J. Sci. Technol. Environ. Inform. 08(01): 583-594 | Pondari et al. (2020).
EISSN: 2409-7632, Journal home: www.journalbinet.com.
Crossref: https://doi.org/10.18801/jstei.080120.60

JSTEI ONLINE JOURNAL Journal of Science, Technology & Environment Informatics

Journal BiNET Scientific Publication

Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies

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Article received: 06.11.19; Revised: 20.12.19; First published online: 14 January 2020.

Article Information

Key Words:
Brahmaputra river, Digital elevation model, Drainage characteristics, Morphometry

Access by Smart Phone

For any information: ask.author@journalbinet.com.

ABSTRACT

River basin analysis is highly useful to understand the hydrological dynamics with concerning the topography. The morphometric properties of a drainage basin will help in describing the quantitative attributes of the landscape. A digital representation of topography enables the computation of more complex morphometric parameters with automated refinement. Digital Elevation Models (DEM) represents the topography of Earth in the form of digital imagery. In this article DEM has been used to compute the linear aspects and areal aspects of the Brahmaputra basin falling in the Indian sub-continent. Linear aspects which include stream characteristics like stream order, stream length, mean stream length ratio, bifurcation ratio have been reported thought this article. The areal aspects of river basin like drainage density, stream frequency, form factor, and circulatory ratio have been investigated and these parameters have been used to analyse the river basin characteristics. Geospatial data and technologies prove to be very efficient in analysing the basin's behaviour.

Citation: Pondari, S., Dandabathula, G., Bera A. K., Nagamani P. V. and Amminedu, E. (2020). Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies. Journal of Science, Technology and Environment Informatics, 08(01), 583-594.
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I. Introduction

In Earth sciences, morphometry is the precise measurement of landforms and measurement of the shape or geometry of any natural forms like relief features (Strahler 1969). Morphometric properties of a drainage basin will help in describing the quantitative attributes of the landscape. Applications of quantitative techniques in morphometric analysis of drainage basins were initially investigated by Horton (1945) from topographic maps using manual methods. The topography of a catchment has a major impact on the hydrological, geomorphological, and biological processes active in the landscape (Moore et al. 1991). A digital representation of topography enables the computation of more complex morphometric parameters with automated refinement (Godone and Garnero 2013). Digital Terrain Models (DTM) represents the topography of Earth in the form of digital imagery (Li et al. 2004). Morphometry governs the dynamics of drainage basin (Biswas et al. 2014). River basin analysis is useful in a hydrological investigation like the assessment of groundwater potential and groundwater management. Derivation of physiographic characteristics of a drainage basin like size, shape, the slope of drainage area, drainage density, and tributaries will help in understanding the hydrologic phenomena (Rastogi et al. 1976).

Primarily a river is a carrier of water along with sediments, and solute from the drainage area to the sea. The characterization of drainage network of river basin is important to engineers and decision makers because water is used for a variety of purposes by humanity; watercourses are used as navigation channels, and also erosion, transportation, and deposition of sediment cause a number of problems in the river and in the catchment that must be solved pragmatically. The direct effect of transportation of sediment and water from the geologist and geomorphologist's point of view is that the structure and form of the river and adjoining areas are continually changed due to erosion and sedimentation. The rates of this change are variable. These channel changes can be in the form of size, shape, composition of bed material, slope, and plan-form. The engineer's primary objective is to understand the basic mechanisms of erosion, transportation, and deposition of sediment by flow in the river and develop qualitative and quantitative methods for prediction of river behaviour. The approach followed by engineers is called Fluvial Hydraulics or river dynamics and this approach has been developed during the past 200–300 years (Garde 2006).

In this paper, we have used digital elevation model to compute the linear aspects and areal aspects of the Brahmaputra basin falling in Indian sub-continent. Linear aspects include stream order, stream length, mean stream length ratio, bifurcation ratio. The areal aspects of river basin include drainage density, stream frequency, form factor, and circulatory ratio. The linear aspects and areal aspects river basin represent the state of dynamic balance that has been developed due to dealing between matter and flow energy over a period of time. All these basins parameters have been reported through this article for Brahmaputra river basin falling in Indian sub-continent.

II. Materials and Methods

Study area: The Brahmaputra, one of the world's largest river systems is first in terms of sediment transport and fourth in terms of water discharge (Sarin and Krishnaswami 1984). The Brahmaputra River finds its origin in the Kubi Kangri and Chemayundung glacier of Tibet and flows through India and Bangladesh (Pranavananda 1939; Hedin 2002). The slope of the river decreases suddenly in front of the Himalayas and results in the deposition of sediment and a braided channel pattern. It flows through the state of Assam, India for about 640 km distance along a valley comprising its own recent alluvium (Sarma 2005). In the course of its 2880 km journey, the Brahmaputra receives as many as twenty-two major tributaries in Tibet, thirty-three in India and three in Bangladesh (Sarkar et al. 2012). In the final form, it gets confluence with the Ganges and flows into the Bay of Bengal. The Brahmaputra basin spreads over 580,000 sq. km and 33.6 percent of its spread is present in India. Figure 01 shows the Brahmaputra basin, its sub-basins, major water resource structure in the India sub-continent.

