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Morphometric Analysis of Ranganadi Watershed in Lakhimpur District of Assam, India, using Remote Sensing and GIS Techniques

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ABSTRACT: The present study makes an attempt to analyse the morphometric characteristics of the Ranganadi watershed in the Lakhimpur district of Assam, India. Such morphometric study helpsin understanding the proper utilization of natural resources of the watershed. The Ranganadi watershed, confining 12174 ha geographical area, is located between 93º59′06.18' E to 94°05′08.55′E longitude and 27°10′36.40′N to 27°20′33.68′N latitude. Using Geocoded FCC of Resourcesat-1 LISS-III data of 2015, three distinct physiographic units of the watershed were demarcated which consists of Piedmont plain (4192 ha), Alluvial plain (4808 ha), and Flood plain (3174 ha). The stream order map of the Ranganadi River Basin was made by on-screen digitization using TNTMips software. Morphometric properties of the studied catchment area were assessed through the measurement of linear, areal, and relief features. The drainage streams of the studied area were delineated up to Third order with stream numbers of 34, 17 and 6corresponding to I, II, and III orders, respectively. The calculated value of areal aspects like elongation ratio, circulatory ratio, form factor ratio and shape factor depicted that the Ranganadi watershed was elongated in shape. The studied relief features included parameters like basin relief, relief ratio, ruggedness number, and relative relief indicating that the basin is of lower relief, higher infiltration, lower runoff and less prone to erosion. The study of morphometric properties of the Ranganadi watershed highlights the permeable nature of the soil. This permeability property suggests that the majority of the precipitation would infiltrate the soil and, as a result, a lower quantity would contribute to the runoff. The current study also showed that the investigation of the linear and aerial morphometric features of drainage basins can be greatly aided by the use of geographic information system software.

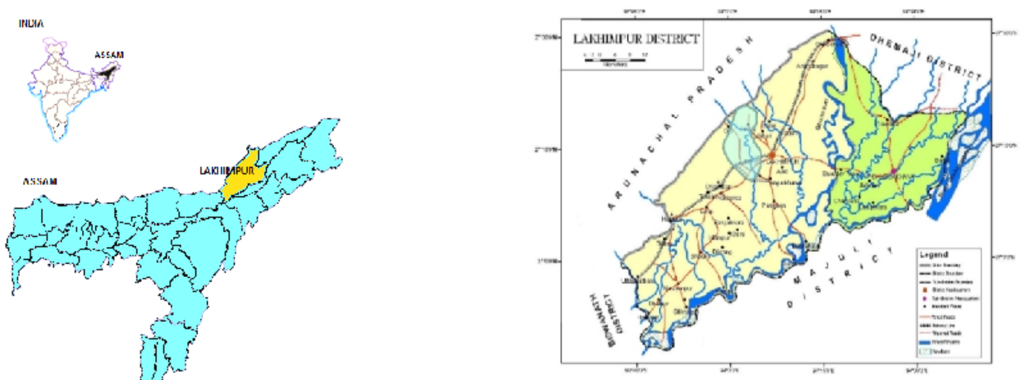
Keywords: GIS, Morphometric analysis, Remote sensing, Watershed.

