Morphometric Status of River Mu Sub-Basin in Makurdi South, Nigeria

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ABSTRACT

River Mu drainage basin morphometric status is assessed against the backdrop of its characteristics and implication on hydrologic processes operating within the watershed. Geospatial techniques of GIS and Remote Sensing was deployed in the analysis and characterization of the basin morphometric attributes. The result showed Mu drainage basin has an area of 1259.26km^2, basin perimeter 240.96km, form factor 0.22, circulatory ration 0.27, and drainage texture 0.51. Mu drainage basin is of 4th order with a dendritic pattern of drainage system indicating the homogeneity in texture and lack of structural control. The stream frequency 0.10 stream segments per square kilometer, drainage density (Dd) 0.40km/km^2, bifurcation ratio of 4.62 and length of overland flow of 1.25km. The drainage density, bifurcation ratio and circularity ratio value indicate that the basin is of gentle slope, elongated, high infiltration capacity, low run off and may have longer duration of flow peaks, less susceptible to flooding.

Keywords: Geographic Information System, Morphometric analysis, Remote Sensing River basin

INTRODUCTION

Drainage basin has long been recognized by earth scientists as a fundamental hydrogeomorphic unit with unique characteristics that influences the processes operating within the basin. Drainage basin or otherwise a catchment is an area drained by a river system, that is a river and its tributaries separated by a watershed or divide (Horton, 1945).Its uniqueness has been explored by researchers in hydrology and water resources investigation such as precipitation, infiltration, run off, water balance, streamflow, stream profile analysis, watershed management, flood, drought, water resources planning, development and management for multifarious purposes.

Early approaches in drainage basin study were mainly qualitative and was attributed mainly to Davisan scheme of stream stages classification (Gregory and walling, 1973).A major revolution in the study of drainage basin was pioneered by Horton in 1945, who introduced measurement and quantitative expression of drainage basin. Later in 1952 Strahler improved on the earlier work by incorporating new measures and proposed general methods for description of drainage basin (Gregory and Walling 1973).This has set a stage for quantitative analysis or otherwise morphometric analysis of drainage basins worldwide. This process has been greatly enhanced with the advent of geospatial techniques of Remote Sensing (RS) and Geographic Information System (GIS)

Morphometric analysis of a river basin refers to the measurement and mathematical evaluation of the surface, shape and dimension of its landform (Agarwal, 1998; Kulkarni, 2015, Alfa et al, 2018). River morphometry represents the topographical expression of land by way of area, shape, length, etc. These parameters affect catchment streamflow pattern through their influence on concentration times(Jones,1999).The morphometric characteristics of a river basin are viewed as significant factors in watershed hydrology as they reflect hydrological behavior of the river basin which are useful in evaluation of hydrologic response of the basin. Quantitative analysis of a river basin therefore enhances our understanding of the basin characteristics and development, surface runoff generation, infiltration capacity of the area as well an groundwater potentials (Ibrampurkar,2012; Raj and Azeez,2012; Alfa et al, 2018).

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The quest to understand the basin morphometry and related issues such as erosion, sediment yield, channel alteration, infiltration/runoff and flooding, surface and groundwater development has attracted investigations worldwide. In Nigeria, river basin morphometric studies have been carried out in different parts of the country with impressive findings(Ebisemiju,1976;1979; Adejuwon et al, et al1983; Anyadike and Phil-Eze, 1989;Ifabiyi,2004; Ajibade etal,2010; Eze and Effiong (2010);Ezemonye and Emeribe (2013)Oruonye et al,2016; Udoka et al (2016); Sule and Bilwa (2017); Bunmi et al(2017); Alfa et al,2018; Adedayo and Eludoyin 2019; Adelalu et al(2020); Okogbue et al (2021); Odiji et al (2021); Ahuchaogu et al (2022). However, more basin studies is required in view of the many basins and sub-basins we have across the Nigeria landscape. This study is a contribution in this direction. There are paucity of studies in the lower Benue river basin. Nwakonobi and Gwaza (2012) pioneered a study on the suitability of River Mu water quality for irrigation within the basin.While Ade (2014) investigated morphological characteristics of River Mu,Iorchir (2018) sediment yield of River Mu, Vambe (2021) determinants of fluvial erosion of River Mu, a comprehensive morphometric analysis of River Mu sub- basin has not been investigated hence the importance of the study.

