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Morphometric analysis of Umtung River basin using GIS and Remote Sensing.

JONESTAR LYNGDOH NONGLAIT

Department of Geography, Union Christian College, Umiam Khwan, India.

Abstract

An investigation of morphometric parameter for the Umtung River basin, situated in Meghalaya, India, employing advanced GIS and remotely sensed data. Various morphometric parameters were quantified, including basin area (224.91 km²), length (24.32 km), perimeter (147.04 km), and drainage density (1.34 km/km²). With 255 streams overall, the research showed a clearly defined stream order system up to the fifth order. Key findings indicate that the basin exhibits low stream frequency (1.13 stream/km²) and a bifurcation ratio (Rb) averaging 4.03, suggesting a complex, interconnected hydrological system with significant tributary contributions. The sinuosity index (SI) of 1.32 indicates a moderately sinuous channel morphology. An extended basin shape that is advantageous for flood management is suggested by a low form factor (0.38) and elongation ratio (0.39). With a ruggedness number (Rn) of 1.18, a relief ratio (Rr) of 35.85, and a basin relief of 872 m, relief metrics show notable topographical diversity driven by tectonic activity and differential erosion. Hypsometric analysis indicates a mature landscape characterized by concave slopes, underscoring the erosion-dominated landforms formed over geological time.

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Digital Elevation Model (DEM); GIS; Morphometric Analysis; River Basin; Remote Sensing.

Introduction

Rivers play an integral role in maintaining balance in the ecosystem and shaping the earth's surfaces, which give rise to different types of topography, natural vegetation and climate. Because of the substantial changes in land use over the past 20 years brought about by developmental activities that negatively affect the river system's natural cycle, basin hydrology analysis is a crucial study in which various materials, techniques and instruments are employed to comprehend the hydrological resource.[1] River basin represents as one of the fundamental units of study in fluvial geomorphology.[2-4] A river basin encompasses the land area bounded by a watershed, separated by the ridge point which act as a water divide where water from river and its tributaries within the watershed converges towards a central outlet. The movement of runoff water within this region is influenced by its distinctive configurations and arrangement.[5] Slope, geological characteristics, geomorphic processes, and the temperature of the basin area across geological

CONTACT Jonestar Lyngdoh Nonglait joneslyng@gmail.com Department of Geography, Union Christian College, North Eastern Hills University, Umiam Khwan, India.

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time all have a major effect on the basin's shape and pattern.[6-7]

"Each river is fed by numerous tributaries from different direction adjusting according to the topography of the area before joining the main trunk of the river, on the process it creates valley, make adjustment along its path".[8] For nearly 150 years, Playfair's law was quoted without any attempt to test it quantitatively.[9] Horton laid the foundation in analysis the morphometric of drainage basin which further elaborated by Strahler.[10-11] Morphometry techniques entail quantifying and analysing the configuration, dimensions and features of the basin area and its landforms. These studies encompass various aspects such as area elevation, morphology, size, slope and the outlines of watersheds.[12-13] From the different calculated drainage elements, that involve stream ordering, basin area, basin perimeter, stream length of drainage channels, texture ratio, drainage density, bifurcation ratio, stream frequency, basin relief, relief ratio, ruggedness number, etc.[14–16], morphometric analysis could be assessed and examined.[17]

GIS tools have been further reinforced and made more effective in the computation of various hydro morphometric parameters by the development of remote sensing technology and the simple and free access to high-quality data resources, such as the Digital Elevation Model (DEM). [7,12,16,18-21]

With most of the river flowing in area where there are lots of anthropogenic activities, shrinking of river are contributed mainly by deforestation, expansion of agricultural activities and climate change, therefore, it is important to understand the river morphology, which give us a much-needed data for watershed and river catchment planning programme.

Study Area

The Umtung river basin is located in the State of Meghalaya, India, at latitude 920 3' 36.36'' N and longitude 250 39' 42.12'' E. It spans three districts: Ri-Bhoi, East Khasi Hills, and Jaintia Hills. The river travels 0.05 km in the Jaintia Hills, 9.65 km in the East Khasi Hills, and 25.01 km in Ri-Bhoi. The drainage basin is 224.91 km² in size. The river is bounded to the north by Umiam river and to the south by the Umkhen river. The major tributaries of the Umtung River are Umket, Wahkut, Umsarang, Umlew, UmSo, and Klew. The river flows in the northeast direction and later joins the river Umkhen, passing through Jaintia Hills before eventually entering the State of Assam.

Materials and Methods

The broad methodology adopted to achieve the objectives includes several steps. Remotely sensed DEM is downloaded from Bhuban NRSC, Open-source satellite imagery, Cartosat-1 with 30 M DEM resolution. The geospatial tool in QGIS software version 3.16 is employed to generate basin areas and extract stream networks from the DEM file. To understand the basin hydrology, morphometric techniques are used to calculate, evaluate, and analyse the different drainage basin aspects using geoprocessing tools (ArcMap 10.8).

