Journal of Geo Research

ISSN: 3139-2539 (Online)

journal homepage: **https://jogr.in**

OPEN ACCESS

2026 (July)
Vol. 1 No. 3

A geomorphological assessment of morphometry in the Upper Umiew river catchment

Dr. Bring Blessing L. Ryntathiang

Assistant Professor, Department of Geography, Captain Williamson Sangma State University, Balalgre, Meghalaya, India

*Corresponding author *E-mail address:* bring24@gmail.com

Article Info

Received: 05 July 2026
Accepted: 15 July 2026

Citation: Ryntathiang, D. B. B. L. (2026). A geomorphological assessment of morphometry in the Upper Umiew river catchment. *Journal of Geo Research, 1*(3), 110-125.

doi:10.5281/zenodo.23074869

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Abstract

Studying a watershed through morphometric analysis is crucial for effective planning. By examining its shape and physical characteristics, we can better understand how different features of the area are connected and influence one another. This study examines the morphometric and drainage characteristics of the Upper Umiew River Catchment in Meghalaya, India, to understand the relationship between landforms, geological structure, and hydrological processes. Using Survey of India toposheets, satellite imagery, and GIS techniques, key parameters such as drainage density, drainage frequency, bifurcation ratio, and slope were analyzed following standard methods. The catchment, underlain by quartzites of the Shillong Group and Mylliem granites, exhibits diverse drainage patterns including dendritic, rectangular, and parallel types, reflecting structural and lithological control. Results indicate moderate to high drainage density (2–4 km/km²) and variable stream frequency, suggesting differences in infiltration and relief conditions. High bifurcation ratios in selected sub-catchments point to structural disturbances and increased flood potential. Slope analysis reveals that moderate slopes support higher drainage density. The study highlights the combined influence of geology, slope, and climate on drainage development and landscape evolution in this high rainfall region.

Keywords: morphometric, drainage characteristics, Shillong group, mylliem granite, structural and lithological control

1. Introduction

Drainage studies have been one of the major aspects in the study of Geomorphology. Right from the ancient period the studies of drainage have been one of the focusing points. ‘Drainage area may be defined as the area which contributes water to a particular channel or set of channels. The drainage basin is the fundamental unit in geomorphology within which may be the relationship between landforms processes and the underlying bedrocks.

A primary feature of any drainage basin is its drainage density, frequency. The length and number of streams in a given area expressed the landscape, regional topography and the underlying geological

structure. The study of the drainage characteristics is an important aspect in the analysis of terrain and it is examined with particular reference to drainage frequency, density, pattern and evolution.

The drainage basin is the fundamental unit in geomorphology within which the relationship between landforms and processes which modified them, may be studied. The basin is the collecting ground and storage container for precipitation, the system of routes by which water and sediment are transported and the expression of the underlying geological structure. The activities of streams, as running water, could either be erosional or depositional. Due to erosion, different types of valleys and interfluvial ridges are formed, depending on the stage of the area. So, to have a better understanding of the drainage analysis is to understand the evolution of landforms.

Gravelius (1914) made the systematic attempt to describe the hierarchical orders of the streams from the mouth to the source. He tried to recognize the trunk stream as the first order and he assigned the second order to those rivers which joined the main stream of the first order and so on. Horton (1945) introduced the term "Bifurcation Ratio" (R_b) to express the ratio of the number of streams of any given order to the next order and he is also the first the define drainage density as "the total length of stream channel per unit area". System of channel ordering has been suggested by Horton, defined the streams ordering is a measure of the position of the stream's hierarchy of tributaries. The first order streams are those which have no tributaries, the second order stream receives as tributaries only, the first order and second order streams and so on.

Strahler (1952*)* further modified Horton's ordering system in order to overcome some of the limitations. According to Strahler, each finger-tip channel is designed as a segment of the first order, at the junction of any two first order segments. A channel of second order is produced and extends down to the point where it joins another second order segments where, upon the segment of the third order produced and so forth. Schumm *(*1986) stated that drainage density is related climatic conditions. Faniran and Jeje (1983*)* noticed that one of the important aspects of river pattern studies related to the relationship between processes and forms.

Selby (1985*)* showed the effect of drainage density on the drainage basin relief. If the relief is constant, a high drainage density is accompanied by steep slopes and if the drainage density is constant, the area of greatest relief has the steeper slopes. Strahler and Strahler (1992) defined stream as, a long; narrow body of flowing water occupying a trench like depression, moving to lower levels under the force of gravity, where the drainage system acts as the total system of down slope water flows from the point of arrival at the ground surface.

Smithson and Addison (1997) network processes measure order, density and pattern reflected on the principal catchment attributes including stage of development and Catchment shape. Hess and McKnight (1999) discussed the two important concepts of stream channel. First, the depth and shape of the stream channel varies over time (cross section of stream). Secondly, the longitudinal profile of the stream depends upon the topography, geologic structure, climate and sediment load of the stream.

Morgan (1976) showed that drainage density is one of the parameters which are most sensitive to environmental conditions, varying with rock type. In his study in 1976, the principal component analysis

used to show climatic factors strongly out weighed other aspects of the denudation system in controlling drainage density. Gregory (1976) dealt with magnitude and range of drainage density values for particular morpho – climatic zones in relation to men annual precipitation amount. Drainage density values and ranges tend to be greatest in semi-arid areas, to decreased in humid – extra tropical areas and perhaps increase again in the seasonally humid and humid tropics. Gregory's findings agreed with those of Woodyear and Brookfield (1966) who found that drainage density is highest in areas with low and sparse vegetation cover. The values for humid, mid – latitude areas show that there is a general tendency for values to increase with an increase in mean annual precipitation. Ryntathiang et al. (2023) conducted a morphometric analysis of the Um-Mawiong River Basin, Meghalaya, for assessing the drainage characteristics and geo-hydrological behaviour. Using GIS-based techniques, the study analysed linear, areal, and relief morphometric parameters, including stream order, drainage density, stream frequency, and elongation ratio, revealing a dendritic drainage pattern, indicating homogeneous geological conditions.