Digital Elevation Models (DEMs) are used for assessing various terrain and morphometric parameters of the watershed and drainage basin analysis. The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale using radar interferometry. SRTM Global 1 arc second product (version 3.0) is void-filled using elevation data from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model 2 (GDEM2), USGS Global Multi-resolution Terrain Elevation Data (GMTED) 2010, and USGS National Elevation Dataset (NED) (Earth-Data 2018). Digital Elevation Model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM) of

30 m resolution for Brahmaputra basin is shown in figure 02 has been used in this study, thus the date setting of the study is post 2000 year. The elevation of Brahmaputra basin ranges from -4 m to 8401 m.

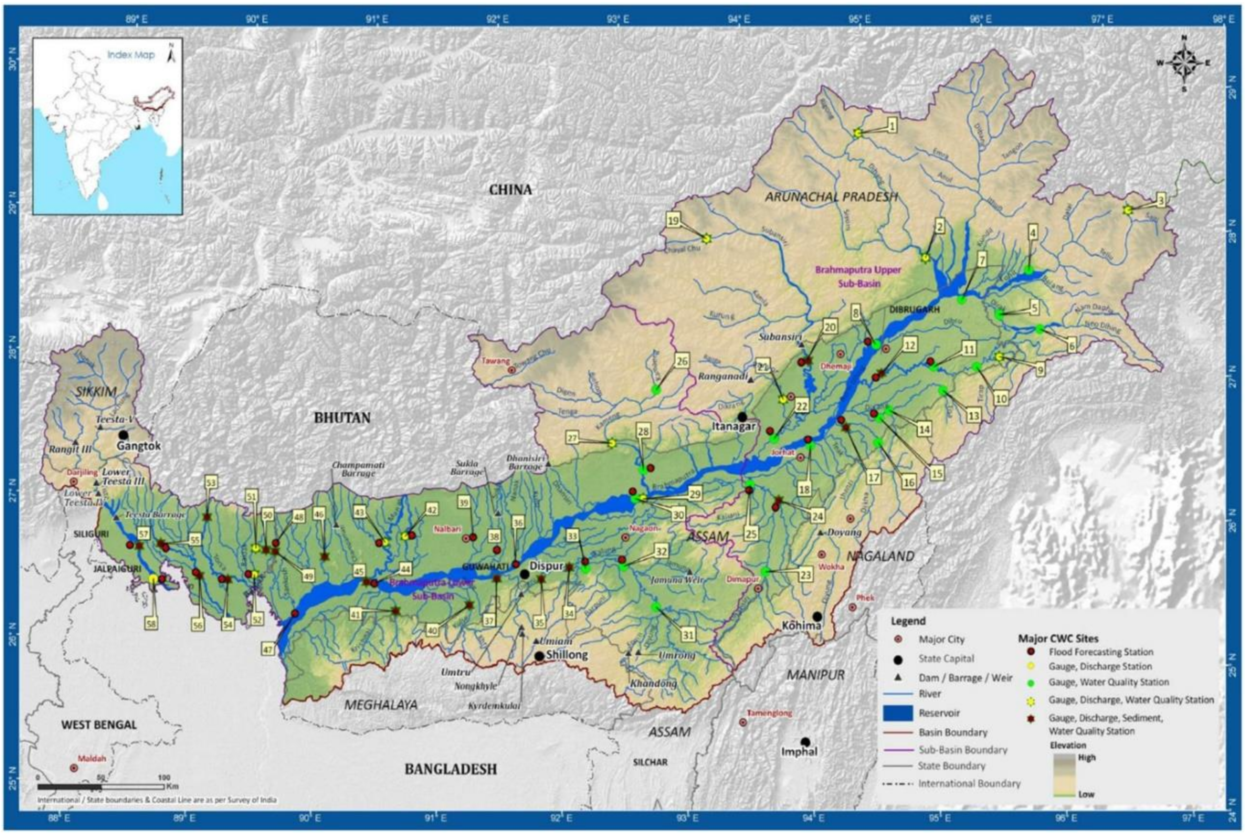

Figure 01. The Brahmaputra basin in Indian Sub-continent (India WRIS 2019).

