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Derivation of Morphometric Parameters of the Jia Bharali River Basin of the States of Assam and Arunachal Pradesh (India) Based on ASTER DEM

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Abstract: ***Morphometric analysis of a drainage basin plays an imperative role in understanding the geo-hydrological behaviour of the basin. Remote sensing and geographic information system (GIS) techniques using satellite images are used as expedient tools for morphometric studies. For this study, the Jia Bharali river basin of the states of Assam and Arunachal Pradesh, India has been selected to derive the morphometric parameters of the basin. The morphometric parameters taken up for the study are linear, areal and relief aspects. Assessment of drainages and their relative parameters such as stream order, stream length, drainage frequency, drainage density, drainage texture, form factor, circulatory ratio, elongation ratio and bifurcation ratio have been taken for evaluation of the basin using GIS techniques based on ASTER DEM of 30 m resolution. The GIS based morphometric analysis revealed that the basin is 9th order drainage basin and is characterized by dendritic to sub-dendritic drainage pattern. The quantitative analysis of morphometric parameters is found to be of immense utility in watershed planning and management.***

Keywords: ASTER DEM, GIS, Jia Bharali river basin, morphometric analysis.

1. Introduction

In light of a scientific and cogent approach to diverse river problems and apposite planning and design of water resources projects, an understanding of the morphology and behaviour of a river is a pre-requisite. Morphometric analysis is referred as the quantitative evaluation of form characteristics of the earth surface or any landform unit. The symphony of the stream system of a drainage basin is expressed quantitatively with stream order, drainage density, bifurcation ration and stream length ratio etc. [1,2]. It incorporates quantitative study of the various components such as stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land etc. which indicate the nature of development of the basin. The morphometric studies, therefore, play a chief role in planning, designing and maintaining river engineering structures. Morphological studies also provide quantitative description of the basin or sub-watershed and fluvial geometry, structural controls, geological and geomorphic aspect of a drainage basin. The quantitative analysis of morphometric parameters is significant in basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro level.

Remote sensing and GIS techniques using satellite images are used as expedient tools for morphometric analysis and to study the morphometric properties of different drainage basins. GIS has become an effective tool in planning integrated development of watershed as remote sensing derived information can be integrated with the conventional data base. For effective planning of any watershed, it is imperative to integrate various resources information and identify land pockets having similarity in terms of characteristics, resource potential, constraints and need similar treatment. It has the potential of performing watershed delineation through techniques such as DEM, rainfall-runoff modeling etc. Thus, it can be said that remote sensing and GIS techniques enable one to arrive at natural resource management solutions by adopting a holistic approach.

2. Research Objectives

This study aims to generate various thematic maps and to derive the mophometric parameters of the Jia Bharali river basin of the states of Assam and Arunachal Pradesh of India based on ASTER DEM of 30 m resolution through GIS. Thus, the objectives of this research work can be summarized as follows:

1) Morphometric analysis and derivation of morphometric parameters of the Jia Bharali river basin using remote sensing and GIS.
2) Generation of various thematic layers for DEM, slope, aspect, flow direction and flow accumulation. Thematic maps, viz. DEM of the basin, drainage, flow direction, flow accumulation, aspect and slope are prepared by adopting standard interpretation techniques using satellite imagery and GIS.

3. Materials and Methods

3.1 Study area

The Jia Bharali river basin of the states of Assam and Arunachal Pradesh of India is taken as the study area. The Jia Bharali river is one the major right bank tributaries of the mighty Brahmaputra river and instigates from the snowfields of the Kangto Massif (7090 m) and is about 257.18 km long. Length within Arunachal Pradesh is 183.36 km and within Assam is 73.82 km. The total area of the Jia Bharali river basin is 10,853 sq km extending between longitudes 91°58' and 93°23' east, and latitudes 26°36' and 27°59' north. The river basin comprises areas of the West Kameng and East Kameng districts of Arunachal Pradesh and Sonitpur district of Assam. The Manas drainage basin lies in the west and the Subansiri drainage basin is in the east. The Jia Bharali river along with its tributaries flows towards south to merge with the river Brahmaputra. The river enters the alluvial plains just near Bhalukpong in Arunachal Pradesh. From Bhalukpong, it first flows to the east-southeast between two boulder ridges and then turns sharply to the south and flows more or less in a straight course right up to its confluence with the Brahmaputra river. Figure 1 shows the study area.