MATERIALS AND METHODS

The Study Area

River Mu drainage basin is a sub-basin of the lower Benue River basin. River Mu is one of the major tributaries that takes it source from Gboko highland and flows through to empty its water in River Benue at Makurdi South. The basin is located between Lat. 7^0 45’ and 8^0 00’ and Long. 8^0 28’ and 8’ 32’ covers an area of 1259.26 km^2 (Fig 1). The basin is located within the River Benue flood plain which is generally lowlying, gentle sloping and undulating. The geology is of Precambrian period which originated from early cretaceous rift and contains layers of alluvium deposits. According to Ade (2014) Iorchir (2018) the soils are typical entisols, which are loamy, slightly acidic, less leached with very high base saturation derived from basement complex rocks. The uniform forms of soils are either sandy or clayed, and the gradation is usually a gradual shift from sandy surface to more clayed sub-soil.

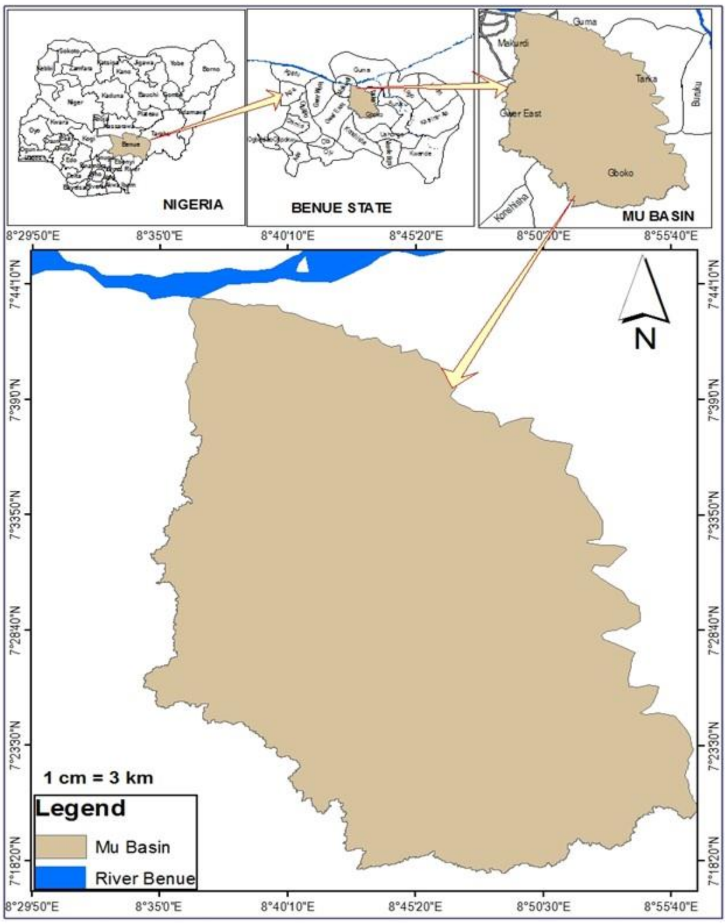

Figure 1: River Mu Sub-Basin

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Source: Author's GIS Laboratory work

The climate is of "AW' Koppen climatic classification characterized by wet, hot, dry and cool seasons. The onset and cessation of rain is April and October respectively. The annual rainfall ranges between 1200-2000mm. Dry seasons are relatively of low humidity. Temperatures are generally high with mean annual temperature of 32.5^{0}C (Tyubee, 2009). The basin lies within the Southern Guinea Savana region characterized with shrubs, grasses and trees.

In this study, the 21 selected morphometric parameters were evaluated by delineating the drainage basin guided by topographic map of the state. This was followed by the computation of various morphometric parameters and preparing the required thematic maps in GIS environment for better understanding and interpretation.

The principal source of the data for delineating the basin and extracting the drainage network is Shuttle Radar Topographic Mission Digital Elevation Model (SRTM-DEM) with 30 meter spatial resolution obtained from Earth explorer, a United State Geological Survey portal. The delineation of the Mu River basin boundary was achieved by using snap pour point and extraction of the drainage network using Hydrology Tool Kit from Spatial Analyst Extension toolset in ArcMap 10.2 software.