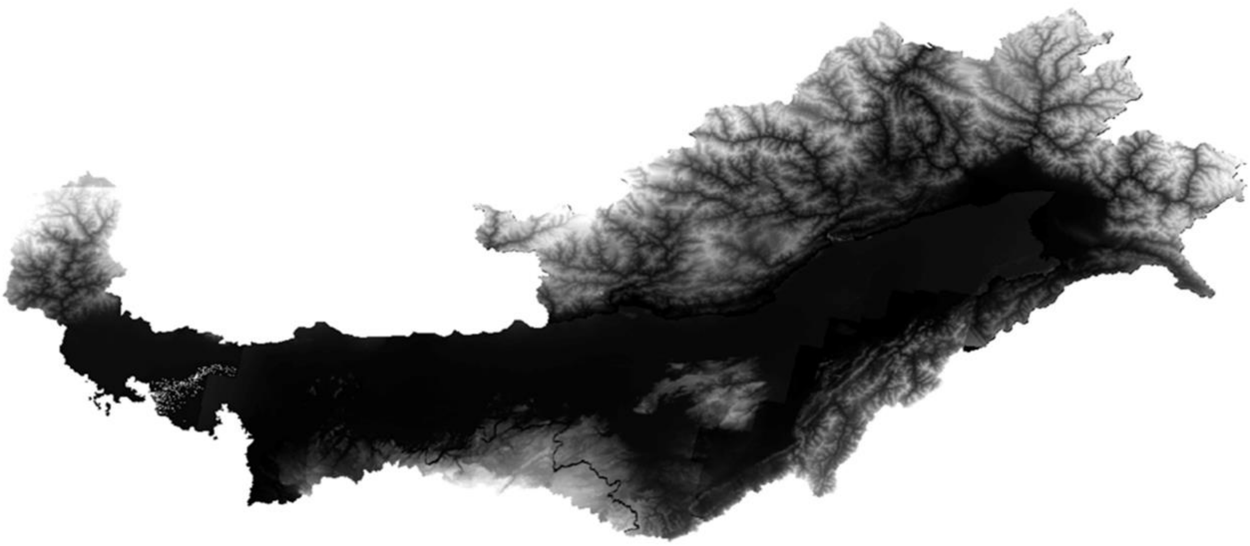

Figure 02. SRTM based Digital Elevation Model of Brahmaputra river basin.

The figure 03 below represents the methodology adopted for morphometric analysis, which includes stream ordering and delineation of sub–watersheds prior to morphometric analysis.

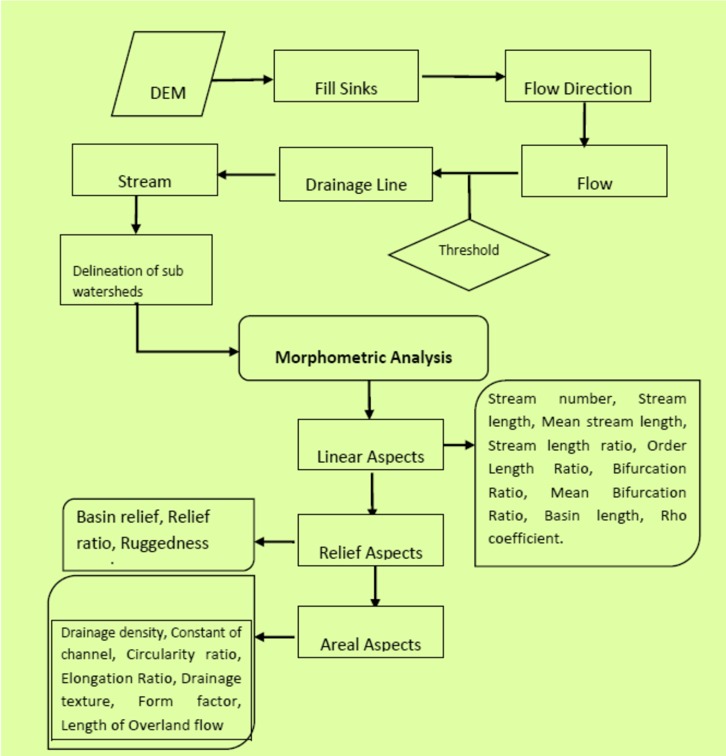

Figure 03. Methodology adopted for morphometric analysis.

III. Results

Stream order is a method of assigning a numeric order to the links in a stream network. This ordering is a method for identifying and classifying types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order (ESRI 2019). First-order streams are dominated by the overland flow of water so that they have no upstream concentrated flow. The stream ordering of the entire Brahmaputra river basin is shown in figure 4. The Strahler method is the most common stream ordering method and has been used in this study. The stream order increases when streams of the same order intersect. Therefore, the intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on. The intersection of two links of different orders, however, will not result in an increase in order. For example, the intersection of a first-order and second-order link will not create a third-order link but will retain the order of the highest ordered link.

The slope calculated in percent wise for Brahmaputra basin from SRTM DEM is shown in figure 05. Brahmaputra basin was categorized into 6 classes as per National Bureau of Soil Survey and Land Use Planning (NBS S& LUP) such as 0 – 1% as level to nearly level, 1 – 3% as very gently sloping, 3 – 8% as gently sloping, 8 – 15% as moderately sloping, 15 – 30% as moderately steep sloping, 30 – 50% as steeply sloping and >50% as very steeply sloping. Area covered by each slope category is given in table 01.

Relative relief may be defined as the difference between maximum and minimum elevation of the area. The maximum elevation of Brahmaputra basin is 8401 m and minimum elevation is -4 m. The relative relief computed using GIS software is shown in figure 06. The relative relief of Brahmaputra basin ranges from 0 m to 1346 m and higher elevation difference occurs majorly in the upper part of Brahmaputra basin.