2. Data base and methodology

The data for the present study have been based mostly on Survey of India toposheet data. Satellite imagery was also consulted to detect any change of the channels. The data for the entire Catchment is available from two toposheets namely, 78 O/14 and 78 O/15. The satellite image was downloaded from the NASA site.

Morphemetric techniques have been used to substantiate the understanding of the drainage characteristics of the study area. Drainage density, frequency, bifurcation ratio, slope have been calculated using standard formulae basing on the toposheet data. The toposheet data of the area of interest have been digitized using MAPINFO 7.0 after registering the coordinates. The satellite image was also registered and overlaid on the toposheet for correlating the features. Over and above this field observation was undertaken to visualize the real time features. Thematic maps for the same were prepared with the help of the above GIS software.

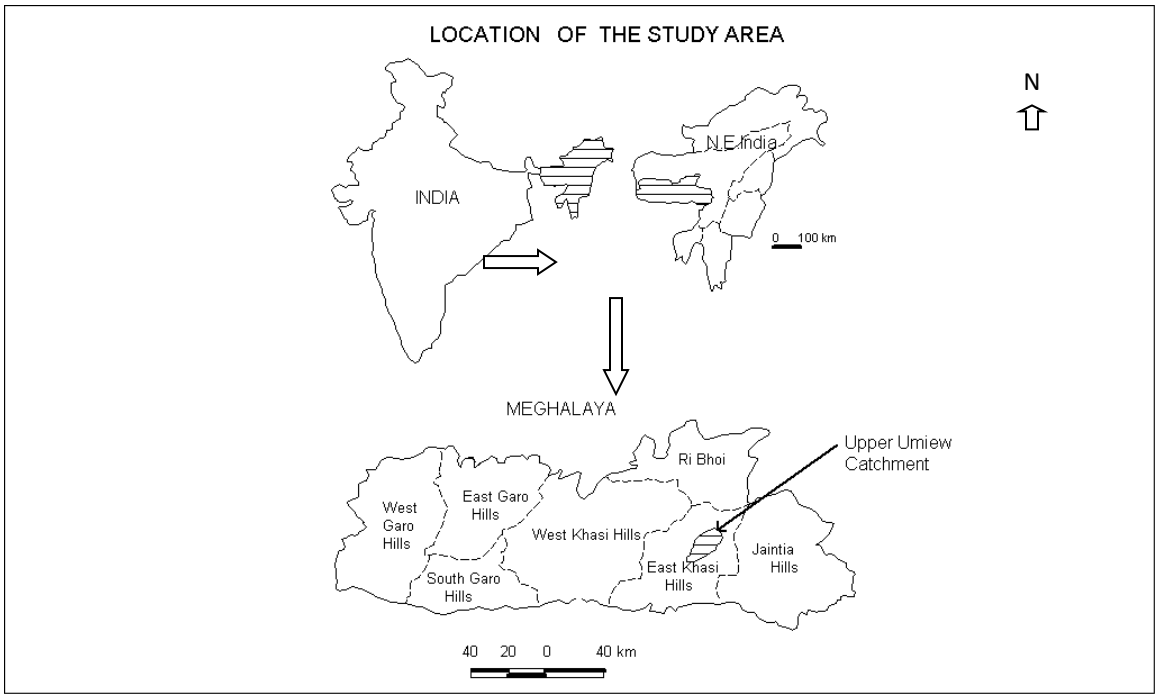
To supplement the details presented in this study, photographs, maps, diagrams and tables have been incorporated.

3. Objective

The main objective of this study is to understand the drainage characteristics of the Upper Umiew River Catchment.

4. Study area

The river Umiew originates at an altitude of 1829 m. The Catchment boundary extends from longitude 91°46' to 91°56' east and latitude 25°27' to 25°32' north approximately. The Catchment on the upper reaches drains southern slopes of Shillong peak. The river Umiew negotiates a fall of 60 m in its initials 600 m. The next 14 km reaches has a drop of 60m. The remaining 6 km negotiates a fall of 105 m. The Catchment area of the river up to the dam site is 142 sq km. The climate condition of the basin experiences mild summers with cool winters. The summer temperature varies form 14°C - 24°C whereas the winter temperature touches up to 3°C. The average annual rainfall has been registered to 3309mm.



5. Results and Discussion

5.1 Geology

The geology of the upper Umiew basin comprises of mainly two rock types:

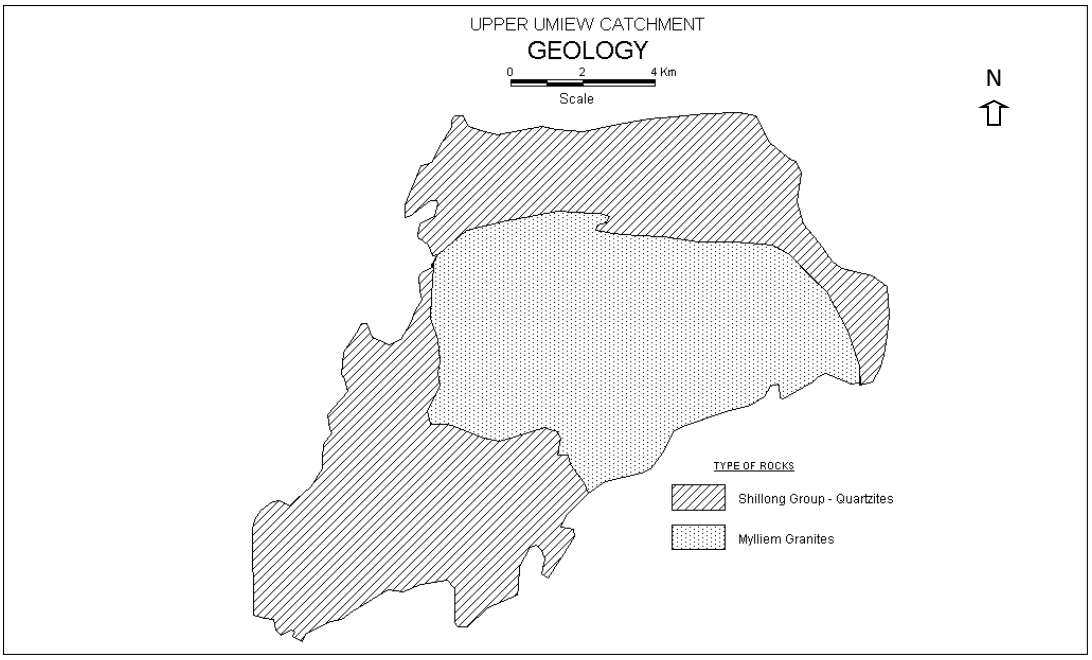


Fig.-1: Geology of Upper Umiew Catchment

(a) The Shillong Group - quartzites.

The Shillong Group consisting of quartzites cover the northern and southern parts of the Catchment. They account for about 80.04 km^2. There is a clear demarcation between the Shillong group – quartzites and the Mylliem granite.

(b) The Mylliem Granites.

The granites are clearly exposed, covering almost the central part of the study area. These rocks cover about 60.96 km^2. These rocks are displayed prominently with signs of deep weathering.

5.2 Drainage

Umiew or Umiam Mawphlang is the third principal river in Khasi hills that originates in the neighbourhood of Shillong Peak. It flows through precipitious part of the plateau within the study area. It flows through two geologic structures, Shillong group and Mylliem granites. It has been dammed near Mawphlang village for the purpose to supply of water to Shillong through the Greater Shillong Water Supply Scheme (Simon, 1991). The river Umiew initially flows towards the eastern side up to about 10 Kms and then towards the west up to the confluence with its major tributaries such as the Umtyngngar and Umjyllieng. Thus, the profile gives the idea that the river flows through different rock formations. There are also some minor breaks in the profile gradient which indicated that the region has uplifted in the different geologic period. It has been observed that the granite area shows frequent floodings during the raining season.

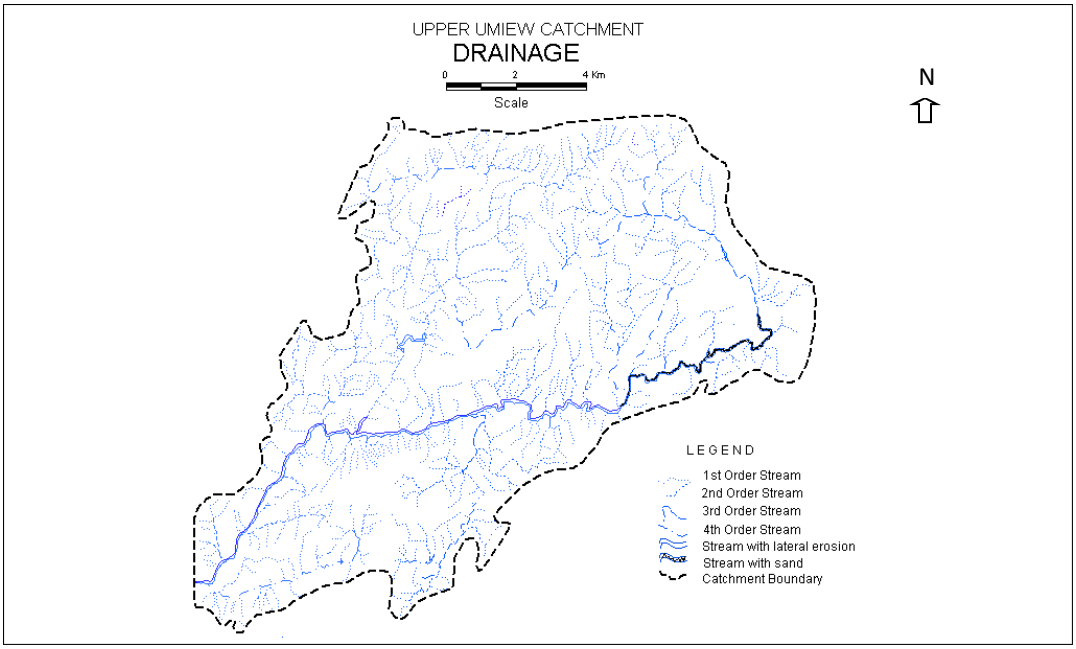


Fig.-2: Drainage of Upper Umiew Catchment

5.3 Drainage Pattern

The drainage pattern reflects the influence of slope, lithology and structure of the basin. In the study area, the lithology and structure of the basin play an important part in determining the pattern of drainage system. The drainage patterns found in the study area are as follows:

a) Dendritic Pattern: The tributary streams of the main stream or river comes from all directions to meet it, which looks like the main stream joined by various branches. This pattern of drainage is very common and found all throughout the study area. These are associated with areas of uniform lithology, gently – dipping strata and generally low relief.

