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Morphometric analysis of Moridhal watershed in Dhemaji District of Assam, India using remote sensing and Geographic Information System techniques

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ABSTRACT

The present investigation was carried out to study the morphometric properties of the Moridhal watershed in the Dhemaji district of Assam, India to understand its nature for proper utilization of natural resources of the watershed. The Moridhal watershed, encompassing a 30,730 ha geographical area, is situated between 94°52 E to 94°69 E longitude and 27°38 N to 27°64 N latitude. Based on total variation in satellite data (Resourcesat-2, LISS-4), four distinct physiographic units of the watershed were delineated which included: upper piedmont plain (1,844 ha), lower piedmont plain (2,391 ha), alluvial plain (9,888 ha), and flood plain (16,607 ha). The stream order map of the Moridhal River Basin was prepared by on-screen digitization using QGIS 3.12.0 software. Twenty-nine numbers of morphometric parameters were evaluated through the measurement of linear, areal, and relief aspects of the river basin. The drainage streams were delineated up to fourth order with stream numbers of 36, 14, 5, and 1, for I, II, III, and IV order, respectively. The computed value of aerial aspects like elongation ratio, circulatory ratio, and form factor revealed the elongated shape of the watershed area. The studied relief aspects included parameters like basin relief, relief ratio, ruggedness number, and relative relief. The morphometric properties of the Moridhal watershed depicted the permeable nature of the soil which indicated that the precipitation would mostly penetrate the soil and, thereby, a lesser amount would contribute to the runoff. The present study also revealed that Geographic Information System software has immense utility in the analysis of the linear and aerial morphometric aspects of the drainage basins.

Keywords: Geographic Information System; Morphometric analysis; Remote sensing; Watershed

1. Introduction

Morphometric analysis of a watershed is an essential first step in understanding the basics of watershed dynamics [1]. According to Clarke [2], morphometric analysis is the mathematical analysis of the earth's surface configuration including its shape, size, landforms dimension, etc. Morphometric analysis of a river basin offers a quantitative description of the drainage system, which is an important aspect of the characterization of basins [3]. The geomorphologic features of the catchment area control the dynamic nature of runoff, which is very sensitive to the morphometric characteristics of the watershed [4]. Morphometric parameters are mainly dependent upon lithology, bedrock, and

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geological structures [5]. Both at basin and watershed scale, the drainage network is the manifestation of the combined influence of geology, geomorphology climate, and soil [6,7]. Detailed morphometric analysis of a watershed can give us some insight into how the landform characteristics can be manipulated by drainage morphometry. Therefore, morphometric analysis of a watershed is the prerequisite to comprehending the processes involved to develop a landform within a watershed [8]. The morphometric analysis is performed through measurement of linear, aerial, relief, the gradient of channel network and contributing ground slope of the basin [9,10]. Drainage characteristics of many river basins and sub-basins in different parts of the globe have been studied using conventional methods [3,11]. However, remote sensing and Geographic Information System (GIS) techniques are nowadays used widely for assessing various terrain and morphometric properties of the drainage basins and watersheds, as they provide a powerful tool for the manipulation and analysis of spatial information [12,13]. The use of GIS in assessing the morphometric parameters of the watersheds and drainage basins is gaining popularity because it saves time and gives more accurate results. Many researchers have carried out morphometric analysis and prioritization of the watersheds using remote sensing and GIS techniques. A GIS-based study conducted at Yamuna River of Uttar Pradesh, India revealed that the remote sensing technique is a competent tool in morphometric analysis of drainage basin and channel networks [14]. Remote sensing and GIS techniques were used at the Wadi Shueib watershed of Central Jordan for estimating morphometric parameters and soil erosion susceptibility [15]. The SRTM-DEM data coupled with geoprocessing techniques were successfully used for evaluating the linear aspects of the Shanur River Basin in Maharashtra, India [16]. Sharma and Mahajan [17] found that the GIS and remote sensing data can be used effectively for the estimation of erosional processes in the Himalayan watershed for improved planning and management. The high ruggedness value of the Khag Micro-Watershed in North-West Himalayas of Kashmir, India indicated that the area is more susceptible to erosion and, thereby, demands instantaneous soil conservation measures for its stability and sustainability [18].