Morphometric analyses require measurement of linear features, the gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal 1994; Nag and Chakraborty, 2003). The morphometric analysis for individual sub-basins has been achieved through measurements of linear aspects and aerial aspects of the basin and slope contribution. Linear (1-dimension) and Aspect (2-dimension) for both lower and upper sub-basins are selected for the morphometric analysis. Linear

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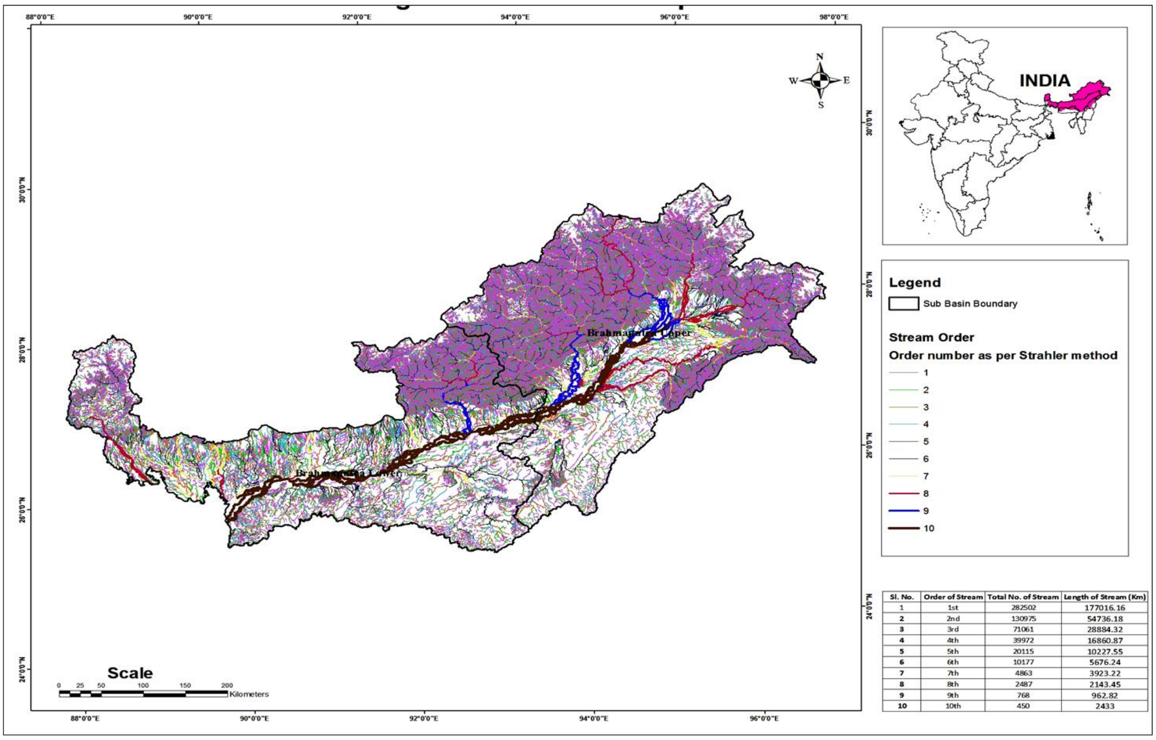
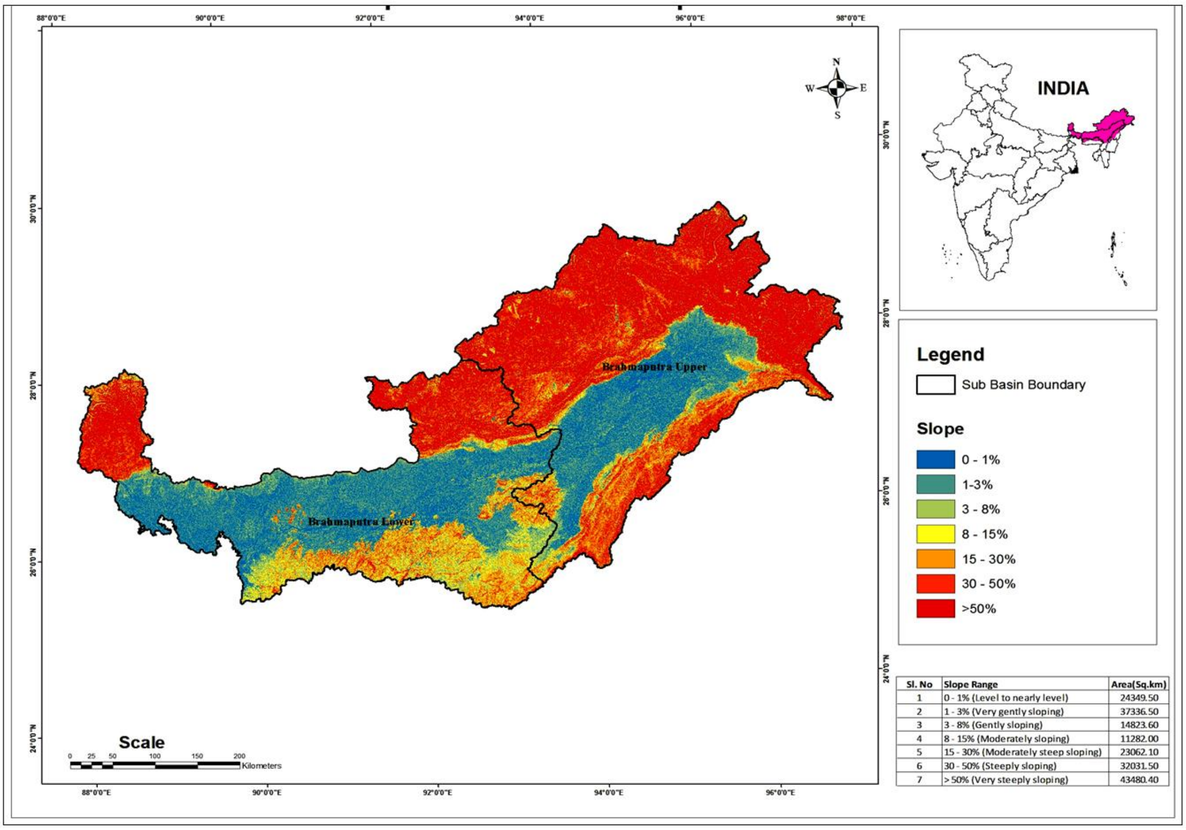
aspects of the basin are related with the channel patterns of the drainage network. Stream order, stream length, mean stream length, stream length ratio, bifurcation ratio and mean bifurcation ratio are linear aspects that are determined and results are given in Table 02.