INTRODUCTION

The morphometric study investigates the processes and features of the river basin, as well as its historical development. The significance of morphometric analysis of a drainage basin is essential to comprehend the geological and geomorphic behaviour of a drainage basin, which affects the soil properties in the basin (Panhalkar *et al.,* 2012). According to Reddy *et al.* (2002), morphometry is the measurement and quantitative study of the configuration of the earth's surface, shape and dimensions of its land forms. Morphometric parameters primarily dependent on lithology, bed rock and geological structures. Thus it provides key details on geomorphology, hydrology, geology and land-use pattern. Further it also gives high information for reliable study of drainage pattern and maturity of the basin, erosion intensity, hydrological peak etc (Astras and Soulankellis 1992; Binjolkar and Keshari 2007). Morphometric study gives the quantitative description of the river basin in order to comprehend the initial slope, structural controls, geology and geomorphology. Thus, it served as a starting step in understanding the basin dynamics. The morphometric assessment of a catchment area and its stream system can be obtained well through measurement of linear, areal and relief aspects of drainage basin (Biswas *et al*., 1999). Conventional approaches have been used to analyse the drainage properties of many river basins and sub-basins in different parts of the world. But nowadays Geospatial techniques such as remote sensing (RS) and Geographical information system (GIS) are some modern powerful tools used for the analysis of the drainage pattern of the watershed. The satellite pictures from the remote sensing technique are highly helpful in the analysis of drainage basin morphometry because they give a synoptic view of a wide area. Many researchers have performed morphometric study using remote sensing and GIS technique. It have been proposed that the morphometric analysis is very useful in determining the suitable site for soil and water conservation structures *i.e.*, check dam, trenches, pits, farm ponds, *etc.* Balakrishna (2008) performed morphometric study for Tippagondanahalli River basin for prioritization of sub watersheds. Vandana (2012) conducted morphometric assessment for Kabini River basin and used as a tool for characterization of sub watershed in the basin. Deka *et al.* (2021) used remote sensing and GIS for morphometric analysis of the Moridhal watershed in Dhemaji district of Assam. Bagyaraj *et al*. (2011) used morphometric tools for forecasting and assessing high runoff in the sub-watershed. Dawod *et al*. (2012) evaluated erodibility of the watershed basin. Using remote sensing and GIS techniques, Arun *et al.* (2005) reported physiographic characterization of a drought-affected Gandeshwari watershed in the Bankura district of West Bengal. The studied watershed area is under uneven land use and poor management practices. Using the knowledge of linear, aerial, and relief aspects of the Ranganadi watershed could help in characterizing and prioritizing the developmental works for the best possible use of the watershed's available natural resources. So in this context, an effort was made to examine and analyse various morphometric parameters of the watershed by using remote sensing and GIS tools.

METHODOLOGY

Study area. The river Brahmaputra has numerous tributaries and their sub-tributaries. River Ranganadi is one such main tributary of Brahmaputra. The Ranganadi watershed is located in Lakhimpur District in a part of the North Bank Plain Zone of Assam, India (Fig. 1). It is situated at 93°59′06.18′E to 94°05′08.55′E longitude and 27°10′ 36.40′N to 27°20′33.68′N latitude. The studied area experiences humid sub-tropical climate with an average annual rainfall of 3194 mm. The average annual temperature, maximum temperature, and minimum temperature in the region are 23.8°C, 32.4°C and 10°C respectively.



(a) (b)

Fig. 1. Ranganadi location map.

Physiographical situation. Using Geocoded FCC of Resourcesat-1 LISS-III data were visually interpreted and in association with Survey of India toposheets (1:50,000), the physiographic map of the Ranganadi watershed was prepared. Visual image interpretation based on colour, tonal and textural variations led to identification of three distinct physiographic units which include: piedmont plain (4192 ha), alluvial plain (4808 ha) and flood plain (3174 ha) (Fig. 2).

Morphometric analysis. The linear, areal, relief features and slope contribution were measured as part of the morphometric analysis of the Ranganadi watershed. For morphometric analysis the drainage map of the watershed (Fig. 3) was prepared by on screen digitization using TNTMips software. The key parameters which are considered as the geometric characteristics *viz.*, basin area, basin perimeter, basin length etc. were retrieved from the GIS software by taking direct measurements using geo toolbox. The measurement of all other morphometric parameters associated to linear, areal and relief aspects were formulated using the standard formulae presented in Table 1-3.

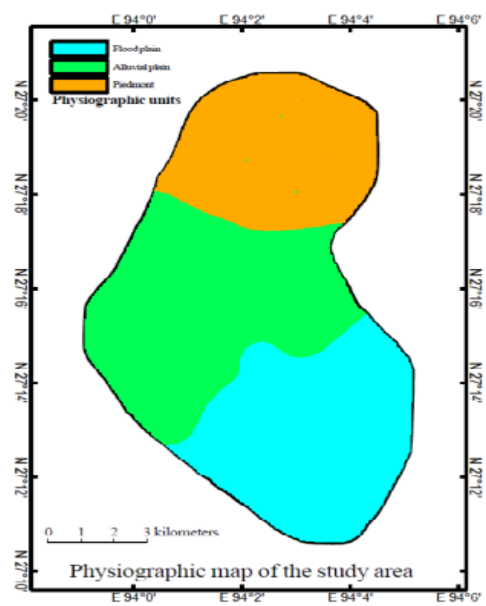


Fig. 2. Physiographic map of Ranganadi watershed.