The Moridhal watershed of Dhemaji District of Assam, India has a niche of different physiographic units and the entire watershed area is under erratic land use and poor management. The knowledge of linear, aerial, and relief aspects of the watershed could help in characterizing the watershed and prioritizing the developmental works for proper utilization of the natural resource of the watershed. Keeping these things in mind an attempt was made to assess and evaluate various morphometric parameters of the watershed by using RS and GIS tools.

2. Methodology

2.1. Study area

The Moridhal watershed is located in the Dhemaji district of the North Bank Plains of Assam, India (Fig. 1). This watershed, which encompasses 30,730 ha geographical area, is situated between 94°52′ E to 94°69′ E longitude and 27°38′ N to 27°64′ N latitude. The area is characterized by a humid climate with an average annual rainfall of 3,064 mm received throughout the year. The average annual temperature, maximum temperature, and minimum temperature in that region are 23.6°C, 28.7°C, and 18.5°C, respectively. The watershed falls under the Brahmaputra Valley which is a part of the Indo-Gangetic Brahmaputra river system of North East India. Being in a confluence of rivers with the mighty Brahmaputra river flanking the district and its numerous tributaries running through the district, the region is perennially affected by floods.

2.2. Physiographical situation

Using the Resourcesat-2, LISS-4 geocoded satellite data and in conjunction with Survey of India toposheets (1:50,000) the Moridhal watershed was delineated. Based on total variation in satellite data, four distinct physiographic units of the Moridhal watershed were delineated which included: upper piedmont plain (1,844 ha), lower piedmont plain (2,391 ha), alluvial plain (9,888 ha) and, flood plain (16,607 ha).

2.3. Morphometric analysis

The morphometric analysis of the Moridhal watershed was carried out through measurement of linear, areal and, relief aspects of the basin and slope contribution. For this, the drainage map of the watershed (Fig. 2) was first prepared by on-screen digitization using Quantum GIS software 3.12.0. The basic parameters which are considered as the geometric characteristics like basin area, basin perimeter, basin length, etc. were obtained from GIS software by direct measurement. The measurement of all other parameters related to linear, areal, and relief aspects were carried out by using the formulae presented in Tables 1–3.

3. Results and discussion

3.1. Morphometric analysis

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

3.1.1. Linear aspects

The morphometric parameters of the Moridhal watershed about linear aspects were computed and the results are presented in Table 4.

3.1.1.1. Stream order and number of streams

The designation of stream order (Nu) is the first step for morphometric analysis of a watershed. The data presented in Table 4 showed that the Moridhal watershed had a fourth-order drainage stream. The first-order stream had 36 streams whereas, the second, third and, fourth-order stream had 14, 5, and 1 stream, respectively The number of stream segments decreased with the increase in stream order. This is in accordance with the findings of Horton's laws.