Sl. No.	Order of Stream	Total No. of Stream	Length of Stream (Km)
1	1st	282502	177016.16
2	2nd	130975	54736.18
3	3rd	71061	28884.32
4	4th	39972	16860.87
5	5th	20115	10227.55
6	6th	10177	5676.24
7	7th	4863	3923.22
8	8th	2487	2143.45
9	9th	768	962.82
10	10th	450	2433

Figure 04. Stream ordering of Brahmaputra river basin.



Sl. No	Slope Range	Area(Sq.km)
1	0 - 1% (Level to nearly level)	24349.50
2	1 - 3% (Very gently sloping)	37336.50
3	3 - 8% (Gently sloping)	14823.60
4	8 - 15% (Moderately sloping)	11282.00
5	15 - 30% (Moderately steep sloping)	23062.10
6	30 - 50% (Steeply sloping)	32031.50
7	> 50% (Very steeply sloping)	43480.40

Figure 05. Slope of the Brahmaputra Basin area in Indian sub-continent.

Table 01. Slope categories in Brahmaputra Basin in Indian sub-continent

Number	Slope Range	Area (sq.km)
1	0 - 1% (Level to nearly level)	24349.50
2	1 - 3% (Very gently sloping)	37336.50
3	3 - 8% (Gently sloping)	14823.60
4	8 - 15% (Moderately sloping)	11282.00
5	15 - 30% (Moderately steep sloping)	23062.10
6	30 - 50% (Steeply sloping)	32031.50
7	> 50% (Very steeply sloping)	43480.40

Table 02. Morphometric Parameters (linear aspects-one dimension) for Brahmaputra River Basin and its Sub Basins

Basin/ Sub Basin	A	B	C	D	E (km)	F (km)	G	H (km)
Basin	1st	282502		2.08	177016.16	0.63	0.67	
	2nd	130975	2.16		54736.18	0.42	0.97	
	3rd	71061	1.84		28884.32	0.41	1.04	
	4th	39972	1.78		16860.87	0.42	1.21	
	5th	20115	1.99		10227.55	0.51	1.10	
	6th	10177	1.98		5676.24	0.56	1.45	4119.09
	7th	4863	2.09		3923.22	0.81	1.07	
	8th	2487	1.96		2143.45	0.86	1.45	
	9th	768	3.24		962.82	1.25	4.31	
	10th	450	1.71		2433	5.41		
		563370			**302863.81**			
Lower Brahmaputra Sub Basin	1st	77716		1.92	54706.24	0.70	0.77	3131.51
	2nd	36890	2.11		20108.58	0.55	1.06	
	3rd	19703	1.87		11415.70	0.58	1.15	
	4th	10986	1.79		7348.93	0.67	1.38	
	5th	5715	1.92		5274.13	0.92	0.99	
	6th	2803	2.04		2550.43	0.91	2.03	
	7th	1106	2.53		2044.92	1.85	0.59	
	8th	528	2.09		573.12	1.09	0.73	
	9th	255	2.07		200.95	0.79	6.73	
	10th	307	0.83		1628.20	5.30		
		156009			**105851.20**			
Upper Brahmaputra Sub Basin	1st	204910		2.32	122221.36	0.60	0.62	2477.15
	2nd	94079	2.18		34621.51	0.37	0.92	
	3rd	51354	1.83		17467.48	0.34	0.96	
	4th	28968	1.77		9501.17	0.33	1.05	
	5th	14397	2.01		4951.32	0.34	1.23	
	6th	7378	1.95		3121.39	0.42	1.18	
	7th	3757	1.96		1878.30	0.50	1.60	
	8th	1959	1.92		1570.33	0.80	1.85	
	9th	513	3.82		761.88	1.49	3.66	
	10th	148	3.47		804.80	5.44		
		407463			**196899.53**			