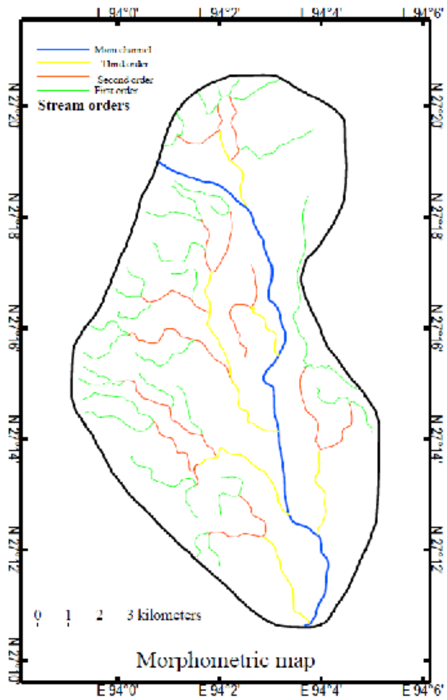


Fig. 3. Drainage map of Ranganadi watershed.

Table 1: Formulas adopted for computing morphometric parameters (linear aspects).

Sr. No.	Morphometric parameters	Formula	Reference
1.	Stream Order	Heirachial rank	Strahler (1964)
2.	Stream Length (Lu)	Length of the stream	Horton (1945)
3.	Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lu = Total stream length of order ‘u’ Nu = Total no. of stream segments of order ‘u’	Schumn (1956)
4.	Stream Length ratio (RL)	RL= Lu/Lu-1 Where, Lu = Total stream length of order ‘u’ Lu-1= The total stream length of its next order	Horton (1945)
5.	Bifurcation ratio (Rb)	Rb = Nu/Nu+1 Where, Nu = Total no. of stream segments of order ‘u’ Nu+1= Number of segments of the next, higher order	Schumn (1956)
6.	Mean Bifurcation ratio (Rbm)	Rbm = Average of Bifurcation ratios of all orders	Strahler (1957)

Table 2: Formulas adopted for computing morphometric parameters (Areal aspects).

Sr. No.	Morphometric parameters	Formula	Reference
1.	Basin area (A) Km^2	Area enclosed within the boundary of watershed divide	Strahler (1964)
2.	Basin perimeter (P) Km	Outer boundary of drainage basin	Schumn (1956)
3.	Basin length (Lb) Km	Lb = Distance between outlet and farthest point on basin boundary	Horton (1945)
4.	Drainage Density (Dd) Km km^{-2}	Dd = Lu/A Where, Lu =Total stream length of all orders A = Area of the basin	Horton (1945)
5.	Stream Frequency (Fs)	Fs = Nu/A Where, Nu=Total no. of streams of all orders A= Area of the basin	Horton (1932)
6.	Drainage Texture (Rt)	Rt = Nu/P Where, Nu =Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
7.	Elongation ratio (Re)	$Re = 2\sqrt{(A/\pi)}/Lb$ Where, Re = Elongation ratio, A = Area of the basin Lb= Basin length	Schumn (1956)
8.	Infiltration Number (If)	If = Dd × Fs Where, Dd = Drainage Density Fs = Stream Frequency	Zavoiance (1985)
9.	Circulatory Ratio (Rc)	$Rc = 4 \pi A/P^2$ Where, Rc = Circulatory ratio	Miller (1953)

