INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN: 2455-0620 [Impact Factor: 6.719]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 8, Issue - 4, APRIL - 2022 Publication Date: 30/04/2022

DOIs:10.2015/IJIRMF/202204036 --:-- Research Article

Morphometric Analysis of Um Nongspung Catchment, East Khasi Hills, Meghalaya

Baiaishah Gassah
Research Scholar,
Department of Geography, North Eastern Hill University, Shillong, India
Email – baiaishahgassah@gmail.com

Abstract: *The study is focussed on the morphometric analysis of Um Nongspung catchment through Remote Sensing and GIS by utilising the linear, areal and relief aspects. Located in the western part of East Khasi Hills, Meghalaya Um Nongspung river provides a sustainable livelihood to the people of Nongspung and the surrounding areas however there is a lack of any activities taken up in protecting and conserving the catchment area. Quantitative analysis of the different morphometric parameters helps in better understanding about the hydrological and morphological characteristics of Um Nongspung catchment. This work will provide a framework for various organisations, stakeholders and even the government to start the initiatives for soil and water conservation especially with the area having a huge potential for the overall development of the area.*

Key Words: *Um Nongspung, morphometric analysis, GIS, soil and water conservation*

1. INTRODUCTION

Geomorphology has developed over the years with quantitative description of the characteristics of drainage network. Quantitative analysis of basins in different environments and geological setting has been conducted by Horton (1932, 1945), Strahler (1950, 1952, 1957, 1964), Smith (1935, 1950), Miller (1953) and Schumm (1956). Morphometry becomes more of scientific value when form is related to hydrologic process (Strahler, 1957). Drainage morphometry analyze and compare the form and processes of landscape evolution irrespective of time and space (Easthernbrook, 1993). It is the mathematical analysis of the earth’s surface configuration, dimension, shape and landforms (Agarwal, 1998). It helps in understanding the nature and characteristics of different processes involved in the formation of fluvial landforms. The shape and dimensions of river landforms is greatly influence by factors such as tectonic movements which led to the formation of folds, faults, upliftment and submergence. The continuous upliftment of Meghalaya plateau (Prokop, 2014) has mainly led to the development of many complex drainage systems in the plateau. Drainage lines of any basin in the plateau explained the three dimensional geometry of a region and the streams arrangement consequently leads to the drainage pattern that reflects structural and lithological controls of underlying rocks. Morphometry relates the basin and stream network geometries to the flow of water and sediment. Drainage systems are made active by fluvial runoff which has important biologic, climatic and geologic effects.

Remote sensing and GIS has emerged as an important tool to quantitatively describe the drainage networks of the drainage basin (Hasan, Adhikari & Bhattacharyya, 2017). Various morphometric parameters are studied using remote sensing technique and GIS through topographical map and satellite images. The present paper describes the morphometric analysis of the Um Nongspung catchment using GIS techniques for understanding the hydrological behavior of basin. The inhabitants are the *Khasi* community who depend mostly on agriculture for their livelihood and Um Nongspung river plays a significant role that supply their agricultural and domestic needs. However with increasing farm lands and settlements in the area there has been an increase rate of deforestation resulting in soil loss through erosion. This can further leads to land degradation and reduce the biodiversity within the surrounding areas. Besides an absence of any watershed management activities in relation to this catchment posed a great threat to the community as well as their livelihood. The morphometric analysis of Um Nongspung catchment will give a quantitative description of the drainage system which is of great significance on the hydrological analysis such as watershed prioritization for soil and water conservation and natural resources management.

2. THE STUDY AREA:

Um Nongspung catchment is enclosed between 91˚30’ to 91˚40’E longitude and 25˚ 20’ to 25˚35’ N latitude in the East Khasi Hills district of Meghalaya and is bounded by Lyngdoh Maram in the north, Pongkung in the south, Kut Madan in the east and Um Khonglang river in the west. The watershed covers a total area of about 74.26 km^2. Um

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN: 2455-0620 [Impact Factor: 6.719]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 8, Issue - 4, APRIL - 2022 Publication Date: 30/04/2022

Nongspung river is one of the main tributary of the Umngi river. It originates from Mawknong at an elevation of 1820 m and flows downstream to an elevation of about 1400 m. The study area falls under sub-tropical monsoonal region having cool and rainy summers and cold winters. The catchment experiences heavy rainfall during summers mainly from June to September for about 5000 mm (India Meteorological Department) approximately. Physiographically, the area is characterized by upland plains, hills, ridges and flat lands.