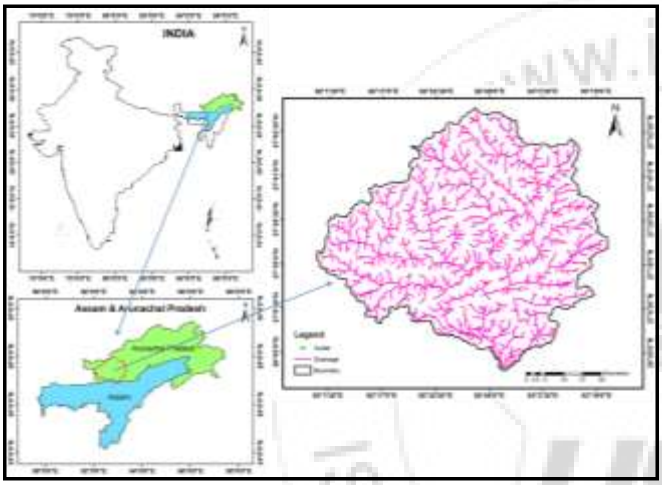

Figure 1: The Jia Bharali river basin – the study area.

3.2 Methodology

Remote sensing and GIS techniques have been used for the processing of satellite data and to derive the thematic maps. GIS has been used as an added tool for preparation of many vector layers. Using all thematic maps and GIS information, a detailed analysis is performed using morphometric analysis. The detailed methodology is shown in the following flowchart (Figure 2).

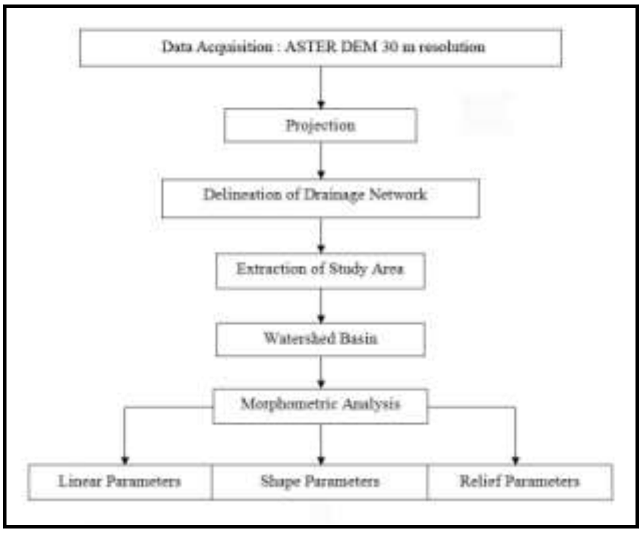

Figure 2: Flowchart of research methodology

3.3 Computation of morphometric parameters

The morphological characteristics of a basin govern its hydrological response to a considerable extent. Basin characteristics when measured and expressed in quantified morphometric parameters can be studied for their influence on runoff and sediment yield. In the present study a few of the important morphological parameters for the study area have been derived using ArcGIS software and mathematical formulae [1,2,3,4,6,7,8] that are listed below in Table 1.

