0.8), (0.5-0.7) and(< 0.5) respectively. The elongation ratio is 0.7034 of the Bhadar river basin which is less elongated observed (Table 4).

5.7. Form Factor (F_f)

The ratio of area of the basin to the square of length of basin is known as Form Factor (Horton, 1932). When the form factor is less than 0.754 then the watershed is always perfect circular in shape. Smaller the value of form factor will indicates more elongated watershed. Form factor of the given basin is 0.388573 which means that the basin would be less elongation shape because of lower value (Table 4).

5.8. Infiltration Number (I_f)

Some researchers (Subyani et al., 2010) proposed that the product of drainage density and stream frequency of the watershed is the infiltration number of watershed and given an idea about the infiltration characteristics. Higher infiltration number shows the lower infiltration and higher runoff (Table 4). Infiltration and runoff are highly depends on the slope of the area (Figure 6).

5.9. Length of Overland Flow (L_g)

This term is comes into existence in year 1945 and given by Horton and it refers the rainwater on the ground surface before it is fall down into definite channels (Horton, 1945). Horton proposed that the length of overland flow is almost equal to the half of the reciprocal of drainage density. The obtained value of the length of overland flow of the given basin is 0.7855.

Table 4: *Areal Aspect of the Watershed*

Parameters	Results
Basin area(sq km)	12385.7852
Perimeter (Km)	779.2121
Basin Length L_b	178.5359
Relative perimeter (P_r)	15.8971
Form factor	0.3885
Elongation ratio(R_e)	0.7034
Circularity ratio(R_c)	0.2565
Drainage density km^2	0.6365
Drainage intensity	3.9368
Infiltration Number I_f	1.5949
Stream frequency	2.5057
Texture ratio	4.9306
Drainage texture	39.8299

Length of overland flow	0.7855
Shape factor ratio	2.5735

6. Conclusion

The study reveals that the basin is of seventh order and is of dendritic pattern. All parameters were identified using ArcGIS software and data obtained for USGS website i.e. ASTER (DEM) with 30 m spatial resolution. Different morphometric parameters were carried out by measuring the linear and areal aspects of the basin with bifurcation ratio between 1.9542 and 17.2727. The mean Bifurcation ratio of the basin is observed 4.4876. Where this value indicating towards a strong structural control in the drainage network and if values are low then the basin will be less affected by structural disturbances. The drainage density of the watershed has been obtained is 0.6365 km^2 which indicates drainage texture is very coarse. There is conservation of running water is needed at some place where drainage density is high and utilization of water where drainage density is low in irrigation, rural development etc. The elongation ratio is 0.7034 which is indicating less elongated basin. Stream Frequency (Fs) is 2.5057; a positive co-relation has been indicated with the drainage density. The Circulatory ratio of the basin is 0.2565, it indicate low discharge of runoff and highly permeability of soil. Automated delineation has been done from free and low cost ASTER GDEM and the processing would be fast, but the accuracy of basin delineation is highly dependent on quality of the available GDEM which can be helpful for the evaluation of a Basin for further detailed study with respect to the availability of water resources.

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