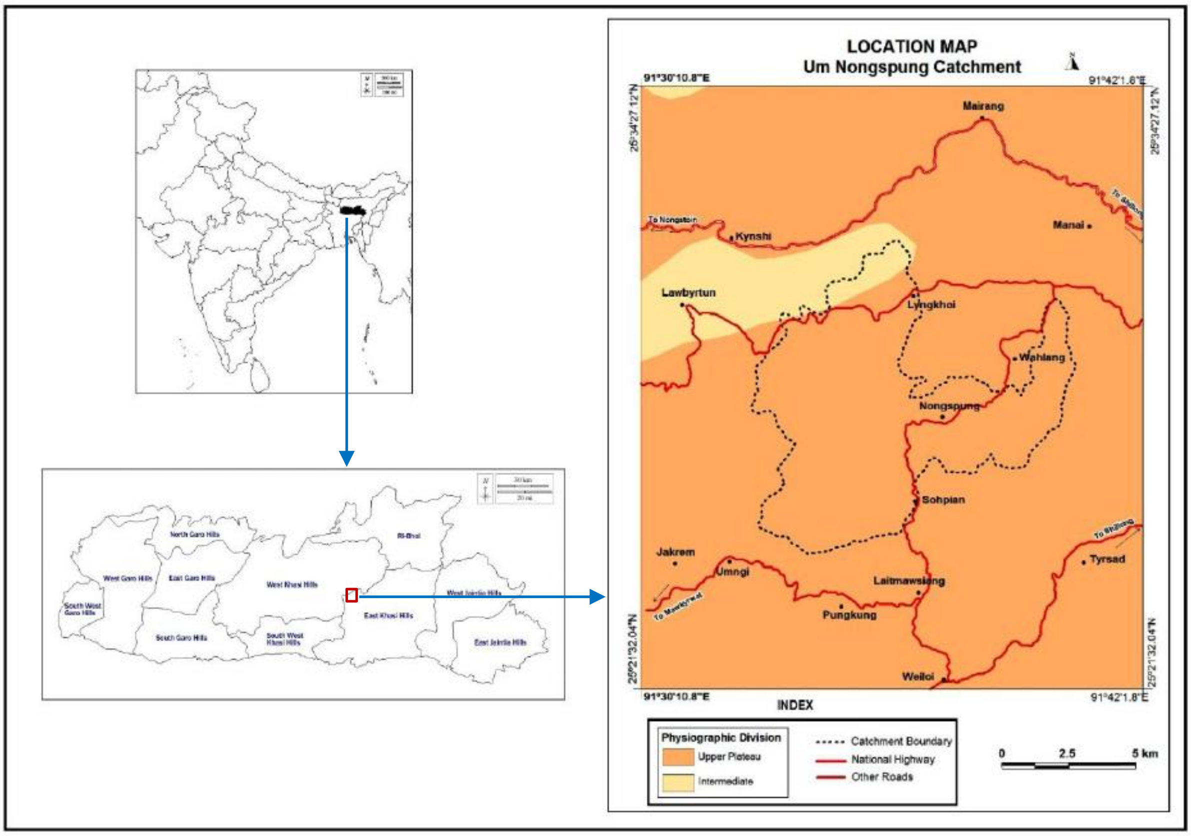

Figure 2: Location of the Study Area

Um Nongspung river originates from the undulating topography and as it flows downstream it forms flat lands at Pyndenlitha. These lands are used for paddy cultivation. Um Nongspung as it flows for a distance of 20.22 kms it joins Umngi river before flowing to the plains of Bangladesh. Its main tributaries are Um Lyngkhoi, Um Mynrat and Um Sohphoh. All these three main tributaries are on the left bank of Um Nongspung whereas on the right bank small tributaries are noticed mainly of first and second order streams. The variation in order and size of the sub-catchments are basically due to endogenic forces, climatic conditions, erosion processes, slopes and vegetation cover. The soil organic carbon are ranging from 1.04 to above 3.05% and the surface soil texture has a water holding capacity of above 60% which indicate that the soil in the study area is fertile. Geologically the study area is dominated by aplite, porphyritic and non-porphyritic granites of South Khasi Batholith group of rocks and belonging to the age group of Neoprotozoic to early Palaeozoic (Geological Survey of India, 1851).