Table 1: Formulae and relationships for the computations of the morphometric parameters

Morphometric parameter	Formulae/Relationship	Reference
Stream order	Hierarchical rank	Strahler, 1964
Stream length (L_u)	Length of stream	Horton, 1945
Mean Stream length (L_{um})	$L_{um} = L_u/N_u$, where L_u is the total stream length of order 'u', Nu is the total number of stream segments of order 'u'	Strahler, 1964
Stream length ratio (R)	$R = L_u/L_{u-1}$, where L_u is the total stream length of order 'u', L_{u-1} is the total stream length of its next lower order	Horton, 1945
Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$, where N_u is the total number of stream segment of order 'u', N_{u+1} is the number of stream segments of the next higher order	Schumn, 1956
Mean bifurcation ratio (R_{bm})	R_{bm} = average of the bifurcation ratio of all the order	Strahler, 1957
Relief ratio (R_h)	$R_h = H/L_b$, where H is the total relief (relative relief) of the basin, L_b is the basin length	Schumn, 1956
Relative relief (R_r)	$R_r = H/P$, where H is the total relief (relative relief) of the basin, P is the perimeter (km) of the basin	Melton, 1957
Drainage density (D_d)	$D_d = L_u/A$, where L_u is the total stream length of order 'u' and A is the basin area in km^2	Horton, 1932

Constant of channel maintenance (C_m)	C_m = 1/D_d, where D_d is the drainage density	Schumn, 1956
Length of overland flow (L_g)	L_g =1/(2 x D_d), where D_d is the drainage density	Horton, 1945
Ruggedness number (R_n)	R_n = D_d x H, where D_d is the drainage density and H is the total relief (relative relief) of the basin	Strahler, 1958
Stream/Drainage frequency (D_f)	D_f = N_u/A, where N_u is the total number of stream segment of order 'u' and A is the basin area in km^2	Horton, 1932
Drainage texture (T)	T = N_u/P, where N_u is the total number of stream segment of order 'u' and P is the perimeter (km) of the basin	Horton, 1945
Form factor (R_f)	R_f = A/L_b^2, where A is the basin area in km^2 and L_b is the basin length (km)	Horton, 1932
Circulatory ratio (R_c)	R_c = (12.57 x A)/P^2, where A is the area (km^2) and P is the perimeter (km) of the watershed	Miller, 1953

4. Results and Discussions

Various thematic layers are generated for DEM, slope, aspect, flow direction and flow accumulation. Different thematic maps, namely DEM of the basin, drainage map, flow direction map, flow accumulation map, aspect map and slope map are prepared by adopting standard interpretation techniques using GIS. The results of the software analysis and derived morphometric parameters based on ASTER DEM are presented in this section.

4.1 Thematic maps

A thematic map is a type of map designed to illustrate a particular theme connected with a specific geographic area. Thematic maps emphasize spatial variation of one or a small number of geographic distributions. These maps show the relationship between several different attributes. In this study various thematic maps have been prepared which are depicted in the following sections.

4.1.1 DEM of the basin

DEM was generated in this study to characterize the topography of the study area. The elevation raster data should be free from sinks to create an accurate representation of flow direction and accumulated flow. 'Fill sinks' option has been used under hydrology function to remove sinks from the elevation raster data (DEM). The ASTER DEM of the study area (Figure 3) has elevation values ranging from a minimum of 65 m to a maximum 7049 m.

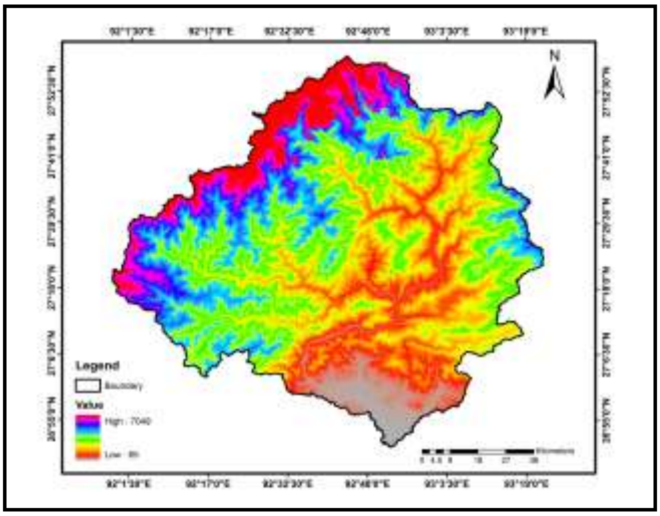

Figure 3: ASTER DEM map of the study area.

