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Drainage Morphometry of Dzükou Sub-Watershed in Kohima District, Nagaland Using GIS Tools and Techniques

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Abstract

The in-depth study of morphometric analysis associated with the geometrical properties of drainage systems has helped in understanding the types of drainage patterns, density, geology, geomorphology, etc., and their interrelation with one another. This paper aims to understand the morphometric parameters in Dzükou sub-watershed such as linear, textural, and areal aspects. The paper also focused to identify the different landscape formations through various techniques such as stream order, stream number, stream frequency, stream length, drainage density, texture, bifurcation ratio, mean stream length, relief aspect, gradient ratio, etc. In order to analyze drainage morphometry, Remote Sensing and GIS, the two most advanced technology has been applied. The high-resolution images generated have helped in identifying the origin, nature, and types of the drainage basin. The present study of drainage morphometry is an attempt to understand the stages and evolution of the Dzükou sub-watershed in Kohima district, Nagaland using GIS tools and techniques.

Keywords: Morphometry, Parameters, Geo-hydrological, Dzükou, Geo-referenced, Remote sensing and GIS, Kohima district.

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Introduction

Morphometric analysis is the method of making measurements of the dimensions of landforms along with the various terrain properties. Drainage morphometry is the technique and method of measuring the configuration of the "earth's surface dimensions and the shape of landforms" (Clarke 1966:235-236). The function of the geo-hydrological system and its characteristics can also be studied and illustrated through the application of drainage morphometry. The drainage characteristics are also useful to delineate groundwater potential in an area. Further, drainage morphometry is a useful method for area development planning as it provides useful information of land and water. The conservation and management of natural resources can also be assessed easily with the successful implication of drainage morphometric techniques. Geographical Information System (GIS) is an information technology used to process geo-referenced spatial data. It provides highly accurate data with time-saving and economical techniques with great efficiency.

The objective of the present study is to assess the morphometric and evolutionary aspects of Dzükou sub-watershed by using geospatial technology. The application of GIS and Remote sensing techniques in this field is important for better understanding and detailed analysis of different drainage sub-basin and landscape formations. The different types of drainage pattern and density can also be verified easily through careful observation and interpretation of satellite images. The study of slope aspects and contour line is of paramount interest for the generation of Digital Elevation Model by which relief aspects and various parameters can be analyzed and interpreted.

However, there are a few limitations and likely errors are expected to arise while calculations of data are being evaluated. The conversion of unit value (meters to km) is sometimes very extensive and puzzling and this may lead to incorrect findings if careful observations are not made.

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Materials and Methods

The total study area has been demarcated from the Survey of India topo sheet nos. 83 G/14 and 83 K/2 covering parts of the Kohima, Peren and Dimapur districts of Nagaland. Arc-GIS-9.3 software has been used to delineate drainage network and other relevant topographic information for drainage analysis in the present study. This drainage map was digitized and assigned stream orders following Strahler's (1964) stream ranking and edited using ArcGIS (9.3 version) software tools. The attributes were generated for digital database for drainage layer of the river basin. The drainage layers have been projected to polyconic coordinate system to make all measurements in metres or kilometres. The significant morphometric parameters such as linear, textural and areal aspects of the drainage basin were computed and interpreted to draw conclusions. The entire drainage basin was divided into 17 sub-basins (Fig. 1) to study the parameters at the sub-basin level using Robert Elmer Horton, Arthur Newell Strahler methods of drainage morphometry. The different formulae used in this study to compute various drainage parameters are presented in **Table 1.**

Table 1: Methods of computing morphometric parameters

Linear Aspects			
1	Stream Order (U)	Hierarchical rank	Strahler (1964)
2	Stream Length (Lu)	Length of the stream	Horton (1945)
3	Stream Length Ratio (Rl)	Rl = Lu/Lu-1; Lu= Length of streams in a given order	Horton (1945)
4	Mean stream length (Lsm)	Lsm = Lu/Nu	Horton (1945)
5	Bifurcation Ratio (Rb)	Rb = Nu/Nu + 1; Nu = Number of streams in a given order	Schumm (1956)
6	Mean Bifurcation Ratio (Rbm)	Rbm = Average Rb ratio	Strahler (1957,1964)
7	Rho co-efficient (ρ)	ρ = Rl/Rb	Horton (1945)
Textural Aspects			
8	Drainage Density (Dd)	Dd = Lu/A; Lu = Length of streams; A = Area of the basin	Horton (1932, 1945)
9	Drainage Frequency (Df)	Df = Nu/A; Nu = Number of streams in a given basin	Horton (1932, 1945)

