Eco. Env. & Cons. 31 (4) : 2025; pp. (1495-1503)
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ISSN 0971–765X

DOI No.: **http://doi.org/10.53550/EEC.2025.v31i04.024**
Website: www.envirobiotechjournals.com

Morphometric Analysis of Dhalai River Basin using GIS and Remote Sensing

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(Received 29 July, 2025; Accepted 25 September, 2025)

ABSTRACT

GIS and Remote sensing approach is an effective tool to determine the morphological characteristics of the basin. The Dhalai River basin located between 23°49′6′′and 24°13′41′′N latitudes and 91°45′56′′ and 91°57′47′′ E longitude. The present study addressed linear, areal and relief aspects of the drainage basin. Toposheets and SRTM (Shutter Radar Topography Mission) DEM at 30 m resolution has been used to delineate the basin and drainage network in the Arc GIS software.From this study we have derived that the basin is having sub-dendritic pattern and the average drainage density of the basin is 4.1km/km² which indicates, moderate drainage texture and steeply to very steeply sloping mountainous terrain with variation in vegetation coverage. The elongation ratio of the Dhalai River basin is 0.19 which implies that the basin is elongated. Morphometric analysis based on GIS & Remote sensing techniques is a competent tool for hydrological studies. The present study would be beneficial to various decision-makers and policy makers for the integrated river basin management.

Keywords: *Dhalai, Morphometric Analysis, Drainage basin, Drainage system, GIS, DEM*

Introduction

The systematic study of drainage encompasses within its bounds numerous aspects of its distributional character such as drainage patterns, drainage density i.e., the measure of the- drainage frequency, profile characteristics of the main and sub-streams, etc., (Singh, 1980). Drainage basin analysis is one of the important criteria for any hydrological investigations. It provides valuable information regarding the characterization of a basin must include the quantitative description of its drainage system as it is considered a crucial aspect (Strahler, 1964). The term ‘Morphometry’ literally means measurement of forms introducing quantitative description for landforms (Horton, 1945). The morphometric study of the drainage basin provides accurate information on measurable features of the stream network of the river basin. The various morphometric parameters like area, altitude, volume, slope, profile and texture of landforms comprise important parameters of study (Dury, 1952). Remote Sensing and GIS techniques are proven efficient tools in any hydrological investigation like the assessment of water resources. In recent years, drainage delineation, updating, and morphometric analysis of basins are frequently performed using Remote Sensing and GIS techniques. In India, some recent studies on morphometric analysis using remote sensing and GIS technique are done by Pareta and Pareta (2011), Magesh *et al*., (2012), Kumar *et al.* (2014), Gajbhiye (2015), Gupta and Punwatkar (2017), Manjunatha *et al.* (2017).

The Dhalai River, being rainfed, carries a significant amount of water, especially in the monsoon season. This abundance of water often leads to flooding in the lower portions of the valleys. Additionally, the forceful flow of water can occasionally result in alterations to the river's course (Chatterjee, 1984). During the winter season, the water level of these rivers falls drastically and the rivers become almost stagnant, the channel sometimes gets disconnected (Chatterjee, 1984).

Study Area

DhalaiRiver located in India (Dhalai District, Tripura) as well as in Bangladesh. The Dhalai river basin is located between 23°49′6′′N and 24°13′41′′N latitudes and 91°45′56′′E and 91°57′47′′ E longitude (**Figure 1**). The Dhalai River rises in the Dolajari peak of the Longtarai range having a total length of about 117 km. (Chatterjee). The Dhalai river flows towards the north through the parallel hill ranges of Atharamura and Longtarai, entering Bangladesh near Kamalpur and meeting with the Manu River southwest of Rajnagar. The combined rivers then flow towards Maulvi Bazar before turning north and eventually emptying into the Kushiyara at Manumukh (Murshed 2012). The entire river basin in India is contained within the Dhalai district, which is named after the river, covering an area of 592 sq.km with altitudes ranging from 27 m to 510 m. The basin is bordered by Bangladesh and the Unakoti district of Tripura to the north, its own district to the south, and the Manu basin to the east with the north district of Tripura and Khowai districts of Tripura to the west.