Using the Horton (1945) method[6] for basin length, stream length, mean stream length, stream length ratio, basin perimeter, drainage density, stream frequency, texture ratio, form factors, and length of overflow, and Strahler (1964)[2] for the hierarchical method of stream ordering, a number of parameters were measured. Bifurcation ratio, sinuosity index, elongation ratio, constant channel maintenance, basin relief, relief ratio, and ruggedness number (Rn) were all calculated using Schumm's (1956) method.[30] The circulatory ratio was calculated using Miller's (1953)[4] technique. The outcomes are provided in Tables 1, 2, and 3.)

Results

Table 1: linear morphometry morphometric parameters of Umtung river drainage basin

Linear Parameters	Results
Order	1-5
Number	255
Total stream length (km)	302.73
Mean stream length (km)	
Mean length of first order stream (L̄1)	0.75
Mean length of second order stream (L̄2)	1.61
Mean length of third order stream (L̄3)	5.78
Mean length of fourth order stream (L̄4)	9.75
Mean length of fifth order stream (L̄5)	12.23
Bifurcation ratio (Rb)	4.03
Stream length ratio (r_l)	2.17
Sinuosity Index (Si)	1.32

Table 2: Basin and areal morphometric parameters of Umtung river drainage basin

Areal aspects of the basin	Results
Area (A)	224.91 km^2
Length (l_b)	24.32 Km
Perimeter (P)	147.04 Km
Drainage density (D_e)	1.34 per/ km^2
Stream frequency (Fs)	1.13 per/ km^2
Texture ratio (Dt)	1.73
Form factor (Rf)	0.38
Elongation ratio (Re)	0.39
Circulatory ratio (Rc)	0.13
Length of overland flow (Lg)	0.67
Constant channel maintenance(C)	0.75

Table 3: Relief Aspect

Relief aspect parameters	Results
Basin relief (R)	872
Relief ratio (Rr)	35.85
Ruggedness number (Rn)	1.18

Discussion

Analysis of morphometric parameters is done by quantifying different morphometric data which help us to understand the relationship between landforms evolution, it types and drainage characteristics.[22] The study relied heavily on geo-spatial data, however there are certain limitation with lack of ground truth verification, particularly in identifying the types of rock formation, soil types, vegetation and their classification. These gaps in data verification may affect the accuracy of the hydrological analysis, as such factors play a critical role in understanding water flow, infiltration rates and overall watershed dynamics in the Umtung Basin

Linear Aspect

The one-dimensional features of the drainage network that involve the mean stream length, bifurcation ratio, stream length ratio, stream length, and hierarchical order of streams are studied by the linear aspect.

Stream Ordering

To understand how stable the river in the watershed is, Strahler stream ordering was used which is the most common and widely accepted method which shows a slightly modified way of stream ordering from Horton (1945) where, “all fingertip affluents are regarded as first order and when two first order tributaries confluent forming the second order stream”,[2, 23-25] the same concept was later devised by Milton and Ollier (1965).[26] The Observation from Table 1 indicated that the river has up to 5th order of stream (Figure 2). There are 195, 49, 08, 02 and 01 number of streams for 1st, 2nd, 3rd, 4th and 5th order respectively, a total number of 255 streams. First order makes up 76.50 percent, second order 19.21 percent, third order 3.13 percent, fourth order 0.78 percent and fifth order 0.39 percent respectively.

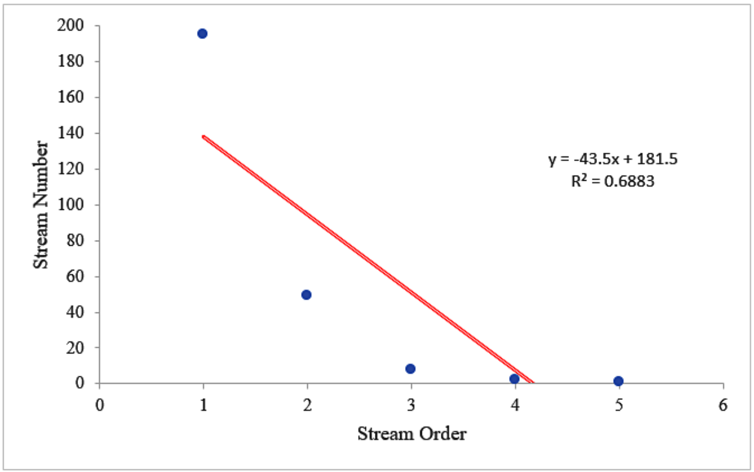

Fig. 1: Relation between order of stream and number of streams

Stream Numbers

As per Horton's law the relation of stream ordering and stream number shows approximately an inverse geometric series implies "that the stream number declines exponentially as the stream order increase.[6, 24, 27,31] There are 255 streams in all. With an elevation in stream order, Table 1 displays a deviation and fewer streams. The best fit model to describe the relationship between stream order and number" is shown in Figure 1 with R2 = 0.6883.