b) Rectangular Pattern: Under this pattern of drainage, the larger rivers are generally met by their tributaries at a right angle. This pattern is found to develop in the north western part of the study area which is rugged and more jointed rocks.

c) Parallel Pattern: These comprise a series of streams running parallel to each other. They are especially common in areas of uniformly dipping rocks. The alignment of joints and faults can also lead to the development of sub – parallel patterns. This pattern is found in the northern part of the study area. This most probably guided by the topographic features.

d) Centrifugal pattern: This pattern is associated with a dome when the streams emanating from the central plateau or dome hills spread outwards to various directions. This pattern is well developed in the southern part of the study area.

e) Centripetal pattern: This pattern is developed when there is a basin like formation and streams tend to meet towards a central point. This is observed in the south eastern part of the Catchment in the Shillong Group of rocks.

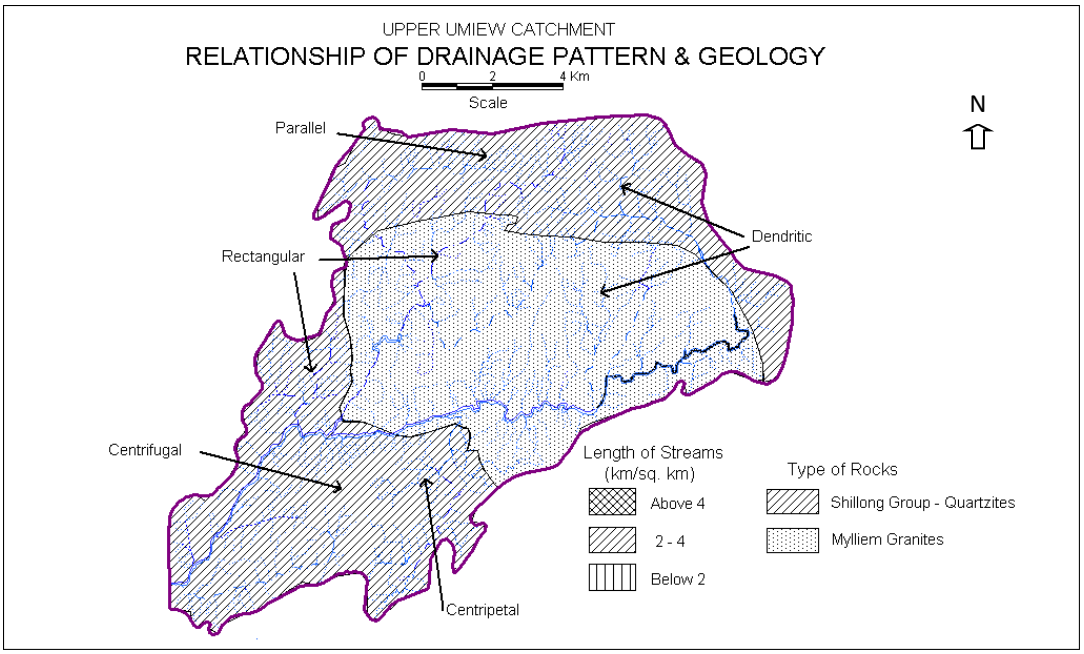


Fig.-3: Drainage Pattern and Geology of Upper Umiew Catchment

5.4 Drainage Analysis

In the present study, the drainage was analysed by undertaking three parameters which are as follows.

(1) Bifurcation Ratio (by Strahler's method)
(2) Drainage Density (by Horton's method)
(3) Drainage Frequency (by Horton's method)

Bifurcation Ratio: It is the ratio between the number of lower order streams and higher order streams. It is derived by applying the following formula.

$$R_b = N_u/N_u+1$$

Where, u = order of stream segment

N_u = number of segments of the given order

And, N_u+1 = number of streams of the next higher order.

Bifurcation ratio is related to the branching pattern of the drainage network. The study of

5.5 Bifurcation Ratio

Sub - catchment	**Stream Order**	**No. of stream Segments**	**$R_b = N_u/N_u+1$**
A	I	235	
			7.12
	II	32	
			8
	III	3	
			1.5
	IV	1	
B	I	53	
			4.41
	II	11	
			3.66
	III	2	
			1
	IV	1	
C	I	161	
			4.23
	II	37	
			9.25
	III	3	
D	I	53	
			6.62
	II	7	
			3.5
	III	1	
E	I	31	
			3.44

	II	8	
			4
	III	1	
F	I	30	
			3.75
	II	7	
			2.33
	III	2	
			1
	IV	1	
All Sub-catchments	**I**	**463**	
			4.50
	II	**102**	
			5.36
	III	**18**	
			4.5
	IV	**13**	

bifurcation ratio in different places indicates marked seasonal variation due to different climatic conditions, geological and structural characteristics, lithology, relief features and stage of basin development.

From the result of the bifurcation ratio of the sub – catchments, the sub – catchments C and E show a similar progressive increase portraying abnormal tendencies. On the other hand the sub – catchments A, B, D and F indicates a progressive decrease indicating normal conditions.