A: Stream Order, B: Total no. of Stream, C: Bifurcation Ratio, D: Mean Bifurcation Ratio, E: Length of Stream, F: Mean Length of Stream, G: Stream Length Ratio, and H: Perimeter

EISSN: 2409-7632, Journal home: www.journalbinet.com.
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Table 03. Morphometric parameters (areal aspects - two dimensions) for Brahmaputra River Basin and its sub-basins

Parameters	Brahmaputra Basin	Upper Brahmaputra Sub-basin	Lower Brahmaputra Sub-basin	Formula
No. of Streams (Nu)	563370	407463	156009	N_1+N_2+……. $+N_n$
Basin Area (A) km^2	186365.1	98972.87	87392.23	
Total Length of Streams (L) km	302863.81	196899.53	105851.20	L_1+L_2+……… …$+L_n$
Drainage Density (Dd) km/km^2	1.63	1.99	1.21	L*A
Stream Frequency (Fs) km^{-2}	3.02	4.12	1.79	Nu/A
Perimeter (P) km	4119.08	2477.15	3131.51	
Circularity Ratio (Rc)	0.14	0.20	0.11	$(4\pi Au)/P^2$
Form Factor (Rf)	0.22	0.37	0.25	Au/Lb^2
Infiltration Number (If) km^{-3}	4.91	8.19	2.16	Dd*Fs
Max Basin Length (Lb) km	919.684	514.44	593.384	

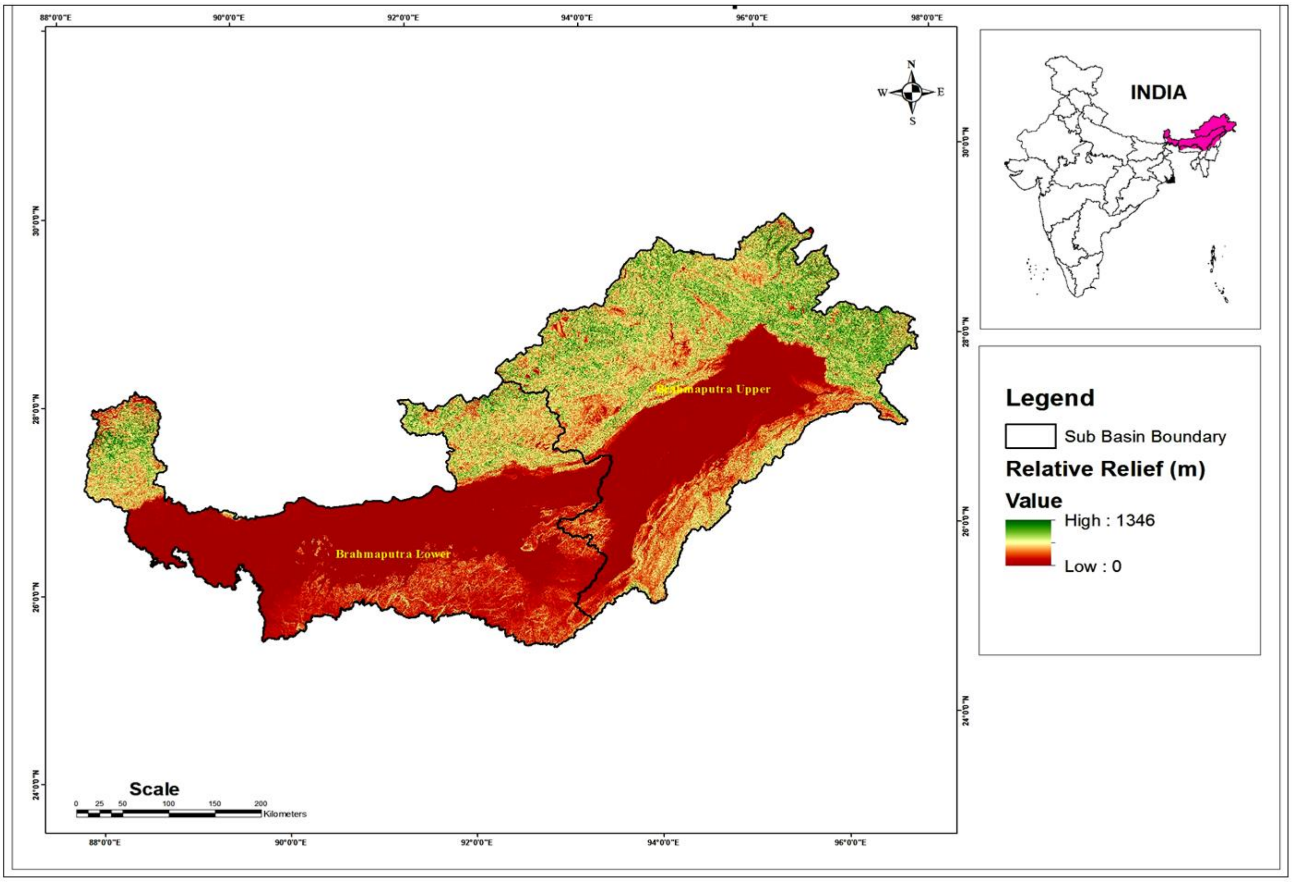

Figure 06. Relief of the Brahmaputra basin area in Indian sub-continent.