4.1.2 Drainage map

Drainage patterns are formed by the sluice, tributaries, streams, rivers, and lakes in a river basin or drainage basin. The drainage pattern and density of drainage have a profound influence on watershed as to runoff estimation, infiltration, land management and sedimentation etc. The surface water drainage network was delineated with the help of satellite imagery and ASTER DEM. The entire drainage segments were digitized as lines separately for each order and was ordered using Strahler's method of nomenclature [5].The map pertaining to the watershed boundary and drainage is shown in Figure 4. The drainage map contains the drainage network information. The highest order of drainage that flows through the study area was found to be of 9th order and the drainage was observed to be of dendritic to sub-dendritic drainage pattern.

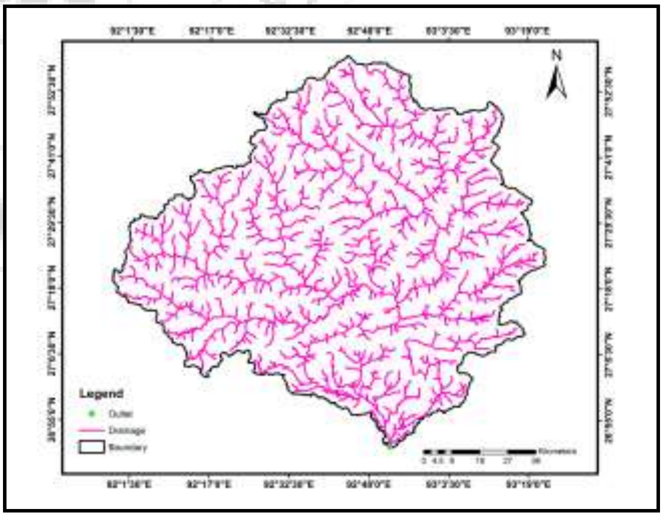

Figure 4: Drainage map of the study area.

4.1.3 Slope map

Slope is the degree of inclination of the surface from horizontal expressed in percent or degrees. It is one of the important terrain parameters, which can be explained by horizontal spacing of the contours. Here, the lower slope values indicate the flatter terrain (gentle slope) and higher slope values correspond to steeper slope of the terrain. The slope information is useful in understanding the topography, geomorphology, soil types and their erodability, surface drainage etc. Slope and relief also play an important role in designing various water harvesting structures, check dams, canal alignments, and transportation design and planning. Furthermore, slope is a vital for land capability assessment, formulating soil and water conservation measures. The slope map of the study area is presented in Figure 5.

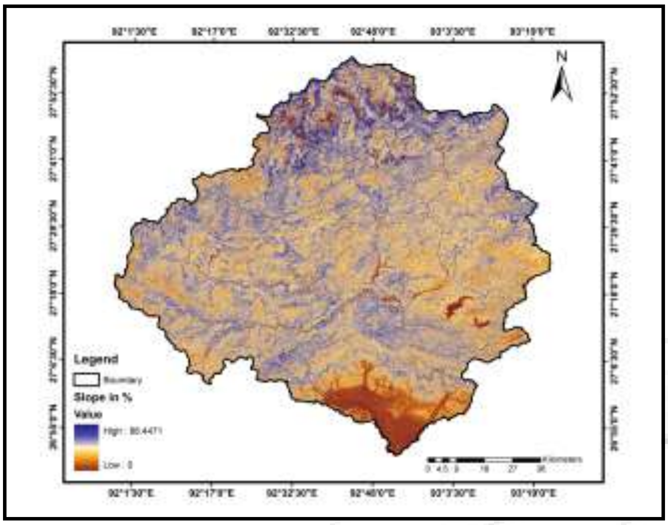

Figure 5: Slope map of the study area

4.1.4 Aspect map

Aspect is the direction of slope with respect to north. In output slope raster, aspect identifies the down-slope direction from each cell to neighbouring cells. The aspect values of the output raster will be measured in the clockwise direction, i.e. from N-NE-E-SE-S-SW-W-NW. Flat surfaces (having no direction) were shown. Figure 6 shows the aspect map of the study area.