2.1 Landuse Landcover (LULC)

The landuse and landcover map shows that open forest dominates the entire area covering about 35.81 % and spreads over the entire catchment except in the north westernmost part open forest are negligible (figure 2). Scrub land, scrub forest, dense forest and grasslands occupy 22.94 %, 13.88 %, 5.26 % and 1 % of the area respectively. Scrub lands are mainly observed in the north western most part and are scattered in other areas of the catchment. Dense forests are mostly found in the south eastern part in areas of steep slopes. Grasslands are noticed on the western part mainly on the left bank of Um Mynsat river. Agricultural lands or croplands accounted for about 17.95 %. Agriculture is practiced mainly in areas of flat lands and moderate slopes. Built up areas are the settlement areas which covers about 2% and the main settlements in the area are the Nongspung, Mawknong, Sohpian, Sohphoh, Lyngkhoi and Laitlarem.

3. MATERIALS AND METHODS:

3.1 Data collection

The data collected for preparing and conducting this study is from the primary and secondary source. The two Survey of India (SOI) toposheets numbering 78 0/10 and 78 0/11 with the scale of R.F. 1:50000 are used as base material for this study. For understanding the geology, the District resource map of East Khasi Hills, Meghalaya published by the Geological Survey of India (2012) is used. USGS Landsat 8-2015 of 30 m resolution and USGS Landsat Panchromatic Band 8 of 1.5m resolution are also used for LULC (figure 2). Reviews of other literatures correlated to this work are also studied for enhancing more information. Further field surveys are also conducted in the catchment for ground truth information.

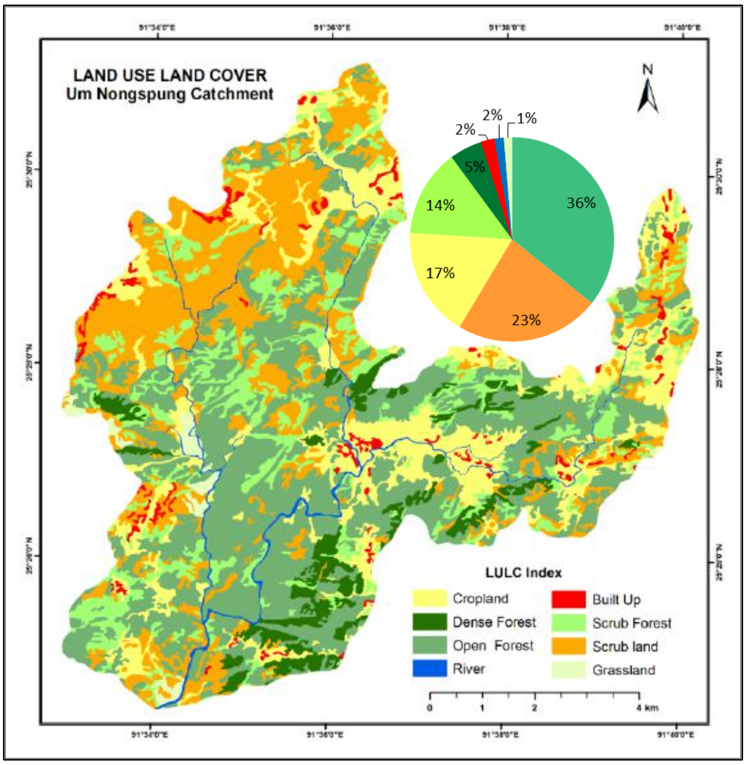

Figure 2: LULC of Um Nongspung Catchment

3.2 Methods:

The methods undertaken for carrying out the work related to the morphometric analysis of the Um Nongspung catchment are discussed as follows.

The two Survey of India (SOI) toposheets are georeferenced within the ArcMap 10.1 software for extracting the shape files of the study area. For generating the catchment boundary a manual digitization method is used by identifying and marking the surrounding ridge lines (which act as a drainage divide between two separate catchments) present in the area. The drainage networks are also digitised from the toposheets for calculating the different morphometric parameters (figure 3). The linear aspects which include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio are shown in the following along with their methods of calculation (table 1).