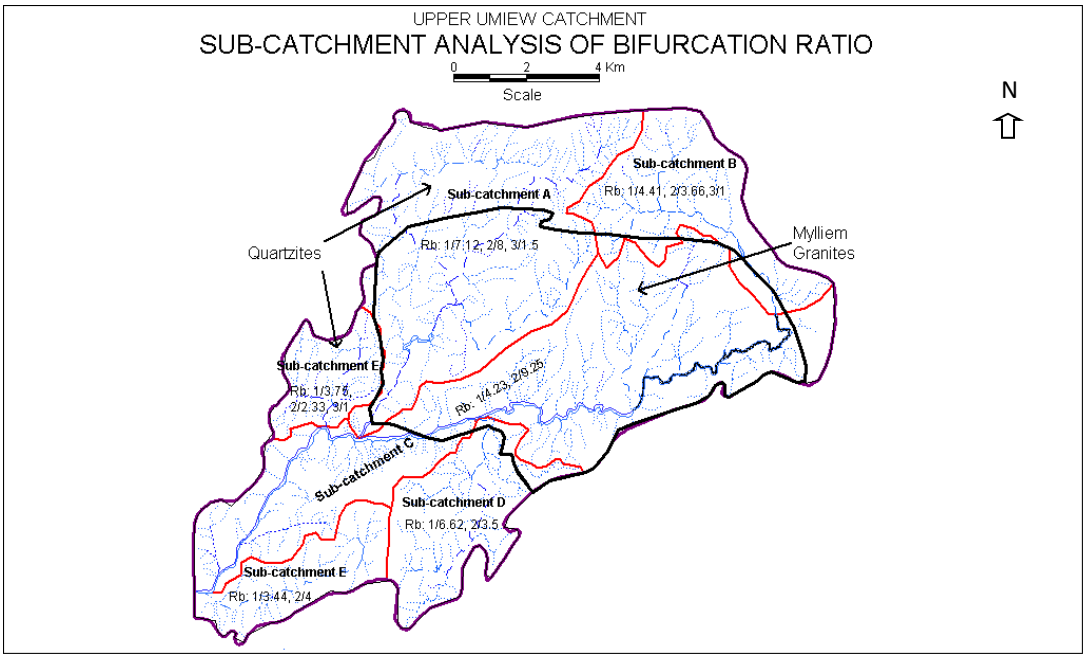


Fig.-4: Bifurcation Ratio and Geology of Upper Umiew Catchment

It is seen that this index has the highest ratio of 9.25. This would mean incessant flooding throughout the rainy season in certain sub-catchments of the study area since it exceeds the normal value of 3.5 (Leopold et. al. 1963). The sub-catchments A and C may flood frequently throughout the rainy season as bifurcation ratio in IInd order streams of these sub-catchments are 8 and 9.25 respectively. These sub-catchments have a larger area under granites which tend to display this type of anomaly associated with undulating terrain (Syiemlieh 1997). Sub-Catchment D also displays a higher bifurcation ration of 6.62 in 1st order streams since these are located mostly over undulating terrain but under the Shillong group of rocks.

5.6 Drainage Density

It is simply the ratio between the total length of streams of all orders and the area. The length of the streams has been measured for every sq.km. through the prepared 1x1 km grids. The formula for calculating drainage density as given by Horton is as follows:

Drainage Density =Total Length of Streams /Total Area

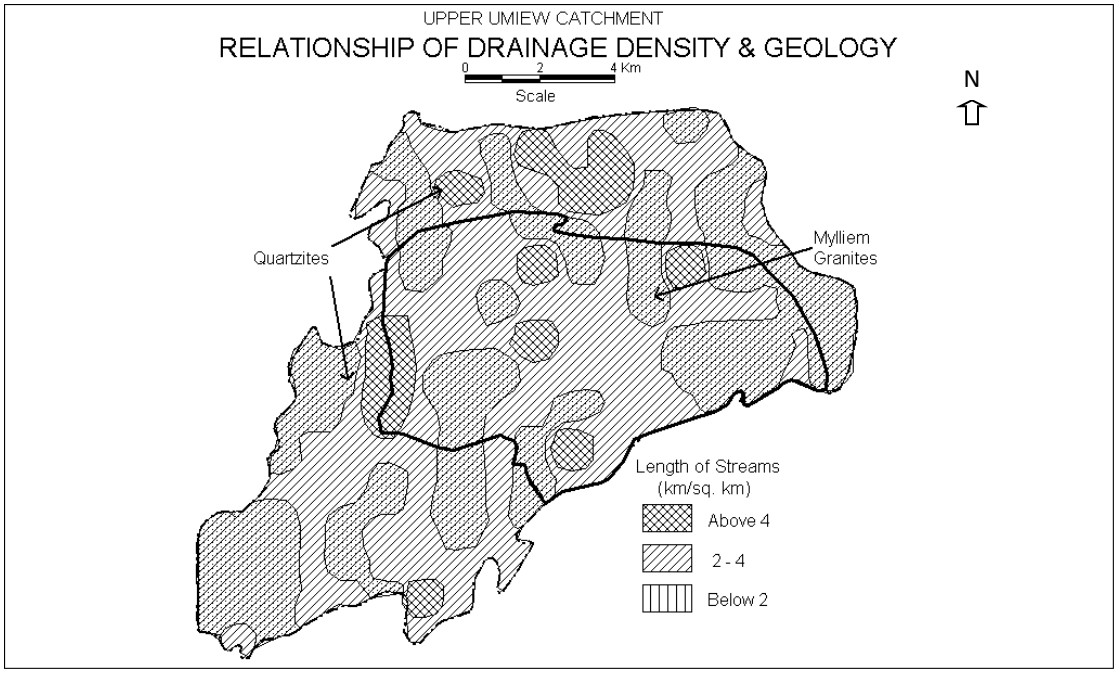


Fig.-5: Drainage Density and Geology of Upper Umiew Catchment

Stream flowing over a surface are influenced by the structure of the under lying rocks, and one of the most important factors that determines the drainage density is rock types, over which the stream flows. From the above Fig.5, it is clear that denser drainage is distributed in both the rock types. However, towards the end of the granitic surface there seems to be some kind of modification of the rocks which is reflected by higher drainage density. A large area is dominated by drainage density between 2-4 km/km^2 reflecting reasonably good percolation of water.