Table 1. Data Source

DATA	YEAR	SOURCE
78P/16 Open Series map with scale of 1:50000	2018	www.surveyofindia.gov.in
79M/13 Open Series map with scale of 1:50000	2010	www.surveyofindia.gov.in
SRTM DEM	2021	USGS

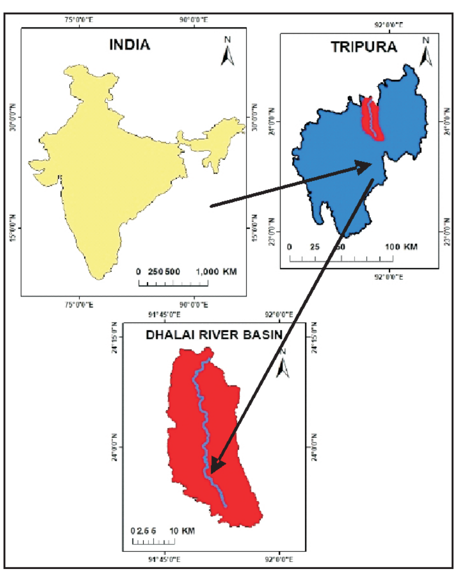

Fig. 1. Location map of study area

Materials and Methods

The base map (Figure 1) has been prepared from Open Series map with scale of 1:50000 Topographical maps were georeferenced and mosaicked for the entire study area. Dhalai River Basin was digitized in a GIS environment with the help of Arc-GIS 10.8 software assigning Universal Transverse Mercator (UTM), World Geodetic System 84 (WGS dating from 1984). Stream order and drainage network map have been prepared manually from OSM and ArcGIS10.8 software, and other maps like drainage density map, slope map were created from extracted DEM **(Figure 3)** based on the study area. Different morphometric parameters and empirical formulae are used in the study.

Results and Discussion

The total basin area of the Dhalairiver is 592.71 km^2. The drainage pattern is a dendritic pattern and it is dependent on the topography, geological and rainfall conditions of the area. Aster DEM is used to make slope, aspect and contour maps of the basin. Based on the stream order, the Dhalairiver basin is designated as the 7th order basin. In the present study, the morphometric analysis has been carried out about parameters such as stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, basin relief, relief ratio, channel gradient using mathematical formulae as given in **Table 2** and the following calculation and evaluation have shown the descriptions regarding the basin characteristics.

Morphometric Characteristics

The various morphometric parameters such as linear aspects, areal aspects & relief aspects were computed using the methods of Horton (1945), Strahler

(1964), Schumm (1956) for linear aspects studies, for areal aspects studies using Horton (1945), Miller (1953) and Schumm (1956), Horton (1932), technique, and the technique applies to relief aspects are Schumm (1956) and Miller (1953). The following calculation and evaluation have shown the descriptions regarding the basin characteristics.

Linear morphometric parameters

Linear aspects give information about one-dimensional parameters like Stream Order, Stream length ratio (RL), Bifurcation Ratio, mean bifurcation ratio (Rbm), Stream Length, mean stream length (Lsm). This indicates channel patterns of the drainage network with the topological characteristics of the stream segments and analysis are based on open links of the stream network.

Stream order

It is a method of classifying streams and rivers based on their relative size and hierarchical position in the drainage network. Stream order is the first step of the quantitative analysis of the watershed. It is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold, *et al.*, 1964). For the analysis modified Horton's law by (Strahler, 1964) Figure 3, has been followed because of its simplicity. The designation of stream segment order is based on the size and branching of the streams. The smallest streams, without any tributaries, are classified as 1st order. When two 1st order streams meet, they form a segment of 2^{nd} order. Similarly, two 2^{nd} order streams combine to form a stream segment of 3rd order, and this pattern continues for higher order streams. While designating stream order between two channels of different order than the higher order. The observation shows that Dhalai river has up to 7th order tributaries where 1st, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th} and 7^{th} stream are 2636, 631, 167, 55, 18, 4 and 1 respectively in numbers (Figure 3), Table 3 depicts the

Table 2. Strahler's scheme of stream ordering

Stream order	No. of streams	Bifurcation ratio (Rb)= Nμ/(Nμ+1)
1	2636	4.18
2	631	3.78
3	167	3.04
4	55	3.06
5	18	4.50
6	4	4.00
7	1	

relationship of the number of streams and stream order. Stream order can also be used to guide management and restoration efforts, such as prioritizing conservation efforts in high-order streams (Strahler, 1952).