***Table 1**. Linear aspect*

Parameters	*Formula*	*Reference*
Stream order (u)	Hierarchical rank	Strahler (1964)
Stream Length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm}=L_u/N_u$, (L_u=Total stream length, N_u=Total no. of stream segments)	Strahler (1964)
Stream length ratio (R_l)	$R_l=L_u/L_u$-1, (L_u=The total stream length, L_u-1=The total stream length of its next lower order)	Horton (1945)
Bifurcation ratio (R_b)	$R_b=N_u/N_u$+1, (N_u=Total number of stream segments , N_u+1=Number of segments of the next higher order)	Schumm (1956)

The areal aspects of morphometric analysis include parameters such as drainage density, stream frequency, drainage texture and elongation ratio. A 'fishnet' tool within the Data Management Tools of ArcMap is also used for dividing the catchment into smaller areas of per square kilometer. The parameters of areal aspects as well as the proposed formula are shown in the following table (table 2).

***Table 2.** Areal aspect*

Parameters	*Formula*	*Reference*
Drainage Density	D_d=L/A (L=Total length of stream,	Horton

(D_d)	A= Area of basin)	(1945)
Stream frequency (F_s)	F_s =N/A (L=Total number of stream, A = Area of basin)	Horton (1945)
Drainage texture (D_t)	D_t= Nu/P (Nu=Total number of all stream, P=Perimeter of basin)	Horton (1945)
Elongation Ratio (R_e)	R_e= (2/ Lb)* 2√(A/π)	Schumm (1956)

The relief aspects deals with elevation or height and for this aspect contour lines with 20m intervals are digitised from the SOI toposheet to generate a digital elevation model (figure 4) of the study area. The relief aspect which includes parameters such as relative relief, dissection index and ruggedness index are shown in the following table (table 3).

Table 3. *Relief aspect*

Parameters	*Formula*	*Reference*
Relative relief (R_h)	R_h= H-h (H= Maximum elevation h = Minimum elevation)	Smith (1935)
Dissection Index (D_i)	D_i = Rh/Ra (Rh= Relative relief Ra= Absolute relief)	Dovnir (1957)
Ruggedness Index (R_i)	R_i = Rh*Dd/1000 (Rh= Relative relief Dd= Drainage density)	Strahler (1968)
Hypsometric Integral (H_i)	H_i=(Hmean – H) / (H max – h) (Hmean = mean elevation, Hmax = maximum elevation, h= minimum elevation)	Pike and Wilson (1971)

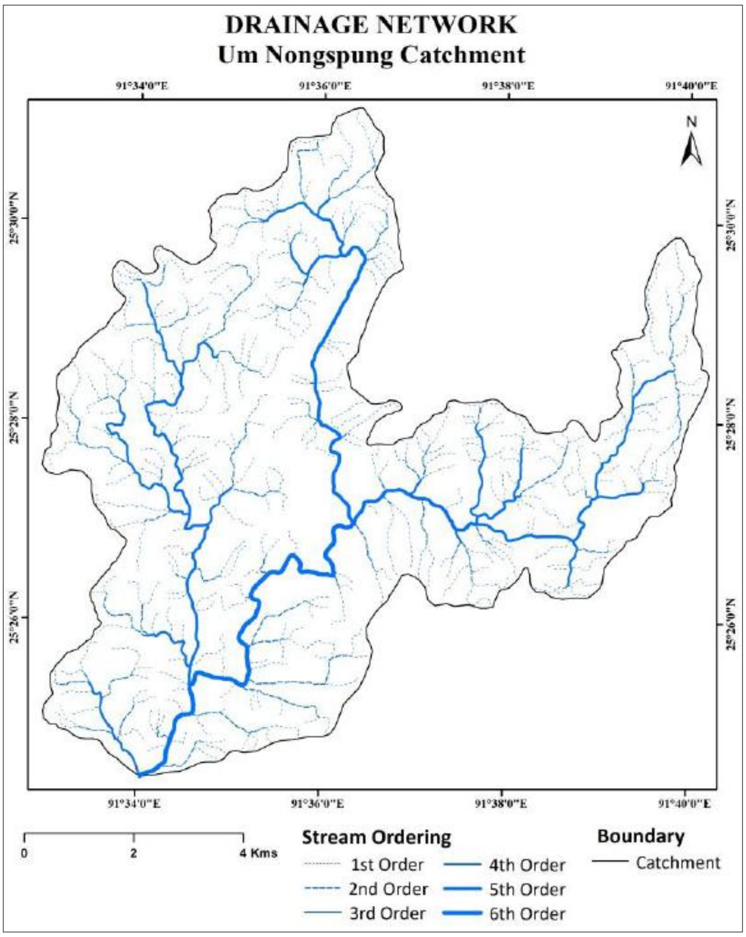

Figure 3: Drainage Networks of Um Nongspung Catchment

3.3 Analysis:

For interpretation and analysis of the linear, aerial and relief aspects, the study area is divided into grids of one square kilometer each and various formulae have been adopted for computation. ArcMap 10.1 software is also used for visual analysis and interpretation in the form of maps by using different statistical tools and interpolation techniques. Besides, simple statistical calculations are also used to bring out the relationship between some of the morphometric parameters.