The extracted drainage network was integrated into ArcMap 10.7 for calculation of various morphometric parameters in line with the standard mathematical and hydrological methods. The computed watershed-based drainage morphometric parameters include stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, form factor, elongation ratio, circularity ratio, length of overland flow, relief ratio, Ruggedness number, Hypsometric integral and Dissection index of the basin (Table1). Mathematical calculations were performed using Microsoft Excel Software.

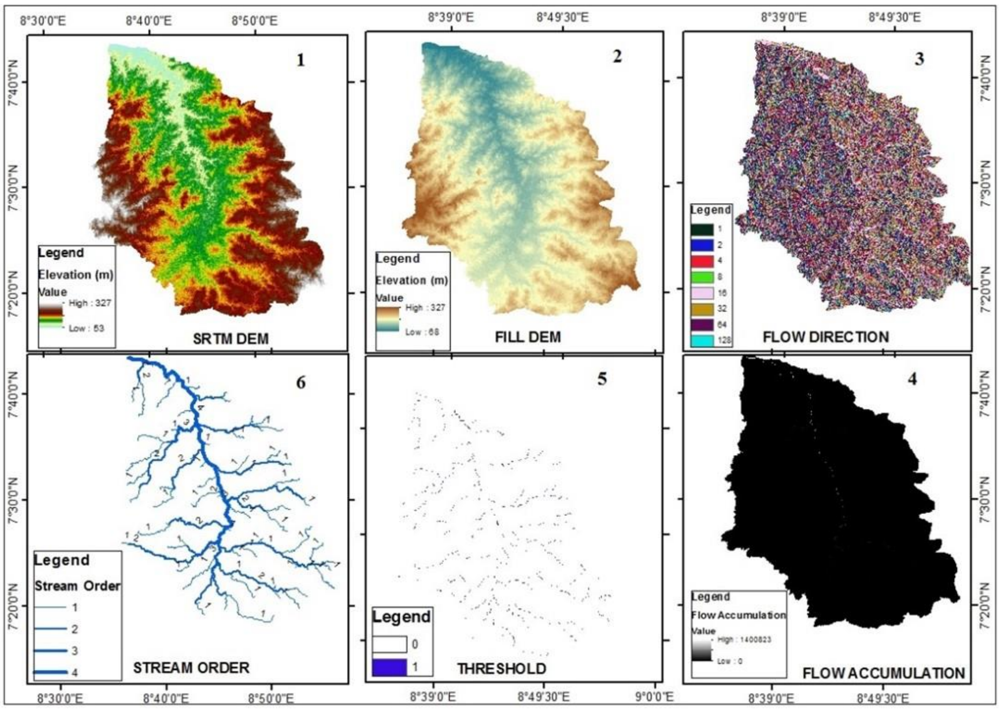

Figure 2: Procedure for the extraction of drainage networks River Mu Sub-basin

Source: Department of Geography, Benue State University GIS laboratory.

Table 1: Morphometric parameters and formulae

S/N	PARAMETER	SYMBOL	FORMULAE	Reference
1	Stream Order	Sɥ	Hierarchical Rank	Strahler (1952)

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2	Bifurcation Ratio	Rβ	Rb=Nμ/(Nμ+1) Where Rβ= Bifurcation ratio, Nɥ= Total no. of stream segments of order 'ɥ', Nɥ + 1 = Number of segments of the next higher order	Horton (1945)
3	Mean Bifurcation Ratio	Rβm	Rβm = Average of bifurcation ratios of all orders	Schumm, S. (1956)
4	Stream Length	Lμ	Length of the stream (km)	Horton (1945)
5	Mean Stream Length	Lsm	Lsm=Lμ/Nμ Where, Lμ = Total stream length of order 'μ' Nμ = Total no. of stream segments of order 'μ'	Horton (1945)
6	Stream Length Ratio	R_L	RL=Lsm/(Lsm-1) Where, Lsm=Mean stream length of a given order and Lsm-1= Mean stream length of next lower order	Strahler (1952)
7	Basin Perimeter	P	P= Outer boundary of drainage basin measured in kilometers. (GIS Analysis)	Schumn (1956)
8	Basin Area	B	Area from which water drains to a common stream and boundary determined by opposite ridges. (GIS Analysis)	Horton (1945)
9	Basin Length	Lb	$Lb=1.312\times A^{0.568}$ (GIS Analysis)	Horton (1945)
10	Drainage Density	Dd	Dd=Lμ/A Where, Dd = Drainage density (Km/Km^2) Lμ = Total stream length of all orders and A = Area of the basin (Km^2).	Strahler (1952)
11	Drainage Frequency	Fs	Fs=Nμ/A Where, Nμ = Total no. of streams of all orders and A = Area of the basin (Km^2).	Singh (1997)
12	Drainage Texture	Dt	Dt=Nμ/P Where, Nμ = No. of streams in a given order and P = Perimeter (Kms)	Horton (1945) Pareta and Pareta (2011)
13	Form Factor Ratio	Rf	$Rf=A/Lb^2$ Where, A = Area of the basin and Lb = (Maximum) basin length	Strahler (1952)
14	Elongation Ratio	Re	$Re=(2/Lb)\ (A/\pi)^{0.5}$ Where, A= Area of the basin (Km^2)	Horton (1945)