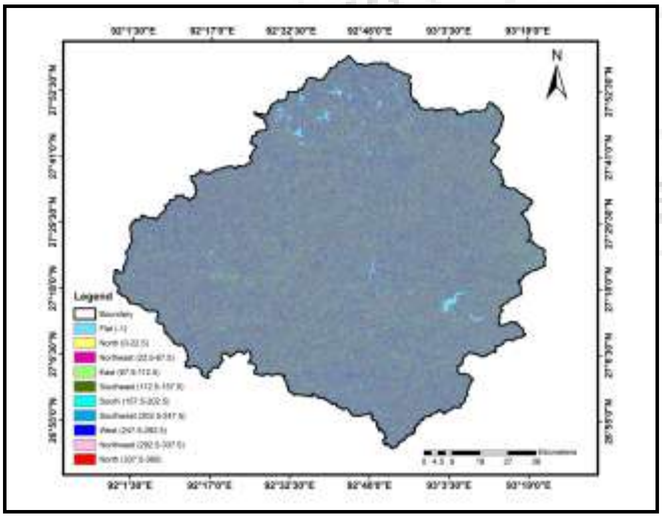

Figure 6: Aspect map of the study area.

4.1.5 Flow direction map

The flow direction map (Figure 7) indicates the direction of surface flow which is an integer raster value ranges from 1 to 128. In an elevation raster if a cell is lower than its neighbouring cells, the direction of the flow will be towards that cell. In some elevation rasters when multiple neighbours have the values then the flow will be defined by filtering out one-cell sinks.

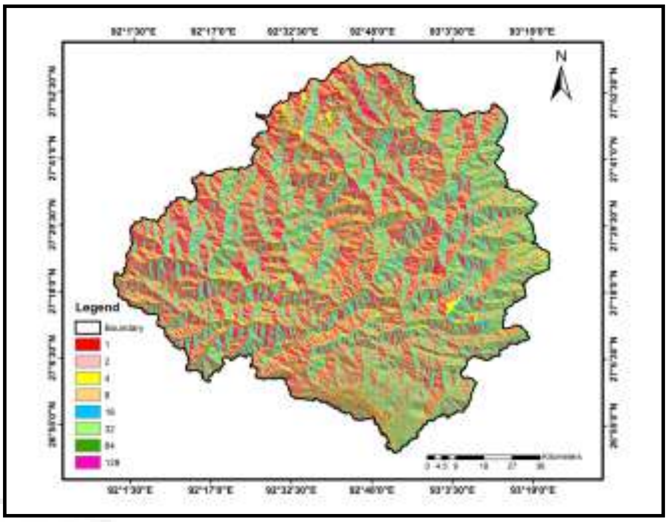

Figure 7: Flow direction map of the study area.

4.1.6 Flow accumulation map

Flow accumulation is generated from the error free elevation raster data. The cells of undefined flow directions other than (1 to 8) will only receive flow accumulation. The accumulated flow in the raster output is calculated based upon the number of cells flowing towards each cell. The high flow areas in the output raster are the areas of concentrated flow, which are important to identify possible stream channels. Similarly, those areas with flow accumulation value zero (low) are the areas, which are topographically high like ridges. A stream network is created by using the results of the high-accumulated flow. Similarly, this stream network is used as input to generate stream order, stream line and stream link. The flow accumulation map of the study area is shown in Figure 8.