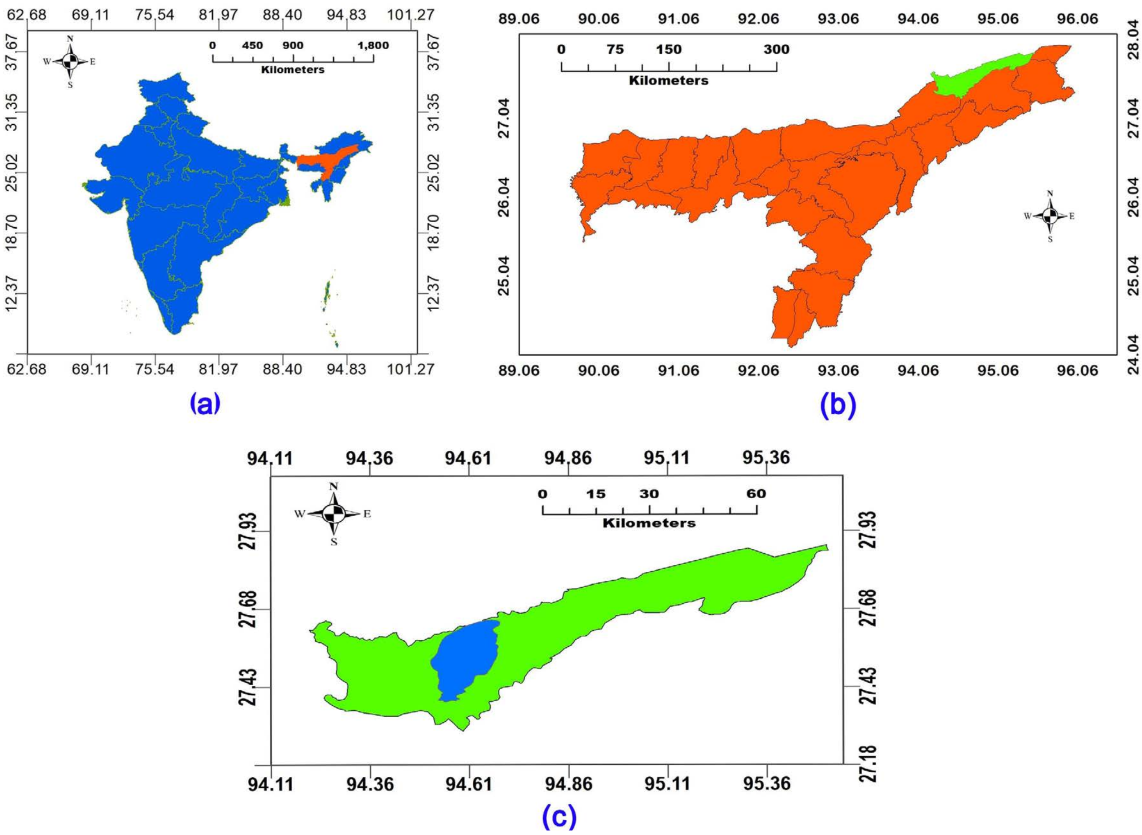

Fig. 1. Moridhal location map.

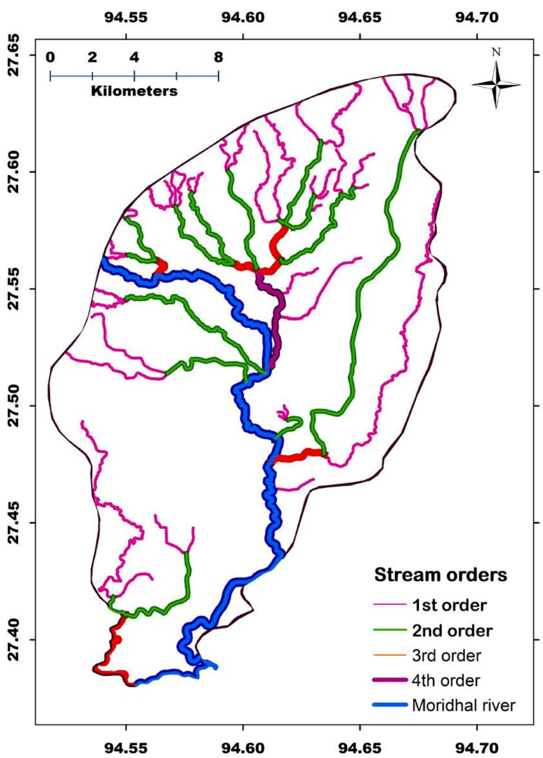

Fig. 2. Drainage map of Moridhal watershed.