4. Results and discussion

4.1 Linear Aspect

The drainage networks digitised from the toposheets are used for analysing and interpreting the linear aspects of Um Nongspung catchment. The results are discussed as follows.

4.1.1 Stream Order and Stream number

The method of ranking streams has been proposed by Horton (1945), Shreve (1966) and Strahler (1964). However for this study the stream ordering method proposed by Strahler is adopted. The first order streams are the un-branched fingertip like and when two first orders meet the second order stream developed. At the confluence of the two second order streams, the third order stream developed and so on until they join the main trunk of the highest order. Um Nongspung river has been classified as a sixth order stream (figure 3) having a total of 429 streams out of which 323 are first order, 80 are second order, 18 are third order, 5 are fourth order, 2 are fifth order stream accounting for 74.29 %, 18.65 %, 4.20 %, 1.17 % and 0.47 % respectively. It is apparent that the number of streams decreases with increasing order.

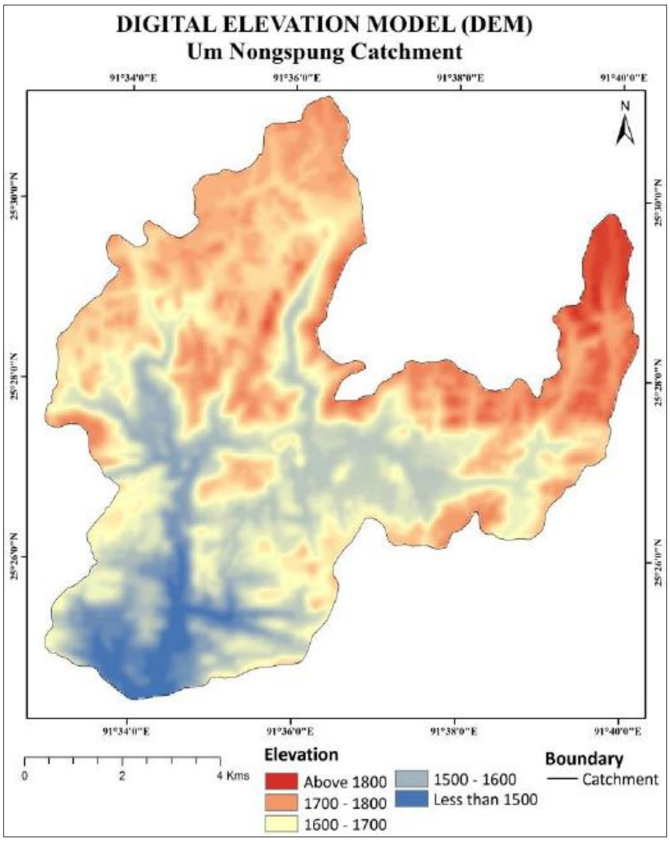

Figure 4: DEM of Um Nongspung Catchment

Table 4.1

Stream Order vs Stream Number				
Catchment	Linear Regression	R	R2	Probable Error
Um Nongspung	y=2.9021-0.5117x	-0.99	0.98	0.001

In the above table (Table 4.1), it is evident that the relationship between stream orders and numbers followed Horton's law (1945). The statistical computation of linear regression, Pearson's correlation and coefficient of determination supports the same. The probable error shows strong level of significance between the two variables.

4.1.2 Stream length

Stream length is the total length of stream of a particular order. It reveals surface runoff characteristics in the catchment. Stream length characteristics have an inverse relation to stream order. The length of the segments decreases with higher order. Stream length also governs the slope of the area for e.g., longer length indicates that the steepness of the slope is less.

Table 4.2

Stream length vs Stream Number				
Catchment	Linear Regression	R	R2	Probable Error
Um Nongspung	y=2.2584-0.2498x	-0.94	0.8994	0.003

In the study area, the total length of all the streams is 266.59 kms. It is identified that the total length of the first, second, third, fourth, fifth and sixth order streams are of 162.49 kms, 50.07 kms, 22.29 kms, 13.7 kms, 9.21 kms and 8.83 kms respectively. It also confirms to Horton's (1945) law of stream length which states that the length of streams of each orders in a drainage basin tends to have a direct geometric ratio. The statistical relationships of the two variables i.e. stream order and stream length also supports the same (Table 4.2).