		A = Area of the basin (km^2) P^2 = Square of the perimeter (km^2)	
10.	Form Factor (Rf)	$Rf = A/Lb^2$ Where, A = Area of the basin Lb^2 = Square of Basin length	Horton (1932)
11.	Length of overland flow (Lg)	$Lg = 1/2 \times Dd$ Where, Lg = Length of overland flow Dd = Drainage Density	Horton (1945)
12.	Constant of channel maintenance (C)	C=1/ Dd Where, Dd = Drainage Density	Schumn (1956)
13.	Compactness coefficient (Cc)	$Cc = 0.2821\ P/A^{0.5}$ Where, P = Basin perimeter A = Area of the basin	Horton (1945)
14.	Shape factor (Ru)	$Ru = Lb/(A)^{1/2}$ Where, Lb = Basin length A = Area of the basin	Horton (1932)
15.	Fineness ratio (Rfn)	Rfn=Lb/P, Where, Lb = Basin length P = Basin perimeter	Melton (1957)

Table 3: Formulas adopted for computing morphometric parameters (relief aspects).

Sr. No.	Morphometric parameter	Formula	Reference
1.	Maximum elevation, m	GIS analysis	
2.	Minimum elevation, m	GIS analysis	
3.	Basin relief (H)	(Elevation of basin mouth – Elevation of highest point on the basin perimeter)	
4.	Relief ratio (Rh)	Rh = H/Lb Where, H= Maximum basin relief Lb = Basin length	Schumn (1956)
5.	Ruggedness number (Rn)	$Rn = H \times Dd$ Where, H= Maximum basin relief Dd= Drainage density	Strahler (1964)
6.	Relative relief (Rp)	$Rhp = H \times (100) / P$ Where, H = Maximum basin relief P = Perimeter of the basin	Melton (1957)

RESULTS AND DISCUSSION

Morphometric analysis. The morphometric parameters of the studied watershed corresponding to linear, aerial and, relief aspects are discussed below.

Linear aspects. The morphometric parameters of the Ranganadi watershed related to linear aspects were calculated and the results are presented in Table 4.

Stream order (Nu). Designation of stream order is the basic step towards drainage basin analysis as it depicts the relative and hierarchical relationship between stream segments, their connectivity and the discharge contributions of the main watershed and its sub-watersheds. When two first order streams join together a 2nd order stream is formed. Similarly, when two 2nd order streams join together a 3rd order stream is formed. Likewise, when two lower order streams join together a next higher order stream is formed. From Table 4, it was found that the study area in Ranganadi watershed is of third order *i.e.* stream order I, II and III with the stream numbers of 34, 17 and 6 respectively. The studied watershed data depicts that the number of stream segments decreased with increase in stream order. This is in conformity with Horton's laws observations.

Stream length (Lu). Stream Length is defined as the total length of individual stream segments. The stream length of stream order I, II and III were found to be 64.13, 41.86 and 23.73 Km, respectively (Table 4). From the data it was seen that the total length of stream segments is maximum in first order streams and then decreases as the stream order increases indicating the watershed to exhibit normal distribution of the streams. The total stream length was calculated to be 129.72 Km. This is in agreement with the reports by Waikar and Nilawar (2014).

Mean Stream Length (Lsm). Mean stream length is a dimensionless property. It defines the characteristic size of the drainage network and its associated surface. The mean stream length of Ranganadi watershed was calculated and the values were 1.89, 2.46 and 3.96 for the three orders i.e. I, II and III respectively (Table 4).

Stream length ratio (RL). Stream length ratio is the ratio of the stream mean length of a particular order to the mean stream length of the next lower order. The stream length ratio of the lower order streams indicates the existence of the juvenile and mature stage of development. The studied watershed has stream length ratio values ranged from 0.65 to 0.57 for stream order II and III respectively, which showed a decreasing trend from lower order to higher order. Similar kind of distribution was also observed by Chavare and Shinde (2013).

Table 4: Morphometric parameters (linear aspects) of Ranganadi watershed.