3.1.1.2. Stream length

In the Moridhal the stream lengths of order I, II, III, and IV were found to be 119.87, 81.73, 14.16, and 6.02 km, respectively. The total stream length in the studied watershed was found to be 221.78 km. It was observed that the total length of the stream segment was maximum for the first-order streams and it decreased with the increase in stream order. Similar findings were obtained by the study of Naitam et al. [26] in the Chanavada-II watershed in the Aravali hills of Southern Rajasthan, India.

3.1.1.3. Mean stream length

The mean stream length value of the Moridhal watershed was calculated for all four orders which were found to be 3.33, 5.84, 2.83, and 6.02 (Table 4) for stream orders I, II, III and IV, respectively. It was found that the mean stream length of the studied watershed did not follow any definite trend.

3.1.1.4. Stream length ratio

The stream length ratio of the Moridhal watershed varied from 0.17 to 0.68. It was found that the stream length ratio showed an increasing trend from lower order to higher order which indicated a mature geomorphic stage. The results are in conformity with the findings of Nayar et al. [27] in the Kosasthalaiyar River of India.

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

Morphometric parameters	Formula	Reference
Stream order (u)	Hierarchical rank	[3]
Stream number (Nu)	Nu = $N_1 + N_2 + \ldots\ldots + N_n$ where N_1 = Order of stream	[11]
Stream length (Lu)	Lu = $L_1 + L_2 + \ldots\ldots + L_n$ where L = Length of the basin	[11]
Mean stream length (Lsm)	Lsm = Lu/Nu where Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	[3]
Stream length ratio (Lur)	Lur = Lu/Lu – 1 where Lu = Total stream length of order 'u' Lu – 1 = Total stream length of its next lower order	[11]
Bifurcation ratio (Rb)	Rb = Nu/Nu + 1 where Nu = Total steam segments of order 'u' Nu + 1 = stream length of its next higher order	[19]
Rho coefficient (ρ)	ρ = RL/Rb where RL = stream length ratio; Rb = bifurcation ratio	[11]

Table 2
Formulas adopted for computing morphometric parameters (areal aspects)

Morphometric parameter	Formula	Reference
Basin area (A), km^2	Area enclosed within the boundary of watershed divide	[3]
Basin length (Lb), km	Lb = Distance between outlet and farthest point of basin boundary	[11]
Basin perimeter (P), km	P = Outer boundary of drainage basin	[19]
Drainage density (D), km/km^2	D = Lu/A where Lu = Total stream length of all orders; A = Basin area	[11]
Drainage pattern (Dp)	GIS analysis	[20]
Lemniscate's (K)	$K = Lb^2/A$ where Lb = Basin length; A = Basin area	[21]
Length of overland flow (Lg)	Lg = 1/2 × Dd where Dd = Drainage density	[11]
Stream frequency (Fs)	Fs = Nu/A where Nu = Total no. of streams of all orders; A = Basin area	[20]
Drainage texture (Dt)	Dt = Nu/P where Nu = Total no. of streams of all orders; P = Perimeter (km)	[11]
Drainage intensity (Di)	Di = Fs/Dd where Fs = Stream frequency; Dd = Drainage density	[22]
Elongation ratio (Re)	$\mathrm{Re} = 2\sqrt{(A / \pi / \mathrm{Lb})}$ where A = Basin area; Lb = Basin length	[19]
Infiltration number (If)	If = D × Fs where D = Drainage density; Fs = Stream frequency	[23]
Circulatory ratio (Rc)	$\mathrm{Rc} = 4\pi A/P^2$ where A = Basin area (km^2); P^2 = Square of the perimeter (km^2)	[24]
Form factor (Rf)	$\mathrm{Rf} = A/\mathrm{Lb}^2$ where A = Basin area; Lb^2 = Square of basin length	[20]
Constant of channel maintenance (C)	C = 1/Dd where Dd = Drainage density	[19]
Compactness of coefficient (Cc)	$\mathrm{Cc} = 0.2821P/A^{0.5}$ where P = Basin perimeter; A = Basin area	[11]