4.1.3 ***Mean stream lengt:h***

The mean stream length is the average length of all the segment of different hierarchical orders. It is associated with the networks of drainage and their surface attributes (Strahler 1964). It is apparent from the drainage network map that the first order segments have on the average the shortest length and that segments are longer as order increases. It is noted that it increases from 0.50 kms in the first order to 8.83 kms in the sixth order.

4.1.4 ***Stream length rati:o***

The average lengths of the streams of successive orders are related by stream length ratio (Horton, 1945). The length ratio is the ratio calculated between the higher order stream and the next lower order stream. The R_l of Um Nongspung ranges from 1.24 to 2.21. It is apparent that the ratio varies from 1.98 in the second order to 2.21 in the segments of the fourth order and decreases to 1.68 in the third order and again increases to 1.92 in the sixth order. This variation on a granitic bedrocks maybe attributed due to differences in slope and topographic conditions (Prabhakaran & Raj, 2018) with erosion, vegetation and endogenic forces playing a role.

4.1.5 Bifurcation ratio:

The term bifurcation ratio is defined as the ratio of the number of stream segments of the given order to the number of the segments of the next higher order (Schumm, 1956). Bifurcation ratio shows the degree of drainage integration. The higher the ratios value, the lower the drainage integration and vice versa. The irregularities of bifurcation ratio from one order to the next are dependent on geological and lithological development of the drainage basin (Strahler 1964). According to Horton (1945) bifurcation ratio ranges from 2 to 3 for flat and rolling drainage basin respectively and 4 for mountainous or highly dissected drainage basins. It is evident that in the study area the bifurcation ratio ranges from 2 to 4.44 and the differences in these bifurcation ratios maybe attributed to change in stream network due to climatic conditions, slope, erosion and influence of vegetation. The bifurcation ratio of the entire watershed is 3.32 which show the overall less structural disturbances in the watershed.

4.2 Arial Aspect:

4.2.1 ***Drainage density***

Horton (1945) defined drainage density as the total stream length divided by the area of the drainage basin. The drainage density of the catchment is 3.59 km/km^2 which according to Smith's (1950) classification fall under the moderate class. The Um Nongspung catchment when calculated per square kilometer, the area of D_d with less than 2 km/km^2covers 6.72%, 2 to 4 km/km^2 covers 85.31% and above 4 km/km^2 covers 7.97%. Due to the presence of granitic rocks which are highly resistant and impermeable (Nag, 1998), the drainage density of the catchment is not high but mostly moderate.

4.2.2 ***Stream frequency***

Horton (1945) defines stream frequency as the ratio of the total number of stream segments of all order to the basin area. High degree of stream frequency indicates high dissection and vice versa. The stream frequency of Um Nongspung catchment is 5.78 streams/ sq.km. When the catchment is calculated per square kilometer the stream frequency varies from 1 stream/ sq.km to 17 streams/ sq.km. Using this scheme of calculation, about less than 5 streams/ sq.km covers an area of 6.09%, 5 to 10 streams/ sq.km covers an area of 70.39 % and above 10 streams/ sq.km covers an area of 23.52%. It is evident from the values that there is a positive correlation with the drainage density which shows the increase in frequency of streams with respect to the density of streams.

4.2.3 ***Drainage Texture***

Drainage texture is the relative spacing of the drainage lines and it mainly depends upon several factors such as climate, vegetation type, density, rock type, soil type, infiltration capacity, relief and stage of drainage development. The drainage texture of Um Nongspung catchment is 7.42 which according to Smith's (1950) grading, falls under the medium textured category. Since drainage texture refers to the closeness of drainage lines, D_t has a direct relationship with drainage density and stream frequency which means an increase or decrease in stream frequency and drainage density affects the space between drainage networks which determines the texture of fineness or coarseness.

4.2.4 *Elongation ratio*

The shape of a basin is influence by the endogenetic and exogenetic processes that affect the discharge of the basin. The elongation ratio was defined by Schumm (1956) as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. The value of R_e varies from 0 (highly elongated) to 1.0 (circular). Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964). The elongation ratio of the Um Nongspung catchment is 0.71 indicating a less elongated shape with moderate relief.