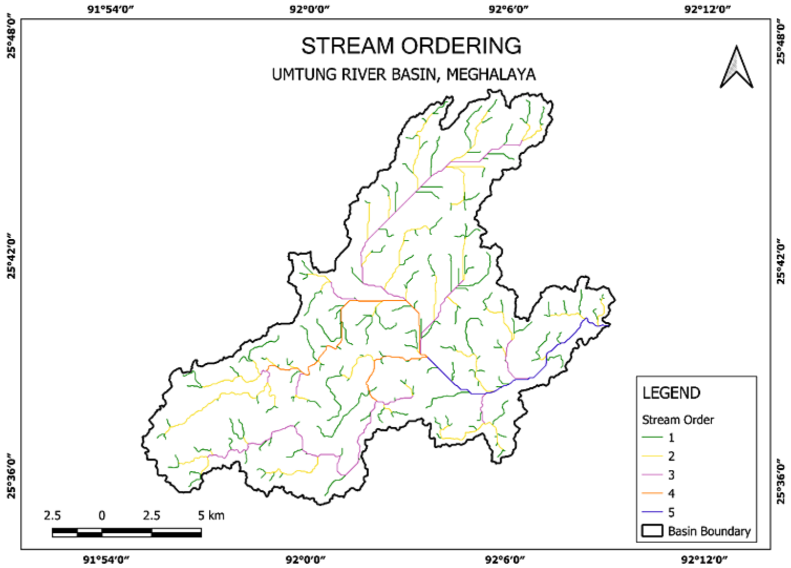

Fig. 2: Stream Ordering (Strahler's Method)

Stream Length (l^u)

Using Horton's Law of stream length (l^u), the basin obtained a l^u value of 302.73 km (Table 1) which do not form a perfect geometric series. The diagram from (Figure 3) indicates a strong relationship with R^2= 0.9007 between length of stream and ordering or stream, where higher the order its length decreases. First order has the longest stream and as the order increases their length increases. Length of stream across different orders indicates erosion and combined influence of geologic and slope on an area.[6,31] Longer streams typically suggest flatter terrain and more resistant lithological compositions. Conversely, shorter streams indicate steeper slopes and less resistant lithology.

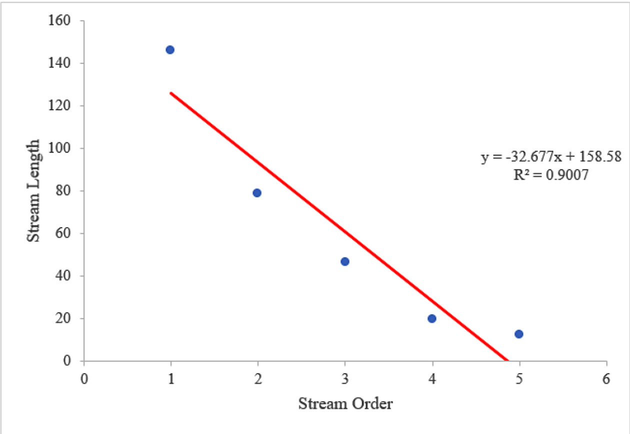

Fig. 3: Relation between stream order and stream length

Mean stream length (L')

Toward understanding the dimension, physical structure of the drainage network and its capacity to grow as more tributaries join the main channels in the network, L' is calculated using Horton's (1945)[6] formula. Strahler (1964) characterised mean stream length as an important property of a surface drainage network system. It is observed from Table 1 that there is an increase from 0.75 km in the 1st order to 12.23 km in the 5th order, whereas the value between 1st and 2nd order are close and there is a big gap between 2nd to 4th and 5th order. Higher slope within the first and second order stream are the reason for smaller length of stream.[31]

Stream Length Ratio (r_l)

"r_l tends to be uniform throughout the sequence order" (Horton 1945).[6] The length ratio (Table 2) of rl 2nd/1st (2.15), r_l 3rd/2nd (3.59), r_l 4th/3rd (1.69) and r_l 4th & 5th (1.26), with a rl of 2.17. The results suggest that with the gradual increase of 3.59 in 3rd and 2nd order and a slower decrease to 1.69 and 1.26 in the 4th and 5th order shows that the watershed has moderate slope, moderate erosion and mature landscape. These changes are also due to the differences in slope and topographic.[28]

Bifurcation Ratio (R^b)

It is the ratio of total stream number of the given order to its next lower order.[6,25,29-30] According to Strahler (1964) range of bifurcation ratio,[4] Rb values (Table 1) ranging from 2 (4th/5th) to 6.13 (2nd/3rd), this shows a moderate to high complexity especially in the higher order stream segments, suggesting a well-developed, dissected and interconnected drainage network with numerous tributaries. According to R.E Horton 1945 classification of R^b values,[6] Umtung basin have a mean Rb (4.03) which revealed that it is situated in the mountainous area. These variation in ratios revealed that the rivers respond differently to geological structure and climatic conditions. In regions with a high bifurcation ratio such as mountainous or highly dissected areas with steep terrain and numerous tributaries, the river system may efficiently drain excess water during heavy rainfall which can reduce the risk of flood.