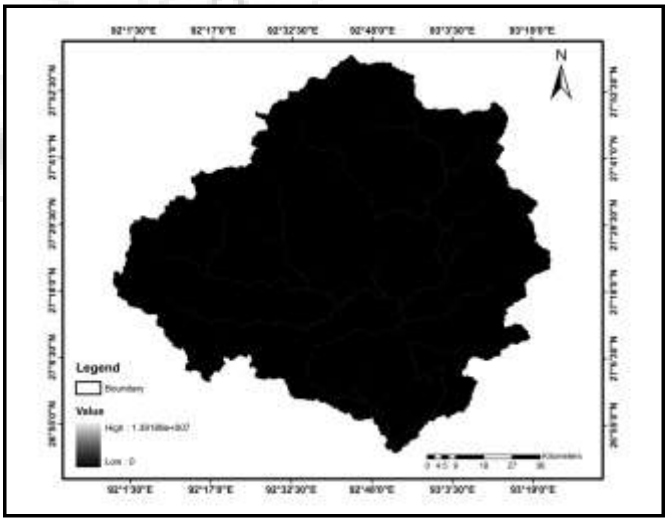

Figure 8: Flow accumulation map of the study area

4.2 Morphometric analysis

The morphometric analysis of the parameters, namely stream order, stream length, bifurcation ratio, relief ratio, drainage density, drainage frequency, form factor, circulatory ratio, elongation ratio, area, perimeter of the basin are carried out using mathematical formulae from ASTER DEM data in ArcGIS. The results obtained from the analysis are shown in Table 3.

4.2.1 Area

Basin area has been identified as the most important of all the morphometric parameters controlling catchment runoff pattern. This is because the larger the basin, the greater the volume of rainfall it intercepts, and the higher the peak discharge that result. In the present analysis, the basin has been considered as a polygon. Area of the basin was derived from ArcGIS software as it gives the area of the polygon automatically. The area of the study area was found to be 10307.16 km^2.

4.2.2 Perimeter

In the ArcGIS software, the study area showed its perimeter as 635.52 km.

4.2.3 Stream order

After analysis of the drainage map, it is found that the study area has a highest 9th order stream and drainage pattern is dendritic to sub-dendritic drainage pattern. The GIS analysis results for stream orders are shown in Table 2.

4.2.4 Stream length

Stream length is one of the most important hydrological features of a basin as it reveals the surface runoff characteristics. Streams of relatively smaller lengths are characteristics of areas with larger slope and finer textures. Streams with longer lengths are generally the characteristics of flatter surface with low gradients. Usually, the total length of stream segments is highest in first stream orders and decreases as the stream order increases. The number of streams of various orders in the basin was counted and their lengths measured from the mouth to the divide of the drainage basin. Stream length is a revelation of the chronological developments of the stream segments including interlude of tectonic disturbances. The stream lengths for respective stream orders for the study area are shown in Table 2.

Table 2: Drainage analysis of the study area

Stream order	No. of streams	Length of streams (km)
1	106375	27339.4651
2	23868	10947.1620
3	5184	5047.7406
4	1109	2466.5215
5	233	1075.4474
6	47	625.5599
7	12	387.8137
8	2	148.6196
9	1	98.4006
	Total = 136831	Total = 48136.73

4.2.5 Bifurcation ratio

Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin. The calculated bifurcation ratio for the study area is 0.01, an indication that the study area is a highland area. This low R_b value indicates low structural disturbance in the study area. This suggests that the study area has low potentials for discharge compared to those of highland areas with bifurcation ratio of 5.0 [5]. Bifurcation ratios are controlled by basin physiographic factors especially basin relief and drainage density [3].

4.2.6 Relief ratio

The maximum basin relief of the drainage area is 6984 m (7049 m - 65 m). The R_h normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin [9]. The relief ratio of the study area is 0.03. The relief ratio of the basin is the characteristic feature of less resistant rocks. The lower values may indicate the presence of basement complex rocks that are exposed in the form of small ridges and mounds with lower degree of slope.