IV. Discussion

Brahmaputra basin has 563370 stream segments, out of which 50.15% of segments (282502) comes under I order stream, 23.25% of segments (130975) in II order, 12.61% of segments (71061) in III order, 7.10% of segments (39972) in IV order, 3.75% of segment (20115) in V order, 1.81% of segment (10177) in VI order, 0.86% (4863) segment is under VII order, 0.44% (2487) segment is under VIII order, 0.14% (768) segment is under IX order and 0.08% (450) segment is under X order stream respectively. The Upper Brahmaputra is associated with the hilly terrains. Therefore, they have more number of streams with the total of 407463, whereas Lower Brahmaputra has 156009 streams. The number of streams decreases with stream order except for lower Brahmaputra basin, which might be due to slope variation.

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a basin are counted and their lengths are measured with the help of GIS software. The total length of the stream in Brahmaputra basin is 302863.81Km. Upper and Lower Brahmaputra has total length of 196899.53Km and 105851.20Km respectively. Upper Brahmaputra has highest first order, second order, third order, fourth order, sixth order, eighth order and ninth order stream lengths of 122221.36 Km, 34621.51 Km, 17467.48 Km, 9501.17 Km, 3121.39 Km, 1570.33 Km, 761.88 Km respectively, which define more undulating topography. Further Lower Brahmaputra has highest fifth order, seventh order and tenth order stream lengths of 5274.13 Km, 2044.92 Km and 1628.20 Km respectively. The total length of the stream in the basin is given in table 04. The relationship between stream order and stream length is shown in figure 07 and its linear regression equation is given in table 05. The linear equation of upper and lower Brahmaputra shows that stream order and stream length are negatively correlated.

Table 04. Length of various order stream

Stream order	Length (km)
1st Order	177016.16
2nd Order	54736.18
3rd Order	28884.32
4th Order	16860.87
5th Order	10227.55
6th Order	5676.24
7th Order	3923.22
8th Order	2143.45
9th Order	962.82
10th Order	2433
Total	302863.81

Table 05. Relationship between stream order and stream length

SN.	Sub-basin	Regression Equation	Regression Co-efficient
1	Upper Brahmaputra	y = -17136x + 134995*	$R^2 = 0.6376$
2	Lower Brahmaputra	y = -6554.9x + 51653*	$R^2 = 0.6424$

Negatively correlated relationship exists between stream order and stream length for Brahmaputra basin.

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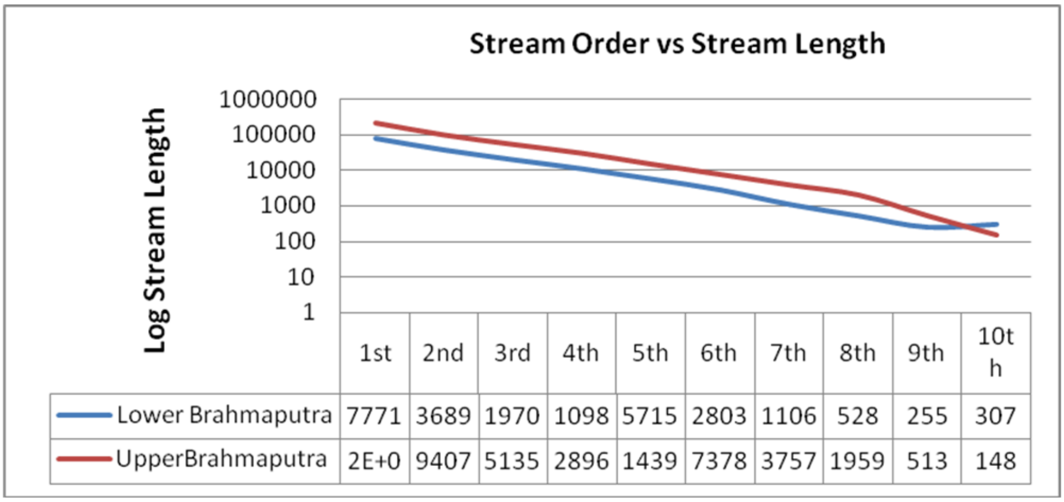

Figure 07. Stream order versus stream length of Brahmaputra basin.

Mean stream length of a stream channel segment of order 'u' is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surface (Strahler 1964). The lengths of stream segments of up to 10th order are measured. The mean stream length of Brahmaputra basin ranges from 0.41 Km to 5.41 Km.

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and having important relationship with surface flow and discharge. The stream length ratio of Brahmaputra basin varies from 0.67 to 4.31. The ratio between stream orders in the study area differs from one order to another, which indicates late youth to mature stage of geomorphic development.