Sinuosity Index

Leopold and Wolman claim that these three types of river networks—straight, sinuous, and meandering—are based on the sinuosity index.[32] S.A. Schumm defines channel sinuosity as a means to find out how much the river shifts from its original course than the expected path and length from the source to mouth. The sinuosity of a straight stream is 1.0, and it increases as the stream deviates from a straight path.30. Sinuosity index (SI) of 1.32 indicate a moderately sinuous channel which deviates from a straight-line path by 32% Table 1 & Figure 4 suggesting some degree of curvature and slightly meandering stream with few variations in flow velocity and sediment transport, typical of gentle slope and mature landscape complementing the results of stream length ratio.

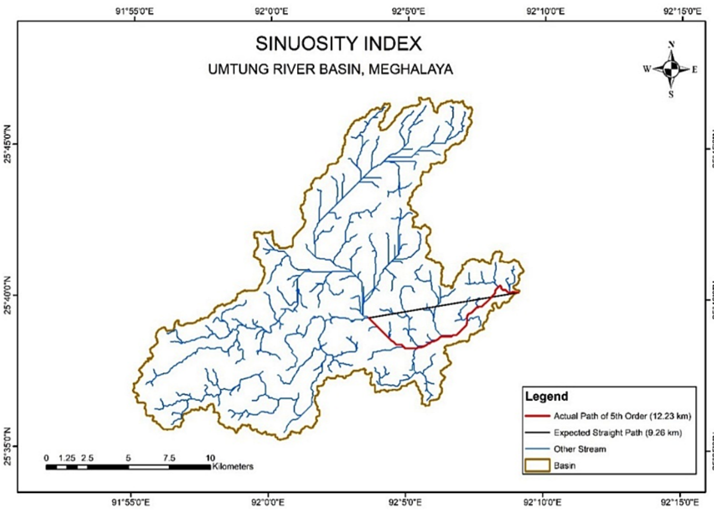

Fig. 4: Sinuosity Index (SI)

Areal Aspect

Drainage Density (D_e)

It is an important evaluation in understanding the geologic structure of an area in relation of how well-drained and poorly drained, which in turn affect the permeability and infiltration capacity, Horton suggested that there are several factors controlling drainage density.[6,31-32] The results reveal a low D_e of 1.34 km/km^2, as the stream is widely spaced having gentle slope, good infiltration and high vegetation covers.[25] However, the drainage density in the basin is not consistent within the range of class from 0 to 9.96 km/km^2 (Figure 5), where maximum area is within 3.32 km/km^2, there are area within the drainage basin which have a moderate density and high density. This shows the influence of lithology on the drainage density of the basin.[31] Higher density increases runoff and high risk of flood during heavy rainfall which occur mostly on the main branch and higher order of stream.

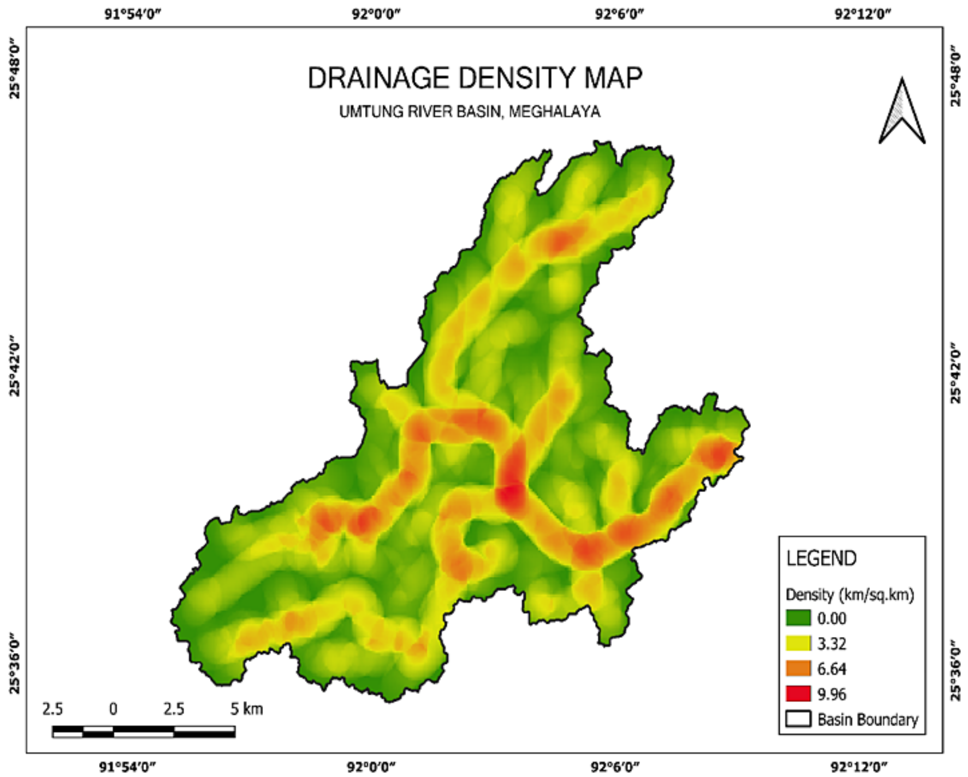

Fig. 5: Drainage Density (De)