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10	Drainage Texture (Rt)	T= Nu/ P, Nu = total no. of stream P= perimeter of the basin	Horton (1945)
11	Infiltration number	If = Dd*Df	Faniram (1968)
12	Length of overland flow (Lg)	Lg = Dd/2	Schumm (1956)
13	Constant of Channel Maintenance (Cm)	Cm = 1/Dd	Schumm (1956)
Relief Aspects			
14	Basin Relief (R)	R = H-h; H = Basin highest relief; h = Basin lowest relief	Schumm (1956)
15	Relief Ratio (Rr)	Rr = R/Lb; Lb = Basin Length	Schumm (1963)
16	Ruggedness Number (Rn)	Rn = R×Dd; Dd = Drainage density	Schumm (1956)
17	Gradient Ratio (Gr)	Gr = (a-b)/Ls; Ls = Length of the main channel	Sreedevi, et al., (2005)
18	Relative Relief	Rhp = R/P; R = Basin Relief (P) = Basin Perimeter	Melton (1957)
19	Dissection index (Di)	Di = Rr/Ar; Rr = relative relief, Ar = Absolute relief	
20	Absolute relief (Ar)	Ar = (H+h)/2	

Source: Robert Elmer Horton & Arthur Newell Strahler 1964

Where, Nu = Total no. of streams of order 'u', Lu = Total stream length of order 'u', Nu + 1 = Number of stream segments of the next higher order, Lu-1 = Total stream length of its next lower order, A = Area of the basin, P = Perimeter, Lb = Maximum length of the basin, Ls = Length of the main channel, H = Maximum elevation of the basin, h = Minimum elevation of the basin, Ra = Absolute relief, a = elevation of source, b = Elevation of confluence.

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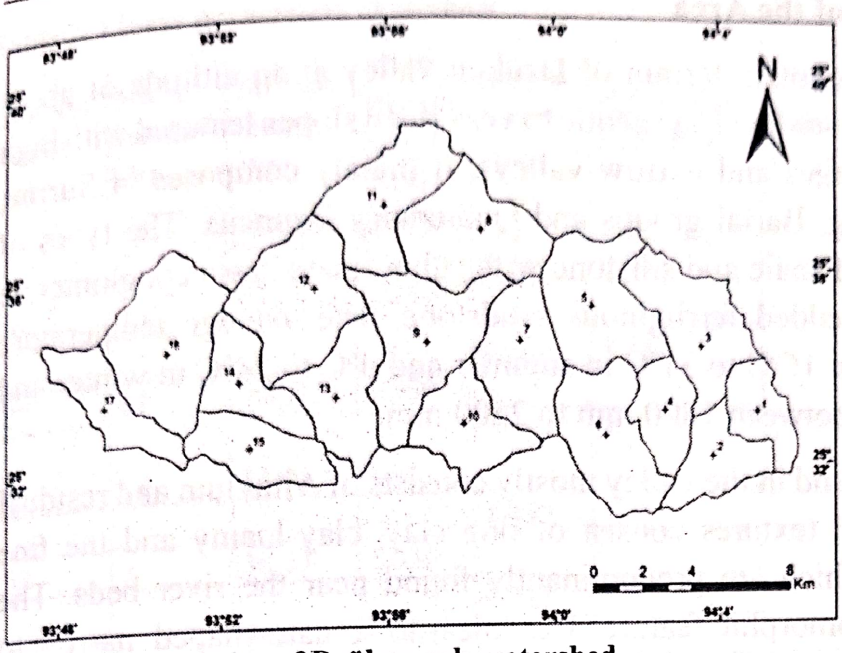


Figure 1: Sub-basins of Dzükou sub-watershed

Study Area

The Study area of Dzükou basin is a tributary of Brahmaputra River covering a total area of **252.87** km^2. It is enclosed between longitudes 93°43'30"E and 94°5'50"E to 25°30'50"N and 25°39'10"N latitudes falling in the Survey of India (SOI) topo sheet nos. 83 G/14 and 83 K/2 **(Fig. 2)**. The elevation in the study area varies from 2998 m to 850 m above sea level with gentle to very steep slopes. It featured high hills, sharp crest ridges, deep gorges and narrow valleys.