The drainage density of the study area ranges slightly below 2 kms/sq.km. to slightly more than 4 kms/sq.km. the area having density of about 4 kms/sq.km comprises only small pockets of the northern part and the central part of the study area having an area of 13.09 sq.km moderate density of 2 – 4 km/sq.km. covers the entire study area of an area of 69.72 sq.km and the lowest density of less than 2 km/sq.km. is found in the south western part, small pockets in the central, north and eastern parts of the study area.

5.7 Drainage Frequency

It can simply be defined as the total number of streams present in a particular area or it can be said to be the ratio of the total number of streams to the unit area. For determining this drainage density, the number of stream order occurring in each grid was counted. The formula for drainage density is as follow;

Drainage Frequency = Total Number of Streams / Total Area.

The high frequency of streams of above 5 is found in the central part and the western part consisting of an area only 9.22 sq.km. The frequency of 3 to 5 covers almost the entire central part of the study area of 57.45 sq.km and the low frequency of below 3 are found in the southern portion of the area, consisting of an area of 63.99 sq.km.

5.8 Slope Analysis

Slope is the fundamental element of the landscape. The slope element of an area reflects the evolutionary history of the paramount importance in the study of geomorphology. In the present study we are concerned with the slope and drainage characteristics of the upper Umiew catchment.

For this study, the slope map calculated on the basis of Wentworth's method to determine the nature and degree of slope. According to this method, the number of contours is being counted for every sq.km by making grids, the results derived fro each grid is substituted by the following formula:

$\text{Tan } \theta = N \times I / 636.6$

Where N = average number of contours crossing per sq.km

I = contour interval

636.6 = standard value for metric sheets (constant)

Finally, Tan θ is converted into degrees

As shown Fig. 6 the steepest slope (above 20^o) is found in the south western part of the area of an average 19.99 sq.km. Slope about $10^o – 20^o$ are found in a large extent in the central part and in some pockets in the east and the north of the study area. It comprises of an area of 59.34 sq.km. The slope below 10^o covers the eastern part of the area and small pockets in the north western parts with an area of 52.06 sq.km Thus, broadly speaking, the slope of the area is lowest in the east and highest in the south western part.

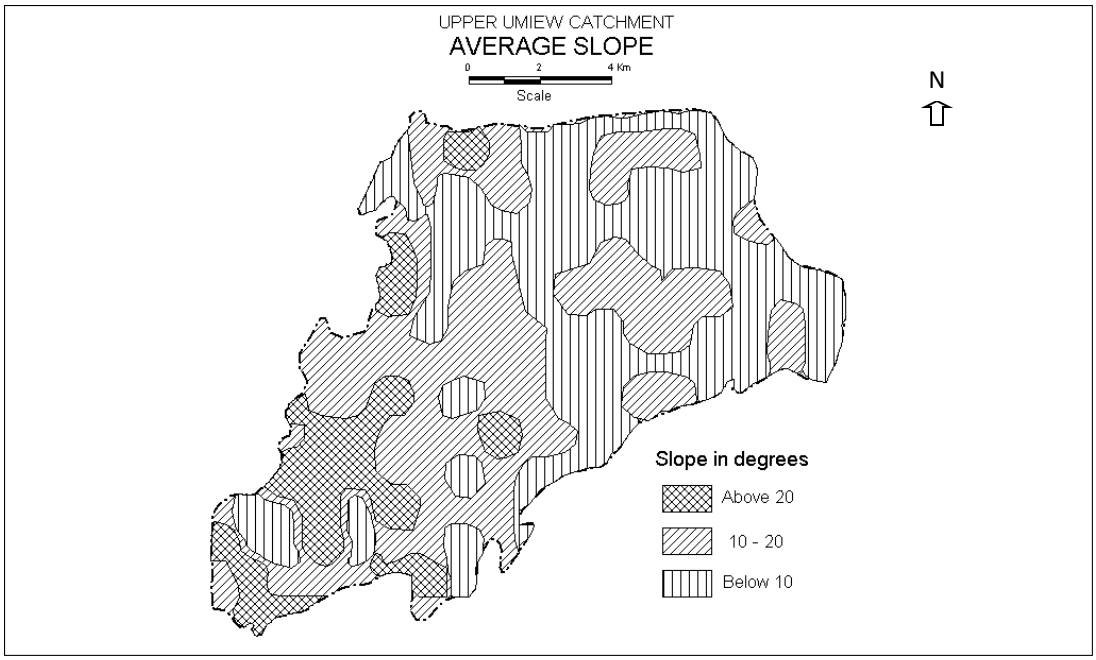


Fig.-6: Average Slope of Upper Umiew Catchment

5.9 Longitudinal Profile

The longitudinal profile of a stream indicates its gradient through its length. As channel slopes are commonly steep in the head waters and gentle in lower reaches, profile is normally concave upwards with increasing that segment towards the mouth.

The length of the Umiew river has been measured with the help of GIS software and with a vertical scale of 1cm is to 100meters and horizontal scale of 1cm is to 2Km, the longitudinal profile of the river had been drawn.