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			Lb=(Maximum) Basin length (Km)	
15	Circularity Ratio	Rc	$Rc=4\pi A/P^2$ Where, A = Basin area (Km2) and P= Perimeter of the basin (Km)	Schumn (1956)
	Constant Channel Maintenance	C	C=1/D Where, D = Drainage density (Km/Km^2)	
16	Length of Overland Flow	Lg	Lg=1/2D Where, D = Drainage density (Km/Km^2)	Horton (1945)
17	Basin Relief	H	H = Z – z Where, Z = Maximum elevation of the basin (m) and z = Minimum elevation of the basin (m)	Rudraiah, Govindaiah and Vittala (2008)
18	Relief Ratio	Rr	Rr=H/Lb Where, H = basin relief (m) and Lb = Basin length (m)	Rakesh , Lohani, Sanjay and Nema (2000)
19	Ruggedness number (Rn)	(Rn)	Rn= Rr*Dd Where Rn =Ruggedness Number, R= Basin relief, , Dd = Drainage Density	Horton (1945)
20	Hypsometric integral	(Hi)	Hi=avg. elev.-Min. elev./Max. elev.-Mini. Elev.	Pike and Wilson(1971)
21	Dissection index	(Di)	Max. elev.-Mini. Elev./Max.elev.	Singh and Dubey (1994)

RESULTS AND DISCUSSIONS

In the morphometric characterization of Mu basin, the following attributes were considered; Linear, areal and relief aspects.

Linear Aspects of Mu River Sub-Basin

Linear aspects include stream order (Su), stream number (Nu), stream length (Lu)mean stream length(Lsm) stream length ratio(Rl) bifurcation ratio(Rb) mean bifurcation ratio(Rbm).

a. Stream Order (Su) stream ordering is the first step in quantitative analysis of a drainage basin as pioneered by Strahler(1952).This involves assigning numbers to stream segment designated as 1st order stream, 2nd order stream to as many orders as the case may be. In this study, River Mu is of the 4th order.

b. Stream Number (Nu) The law of stream was introduced by Horton (1945) on the basis of stream ordering. It is the total number of stream segments present in each order. That is the hierarchal determination of a position of a stream within a basin. It forms an inverse geometric sequence with the order number. The Nu of any order for example 2nd order stream is fewer than the next lower 1st order but more than the next order 3rd order. From Table 2, Mu basin has 122 streams, covering an area of 1259.26 Km^2. A total of 79(79.51%) are of the 1st order stream, 20(16.39%) of 2nd order stream, 4(3.28%) of 3rd order and 1(0.82%) of the 4th stream. Stream frequency decreases as the stream order increases. The plotting of the logarithim of number of streams against stream order (Fig.3) is in conformity with Horton law of stream order which states that the number of stream segment of each

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order forms an inverse geometric sequence with the number of streams of that order.

c. Stream Length(Lu) Hydrologically, stream length is seen as one of the most significant feature of the drainage basin as it reveals the surface run off characteristics. The streams of relatively smaller length are characteristic of area with larger slope and finer textures. Whereas longer length of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as the stream order increases. In this study, 1st order stream has a total length of 257.8, 2^{nd} order stream 174.75, 3^{rd} order stream 24.33 and 4^{th} order stream 48.80 totaling 505.68 for the stream orders. This conforms with the law of stream length and consistent with the findings of Oyatayo et al (2017) on Kereke and Ukogbor drainage basins in the lower Benue sub- basin.