Texture Ratio (Dt)

Dt is calculated as the ratio of the basin's circumference to the total length of all streams from each order. Climate, precipitation, rock composition, topography and stage of development are important factors that control the texture ratio where basin infiltration stand as the single most significant factor controlling texture.[6] The basin has a very coarse texture of 1.73 (Table 2) indicating a stable hydrological system with moderately infiltration capacity which is not too fast and not too slow in accordance with Horton about the positive relationship between density, frequency and texture.[31]

Stream frequency (Fs)

Regardless of order divided by the area, it is based on the number of streams per unit area.[33] Fs is mostly controlled by several natural factors such as topography, geology, soil permeability and vegetation but it may not be directly dependent to drainage density.[6,33] Umtung drainage basin has a moderate to low Fs 1.13 stream/km^2 (Table 2 & Figure 6) which indicated permeability, runoff and gentle sloping. There is a variation of stream frequency in the drainage basin which varies from moderate to low. Figure 7 show that a density and frequency data are positively correlated where all variability in frequency can be explained with linear relationship with density.

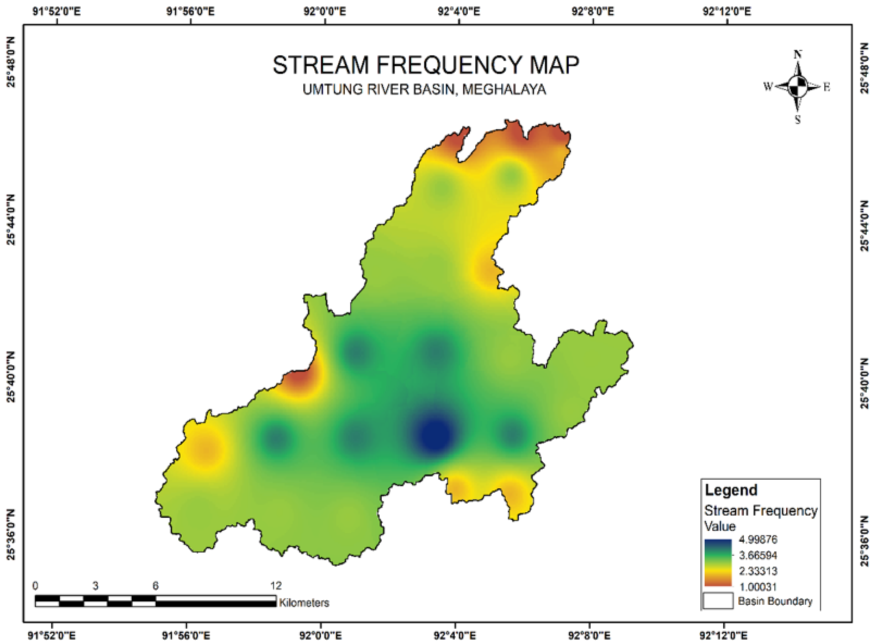

Fig. 6: Stream Frequency Map

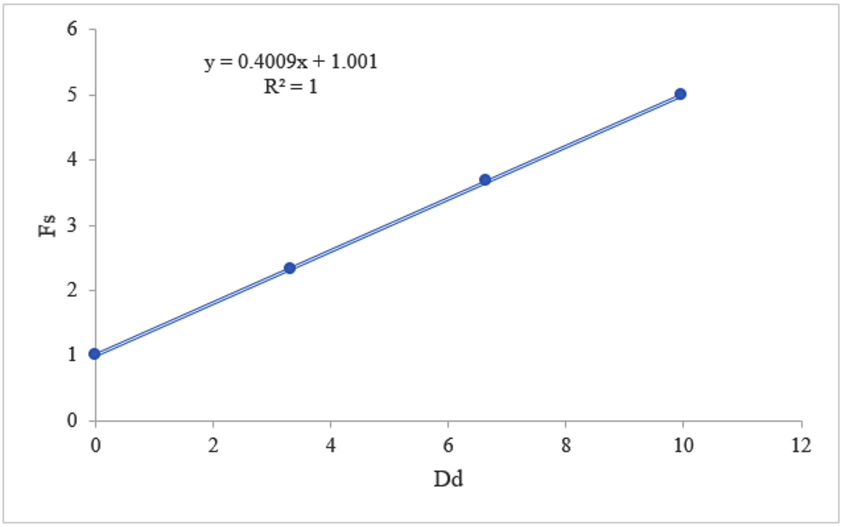

Fig. 7: Relation between drainage density and frequency

Form factor (Rf)

As per Horton (1932), form factor is the ratio of the drainage basin's width to length, which is determined by $Rf=A/(l_b)^2$.[33] Form factor value of 1 indicate basin shape which are round and circular, elongated have values of 0 to less than. This basin has a value of

0.38 (Table 2) indicating an elongated shape and low peak flows for longer duration[34] as depicted in Figure 8. Elongated form basin has a more stable and predictable flow pattern which is more manageable flood management and soil conservation.