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

Morphometric parameter	Formula	Reference
Maximum elevation, m	GIS analysis	–
Minimum elevation, m	GIS analysis	–
Total basin relief (*H*)	(Maximum elevation – Maximum elevation)	[3]
Relief ratio (Rh)	Rh = *H*/Lb where *H* = Maximum basin relief; Lb = Basin length	[19]
Ruggedness number (Rn)	Rn = *H* × Dd where *H* = Maximum basin relief; Dd = Drainage density	[3]
Relative relief (Rp)	Rp = *H* × (100)/*P* where *H* = Maximum basin relief; *P* = Basin perimeter	[25]

Table 4
Morphometric parameters (linear aspects) of Moridhal watershed

Stream order (u)	Number of stream (Nu)	Stream length (Lu)	Mean stream length (Lsm)	Stream length ratio (RL)	Bifurcation ratio (Rb)	Rho coefficient (ρ)
I	36	119.87	3.33	–	2.57	–
II	14	81.73	5.84	0.68	2.80	0.26
III	5	14.16	2.83	0.17	5.00	0.06
IV	1	6.02	6.02	0.43	–	0.08
Total	56	221.78		1.28	10.37	0.41

3.1.1.5. Bifurcation ratio

The bifurcation ratio (Rb) is a dimensionless property and shows the degree of integration between streams of various orders in drainage. A high bifurcation ratio (>5) indicates the distorted drainage pattern which exits in the regions of steeply dipping rock strata. The calculated value of the bifurcation ratio for the Moridhal watershed was found to be 2.57, 2.80, and 5.00 for I, II, and III order streams, respectively. The bifurcation ratio of the Moridhal watershed was not the same from one order to the next which might be due to the possible variations in basin geometry and lithology. A similar finding was also reported by the study of Desai et al. [28].

3.1.1.6. Rho coefficient (ρ)

Rho coefficient represents the relationship between drainage density and physiographic development of a watershed which helps in evaluating the amount of water storage capacity in a watershed. The higher values of the Rho coefficient indicate a high capacity for the storage of water. The Rho coefficient for the Moridhal watershed was computed to be 0.41, which indicated high capacity of hydrologic storage during the period of floods.

3.1.2. Aerial aspects

Various morphometric properties related to the aerial aspects were computed for the Moridhal watershed and the results are presented in Table 5.

3.1.2.1. Basin area

The rate of runoff of any drainage basin depends on its area and physiography. The larger the basin area (*A*), the smaller is the runoff and vice versa. A relation between the total basin areas and the total stream lengths was established by Schumm [19]. The basin area for the Moridhal watershed was found to be 307.30 km^2 and 7.48 km, respectively.

3.1.2.2. Basin length

Basin length (Lb) is the lengthiest (outlet and farthest) measurement of the basin parallel to the principal drainage line [19]. High basin length signifies elongated basin. The calculated value of basin length for the Moridhal watershed was 41.11 km which indicated that the watershed was elongated in nature.

3.1.2.3. Basin perimeter

The basin perimeter (*P*) is the outer boundary of the drainage basin that encloses its area and is measured along the divides between basins. The basin perimeter may be used as an indicator of basin size and shape [19]. The basin perimeter for the Moridhal watershed was found to be 81.69 km.

3.1.2.4. Drainage density

The drainage density (Dd) is the measure of the total length of the stream segments of all orders per unit area

Table 5
Morphometric characteristics (aerial aspects) of Moridhal watershed

Aerial parameters	Value	Sl. No	Aerial parameters	Value
Basin area	307.30 km^2	9	Drainage texture	0.69
Basin length	41.11 km	10	Drainage intensity	0.25
Basin perimeter	81.69 km	11	Elongation ratio	0.48
Drainage density	0.72 km/km^2	12	Infiltration number	0.13
Drainage pattern	Dn and Rn	13	Circulatory ratio	0.58
Lemniscate's	5.50	14	Form factor ratio	0.18
Length of overland flow	0.69	15	Constant of channel maintenance	1.39
Stream frequency	0.18	16	Compactness coefficient	1.31

of the watershed. The calculated value of drainage density for the Moridhal watershed was found to be 0.72 km^2 which could be the result of permeable subsurface material, dense vegetation, and low relief [29].