Avg=3.76

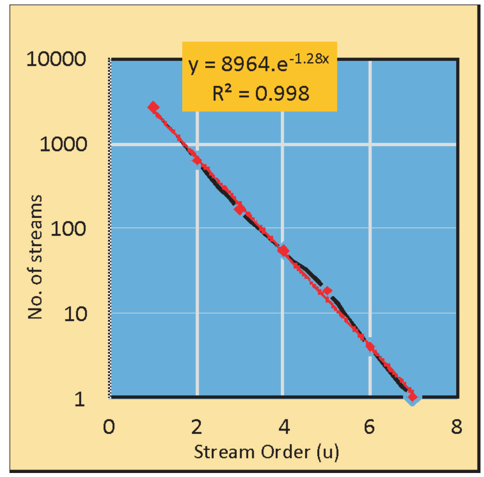

Fig. 2. No of Streams vs Stream Order

Bifurcation ratio (Rb)

This is an important parameter that helps to understand the drainage characteristics and the hydrological processes operating in a river basin. The bifurcation ratio is mainly used in drainage basin analysis. The bifurcation ratio quantifies the branching pattern of a drainage network by comparing the total number of stream segments at one order to the total number of stream segments at the next higher order within a drainage basin (Schumm, 1956). Theoretically minimum bifurcation ratio is 2.0 and generally natural drainage systems have Rb values between 3.0 and 5.0 (Strahler, 1964). The bifurcation ratio of drainage basin is highly influenced by the geological characteristics like terrain, structure, slope of terrain and amount of water. If Rb value is low (between 2.0 and 3.0), it indicates plain terrain, permeable and soft bed rock, which facilitates sufficient time for infiltration and also makes a better groundwater recharge potential zone.

Where in this study, the average Rb of Dhalai river basin is 3.76 (Table 2), which indicates moderate hilly region, moderate ground slope and moderate permeability of bed rocks

Stream length (Lu)

Length of the stream is higher in first order and it decreases as stream order is on the increase (Waikar

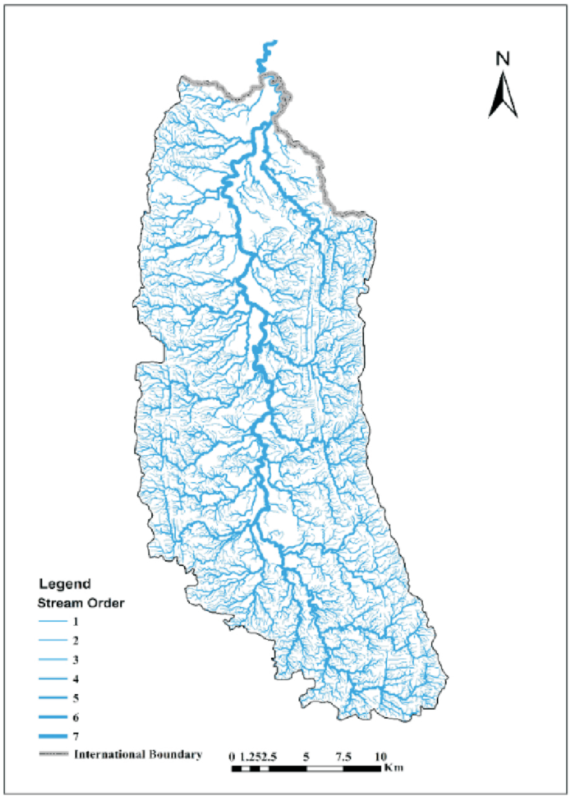

Fig. 3. Strahler stream order of the Dhalai river basin, Tripura, India

and Nilawar, 2014). High stream length indicates flatter gradients and small stream length represents high slope and fine texture. Figure 3 depicts the relationship of the stream number and stream length. The 1st, 2nd, 3rd& 4th order drainages are confined predominantly to hilly areas whereas the 5th, 6th and 7th order drainages are characteristic of gentle and flat surfaces. The total length of 1st and 2nd order streams contributes about 75 % of the total stream length,