4.2.7 Relative relief

Melton (1957) used this term to measure the relief of watershed and is defined as H/P, where H is the total relief (relative relief) of the basin and P is the perimeter of the basin. The relative reliefs are classified into three categories viz. (i) low relative relief = 0 km - 0.1 km, (ii) moderately relative relief 0.1 km - 0.3 km, and (iii) high relative relief = above 0.3 km. The value of R_r is found to be 32.62, which indicates high relative relief.

4.2.8 Drainage density

Drainage densities can range from less than 5 km/km^2 when slopes are moderately steep, rainfall not very high and bedrock permeable (e.g. sandstones), to much larger values of more than 500 km/km^2 in mountainous areas where rocks are impermeable, slopes are steep and rainfall totals are high. The drainage density (D_d) of the study area is 4.67 km/km^2. Thus, in this study, the drainage density falls less than 5 km/km^2 which indicates that the area has a moderately steep slope, not very high rainfall and less permeable bedrock. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant surface materials (lithologies or rock types), or those with high infiltration capacities. A low drainage density indicates that most rainfall infiltrates into the ground and few channels are required to carry the runoff. In general, low drainage density leads to coarse texture while high drainage density leads to fine texture [5].

4.2.9 Constant of channel maintenance

The value of C_m is found out to be 0.21 for the study area.

4.2.10 Length of overland flow

Overland flow is significantly affected by infiltration and percolation through the soil, both varying in time and space. Generally higher value of L_o is indicative of low relief and where as low value of L_o is an indicative of high relief. In this study, the length of overland flow of the study area is 0.11 km. The study area falls under high relief area.

4.2.11 Ruggedness number

An extremely high value of ruggedness number (R_n) is encountered, particularly when both H and D_d are large i.e. when slope is steep and long. The value of R_n is found to be 0.61 for the study area, which is quite high.

4.2.12 Stream/drainage frequency

Stream/drainage frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network. The basins of the structural hills have higher stream frequency, drainage density while the basins of alluvial has minimum. The stream frequency of the study area is 13.28 stream segments per km^2. The existence of less number of streams in a basin indicates matured topography, while the presence of large number of streams indicates that the stream is youthful and still undergoing erosion.

4.2.13 Drainage texture

Smith (1950) have classified five different drainage textures related to various drainage densities as very coarse (below 2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (8 and above). Drainage texture depends on a number of natural factors such as climate, rainfall, vegetation, rock and soil types, infiltration capacity, relief and stage of development. Weak rocks devoid of vegetative cover produce fine texture, while rocks which are hard and with vegetative cover produce coarse texture. The value of drainage texture is 215.31 unit/km for the study area, i.e. the basin comprises of fine to very fine textures.

4.2.14 Form factor

Form factor is the numerical index commonly used to represent different basin shapes [1]. The form factor of the study area is 0.17. Low form factor shows that the basin is elongated and thus has low peak flow of longer duration. Consequently, the flood flow of this type of basin is difficult to manage than the circular basin. The smaller the value of form factor, the more elongated will be the basin. The basins with high form factor have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration.

4.2.15 Circulatory ratio

The calculated R_c value for the study area is 0.32, which indicates that the drainage basin is more elongated than circular. The value of circularity ratio varies from 0 (in line) to 1 (in a circle). It is affected by the lithological character of the basin. The ratio is more influenced by length, frequency (D_f), and gradient of streams of various orders rather than slope conditions and drainage pattern of the basin. It is a significant ratio, which indicates the dendritic stage of a basin. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins. Watershed having circular to oval shape allows quick runoff and results in a high peaked and narrow hydrograph, while elongated shape of watershed allows slow disposal of water, and results in a broad and low peaked hydrograph.