d. Mean Stream Length (Lsm) Mean stream length is calculated by dividing the total stream length of given order by the number of streams of that order. The value for any given order is greater than that of the lower order and less than that the next higher order in in the whole drainage basin. The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964).The mean stream length of Mu river is 2.66 for 1^{st} order,8.74 for 2^{nd} order, 6.08 for 3^{rd} order and 48.80 for the 4^{th} order stream.

e. Stream Length Ratio(Rt) is the ratio of the mean stream length of a given order to the mean length of the next lower order and has an important influence on surface flow and discharge(Horton,1945). The Rt values between streams of different basins reveal that there is variation in slope and topography. The Rt of Mu river ranges from 3.29, 0.70 to 8.02.

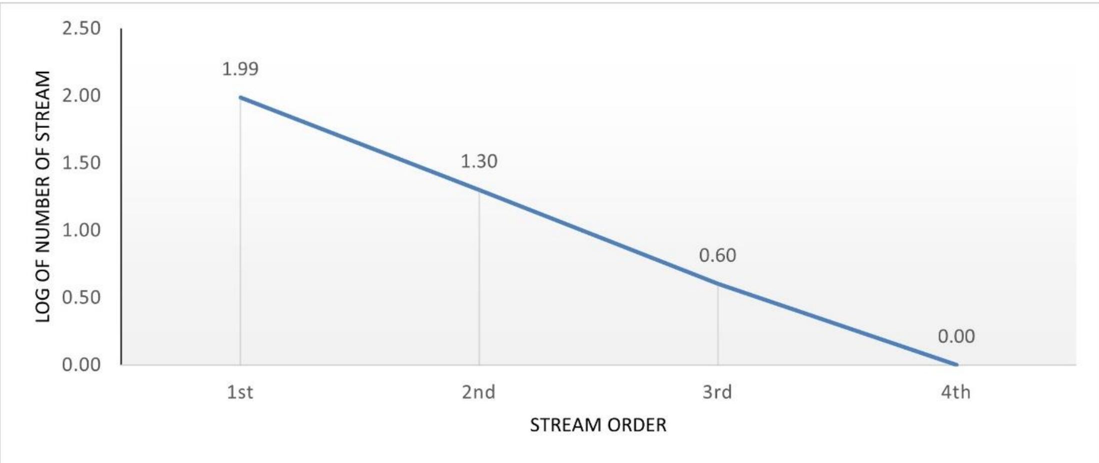

Fig.3: Log of Number of Streams

Table 2: Morphometric Characteristics of River Mu Sub-basin

Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Mean Stream Length	Cumulative Mean Stream Length	Stream Length Ratio	Log of Stream number	Log of Stream Length	Mean Bifurcation Ratio
1st	97	4.85	257.8	2.66	11.40	3.29	1.99	2.41	4.62
2nd	20	5.00	174.75	8.74	20.13	0.70	1.30	2.24	
3rd	4	4.00	24.33	6.08	26.22	8.02	0.60	1.39	
4th	1		48.8	48.80	75.02		0.00	1.69	
	122		505.68						

f. Bifurcation Ratio (Rb) may be defined as the ratio of the number of streams segments of a given order to the number of segments of the next higher order (Schum, 1956). Horton (1945) considered the bifurcation ratio as the index of relief and dissections. The implication of Rb is that as the ratio is reduced so also is the risk of flooding for concerned part, rather than entire basin (Chorley 1969). Bifurcation ratios are controlled by the physiographic factors especially basin relief and drainage density (Milton, 1966). Bifurcation ratio ranges between 3.0 and 5.0 for watershed in which geological formations do not distort the drainage pattern of the watershed. In this study the bifurcation ratio of Mu drainage basin is 4.62 revealing that the geology of the area did not interfere with the drainage system.

g. Length of Overland Flow (Lg) Length of overland flow is one of the most important characteristics of a river basin which affect both the hydrologic and physiographic development of watershed. Length of overland flow is actually that flow of the precipitated water which moves over the land surface leading to the stream channel whereas the channel flow reaching the outlet of watershed is referred to as the surface run off. The overland flow is significant in smaller watershed but run off is in bigger watershed. Overland flow is significantly affected by infiltration (exfiltration) and percolation through the soil, both varying in time and space (Schmid, 1997). In this study, the length of overland flow of the Mu drainage basin is 1.25km shows low surface run off in the area.