Elongation ratio (Re)

The Re is utilized for interpreting the drainage basin's form. The diameter of a circle with the same area as the basin and the basin's longest length are employed to compute this ratio.[29] Elongation and shape range[35] classify <0.5 as more elongated, "elongated between 0.5 and 0.7, Less elongated between 0.7 and 0.8, Oval between 0.8 and 0.9, and circular between 0.9 and 0.1. A" small drainage basin with a length greater than its breadth and a quicker rate of water discharge during periods of heavy rainfall that impact erosion is indicated by the elongated ratio of 0.39 (Table 2).

Circulatory ratio (Rc)

Miller "(1953) employed circularity, which is impacted by the lithological features of the watershed, to compare the surface area of the watershed to the size of a circle with the same perimeter as the watershed. The Rc value of the basin is 0.13 (Table 2) which according to Miller's classification refer to a dendritic pattern that is common in regions which has gentle slopes and also implies that the basin is at the initial stage of development[1]

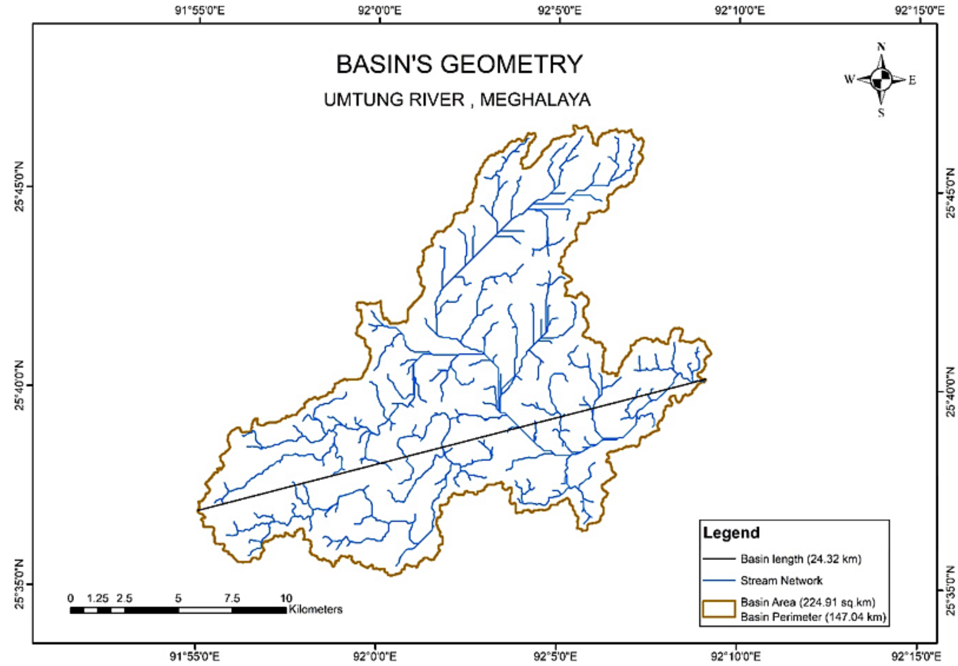

Fig. 8: Basin Geometry

Length of Overland Flow (Lg)

According to Horton, Lg is the amount of time that water flows over the ground before its accumulation into distinct stream channels.[6] One important independent variable that has a big impact on drainage basins' hydrological and physiographic evolution is Lg.[6] This basin's Lg value is 0.67 (Table 2), indicating that 0.67 kilometers must pass before the precipitation enters the main canal. More surface runoff enters the stream when the overland flow is shorter.[36]

Constant Channel Maintenance (CCM)

To measure watershed erodibility Schumm Constant of channel maintenance is used to find out area in the watershed or drainage basin to support and maintain a certain length of river or stream.[29] The property utilized to define overland flow is CCM, which is the inverse of drainage density.[29] The CCM value of 0.75 suggests a gradual infiltration, permeability of the materials, lower surface runoff, and fairly good vegetal cover.[36]

Relief Aspect

Basin Relief (R)

Understanding the basin's hydrological morphology, which is influenced by the land's structure, composition, and drainage properties, requires an understanding of its relief. The findings will have an impact on the river basin's erosional phases.[36] The R and H (Figure 9, 10) values are 1616 and 744, respectively, where the R is 872 (Table 3). The basin represents high relief, indicating youthful stage in the evolution of the river with pronounced variations in elevation within the basin and at the early stage in the cycle of erosion as per the W M Davis 1899, affected by differential erosion.