Stream order (u)	Number of stream (Nu)	Total length of stream (Lu)	Mean stream length (Lsm)	Stream length ratio (RL)	Bifurcation ratio (Rb)	Mean bifurcation ratio (Rbm)
I	34	64.13	1.89	-	2.00	2.42
II	17	41.86	2.46	0.65	2.83	
III	6	23.73	3.96	0.57	-	
Total Stream Length	57	129.72				

Bifurcation ratio (Rb). Bifurcation ratio is referred as the ratio of streams in one order to streams in the next higher order. A high bifurcation ratio (Rb) values indicates an elongated basin, whereas a low bifurcation ratio (Rb) shows circular basin. If the ratio is low then there is a high probability of flooding and reveals which part of the basin is more prone to be affected by flooding. The most typical bifurcation ratio ranges from 3 to 5 suggesting uniform lithology of the drainage system and preventing the geological structure from distorting the drainage pattern. The bifurcation ratio of the watershed were 2 and 2.83 for I and II order streams, respectively (Table 4). The mean bifurcation ratio (Rbm) of the studied watershed was computed as 2.42 which thus categorized the basin as elongated. Similar findings were reported by Yadav *et al.* (2021) in Khag Micro-Watershed in North-West Himalayas of Kashmir.

Areal aspects. Various morphometric properties related to the areal aspect of the drainage basin includes basin area (A), basin perimeter (P), drainage density, stream frequency, elongation ratio, infiltration number (If), circularity ratio, form factor ratio, length of the overland flow (Lg), constant of channel maintenance (C), compactness coefficient (Cc) and shape factor (Bs) were derived and the values have been presented in Table 5.

Basin length (Lb). Basin length is the measure of geometrical size and shape of a drainage basin. The basin length of the studied basin was computed to be 18.38 km which depicts that the watershed is elongated in nature.

Basin area (A). The total area confined within the basin defines the basin area. It is the most significant basin characteristic that has an impact on how much water precipitation produces. It is the first step which determines the average depth of rainfall over the basin. The basin area (A) of the study area within the transect in Ranganadi watershed was calculated and the values found to be 121.74 km^2 representing the basin to have large run-off volume.

Basin perimeter (P). Total length of the boundary of the basin is defined as basin perimeter. It defines the watershed's dimension and form. Elongation ratio and circulatory ratio are the factors dependent on the basin perimeter. The basin perimeter of the Ranganadi watershed area was computed as 46.88 km.

Drainage density (Dd). Drainage density (Dd) is defined as the total length of channels (Lu) in a catchment divided by the area (A) of the catchment. It is an important indicator in stream eroded topography. It also indicates the closeness of the channels spacing. According to Nag (1998); Ramaiah *et al.* (2012), low drainage density leads to the areas of highly impervious or permeable subsoil material, dense vegetation and low relief, whereas high drainage density is the outcome of weak or impermeable subsurface material, sparse vegetation and mountainous relief. The drainage density of the Ranganadi watershed was calculated to be 1.07 km km^{-2}. The low drainage density of Ranganadi watershed is due to the result of permeable sub surface material, dense vegetation and low relief. Similar findings were also recorded by Ingle *et al.* (2014).

Table 5: Morphometric characteristics (Aerial aspects) of Ranganadi watershed.

Sr. No.	Morphometric parameters	Value
1.	Basin length (Lb)	18.38 km
2.	Basin area (A)	121.74 km^2
3.	Basin perimeter (P)	46.88 km
4.	Drainage density (Dd)	1.07 km^{-2}
5.	Stream frequency (Fs)	0.47
6.	Drainage texture (Rt)	1.22
7.	Elongation ratio (Re)	0.75
8.	Infiltration number (If)	0.50
9.	Circulatory ratio (Rc)	0.70
10.	Form Factor ratio (Rf)	0.36
11.	Length of overland flow (Lg)	0.47
12.	Constant of channel maintenance (C)	0.94
13.	Compactness coefficient (Cc)	1.20
14.	Shape factor (Ru)	1.67
15.	Fineness ratio (Rfn)	0.39

Stream frequency (Fs). Stream Frequency (F) is defined as the number of stream segments per unit area. Generally, stream frequency has a positive correlation with drainage density. The studied Ranganadi watershed area has a stream frequency of 0.47 indicating drainage network texture to be coarse. Similar type of findings was reported by Shah *et al.* (2017).