4.3 *Relief Aspect*

4.3.1 *Relative relief*

Relative Relief is the actual variation of height between two points i.e., between the highest and the lowest elevation. The relative relief of the catchment is 460 meters which according to Smith's (1935) is a high relief area. High relief value indicates high rate of erosion (Bharath et al., 2021), high gravity of water flow and high runoff conditions. When the catchment is distributed per square kilometer, the relative relief of the catchment varies from 20 m to 240 m. The R_h below 100 m covers an area of 16.46%, 100m to 200m covers an area of 80.07% and above 200m covers an area of 3.46%.

4.3.2 *Dissection index*

Dissection index indicates the nature and magnitude of dissection of a terrain (Singh, 1998). It is the ratio of the relative height and the absolute relief which indicates the degree of vertical erosion and explains the stages of landscape development. According to Nir (1957), the value of dissection index ranges from 0 (these are flat plain areas with no dissection) to 1 (represents the area of vertical cliffs). The dissection index of Um Nongspung catchment is 0.25 indicating a medium relative altitude. When the catchment is distributed per square kilometer the D_i of less than 0.1 covers an area of 62.76%, 0.1 to 0.2 covers an area of 10.24% and 0.2 covers an area of 1.26%.

4.3.3 *Ruggedness index*

Ruggedness Index measures the surface ruggedness or the unevenness. It is indicative of the complexity of topography and the roughness of the terrain. It is measured by taking into account the maximum basin relief and drainage density of a basin (Chorley & Kennedy, 1971). The ruggedness index of Um Nongspung catchment is 1.65 which is moderate, indicating gentle and moderate slopes.

4.3.4 *Hypsometric Integral*

Hypsometric integral is the study of different geological stages of development of any river basin. These stages are determined by the erosional processes occurring within the river basin. The hypsometric integral is plotted on a graph with a curved indicating a scale of 0 to 1. Strahler (1952) proposed that when the HI $\geq$ 0.60 it is the inequilibrium or young stage, when the HI $\leq$ 0.35 it is the monadnock or old stage and in between 0.35 to 0.60 it is the equilibrium or mature stage. The hypsometric integral of Um Nongspung catchment is 0.5 indicating that the catchment is in the early mature stage of development. The mature stage of the catchment also means that the activities of erosional and depositional processes within the catchment are in a steady state or in equilibrium (Strahler, 1950).

5. FINDINGS AND CONCLUSION:

In an attempt to study the Um Nongspung catchment using the linear, areal and relief aspects the major findings are highlighted here. The Um Nongspung is classified as a sixth order stream and it is also noted that the development of drainage patterns are dendritic, radial and parallel which are influenced by geology and rainfall besides the endogenic and exogenic forces of the area. The drainage density reveals that the subsurface strata are resistant and impermeable. This is a characteristic feature of granitic bedrocks. Um Nongspung river has a total length of 22 kms and the total length of all the streams is 266.59 kms. It also confirms to law of stream length which states that the length of streams of each orders in a drainage basin tends to have a direct geometric ratio. The bifurcation ratio of the catchment is 3.32 which indicate less structural disturbances.

The study area has moderate relative relief occupying about 80.07 % and very low dissection index spread all over the catchment. It is observed that Um Nongspung catchment is dominated by low and moderate ruggedness index occupying about 57% and 40.39% respectively. It is noted that the moderately high slopes of 10° to 18° dominates the entire watershed occupying about 33% whereas very steep slopes of > 45° are absent in the watershed.

Um Nongspung catchment has the highest area coverage of moderate drainage density, moderate drainage frequency and medium drainage texture of about 85.31%, 70.39 % and 92.73 % respectively.

Watershed management is one of the key areas to take up where urgent actions is needed right at the grass root level especially with climate change and anthropogenic activities posing a threat to the balance in our environment. Morphometric analysis through Remote sensing and GIS made a huge utility in providing accurate information, measures and help in decision making for the overall management of the river system. There is an indiscriminate change in the landuse pattern of the area which can lead to more hazards especially with the absence of any initiative to safeguard the Um Nongspung catchment. Water is a precious resource which is also a lifeline for the livelihood of people of Nongspung and the surrounding areas. This study in general will provide an outline for stakeholders, various organisations and even the government to start the initiatives for soil and water conservation especially with the area having a huge potential, in fertile soil and rich biodiversity, for the overall development of the area.

6. ACKNOWLEDGEMENT:

I would like to express my thanks to Dr. Jane E. Warjri for her guidance and support in completing this paper. I would also thank my good friend Mr. Lobsang Tenzin Com and James Lyngdoh for helping me in time of needs and for that I am grateful beyond words.