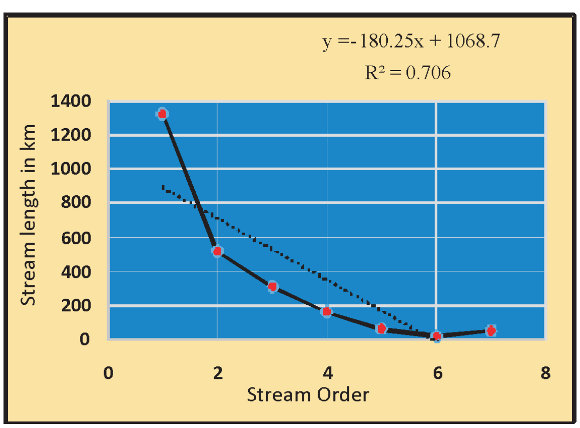

Fig. 4. Stream Order vs Stream length

while all the other stream orders together share the remaining 25%. The stream length of different order wise was computed based on the law proposed by (Horton, 1945) using Arc GIS Figure 3. The total stream length of all order in the study area is 2433.84km.

Mean stream length (Lsm)

The mean length of a channel is a dimensional property and reveals the characteristic size of drainage network components and contributing basin surface. The mean stream length is calculated as per (Horton) by dividing the total stream length of given order by number of streams of that order, Table 3 shows that the mean length in the study area ranges from 0.50 to 49.91. The result also shows that a particular order is greater than that of the next order and less than that of its next higher order.

Table 4. Mean Stream length measurement

Stream order(u)	No. of streams (Nu)	Length (km)	Mean stream length (Lsm) km	Stream length ratio (RL)
1	2636	1319.59	0.50	
2	631	514.33	0.82	0.60
3	167	309.36	1.85	0.4
4	55	159.84	2.91	0.63
5	18	61.62	3.42	0.85
6	4	19.19	4.80	0.71
7	1	49.91	49.91	0.09
Total	2433.84			

Stream length ratio (RL)

It is the ratio of the mean length (Lμ) of all the stream segments of a given order (ì) to the mean length of the streams of the next lowest order (Lμ-1), with the help of stream length ratio we can determine discharge of surface flow and erosional stage of the basin (Horton, 1945). In the Dhalai basin 5th-order stream has highest stream length ratio (0.85), 7th order stream has lowest value of stream length ratio (0.09), the highest value indicates that the area drained by the 5th-order stream is enough permeable, gradients are gentler than in the area drained by the lower-order streams.

The calculation is shown in (Table 3).

Basin Elevation

Digital Elevation Model (DEM) is frequently used to refer to any digital representation of a topographic surface. For this study area SRTM DEM of 30 meters resolution from USGS has been downloaded and after computing in ARC GIS its elevation starts from 22m to 510m.Colour in red depicts highest elevation, deep green represents low lying areas, yellow and orange depicts moderate elevation.

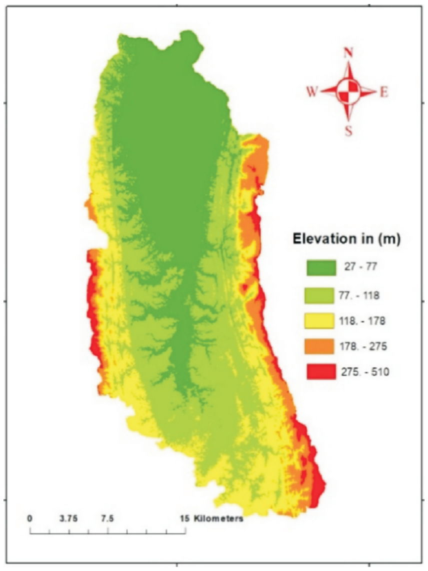

Fig. 5. Elevation Map of the Dhalai river basin, Tripura, India.

Areal Aspects

Areal Aspects refer to shape and area of the basin and related parameters.