Relief Ratio (Rr)

A dimensionless ratio called the relief ratio provides a useful evaluation of the watershed's gradient characteristics by comparing the height of the basin to its length.[29] It displays the drainage basin's overall slope and associated deterioration processes.[29]. The Rr value is 35.85 (Table 3), showing low ratio, which suggests a basin with gentle slope and relatively uniform terrain, where the difference in elevation is not pronounced compared to its horizontal extent.

Ruggedness Number (Rn)

The Rn, which can be expressed in kilometers, can be computed by multiplying the drainage density by the basin elevation.[29] It incorporates both the length and gradient of slope; when slope is both long as well as steep, the values are higher.[4] Higher Rn values (> 1) (Table 4) indicate more elongated basins with steeper slopes, enhancing erosional forces due to increased water flow velocity.

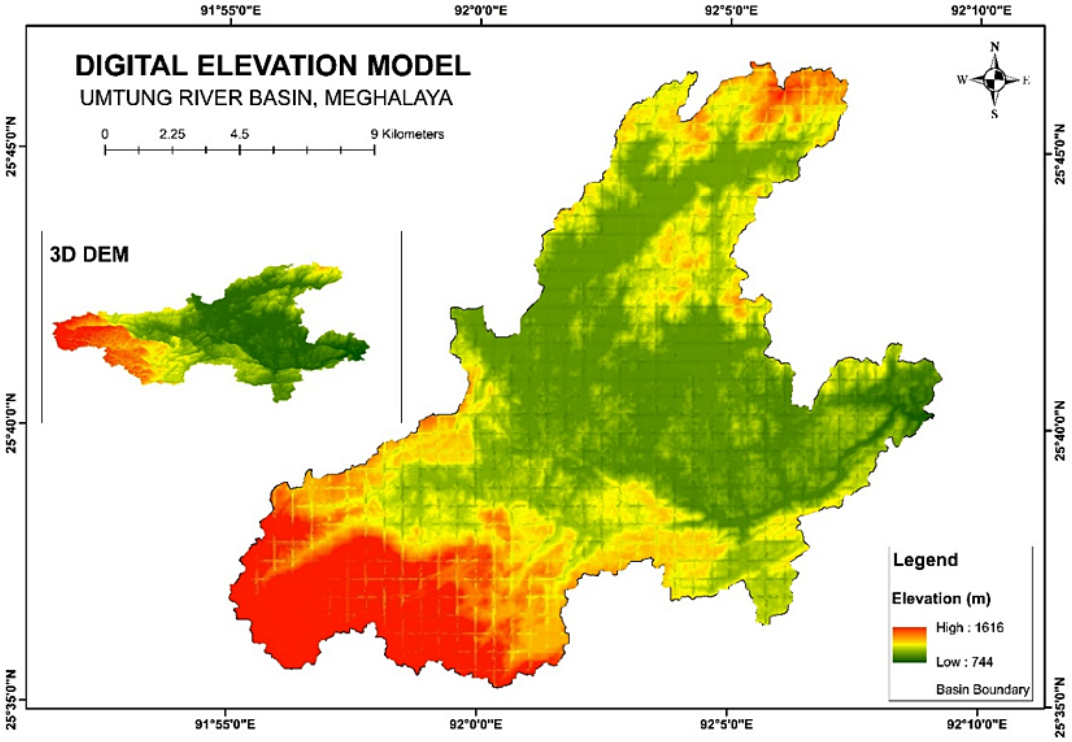

Fig. 9: DEM

Hypsometric Curve

The hypsometric curve (Figure 11) indicates a mature landscape with concave slope characterized by valleys or basins at lower elevations and hilly or plateau terrain at higher elevations, where erosion and tectonic forces have shaped the topography over geological time scales. R^2=0.6867 (Figure 11) suggest a reasonably good fit linear model, as elevation increases, the percentage of total area below that elevation decreases. The future landscape may experience increased erosion in lower elevations, more frequent flooding and sediment accumulation in rivers. Higher elevations may erode or flatten over time and vegetation could shift towards species suited for wetter, lowland conditions.