REFERENCES:

1. Horton, R. E. (1932). Drainage Basin Characteristics. Transactions, A*merican Geophysical Union*, 13, 350-361. http://dx.doi.org/10.1029/TR013i001p00350
2. Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydro physical approach to quantitative morphology. *Bulletin of the Geological Society of America*, 56 (3), 275–370.
3. Strahler, A. N. (1950). Equilibrium theory of erosional slopes approached by frequency distribution analysis. *American Journal of Science*, 248 (10), 673–696. https://doi.org/10.2475/ajs.248.10.673
4. Strahler, A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Geological Society of America Bulletin*, 63 (11), 1117-1142. https://doi.org/10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2
5. Strahler, A. N. (1957). Quantitative analysis of Watershed Geomorphology. *Transactions, American Geophysical Union*, 38, 913–920. http://dx.doi.org/10.1029/TR038i006p00913
6. Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow, V.T. (eds.) *Handbook of applied hydrology*. (pp. 439–476) McGraw-Hill, NewYork.
7. Smith, G. H. (1935). The relative relief of Ohio. *Geographical Review*, 25(2), 272-284.
8. Smith, K. G. (1950). Standards for grading texture of erosional topography. *American Journal of Science*, 248, 655–668. doi:10.2475/ajs.248.9.655.
9. Miller, V. C. (1953). *A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area, Virginia and Tennessee*. Department of Geology, Columbia University, New York.
10. Schumm, S.A. (1956). The evolution of drainage systems and slopes in bad lands at Perth, Amboi, New Jersey. *Bulletin of the Geological Society of America,* 67 (5), 597-646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2.
11. Easthernbrook, D.J. (1993). *Surface processes and landforms*, Macmillan Pub Co, New York.
12. Agarwal, C.S. (1998). Study of Drainage Pattern through Aerial Data in Naugarh Area of Varanasi District, U.P. *Journal of the Indian Society of Remote Sensing*, 26,169-175. https://doi.org/10.1007/BF02990795
13. Prokop, P. (2014). The Meghalaya Plateau: Landscapes in the Abode of the Clouds. In: Kale, V. (eds) *Landscapes and Landforms of India*. (pp. 173–180). World Geomorphological Landscapes. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-8029-2_17
14. Hasan, Sayeed. Mohd., Adhikari, Kalyan., & Soumya, Bhattacharyya. (2017). Morphometric Analysis using Remote Sensing and GIS. *Journal of Civil Engineering and Environmental Technology*, 4 (1), 17-22.
15. Pike, R. J., & Wilson, S. E. (1971). Elevation-relief ratio, hypsometric integral, and geomorphic area-altitude analysis. *Bulletin of the Geological Society of America*, 82(4), 1079-1084. http://dx.doi.org/10.1130/0016-7606(1971)82[1079:ERHIAG]2.0.CO;2
16. Shreve, R. L. (1966). Statistical law of stream numbers. *The Journal of Geology*, 74 (1), 17-37.
17. Prabhakaran, A., & Raj, N. Jawahar. (2018). Drainage morphometric analysis for assessing form and processes of the watersheds of Pachamalai hills and its adjoinings, Central Tamil Nadu, India. *Applied Water Science*, 8 (31). https://doi.org/10.1007/s13201-018-0646-5

18. Nag, S.K. (1998). Morphometric Analysis Using Remote Sensing Techniques in the Chaka Sub Basins, Purulia District, West Bengal. *Journal of Indian Society of Remote Sensing*, 26, 69-76. http://dx.doi.org/10.1007/BF03007341.
19. Bharath, A., Kumar, K. Kiran., Maddamsetty, Ramesh., Manjunatha, M., Tangadagi, Ranjitha. B., & Preethi, S. (2021). Drainage morphometry based sub-watershed prioritization of Kalinadi basin using geospatial technology. *Environmental Challenges.* 5. 1-9. https://doi.org/10.1016/j.envc.2021.100277.
20. Singh, S. (1998). *Geomorphology*. Prayag Pustak Bhawan, Allahabad.
21. Nir, Dov. (1957). The Ratio of Relative and Absolute Altitudes of Mt. Carmel: A Contribution to the Problem of Relief Analysis and Relief Classification. *Geographical Review,* 47(4), 564-569.
22. Chorley, R. J., & Kennedy, B. A. (1971). *Physical geography: A systems approach.* London: Prentice-Hall.