Drainage texture (DT). Drainage texture is defined as the total number of stream segments of all orders in a basin per unit of basin perimeter. It is a product of drainage frequency and drainage density. It also shows the relative spacing of drainage lines. According to Sahu *et al.* (2017), drainage density can be classified into five different textures such as very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The drainage texture of the Ranganadi watershed was calculated and the value found to be1.22. The value shows that the watershed has a very coarse texture and is likely to have higher runoff. Low texture ratio implies low runoff and high infiltration capacity. Similar findings were also reported by Oruonye (2016).

Elongation ratio (Re). Elongation Ratio (RE) is determined when diameter of circle with the same area as the drainage basin is divided by the maximum length of the basin (Schumn, 1956). It is an important index to analyze the shape of the basin. Index of elongation ratio of the drainage basin is classified as circular (>0.9), oval (0.9-0.8), less elongated (0.8-0.7) and elongated (<0.7). Elongation ratio of higher values indicates very low relief. The calculated value of elongation ratio for the Ranganadi watershed was 0.75 which suggests that the basin is less elongated. The finding of Pareta and Pareta (2011) supports the results of the Ranganadi watershed.

Infiltration number (If). Infiltration number shows the infiltration characteristics of the area relating to the capacity of the soils to absorb the water received in the form of rainfall and surface run-off. The higher values of infiltration number indicates lower infiltration rate and higher amount of surface runoff (Das and Mukherjee 2005; Jasmin and Mallikarjuna 2013). The infiltration number of the watershed was calculated to be 0.50.

Circulatory ratio (Rc). Circularity ratio (Rc) is described as the ratio of basin area to the area of a circle with the same perimeter as that of the basin. It mainly deals with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Ramaiah *et al.,* 2012). The high values of circulatory ratio reveals the area is characterised by high relief, elongated and permeable surface resulting in a greater basin lag time whereas low circulatory ratio values show a lower relief and impermeable surface resulting in lower basin lag time (Kottagoda and Abeysingha 2017). Generally, circularity ratio value varies from 0 (in line) to 1 (in a circle). Higher value of circularity ratio indicates more circularity in the shape of the basin and vice-versa. The calculated circularity ratio (Rc) value for the studied area in the Ranganadi watershed was found to be 0.70 indicating intermediate shape of the watershed. Similar observation was reported earlier by Suma and Srinivasa (2017).

Form factor (Rf). Form factor ratio (RF) is the ratio of the basin area to the square of the basin length. It is dimensionless. The smaller value of the form factor indicates more elongation of the basin, while higher value of form factor indicates high peak in short interval and vice versa (Chandniha and Kansal 2017). The form factor (Rf) value for the watershed calculated as 0.36 which shows the basin is less elongated. Similar observation was made by Veeranna *et al*. (2017)

Length of overland flow (Lg). Length of overland flow (Lg) is defined as the length of flow of water over the ground before it becomes confined in a definite stream channel. It is indirectly related to the average slope of the basin. The reciprocal of twice the drainage density is approximately equal to the average length of the overland flow. The shorter the length of overland flow implies the surface runoff will be quicker from the streams. The calculated value for length of the overland flow was 0.47 implying low surface runoff. Hussain and Mishra (2018) reported similar type of observations.

Constant of channel maintenance (C). Constant of channel maintenance (C) is a linear measurement that characterise the drainage pattern in a particular basin. It has an inverse relationship with drainage density. It depends on the rock type, permeability, climatic condition, crop cover and relief as well as the duration of erosion. The constant of channel maintenance denotes the relative size of landform units in a drainage basin. High values of constant of channel maintenance (C) indicates more area is required to produce surface flow which implies that part of water may get lost by evaporation, percolation etc. Similarly, moderate values implies medium to high permeability, moderate slope and moderate surface runoff, while lower value indicates less chances of percolation/ infiltration and hence more run off. The calculated value of constant of channel maintenance of Ranganadi watershed is 0.94 km^2 implying medium to high permeability, moderate slope and moderate surface runoff.