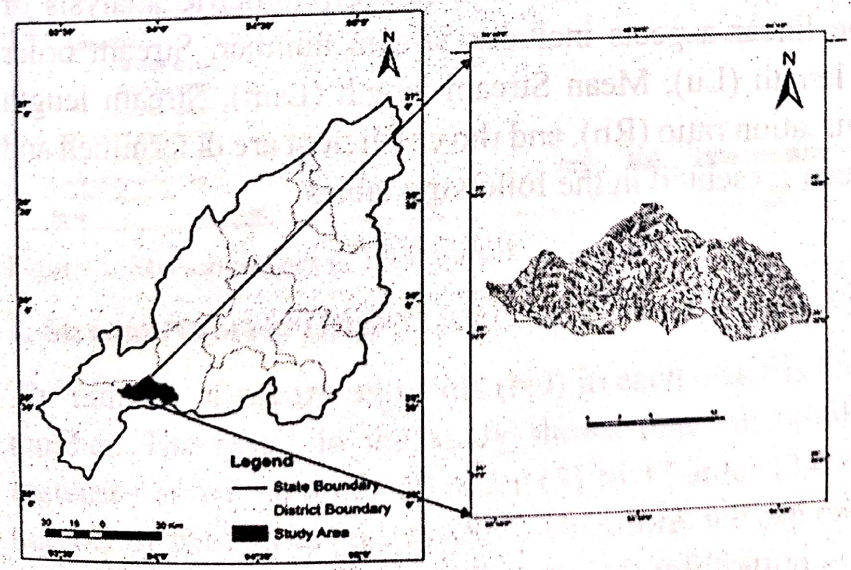


Figure 2: Location map of Dzükou sub-watershed

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Morphology of the Area

The young mountain terrain of Dzükou valley at an altitude of about 2452 m above sea level has gentle to very steep slopes featured with high hills, deep gorges and narrow valleys. It mainly composes of Surma, Tipam, Disang, Barial groups and Quaternary Deposits. The types of rock consist of shale and siltstone with subordinate basin conglomerate and thickly bedded ferruginous sandstone. The average temperature varies between 16°C to 31°C in summer and 4°C to 24°C in winter and Rainfall falls between 1800 mm to 2500 mm.

The soil found in the valley mostly consists of Alluvium and residual soils. The soil textures consist of fine clay, clay-loamy and the fine loamy-clay which are predominantly found near the river beds. The prominent geomorphic features like linear to arcuate-shaped, narrow to the broad crested structural hill ranges with deep and narrow valleys are seen in the area.

Results and Discussion

Linear Morphometric Parameters

Linear aspects of the drainage basin bring out the topological characteristics of drainage channels. Various parameters of linear features such as stream number (Nu), stream length (Ls) and hierarchical order of stream (Su) were computed. The linear parameters of all 6th order streams are shown in **Table 2**. The morphometric analysis of study area, the linear aspects includes Stream number, Stream order (Nu), Stream length (Lu), Mean Stream length (Lsm), Stream length ratio (RL) Bifurcation ratio (Rb), and rho coefficient are determined and results have been presented in the following tables.

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Table 2: Linear parameters of streams

Stream order (u)	No. of streams (Nu)	Stream length (km)	Mean stream length (km)	Stream length ratio	Bifurcation ratio (Rb)	Mean bifurcation ratio	Rho co-efficient
1st	1464	730.135	0.498				
				0.261	4.847		
2nd	302	190.738	0.631				
				0.525	4.793		
3rd	63	100.171	1.590				
				0.249	4.5	2.915	0.148
4th	14	24.95	1.782				
				1.456	1.55		
5th	9	36.33	4.036				
				0.110	1.8		
6th	5	4.017	0.803				
Total	1857						