It is apparent from the figure that there are no major nick points in the profile. The channel slope of the profile shows a gentle slope. It flows through two geological structures that are the Shillong group and Mylliem granite. The profile between 1700m – 1700m shows a moderate slope and lateral erosion is significance in this area. This is prominently displayed in the drainage map (Fig.3). In the granite area the river shows a meandering course and vertical erosion is not very significant except towards the edge.

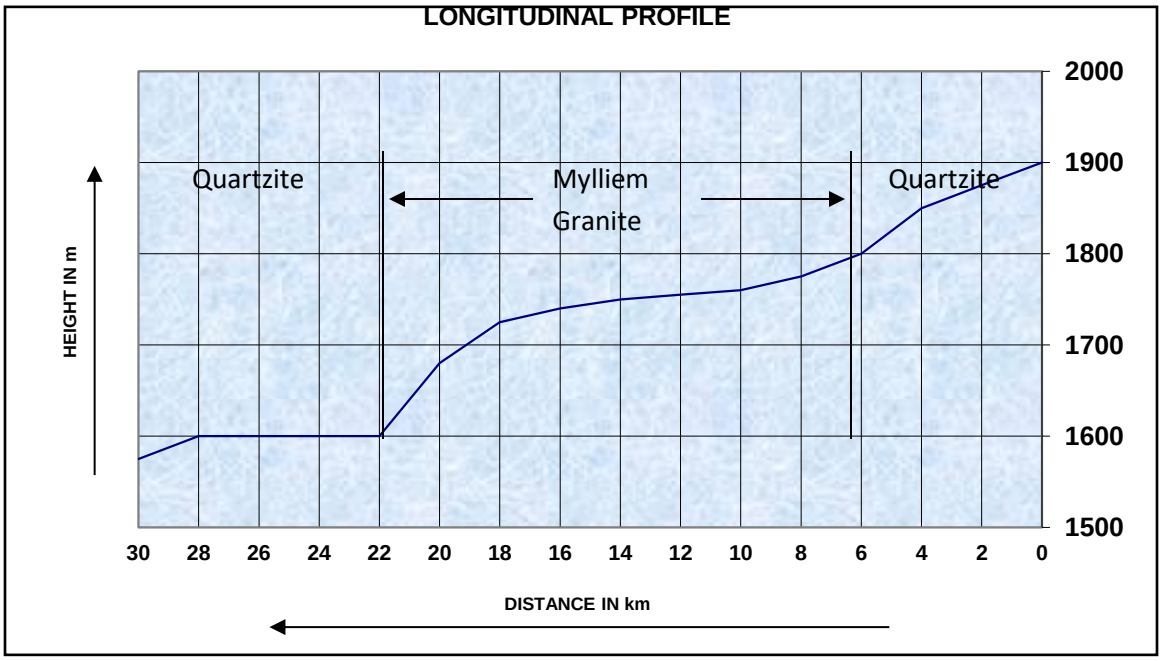


Fig.-7: Longitudinal Profile of Upper Umiew Catchment

The profile gives the idea that as the river flows through different rock formations it encounters different rock characteristics leading to variable erosion patterns. There are also some minor breaks in the profile gradient which probably indicate that the region has been uplifted in the different geologic periods.

6. Conclusion

The Umiew River originates from the Laitkor peak. Initially the river flows towards the eastern side for about 10Km and then turns towards the west up to its confluence with its major tributaries viz., Umtyngngar and Umjyllieng. Within the study area the river flows through two geological structures viz., the Shillong group which consisted mainly of quartzite and Mylliem granite. In its upper course the river shows its youthful stage with 'V' shape valley. When it reached Smit the river shows its early maturity stage with meandering stream. The topography of the land is more rugged in its lower courses.



Flat surface at Smit village **'V' shaped valley (Umtyngngar)**

Besides slope and geology, climate and human interference play a very important role in the study of the drainage characteristics. A rise in the drainage density occurs with increasing slope in the tropical areas than any other climatic zone. This is more meaningful for this area being under a high rainfall regime.

It is seen from the density map that the drainage density of the upper Umiew catchment is high in those areas which have moderate slope of 10 – 20 degrees whereas the areas of low density are mostly confined in those areas of below 10 degrees. These areas are mostly covered by the Mylliem granite.