Compactness coefficient (Cc). Compactness coefficient (Cc) is basin perimeter divided by the circumference of a circle to the same area of the basin. Compactness coefficient is indirectly associated with elongation of the basin area. A low value of the parameter signifies more elongation of the basin and less erosion whereas a high value represents less elongation and high erosion (Kumar *et al*. 2017). The compactness coefficient value of the study area in the Ranganadi watershed has value of 1.20, which implies that the basin is likely to suffer from moderate erosion hazard. Mandi and Soren (2016) reported similar type of findings.

Shape factor (Bs). Shape factor indicates the circular character of the drainage basin (Farhan and Anaba 2016). The shape factor of Ranganadi watershed was calculated to be 1.67 which indicates the studied watershed to be elongated. Similar findings were reported by Kumar *et al.* (2015).

Fineness ratio (Rfn). Fineness ratio is defined as the ratio of main channel length to the circumference of the watershed. It determines the topographic fitness (Melton, 1957). The calculated value of fineness ratio was 0.39.

Relief aspects. The vertical characteristics of the basin which are dependent on the highest and the lowest elevation of the basin define the relief aspect. The findings of morphometric parameters related to relief aspects of the Ranganadi watershed are presented in Table 6.

Basin relief (H). The elevation difference between the highest peak and the lowest point of the valley floor is defined as basin relief. It illustrates the drainage system's potential energy. A region with high relief transmits high energy into the drainage system. The parameter controls the stream gradient, affects flood pattern and volume of sediment that can be transported (Hadley and Schumm 1961). It also plays a vital role in drainage development, surface and sub-surface water flow, permeability, landforms development and erosion characteristics of the terrain. The computed value of the studied basin relief was 42m indicating high infiltration capacity and moderate runoff.

Relief ratio (Rh). Relief ratio is the ratio between basin relief and the maximum basin length. It is an indicator of the intensity of the erosional process operating on the slope of the basin and measures the overall steepness of the basin. The relief ratio of the studied area was found to be 0.0023which indicates gentle slope. Similar type of observation was made earlier by Naitam *et al*. (2016).

Ruggedness number (Rn). The product of the basin relief and drainage density is defined as ruggedness number. Higher value of ruggedness number indicates intense erosional intensity in the basin. The ruggedness number of the studied transect of Ranganadi watershed was 0.045, which shows that the studied area has gentle slope and are moderately prone to soil erosion. Earlier, Dubey *et al*. (2015) also concluded similar report.

Table 6: Morphometric characteristics (Relief aspects) of Ranganadi watershed.

Sr. No.	Relief parameters	Values
1.	Maximum elevation in the area (mts)	112
2.	Minimum elevation in the area (mts)	70
3.	Basin relief (H)	42
4.	Relief ratio (Rh)	0.0023
5.	Ruggedness number (Rn)	0.045
6.	Relative relief (Rr)	0.090

Relative relief (Rr). Basin relief when divided by the perimeter of the basin gives relative relief. The relative relief value of the watershed was computed to be 0.090per cent, indicating the basin shape to be elongated and possibly moderate erosion. Similar type of observation was also made by Suma and Srinivasa (2017).

CONCLUSION

Remote sensing and GIS were utilised to analyse morphometric parameter of the Ranganadi watershed in Assam's Lakhimpur District, India. Hydrological behaviour and landforms are linked by computing the watershed's linear, areal and relief characteristics, which aids water management. According to morphometric research, the watershed has a third order drainage streams with 129.72 km in length. The watershed exhibits less structural disturbance due to the reduced bifurcation ratio and dendritic drainage pattern. High form factor, elongation ratio and circulatory ratio values suggested the watershed to be elongated in shape. Flooding and gully erosion are likely due to the poor drainage density. Watershed erosion priority may benefit from the analysis findings. The drainage morphology must be examined to locate and choose water storage facilities like percolation tanks, ponds, check dams etc. For micro-level natural resource management, this study will help planners and decision makers. Remote sensing and GIS are also more efficient and useful than traditional techniques for identifying drainage basins and updating drainage streams for stream morphometry analysis.

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Conflict of Interest. None.

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