Drainage Density

It is the ratio of total stream length of all orders to the total area of basin or in other words stream length per unit area (Strahler, 1964). It can be derived as follows:

$$Dd = \frac{\Sigma Lu \text{ Total length of all stream) km}}{\text{A (Area of the basin) km}^2}$$

In the present study, the drainage density of the whole basin is 4.1km/km² which indicates, moderate drainage texture and steeply to very steeply sloping mountainous terrain with variation in vegetation coverage. The drainage density map for Dhalai river basin was generated (Figure 5). The map shows that the middle section south-north & north eastern region has high drainage density and eastern most and western most regions have comparatively low drainage densities. This was accom-

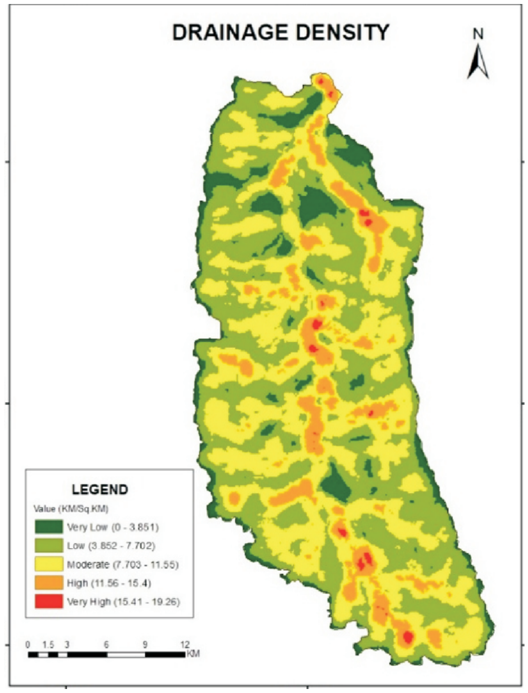

Fig. 6. Drainage density map of the Dhalai river basin, Tripura, India.

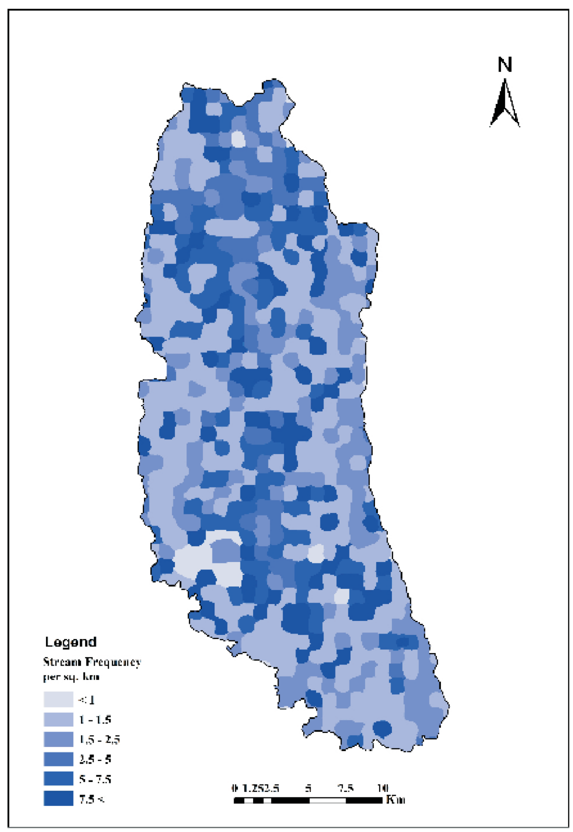

Fig. 7. Drainage Frequency map of the Dhalai river basin, Tripura, India

plished using the ArcGIS10.8, this drainage system was classified into 5 km × 5 km grids and drainage densities were calculated for each grid.

Stream frequency (Fs)

The stream frequency (Fs) of a basin may be defined as the total number of stream segments within the basin per unit area (Horton, 1945). Stream frequency exhibits a positive correlation with drainage density in the basin indicating an increment in stream population with respect to an increase in drainage density. The Fs for the basin is 5.9/km thus, the stream frequency falls under the moderate frequency class in the study area. Greater the drainage density and stream frequency in a basin, the runoff is faster, and therefore, flooding is more likely in basins with a high drainage and stream frequency (Kale and Gupta, 2001).