Source: Robert Elmer Horton & Arthur Newell Strahler 1964

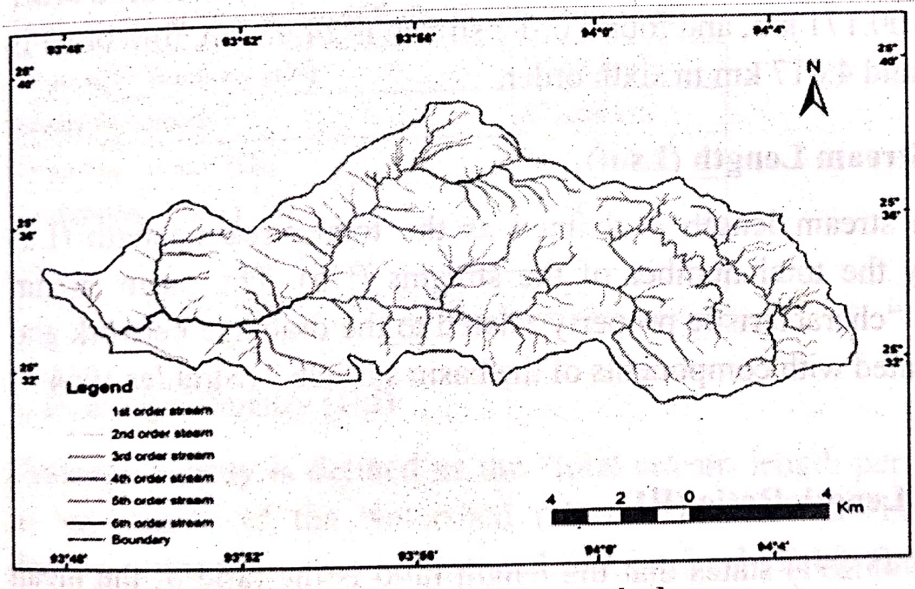


Figure 3: Stream orders of Dzükou sub-watershed

1. Stream Number (Nu)

The number of stream segments (Nu) in each order is known as stream number. The result in the study shows that the number of streams increases as we go from 6th order (5) to 1st order (1464) having total number of streams as high as 1857. Therefore, we can conclude that the bed rock is less permeable resulting to less infiltration.

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2. Stream Order (Su)

Strahler's system has been used because of its simplicity as the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give channels of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. The trunk stream is the stream segment of the highest order. The result shows that the study area is a sixth order drainage basin. The maximum stream frequency is in the case of first order streams and followed by second order. It is also observed that there is a decrease in stream frequency as the stream order increases.

3. Stream Length (Lu)

The stream length (Lu) has been calculated on the basis of the Horton's law. It is the total length of streams in a particular order and also gives information about surface runoff. In the study area the length of first order streams is 730 km, second order stream is 190.738 km, third order stream is 100.171 km, and fourth order stream is 24.95 km, fifth order is 36.33 km and 4.017 km in sixth order.

4. Mean Stream Length (Lsm)

The mean stream length is defined as the total stream length (Lu) divided by the total number of the streams (Nu). The mean stream length is a "characteristic property related to the drainage network and it is associated with components of the basin surface." (Strahler 1964:4) **(Table 2)**

5. Stream Length Ratio (RI)

Horton (1945:291) states that the length ratio is the ratio of the mean (Lu) of segments of order (So) to mean length of segments of the next lower order (Lu-1), which tends to be constant throughout the successive orders of a basin. The stream length ratio of Dzükou Valley varies from 0.1 to 1.4 which indicates that the area has dense vegetation covered with permeable soils. The change in the stream length from one order to the next implies the age of geomorphic development.

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6. Bifurcation Ratio (Rb)

Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher order (Schumm, 1956:602). Higher bifurcation ratio indicates some sort of geological control and lesser the bifurcation ratio, lesser disturbance to the drainage pattern. In the study area, the mean Rb varies from 1.515 to 4.847, which indicates normal environmental circumstances for the development of drainage. The mean Rb of the entire basin is 2.915 which indicate that the geological structure is less disturbing to drainage pattern.

Textural Aspects

The textural aspects are two-dimensional properties of the basin. The parameters such as drainage density, stream frequency, drainage texture and constant of channel maintenance were analyzed to draw significant conclusions to understand the terrain conditions in the Dzükou sub-watershed.