Areal Aspects of the Drainage Basin

The areal aspects of the morphometric parameters of a drainage basin include drainage area (Au), drainage density (Dd), stream frequency (Fs), drainage texture (Rt), basin perimeter(P), elongated ratio (Re) circulatory ratio(rc) form factor (Rf).

Table 3 Areal Aspects of River Mu Sub-basin

S/N	Areal Parameter	Symbol	Computed Value
1	Basin perimeter	P	240.96km
2	Basin Area	Au	1259.26km^2
3	Basin Length	Lb	75.65km
4	Drainage Density	Dd	0.40km^2
5	Stream Frequency	Fs	0.10km
6	Drainage Texture	Dt	0.51
7	Form Factor Ratio	Rf	0.22
8	Elongation Ratio	Re	0.53
9	Circularity Ratio	Rc	0.27
10	Constant Channel Maintenance	C	2.49km
11	Length of Overland Flow	Lg	1.25

Drainage Area(Au) The entire area drained by a stream or system of streams such that all streams originating in the area is discharged through a single outlet is termed as the drainage area. The boundary of the area is determined by a ridge separating water flowing in opposite directions. The area is identified as most important of all the morphometric parameters controlling the catchment run off pattern. This is because, the larger the basin, the greater the volume of rainfall it intercepts, and the higher the peak discharge that results(Morisawa,1959; Pitlick,1994).In this study, the drainage area of Mu river basin is 1259.26km^2 with a basin perimeter of 240.96km^2.

Drainage density (Dd) Drainage density is recognized as an important topographic characteristic of a river basin over time. It is the total length of streams of all orders per drainage area. Drainage basin is expressed as

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the ratio of the total sum of all channel segment within the basin area. Drainage density can range from less than 5km/km2 when slope are gentle, rainfall low and bedrocks are permeable such as sandstone to much larger values of more than500km/km2 in mountainous areas where rocks are impermeable, slopes are steep and rainfall totals are high (Hugget, 2003).Low drainage densities are often associated with widely spaced streams due to presence of less resistant surface (lithologies or rock types) m, or those with low infiltration capacities. Drainage basin with high Dd values indicates that a large proportion of the precipitation run off. Whereas, on the other hand, low drainage indicates that most of the rainfall infiltrates into the ground and few channels are required to carry the run off. In general, low drainage density leads to coarse texture while high drainage density leads to fine texture (Strahler, 1964).In this study, the drainage density is 0.40km/km^2.

Stream Frequency (Fs) or otherwise channel frequency of a drainage basin may be defined as the total number of stream segment within a basin per unit area (Horton, 1945).This this depends mainly on the lithology of the basin and it reflects the texture of the drainage network. The basin structure of high relief have higher stream frequency, while basins of alluvial has minimum. The lower values indicates that the basin possesses low relief less number of streams. The existence of smaller number of streams in the basin indicates matured topography, while the presence of large number of streams indicates that the stream is youthful and still undergoing erosion. In this study, 0.10km which indicates the basin is of a low relief and has few streams of 4th order.

Drainage texture (Rt) According to Horton (1945) drainage texture is the total number of stream segment of all order in a basin (Nu) per perimeter (P).Smith(1950) classified drainage texture into five categories as related to various drainage densities as very coarse(below2) coarse(2-4), moderate(4-6), fine(6-8) and very fine(8 and above). Drainage texture depends on number of factors such as climate, rainfall, vegetation, rock and soil types, infiltration capacity, relief and slope development. Weak rocks devoid of vegetative cover produce fine texture, while rocks which are hard and with vegetative cover produce coarse texture. In this study the drainage texture is 0.51 implying that the basin is of coarse texture.

Basin Perimeter (P) is the outer boundary of the drainage basin that encloses its area. It is measured along the divide between basins and may be used as an indicator of basin size and shape (Schumn, 1956). The basin perimeter of Mu river basin is 240.96km

Elongated Ratio (Re) is defined as the ratio of diameter of a circle of the same area as to the maximum basin length (Schumm, 1956).Basin ratio determines the shape of the basin and are classified based on these values as circular (0.9-1), oval (0.8-0.9) less elongated (0.7-0.8), elongated (0.5-0.7), more elongated (less0.5).In this study, the basin is 0.53 meaning that is of elongated. Elongated drainage basins have low side flow for shorter duration and high main flow for longer duration and are less susceptible to flood hazards. Values close to 1.0 are typical of region of vary low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope.