4.2.16 Elongation ratio

Elongation ratio determines the shape of the basin and can be classified based on these values as circular (0.9 - 1), oval (0.8 - 0.9), less elongated (0.7 - 0.8), elongated (0.5 - 0.7), more elongated (< 0.5). Regions with elongation ratios are susceptible to more erosion whereas regions with high values correspond to high infiltration capacity and low runoff. The elongation ratio of the drainage basin is 0.46, which indicates more elongation and more prone to erosion with less infiltration capacity. Circular drainage basins are more efficient in the discharge of runoff. They are at greater risk from flood hazard because they have a very short lag time and high peak flows than the elongated basins. Elongated drainage basins have low side flow for shorter duration and high main flow for longer duration and are less susceptible to flood hazard.

Table 3: Morphometric parameters of the study area

Morphometric parameters	Parameter values
Area (A) (km^2)	10307.16
Perimeter (P) (km)	635.52
Basin length (L_b) (km)	249.69
Total relief (H) (km)	6.98
Total number of streams (N_u)	136831.00
Total stream length (L_u) (km)	48136.73
Drainage density (D_d) (km/km^2)	4.67
Constant of channel maintenance (C_m)	0.21
Length of overland flow (L_o) (km)	0.11
Stream/drainage frequency (D_f) ($unit/km^2$)	13.28
Drainage texture (T) (unit/km)	215.31
Form factor (R_f)	0.17
Circulatory ratio (R_c)	0.32
Elongation ratio (R_e)	0.46
Relief ratio (R_h)	0.03
Bifurcation ratio (R_b)	0.01
Relative relief(R_r)	32.62
Ruggedness number (R_n)	0.61

5. Conclusion

An attempt has been made in this study to carry out the quantitative morphometric analysis of the Jia Bharali river basin using ASTER DEM 30 m resolution in ArcGIS platform. The present study demonstrates the usefulness of GIS for derivation of morphometric parameters and hence morphometric analysis of the basin. The drainage basin is often selected as a unit of morphometric investigation because of its topographic and hydrological unity. GIS softwares have resulted to be of immense utility in the quantitative analysis of the geomorphometric aspects of the drainage basins. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more appropriate than the conventional methods. The conventional methods of morphometric analysis are time consuming and error prone, so instead GIS technique has been used for more reliable and accurate estimation of similar parameters of watersheds. The drainage density and drainage frequency are the most useful criterion for the morphometric classification of drainage basins that certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. Thus from the study it is highly comprehensible that GIS technique is a competent tool in geomorphometric analysis for geo-hydrological studies of drainage basins. These studies are very useful for planning and management of drainage basins. The present study is valuable for erosion control, watershed management, land and water resources planning and future prospective related to runoff study. Following are the conclusions interpreted from the results of this study:

1) The present study has illustrated morphometric analysis based on several drainage parameters by which the Jia Bharali river basin has been classified under nine order basin.
2) The values of form factor, circulatory ratio and elongation ratio of the study area show that the basin is elongated and thus has low peak flow of longer duration. Consequently, the flood flow of this type of basin is difficult to manage than the circular basin.
3) The low bifurcation ratio of the Jia Bharali river basin of 0.01 is an indication that parts of its segment are liable to flooding. Bifurcation ratios ranging from 3-5 indicate natural drainage system characterized by homogenous rock. This low R_b value also indicates less structural disturbance in Jia Bharali river basin.
4) The drainage density (D_d) of the study area is found to be 4.67 km/km^2.Thus, in this study, the drainage density falls less than 5 km/km^2 which indicates that the area has a moderately steep slope, not very high rainfall and less permeable bedrock.
5) The value of drainage texture for the study area is 215.31 unit/km for the study area, i.e. the basin comprises of fine to very fine textures.
6) The relief ratio of the study area is 0.03. The relief ratio of the basin is the characteristic feature of less resistant rocks. The lower values may indicate the presence of basement complex rocks that are exposed in the form of small ridges and mounds with lower degree of slope. Low relief ratios also indicate that the recharge capabilities of the basin are low.

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