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order. Horton (1945) considered the bifurcation ratio as an index of relief and dissection. It is well demonstrated that Bifurcation ratio shows only a small variation for different regions on different environment except where powerful geological control dominates (Strahler 1952). The Bifurcation Ratio is of fundamental importance in drainage basin analysis, as it is the foremost parameter to link the hydrological regime of a watershed under topological and climatic conditions. It helps to have an idea about the shape of the basin as well as in deciphering the run off behaviour. The bifurcation ratio will not be exactly same from one order to the next order because of possibility of the changes in the watershed geometry and lithology but will tend to be consistent throughout the series. The bifurcation ratio varies from 0.83 to 2.53 for lower Brahmaputra and 1.92 – 3.47 for upper Brahmaputra. As per the Horton (1945) bifurcation ratio having a less value about 2 to 3 is of flat region. Whereas, the bifurcation ratio of higher order streams in upper Brahmaputra basin is 3.47 and 3.82.

The areal aspect represents the two-dimensional properties of a basin. It is possible to delineate the area of the basin, which contributes water to each stream segment. The aerial aspects include drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow in Table 2. Drainage density is the total length of all the streams in the watershed to the area of watershed. It helps in determining the permeability and porosity of the watershed and an indicator of landform elements in stream-eroded topography. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. Low drainage density generally result in the area of highly resistant or permeable subsoil material and high drainage density is the resultant of weak or impermeable subsurface material. The drainage density of the study area ranges from 0 to 5.32 Km/Sq.km as evident form table 6. The high drainage density is noticed in fewer areas of upper Brahmaputra, which represents weak or impermeable subsurface material. The higher drainage density is reported in the regions where slope is steep and very steep.

Table 06. Drainage density Brahmaputra basin in Indian subcontinent

Number	Drainage density (Km/Km^2)	Area (Sq. km)
1	0 - 1	90781.40
2	1 - 2	32485.30
3	2 - 3	23284.00
4	3 - 4	36287.70
5	>4	3662.06

Drainage frequency may be directly related to the lithological characteristics. The stream frequency is defined as the total number of stream segment of all order per unit area. A large basin may contain as many fingertip tributaries per unit of area as a small drainage basin, and in addition, it usually contains a larger stream or streams (Horton 1945). The total drainage frequency of the basins is 3.02 Sq.km and the drainage frequency increase of upper Brahmaputra basin (1.99 Sq. km) is higher than the lower Brahmaputra basin (1.21 Sq.km).

Form factor is the numerical index commonly used to represent different basin shapes. It is be defined as the ratio of basin area to square of the basin length (Horton 1945). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated sub-watershed with low form factors have lower peak flow of longer duration. The value of form factor is 0.37 for upper Brahmaputra and 0.25 for lower Brahmaputra.

Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin. Miller (1953) described the basin having the circularity ratios between 0.4 to 0.5 indicates strongly elongated and highly permeable homogenous geologic materials. The ratio is more influenced by length, frequency, and gradient of streams of various orders rather than slope conditions and drainage pattern of the basin. The circularity ratio of upper and lower Brahmaputra is 0.20 and 0.11.

The infiltration Number is defined as the product of Drainage Density and Drainage Frequency. The higher the infiltration number the lower will be the infiltration and consequently, higher will be run off. This leads to the development of higher drainage density. It gives an idea about the infiltration characteristics of the basin reveals impermeable lithology and higher relief. The upper Brahmaputra has higher infiltration number of 8.19, whereas lower Brahmaputra has infiltration number of 2.16.

V. Conclusion

The details presented in this article shares the characteristics of Brahmaputra River Basin in Indian sub-continent with the help of geospatial data and technologies. Linear aspects like stream order, stream length mean stream length ratio, bifurcation ratio and mean bifurcation have been reported for the Brahmaputra basin. Areal aspects like drainage frequency, form factor, circularity ratio, and infiltration number have been computed and tabulated. Overall basin characters were described using both these linear aspect and areal aspects.

The value of stream frequency for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density. From the reading obtained with respect to Form factors values during this investigation it is evident that that the peak flow of lower Brahmaputra is having lower peak flow of longer duration than that of upper Brahmaputra. The value of upper and lower Brahmaputra shows that it is elongated in nature. The values of the circulatory ratio of Brahmaputra riven shows that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition. Higher the value represents more circularity in the shape of the basin and vice-versa. Naturally, all basins have a tendency to become elongated to get the mature stage. The infiltration number of upper and lower Brahmaputra basin describes that upper Brahmaputra basin has high runoff with high relief and impermeable lithology.

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HOW TO CITE THIS ARTICLE?

MLA
Pondari et al. "Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies." Journal of Science, Technology and Environment Informatics 08(01) (2020): 583-594.

APA
Pondari, S., Dandabathula, G., Bera A. K., Nagamani P. V. and Amminedu, E. (2020). Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies. Journal of Science, Technology and Environment Informatics, 08(01), 583-594.

Chicago
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Harvard
Pondari, S., Dandabathula, G., Bera A. K., Nagamani P. V. and Amminedu, E. 2020. Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies. Journal of Science, Technology and Environment Informatics, 08(01), pp. 583-594.

Vancouver
Pondari S, Dandabathula G, Bera AK, Nagamani PV and Amminedu E. Characterization of drainage network of Brahmaputra river basin in Indian sub-continent using geospatial technologies. Journal of Science, Technology and Environment Informatics. 2020 January 08(01): 583-594.