3.1.2.5. Drainage pattern

The drainage pattern (Dp) reflects the impact of slope, lithology, structure and it helps in recognizing the stage in the cycle of erosion. The drainage pattern for the Moridhal watershed was found to be dendritic and radial which indicates that the time of formation of the drainage basin was longer [15].

3.1.2.6. Lemniscate's

The Lemniscate's (K) value for the Moridhal watershed was calculated to be 5.50. It indicated that the watershed covers the maximum area in its regions of beginning with a large number of streams of a lower order [30].

3.1.2.7. Length of overland flow

The length of overland flow (Lg) refers to the length of water flow over the land surface before it is concentrated into defined stream channels [11]. The value of the length of overland flow for the Moridhal watershed was calculated to be 0.69 km. A relatively higher value of the length of overland flow indicated low relief which suggested low surface runoff in the study area.

3.1.2.8. Stream frequency

The stream frequency (Fs) is associated with lithology, degree of slope, stage of the fluvial cycle, and amount of surface runoff. The calculated value of the stream frequency for the Moridhal watershed was found to be low (0.18) which indicated permeable sub-surface material, high infiltration, and low relief condition coupled with relatively lesser erosion [31].

3.1.2.9. Drainage texture

The drainage texture (Dt) refers to the relative spacing of drainage lines and reflects on the basic lithology, infiltration capacity, and relief of the topography. The drainage density has been classified into five textures [32] which are: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8). The calculated value of drainage texture for the Moridhal watershed was 0.69 which indicated that the drainage texture of the watershed was very coarse. The lower texture ratio indicated lesser runoff and high infiltration capacity.

3.1.2.10. Drainage intensity

Drainage intensity is important for studying runoff potential, climatic condition, landscape, and infiltration capacity of the land of the basin. The lower value of drainage intensity of the Moridhal watershed (0.25) implies that the basin area was highly susceptible to flooding; gully erosion and landslides as surface runoff were not quickly removed from the watershed.

3.1.2.11. Elongation ratio

The elongation ratio (Re) is a measure of the shape of the river basin and it depends on the climatic and geologic types. The elongation ratio has been classified by [3] into three categories, viz., circular (>0.9), oval (0.9 to 0.8) and less elongated (<0.7). The calculated value of elongation ratio for the Moridhal watershed was 0.48, which indicated moderate relief with a lesser elongated shape.

3.1.2.12. Infiltration number

The infiltration number (If) exhibits an inverse relationship with the infiltration capacity of the basin [33]. The calculated value of infiltration number for the Moridhal watershed was found to be 0.13 km/km^2 which indicated that due to high infiltration, the runoff loss from the watershed would be low.

3.1.2.13. Circulatory ratio

The circulatory ratio (Rc) is mainly controlled by geology and slope, structure, relief, stream frequency, climate, and length and land use/land cover within the basin area. The higher the circulatory ratio value, the higher is the flood hazard at peak time at the outlet point. The value of the circulatory ratio for the Moridhal watershed was 0.58, which indicated that the studied basin was elongated and had permeable sub-soil which was associated with the low discharge of runoff materials [24]. A similar circulatory ratio (0.61) was also observed by Narmatha et al. [34] in the Ponnaiyar River basin of Tamilnadu, India indicating low runoff discharge and highly permeable sub-soil.

3.1.2.14. Form factor

The calculated value of the form factor for the Moridhal watershed was 0.18. A lower value of form factor indicated that the shape of the basin was elongated and flows for a longer duration. A low form factor (0.22) was also observed by [35] in the Vishav drainage basin of Maharastra, India indicating a flatter peak of flow for a longer duration in the basin.