Table 3: Textural aspects of Dzükou sub-watershed

Drainage frequency (Df)	7.343 km^{-2}
Basin Perimeter	87.768 km
Drainage texture (Dt)	21.158 km^{-1}
Infiltration number (If)	31.484
Length of overland flow (Lg)	2.156
Constant channel maintenance (Cm)	0.231

Source: Robert Elmer Horton 1945

1. Drainage Density (Dd)

Drainage density is defined as the "total stream length per unit area" in any region of the watershed (Horton 1945:276). The drainage density of the entire study area is 4.313 km/km^2 **(Table 3)** indicating higher drainage density while sub-basins vary from 3.52 to 5.14 km/km^2 showing varying drainage density. The high values of drainage frequency are represented by matured basins whereas; low range of drainage frequency indicates youth stage of development (Sidhu, et. al, 1974). The low drainage density indicates that the watershed is highly resistant and permeable subsoil material, dense vegetation, and low relief which lead to coarse drainage texture.

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2. Stream Frequency (Fs)

Horton in 1945 defined the term stream frequency as the ratio between the total numbers of stream segments per unit area. The value of stream frequency of the entire watershed is 7.343 km^{-2} while sub-watersheds vary from 5.750 to 9.001^{-2} **(Table 3)** which is classified as moderately high frequency (Horton 1945) and are found in areas of sparse to thick vegetation. It is also directly related to the lithological characteristics.

3. Basin Perimeter (P)

Basin perimeter is an important aspect of the morphometrical analysis of drainage. It is the total length of the basin boundary or the length measured along the drainage divide of the basin. It may be used as an indicator of basin size and shape. The basin of the study area has a perimeter of **87.768 (Table 3)** km covering a total area of **252.874** sq. km. It is also a determinant factor of the size of the drainage basin.

4. Drainage Texture (T)

Drainage texture is defined as the total number of stream segments of all orders per perimeter of the basin. It is an important aspect of fluvial geomorphology that affects and depends on natural factors such as climate, rainfall, vegetation, rock and soil type, relief and stages of development. In the present study, the drainage texture value of entire watershed is 21.158 km^{-1} **(Table 3)** and the values of drainage texture of the entire sub basins range from 3.478 km^{-1} to 9.680 km^{-1} which is categorized as fine texture.

5. Infiltration Number (IF)

The infiltration number of a drainage basin is defined as the product of drainage density and drainage frequency. It is the number by virtue of which an idea regarding the infiltration characteristics of the basin is obtained. The higher the infiltration number, the lower will be the infiltration, and higher will be the run-off (Rao Liaqat et. al, 2011). The infiltration number of the study area is 31.484 km^{-1} which indicates low run-off and a higher infiltration rate. The area has a thick vegetative cover and highly aggregated soil which has positive impacts on infiltration.

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6. Length of overland flow

It is used to refer "the length of running rainwater on ground surface" before it is submerged into local channels (Horton 1945:278). It is a very important aspect of water cycle where soil permeability, topography, slope, and type and density of vegetation affect the rate of overland flow. In this study, the length of overland flow of the basin is 2.156 km, range of 17 sub-basins varies from 1.763 to 2.566 which indicate low surface runoff in the study area.

7. Constant of Channel Maintenance (Cm)

The constant of 'channel maintenance' is defined as the area of the watershed surface needed to maintain per unit length of 'stream channel' and is expressed by the reciprocal of drainage density (Schumm 1956:610). The constant of channel maintenance value for the entire watershed is 0.231 km/sq. km, it means 0.231 sq. km of surface area is required to maintain each kilometer of channel length and for all sub-watersheds vary from 0.194 to 0.283 sq. km/km indicating that the area is characterized by low surface runoff, low permeability and high drainage density. **(Table 3)**

Relief Aspects

Relief aspects of drainage deals with certain relief parameters of drainage morphometry like basin relief, relief ratio, relative relief, hypsometric analysis, ruggedness numbers etc. These parameters give an idea of the watershed topography. It is essential to study the relief aspects as they are useful to understand the stage of drainage and the development of landscape in the evolution of watershed. The computed values of relief parameters such as basin relief, relief ratio, relative relief, hypsometric analysis, ruggedness numbers are presented in **table 4**. The digital elevation models downloaded from the United States Geological Survey have been used in this study to derive the parameters **(Fig. 4)**.