Circulatory Ratio (Rc) is similar to measures used in elongated ratio. It is the ratio of the area of the basin to the area of the circle having the same circumference as the basin perimeter. The value of Rc varies from 0(in line) to 1(in a circle). The circulatory ratio has been used as quantitative measure for visualizing the shape of the basin (A) to the area of a circle (Ac) having the same perimeter as the basin (Miller, 1953), Strahler, (1964). It is affected by the lithological character of a basin. In this study, the basin circulatory ratio is 0.27. Drainage basin with higher circulatory ratio are more exposed to flooding incidence because such basin always experience shorter time lag, shorter time of rise and high hydrographic peak (Ajibade et al, 2010). This suggests the River Mu sub-basin with lower Rc is less exposed to flood.

Form Factor (Ff) is the numerical index commonly used to represent different basin shapes (Horton, 1932). The value ranges between 0.1-0.8. The form factor should always be less than 0.784(the value corresponding to a perfectly circular basin. The smaller the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas that elongated watershed with low form factors experience lower peak flow of longer duration. In this study, the Mu river basin has a form factor of 0.22 implies that the basin is elongated and thus have low peak flow of longer duration.

Constant Channel Maintenance (Ccm) This parameter indicates the requirement of units of watershed surface to bear one unit of channel length. In otherward, it is the magnitude of Sq km surface area of watershed required to sustain one linear Km length of stream segment. Shumm (1956) defined the constant channel maintenance as the inverse of drainage density. So, the drainage basin having higher values of this parameter, there be lower of the drainage density. Higher values of constant channel maintenance reveals strong control of lithology with a surface area of high permeability. Alluvial basin of plain and piedmont zone shows highest, as the permeability in this zone is high. The constant channel maintenance of Mu river basin is 2.49km.

Relief Aspects of River Mu Sub-basin.

This includes Basin Relief (R) Relief Ratio (Rr) Ruggedness number (Rn) Basin slope (Sb)

Table 4. Relief Aspects of River Mu Sub-basin

S/N	Relief Parameter	Symbol	Computed Value
1	Maximum Basin Height	Z	**327m**
2	Minimum Basin Height	Z	53m
3	Basin Relief	H	274.00
4	Basin Relief Ratio	Rr	0.27
5	Ruggedness Number	Rn	1.45

Basin Relief(R) Basin relief is the difference in the elevation between the highest point (H) and the lowest point (h) of the basin. It determines the slope of the basin. Thus, the run off and sediment transport rate also depends on it. Low relief ratios indicate that the recharge capacities of the basin are low and chances of groundwater potential are good (Parveen et al, 2012). The basin of Mu river in this study is 274m

Relief Ratio (Rr): In this study Mu river basin has relief ratio of 3.62. Rr is the dimensionless measure of the overall gradient across a basin. It is calculated by dividing the relief (H) of a basin by its length (L). The maximum basin relief is obtained from the elevation difference between the highest point on the basin perimeter and its confluence with the trunk stream. Simply, it is the ratio between basin relief and basin length. Basin relief is directly proportional to the surface run off and intensity of erosion. The high values of Rr indicate steep slope and high relief and vice-versa. Run off is generally faster in steeper basins, producing more peak discharges and greater erosive power. Lower values may indicate the presence of basin complex rocks that are exposed in form of small ridges and mound with lower degree of slope.

Ruggedness Number (Rn) River Mu Sub-basin has ruggedness number of 1.45. Strahler (1968) describe the ruggedness number as the product of maximum basin relief and drainage density. It usually combines slope steepness with length. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long as well. River basin with high ruggedness number indicates higher drainage frequency with high channel gradient which lead to more erosion. The level of dissection is also high in such basin.

CONCLUSION

Geospatial technique of Geography Information System (GIS) and Remote Sensing (RS) has been successfully deployed in the characterization of the morphometric attributes of River Mu Sub- basin of the lower Benue River basin, Nigeria. The drainage density, bifurcation ratio and circularity ratio value indicate that the basin is of gentle slope, elongated, high infiltration capacity, low run off and may have longer duration of flow peaks, less susceptible to flooding.

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