3.1.2.15. Constant of channel maintenance

The calculated value of the constant of channel maintenance (*C*) for the Moridhal watershed was found to be moderate (1.39 km^2/m). The moderate value of *C* indicated moderate to high permeability, moderate slope, and moderate surface runoff [36].

3.1.2.16. Compactness coefficient

The compactness coefficient (Cc) has a direct relation to the erosion risk assessment. Lower values of compactness coefficient signify lesser vulnerability for risk factors, while higher values indicate greater vulnerability and represent the need for implementation of conservation measures [37]. The value of compactness coefficient of the Moridhal watershed was 1.31 which indicated that the studied area has moderate erosion status.

3.1.3. Relief aspects

The results of morphometric parameters related to relief aspects of the Moridhal watershed are presented in Table 6.

3.1.3.1. Basin relief

The basin relief (*H*) refers to the elevation differences between the lowest and highest altitude in a basin. The basin relief for the Moridhal watershed was calculated to be 45 m. The lower value of basin relief indicated higher infiltration and lower runoff which was in accordance with the findings of Chaudhari and Kumar [36].

3.1.3.2. Relief ratio

The relief ratio (Rh) is a measure of the overall steepness of the drainage basin and, thereby, can identify the erosion intensity on the slopes of the basin. The relief ratio normally increases with decreasing drainage area and size of the watershed of a given drainage basin [38]. The calculated value of relief ratio for the Moridhal watershed was 0.0011 which indicated gentle slopes in the study area. The results are in conformity with the finding of Sahu et al. [39] for a similar type of watershed in the Nagpur district of Maharashtra, India.

3.1.3.3. Ruggedness number

The ruggedness number (Rn) signifies the susceptibility of the basin to soil erosion. A higher value of ruggedness number implies more proneness to soil erosion and vice versa. The calculated value of the ruggedness number for the Moridhal watershed was 0.03, which indicated that the basin area had a gentle slope and was less prone to soil erosion. Similar results were reported by Nigam et al. [40] in the Seonath River of Chhattisgarh, India.

Table 6
Morphometric characteristics (relief aspects) of Moridhal watershed

Relief parameters	Value
Maximum elevation, m	140
Minimum elevation, m	95
Basin relief (*H*), m	45
Relief ratio (Rh)	0.0011
Ruggedness number (Rn)	0.03
Relative relief (Rr)	0.055%

3.1.3.4. Relative relief

The relative relief (Rr) is the ratio of the maximum watershed relief (*H*) to the perimeter (*P*) of that watershed. The value of relative relief is lower for an elongated basin. The calculated value of relative relief for the Moridhal watershed was 0.055 percent which indicated that the basin is elongated in shape and has a moderate status of erosion [41].

4. Conclusion

Remote sensing and GIS techniques were used to study the morphometric characteristics of the Moridhal watershed in the Dhemaji District of Assam, India. The computation of linear, areal and relief parameters of the watershed establishes the correlation between hydrological behavior and landforms, which is helpful for water management activities. Based on the morphometric studies, the watershed was found to have fourth-order drainage streams having a total stream length of 221.78 km. The lower value of the bifurcation ratio and the dendritic type of drainage pattern indicates that the watershed has suffered less structural disturbance. High values of form factor, elongation ratio, as well as circularity ratio, indicated the elongated nature of the watershed. The lower drainage density shows that the area is highly susceptible to flooding and gully erosion. The results observed from the analysis could be helpful for watershed prioritization with respect to erosion. The drainage morphology needs to be explored for locating and selecting the water storage structures like percolation tank, pond, check dams, etc. This work shall prove beneficial to the planners and decision-makers for proper natural resource management at the micro-level. The study also demonstrates that remote sensing and GIS are efficient and effective tools over conventional methods in delineating drainage basins and updating drainage streams for analysis of stream morphometry.

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