1. Basin Relief

It is defined as the elevation difference between the highest and the lowest relief on the valley floor. It is the significant factor as it plays a

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Table 4: Relief properties of Dzükou sub-watershed

Relief Aspects			
Sl. No.	Parameter	Formula	Value Obtained
1	Basin relief (R)	R = H – h	2172 m
2	Relief ratio (Rr)	Rr = R/Lb	1.993
3	Relative relief (Rhp)	Rhp = H/p	0.034
4	Gradient ratio (Gr)	Gr = (a – b)/Lb	1.912
5	Ruggedness number (Rn)	Rn = R×Dd	9.367
6	Dissection index (Di)	Di = Rr/Ar	1.042
7	Absolute relief (Ar)	Ar = (H+h)/2	1.912km

Source: Sreedevi et. al. 2009

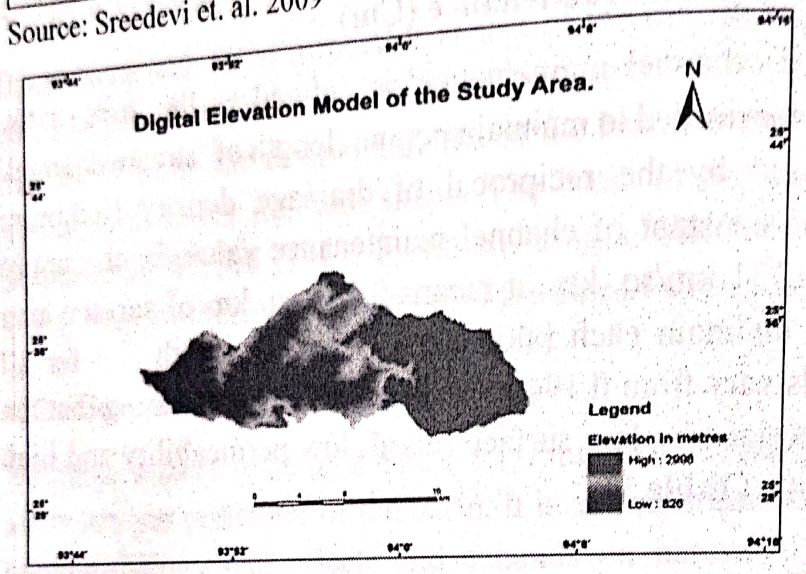


Figure 4: Digital Elevation Model of Dzükou basin

major role in drainage development, landform process, surface as well as in through flow. In addition, erosion and infiltration are controlled by the relief. As seen on the digital elevation model, the maximum elevation is 2998 m seen in the northeastern part and the minimum elevation is 826 m found at its mouth in the western part of the watershed. The total basin relief is 2172 m as computed by using the formula. **(Table 4)**

2. Absolute relief

Absolute relief is an attempt to give some idea about the existing topography. In the study area, high absolute relief are found in western region that is at the source of the basin and low absolute relief tend to decrease as it goes down the sub-basin of higher order. The absolute relief of the study area is 1.912 km and the sub 17 sub-basins range from 1.386 to 2.733 km.

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3. Relief ratio

It is defined as the ratio between the total relief of a basin and total basin length (Schumm, 1956). Relief ratio indicates the correlation between relief and hydrological characteristics. Therefore, erosion in a basin can be predicted with the help of relief ratio. High values of relief ratio indicate hilly region and low values indicate pediplain and valleys structure. The relief ratio of the Dzükou sub-watershed is found to be 1.993 shown in (table 4). The relief ratio of the sub-basins in Dzükou sub-watershed range between 0.09 and 0.32. The low values of the sub-basins indicate the presence of resistant rocks and low degree of slope.

4. Relative relief ratio

Relative relief is expressed as the basin relief to the perimeter per unit area. The lower values indicate gentle topography and the high values suggest steeper slopes of the terrain (Melton, 1958). The relative relief of the sub-basins ranges 0.104 to 0.221. The relative relief of the entire sub-watershed is 0.034. The high values indicate that the area has moderate to very steep slopes.