Form factor (Ff)

The form factor is essential to explain the flow property of the drainage basin. It is computed by dividing the basin area by the square of the basin length. When the value of the form factor decreases, the basin will come more elongated. The smaller the form factor with more elongated shape, low runoff will generate with a long run off duration, whereas rounded-shape watershed with high value of form factor experiences high run off with short time of concentration and is highly sensitive to flooding. The maximum threshold value of form factor is less than 0.7854 (Waikar and Nilawar, 2014). The form factor ratio value for this study area is 0.02 which indicates lower value of form factor and thus the basin is with low pick flow and longer duration due to elongated basin.

Circularity Ratio Rc

Circularity ratio is the ratio of the area of the basin to the area of a circle, with a perimeter equal to the perimeter of the basin (Miller, 1953). Circularity ratio, according to Miller (1953), is an important ratio that defines a watershed's dendritic stage. This is primarily owing to the basin's varied slope and relief structure. Stream length and frequency, geological structure, land use/cover, climate, undulations, and basin slope are the factors which affects the circularity ratio (John Wilson *et al*., 2012). In this study Rc value is 0.36, respectively indicate elongated to slightly elongated shape of the basin

Drainage texture

It is the total number of stream segment of all orders per perimeter of that area (Horton, 1945). Drainage texture means relative spacing of drainage lines (Smith, 1950), the mathematical value of drainage texture is the product of drainage density (Dd) and Stream frequency (Fs). The term drainage texture indicates relative spacing of the streams in a unit area along a linear direction (Howard, 1967). Drainage texture of any drainage basin depends on climate, rainfall, vegetation, soil and rock types, infiltration rate, relief and the stages of development (Horton, 1945; Smith, 1950). Vegetation covers play an important role in determining the drainage texture and density (Kale annd Gupta, 2001). Smith (1950) has classified texture of a basin as coarse (15 per km). In the present study the average drainage texture value of the whole Dhalai basin is 28.91, which falls under the Ultra fine texture category?

Elongation Ratio (Re)

Elongation ratio (Re) Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1964). Schumm's ratio shows values between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying index of elongation ratio can be classified as; circular (0.9-0.10), oval (0.8- 0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). The value of Re for the Dhalai basin was found to be 0.19 which is found to be elongated.

Length of overland flow (Lg)

Length of overland flow (Lg) The Length of Overland Flow (Lg) is defined as the length of water over the ground before it gets concentrated into the mainstream which affect the hydrologic and physiographic development of the drainage basin (Horton, 1945). The high Lg value indicates that the rainwater had to travel a relatively longer distance before getting concentrated into stream channels (Chitra *et al.,* 2011). The value for the length of overland flow in this study is 0.12 km which shows lower distance runoff in the study area.

Relief morphometric parameters

The relief aspects of the drainage basins are significantly linked with the study of three- dimensional features involving area, volume and altitude of vertical dimension of landforms to analyse different geo-hydrological characteristics. Some of the important relief parameters that are related to the study have been analysed as shown below.

Relative relief (R)

It is the relative difference in elevation between a morphological feature and those features surrounding it.Morphological characteristic of a catchment was derived manually from topographic map of the watershed and Geographical Information System (GIS). In the study area, the value of relief ratio was 2856m.

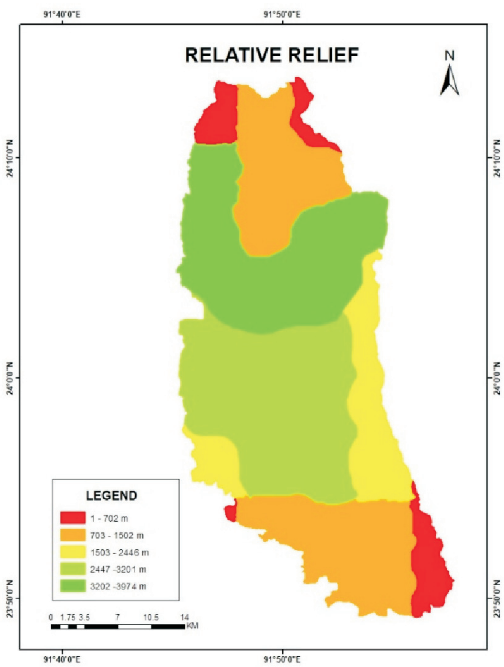

Fig. 8. Relative Relief map of the Dhalai river basin, Tripura, India

Relief ratio (Rr)