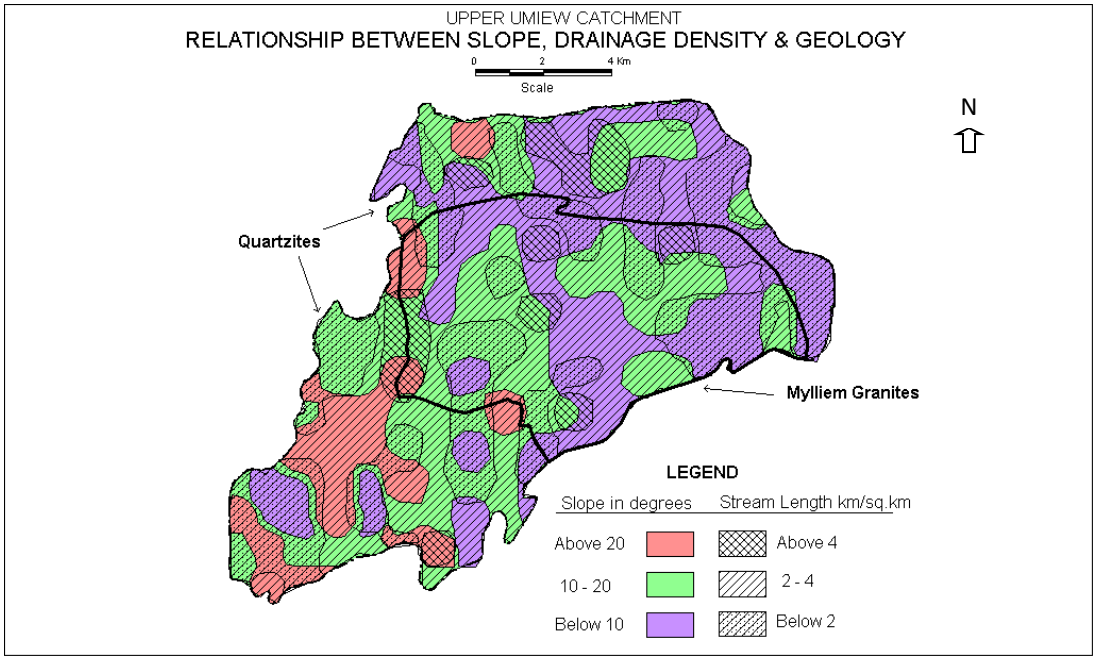


Fig.-8 Slope, Drainage and Geology of Upper Umiew Catchment

The stream frequency of the catchment varies from place to place. This is due to different climate, lithology and structure, relief, infiltration capacity etc. Relief and average slope play a very significant role in the development of streams in this catchment. Drainage lines tend to develop in large numbers on irregular surface than those which lacks conspicuous relief. It is seen from the average slope map (Fig 6) that the relief is low in the northern part and increase towards the southern part. The central part shows moderate slope which explains the coarse stream frequency in this area. It is interesting to note that where even the average slope is low, the stream frequency is also low.

The Hortonian 'infiltration capacity' or what is more appropriately permeability of the bed rock is probably the most important single factor influencing the drainage texture (Thornbury). Here, the rocks of the catchment have shown reasonably good amount of percolation which resulted to moderate stream frequency in the central part which falls under the Mylliem Granite.

The study of the Upper Umiew River Catchment presents a comprehensive understanding of how morphometric parameters influence and reflect the geomorphic evolution of a drainage basin. The analysis clearly demonstrates that the drainage basin functions as an integrated system where lithology, slope, and climatic conditions interact to shape hydrological responses and landscape development.

The predominance of the dendritic drainage pattern across the basin indicates that a large portion of the area is underlain by relatively homogeneous lithological conditions, particularly quartzites, which allow streams to develop freely without significant structural constraints. However, the occurrence of rectangular and parallel drainage patterns in certain parts of the catchment suggests strong structural control, such as joints, fractures, and faults, especially within the granitic terrain. This indicates that the drainage network is not entirely random but partially guided by underlying geological structures.

The bifurcation ratio analysis reveals considerable spatial variation among sub-catchments, with some values significantly exceeding the normal threshold of 3.5. Such high values indicate structural disturbances, tectonic influence, and highly dissected terrain. These conditions contribute to rapid runoff and reduced infiltration, thereby increasing the susceptibility of certain sub-catchments—particularly those underlain by Mylliem granites—to flooding during the monsoon season. In contrast, sub-catchments with lower bifurcation ratios reflect relatively stable geomorphic conditions and a more uniform branching pattern of streams.

The drainage density of the basin, ranging from low to moderately high values, reflects the combined influence of slope, lithology, and rainfall. Areas with moderate drainage density (2–4 km/km^2) dominate the catchment, suggesting balanced conditions between runoff and infiltration. Higher drainage density observed in granitic and steeper regions indicates impermeable rock surfaces and enhanced surface runoff, while lower density areas correspond to zones of higher permeability and infiltration capacity. This demonstrates that rock type plays a critical role in controlling the hydrological behavior of the basin.

Similarly, drainage frequency patterns reinforce these observations, as regions with high stream frequency correspond to areas of greater relief and lower infiltration capacity. The central part of the basin, characterized by moderate slopes, exhibits relatively higher stream frequency, indicating active dissection and efficient drainage development. In contrast, areas with gentle slopes show lower stream frequency, reflecting reduced erosional activity and greater water retention.

Slope analysis further highlights the geomorphic dynamics of the catchment, revealing that moderate slopes (10°–20°) are most conducive to the development of dense drainage networks. Steeper slopes in the southwestern region indicate zones of active erosion and rapid runoff, while gentler slopes in the eastern part suggest depositional tendencies and reduced erosional intensity. This spatial variation in slope directly influences drainage density and stream distribution, confirming the strong interrelationship between topography and drainage characteristics.

The longitudinal profile of the Umiew River, which exhibits a generally concave shape, indicates a normal graded condition typical of rivers progressing from youthful to mature stages. The absence of major knickpoints suggests relative stability in the river's long-term evolution, although minor irregularities in the profile point to localized lithological variations or past tectonic uplift. The transition from steep gradients in the upper course to gentler slopes downstream reflects a shift from vertical to lateral erosion processes.

Overall, the study establishes that the drainage characteristics of the Upper Umiew Catchment are strongly controlled by geological structure, slope, and climatic conditions. The high rainfall regime intensifies surface runoff and enhances the development of dense drainage networks, while lithological differences influence infiltration and erosion patterns. The findings clearly indicate that granitic terrains are more prone to flooding and structural influence, whereas quartzitic regions exhibit relatively stable drainage behavior.

In conclusion, the morphometric analysis provides valuable insights into the hydrological and geomorphological functioning of the basin, highlighting its stage of evolution, erosion dynamics, and flood potential. Such detailed understanding is crucial for effective watershed management, land-use planning, and mitigation of environmental hazards in ecologically sensitive and high rainfall regions like Meghalaya.

Conflict of Interest: *The author declares no conflict of interest.*

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