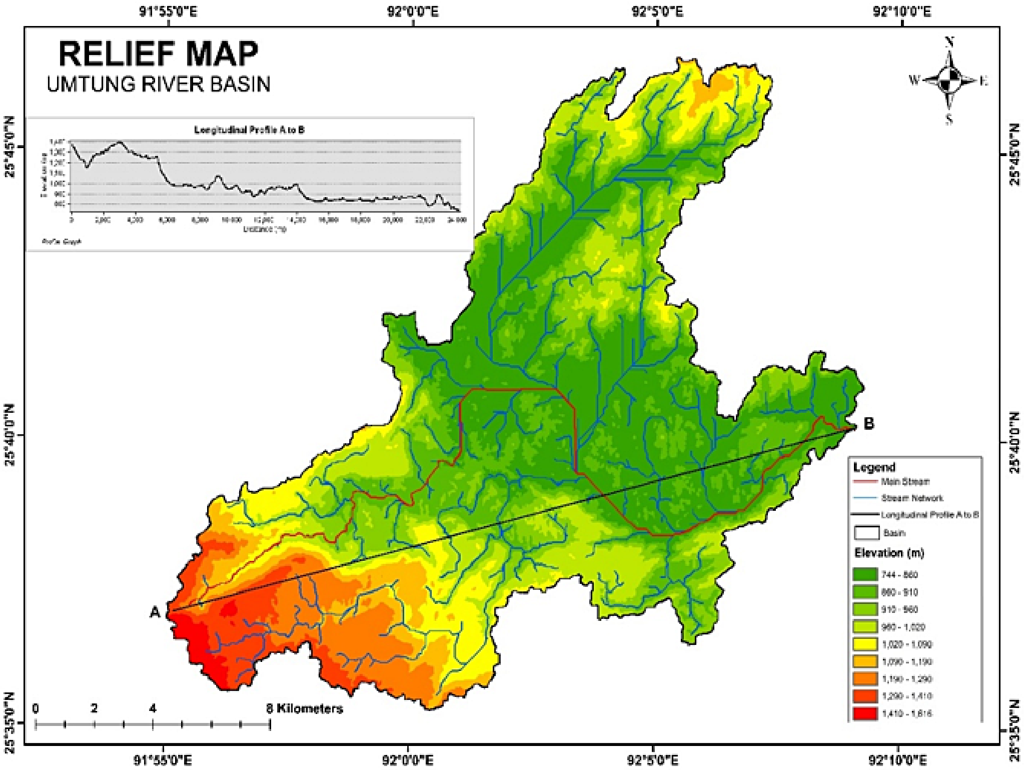

Fig. 10: Relief map and longitudinal profile

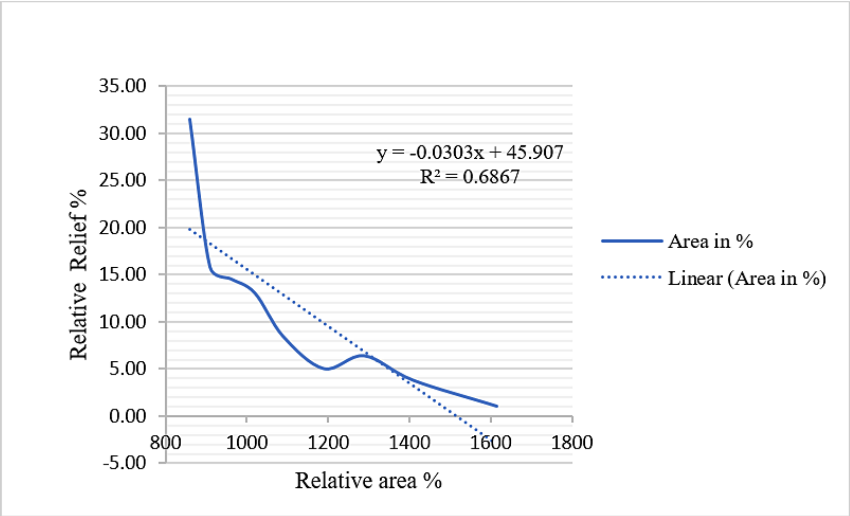

Fig. 11: Hypsometric Curve

Conclusion

The study of the Umtung River drainage basin reveals a well-structured, moderately complex watershed with distinct geomorphological and hydrological characteristics. The basin features a stream network that reaches up to the 5th order, with a significant dominance of 1st-order streams. As stream order increases, stream length and mean stream length decrease, suggesting a mature landscape with moderate slope and erosion. The basin's shifting drainage patterns and increasing network complexity as tributaries merge into main channels are shown by the examination of mean stream length, length ratios, and bifurcation ratios. The basin's moderate stream frequency (1.13 streams/km^2) and low drainage density (1.34km/km^2) indicate healthy plant cover and soil permeability, which support steady runoff and infiltration processes.

Morphologically, the basin is elongated with a form factor of 0.38, which allows for more predictable hydrological behaviour and longer flow durations, which allow better flood management, soil conservation and ecosystem development. The low circulatory ratio (0.13) points to a dendritic drainage pattern, typical of areas with gentle slopes. The basin's high relief (872 meters) and youthful erosional stage are reflected in its ruggedness number (1.18) and relief ratio (35.85), though the relatively gentle terrain suggests slow erosion and uniform development. The hypsometric curve is concave and reveals another evidence of a landforms with varying heights and continuous erosion.

The Umtung River drainage basin study reveals a stable hydrological system with low flood risks, moderate erosion rates and good vegetation cover, making it suitable for sustainable land and water management. Its predictable hydrological behaviour, low circulatory ratio and stable runoff suggest effective flood management and water resource development for agriculture and irrigation. The basin's balanced ecosystem offers opportunities for conservation, while its gentle slopes and mature topography support infrastructure planning with minimal environmental impact. Overall, the basin is well-positioned for sustainable soil conservation, ecosystem preservation and long-term development.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants and therefore informed consent was not required.

Permission to Reproduce Material from Other Sources

Not Applicable

Author Contributions

The sole author was responsible for the entire research work done.

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