5. Gradient ratio

Gradient ratio is an indicator of channel slope (Sreedevi et. al., 2009). The total runoff in an area can be estimated from gradient ratio. The gradient ratio of the sub-basins ranges from 0.005 to 0.025 which indicate the terrain is mostly low gradient. The gradient ratio of the Dzükou sub-watershed is 1.919 **(Table 4)**. The value indicates that as a whole the Dzükou sub-watershed terrain is high gradient.

6. Ruggedness number

Strahler in 1968 defines ruggedness number as the product of basin relief and drainage density. It is useful to predict slope steepness along the length of streams. The Dzükou sub-watershed has a ruggedness index of 9.367 **(Table 4)**. The high ruggedness number of the watershed indicates that the slope is long and steep. In addition, it has also high drainage frequency with predominant erosion.

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7. Dissection index

Singh in the year 2000 expressed the dissection index (Di) as the ratio of basin relief to the maximum absolute relief. It is the most important morphometric indicator which shows the nature and magnitude of the dissection of terrain. According to Deen (1982), the value of the dissection index varies from 0 to 1, where 0 indicates a complete absence of dissection and 1 indicates a vertical cliff. Generally low 'Di' is associated with high altitude or old stage where erosion activities are predominant and the areas with high 'Di' is associated with low relief where the slope of the land is steep. The dissection index of the study area is 1.042 **(Table 4)**. The value indicates the presence of vertical cliffs and steep slopes. The sub-basin-wise dissection index varies from 0.530 to 0.896.

Conclusion

The study area of Dzükou watershed is located in the three districts of Nagaland namely, Kohima, Dimapur and Peren. GIS software has been used for morphometric analysis of linear, areal and relief aspects of Dzükou basin area. The GIS-based software is also found to be more appropriate than the use of conventional methods of evaluation of drainage morphometry. It has also enabled the exploration of the relationship between drainage morphometry and soil erosion and eroded landforms.

From the evaluation of drainage analysis, the total watershed of the study area covers an area of 252.874 sq. km with a total perimeter of 87.768 km. The entire Dzükou basin is divided into 17 sub-basins with a total stream length of 1086.925 km. The watershed is a 6^{th} order basin where the number of streams are as follows; 1464 of 1^{st} order, 302 of the 2^{nd} order, 63 of the 3^{rd} order, 14 of the 4^{th} order, 9 of 5^{th} order and 5 of the 6^{th} order streams are present. The Dzükou watershed numerical value goes on decreasing with increase in hierarchical stream order.

The study area exhibits dendritic, trellis and parallel drainage pattern. Its drainage density is 4.313 km^{-1} and the sixth order sub-basin drainage density varies from 3.93 to 5.14 km^{-1}. In the present study, the drainage

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density suggests that the region is covered with impermeable sub soils and less vegetation cover leading to coarse drainage texture. The sub-basins 1 and 11 have the highest drainage density which is due to the presence of highly impermeable rock, sparse vegetation cover and high mountain relief. However, sub-basins 7, 13 and 15 have very low drainage density which suggests that the basin is covered with thick vegetation cover, high relief and permeable rocks. The stream frequency of the study area is 7.343^{-2} wherein, the sixth order stream frequency varies from 5.75 to 9.001^{-2}. The stream frequency of the sub-watershed in the study area reveals that the drainage basin exhibits a positive correlation with drainage density as values increase with increased drainage density. The drainage texture falls under the category of very fine to fine.

The infiltration number for the study area is 31.484 km^{-1} which indicates that the drainage basin is good with low surface run off and less overland flow. Constant of channel maintenance is found to be less than 0.231 km/sq. km, indicating high drainage density with low run off.

The bifurcation ratio of the entire basin is 2.915 which indicate that the geological structure has less influence on the area exhibiting a well-developed drainage network.

The study reveals that the area is situated at high elevation (2998m) where its relative and basin relief are found to be moderate and high (0.034 & 2.998 km respectively). The gradient ratio also indicates that area is of high gradient terrain and high ruggedness index, with 9.367 indicating long steep slope with high drainage frequency. The outcome of the study reveals that the area has a good rock structure and possibly good water-bearing characteristics.

Thus, the detailed study of these morphometric parameters has become a very useful and important tool for watershed management plans.

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