Relief ratio (Rr) measures the overall steepness of a drainage basin and is an indicator of the intensity of erosional process operating on slope of the basin. Relief ratio (Rr) is the ratio between the basin relief (R) and the basin length (L). It is influenced by the nature of rocks and slope of the basin. If Rr value is high, it indicates a hilly region and a low value relief ratio represents pediplain and valley region (Kumar *et al.* 2011). It is expressed as: Rr =R/ L,

The relief ratio **0.03** of the basin is that indicates moderate relief and steep to moderate slope

Ruggedness number (Rn)

Ruggedness number is the product relief of basin (H) and drainage density (Dd). It gives an idea of overall roughness of watershed. The Ruggedness Number of the Dhalai basin was 1.9 to be indicating that low value of ruggedness and basin implies that area is less prone to soil erosion and haveintrinsic structural complexity in association with relief and drainage density.

Basin slope

Basin slope refers to the gradient or steepness of the terrain within a drainage basin. It is an important parameter in hydrological and geomorphological studies as it affects various processes and characteristics within a basin. Basin slope plays a significant role in determining the flow of water, erosion rates, sediment transport, and overall watershed dynamics. In hydrological modeling, basin slope is a crucial input parameter for simulating surface runoff, estimating peak flows, and predicting flood risk areas. Steeper slopes contribute to higher velocities and volumes of runoff, potentially leading to flash floods and increased erosion. Understanding the basin slope allows for better predictions and management of water resources within a watershed.

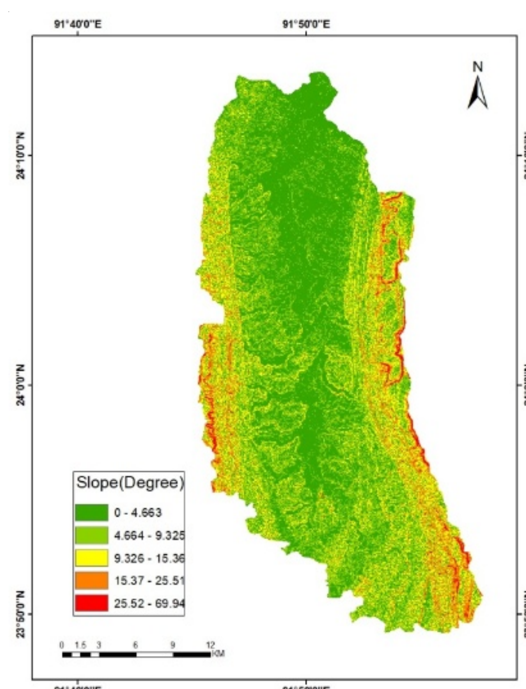

Fig. 9. Slope map of the Dhalai river basin, Tripura, India

Conclusion

The present study has proved that the geo-processing technique used in GIS is an effective tool for computation and analysis of various morphometric parameters of the basin. The study reveals that remote sensing data GIS based approach in evaluation of drainage morphometric parameters is more appropriate than the conventional methods. Morphometric analysis of the Dhalai River basin has been delineated, based on several drainage parameters using Open Series Map, satellite data and latest GIS tools for drainage analysis. The Dhalai River basin is well drained with the stream order varying from 1 to 7. In the given area, the Bifurcation Ratio of the basins is 3.76 (Table 6), which indicates moderate hilly region, moderate ground slope and moderate permeability of bed rocks. Morphometric analysis revealed that the Dhalai drainage basin is characterized by dendritic drainage pattern. The development of stream segments in the basin area is more or less affected by rainfall. Dhalai river has up to 7th order tributaries, total stream length of the study area is 2433.84km, drainage density of the whole basin is 4.1km/km² which indicates, moderate drainage texture and steeply to very steeply sloping mountainous terrain. In this study Circulatory (Rc) value is 0.36, respectively indicate elongated to slightly elongated shape of the basin, Relief ratio 0.03 of the basin is that indicates moderate relief and steep to moderate slope. The Ruggedness Number of the Dhalai basin was1.9 to be indicating that low value of ruggedness and basin implies that area is less prone to soil erosion. The present study is very helpful for basin and watershed development and assist the planner and decision makers in basin development and management studies. The present is also very helpful for sustainable development of natural resource management at micro watershed of the Dhalai basin.

Conflict of Interest- None

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