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Morphometric Analysis of River Benue Basin, Nigeria: Implications Surface Water Development

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ABSTRACT

This study presents a morphometric analysis of the Benue River Basin, Nigeria, and examined its implication for surface water development and management. Linear, areal, and relief attributes of the basin's morphology were analysed using GIS and Remote Sensing approach. Linear aspects assessed include stream order, number, length, mean stream length, stream length ratio, and bifurcation ratio. Areal aspects examined include drainage area, density, frequency, texture, perimeter, and form factor. While relief attributes like basin relative relief, relief ratio, and ruggedness were assessed. Results reveal that the Benue River is a 5th-order stream with a total of 7,143 streams, indicating a high density and extensive surface water network. The total stream length is 8,619.50 km, with a decreasing trend in length with increasing order, consistent with Horton's laws. The bifurcation ratio ranges from 1.81 to 4.70, indicating a mixed dendritic and elongated pattern. The drainage area is 233,030.3 km² with a low drainage density of 0.037 km², signifying a dispersed watercourse network. The basin's form factor ratio is 0.11, suggesting an elongated shape prone to prolonged flooding. Relief attributes like basin relative relief, relief ratio, and ruggedness number are relatively low, with values of 239 m, 1.63, and 0.06, respectively, indicating moderate topographic variation and less rugged terrain. The hypsometric integral (0.50) and dissection index (0.99) reflect a balanced elevation distribution and moderate landscape dissection. The study concludes that the morphometric characteristics indicates the Benue River Basin's substantial surface water resources, low topographic relief, and its implications for hydrological processes and flood management.

Key Words: Morphometric Analysis, River Benue Basin, Development, Linear, Areal and Relief

INTRODUCTION

Water is one of the essential resources that supports all livelihoods on the earth surface, and is stored as surface and groundwater reservoirs. However, its availability in adequate quality and quantity continues to decline in many parts of the world including Nigeria as a result of fluctuations in the hydrological cycle (Omondi, Ndolo, Nyandega & Cohen, 2019). According to Intergovernmental Panel on Climate Change (IPCC, 2007), fluctuations in the hydrological cycle affects both the ground and surface water supplies through fluctuating amount, frequency and intensity of rainfall. Meanwhile, the hydrological regime of any surface water on earth is influenced by the morphology, climatic conditions, land cover- land use system and population growth, and all these affects surface water supply sources and systems, flood structure, reservoirs and spillways in general (Omondi, Ndolo, Nyandega & Cohen, 2019).

The River Benue Basin is an important component of Nigeria's hydrological system and plays a significant role in regional water resources, agriculture, and development. Morphometric analysis, which involves the quantitative study of the shape and structure of landforms, provides valuable basis for understanding the basin's hydrological characteristics and patterns (Strahler, 1964). This follows that morphometric characteristics of a basin play a significant role in understanding the geohydrological characteristics of a drainage basin in relation to the terrain feature and its flow patterns with direct and in direct implications for overall surface water management and development (Brown, White & Wilson (2017). It also helps to estimate the incidence of infiltration and runoff, and other related hydrological character of a watershed like erosion and sediment transport which has a strong implication for natural resource conservation (Asfaw & Workineh, 2019). Morphometric analysis became necessary in this study since geomorphometric attributes characterizing the catchment such as drainage density (Dd), relief ratio (Rh), elongation ratio (Re), circularity ratio (Rc) and ruggedness number (Rn) all play vital role in the erodibility of basin landscape with direct implications for water availability from surface water sources and flood events.

The Benue Basin, spanning approximately 115,000 km^2, is vital for its role in supporting agriculture, fisheries, and drinking water supplies (Kaseke et al., 2019). Understanding the basin's morphometric parameters—such as drainage density, stream order, and basin shape—can elucidate the impacts of land use changes and climatic variability on surface water resources (Ojo, 2020). Such analyses help in predicting flood risks, water availability, and potential for sustainable development within the basin (Ezeabasili & Akinyemi, 2022).

Moreover, Benue river basin is an important source of water for over 10 million people. The River takes its source from the Adamawa Plateau of Northern Cameroon with Lagdo Dam, built across the river about 50km upstream of Garoua in Northern Cameroon as the only dam on River Benue. In Nigeria, however, there are on-going dam's construction on Rivers Katsina-Ala at Kashimbilla and Donga near Gembu, the two major tributaries of River Benue. These dams are designed for hydropower generation, flood control, water and irrigation agriculture. Therefore, understanding the morphology of the basin is fundamental for socio-economic development as well as reduce flood risks and vulnerability in the area.

Studies have shown that surface water sources in Benue basin especially rivers have been strained in recent years due to variability in rainfall regime and changing morphology over the area (Adamu, et al 2013; Ankidawa, Tanko, & Umar, 2015), altering runoff and river discharge particularly at the upper section of the Basin. For instance, Ankidawa, Tanko, and Umar, (2015) reports that over Yola section of the Basin (Northern limit), both runoff and rainfall total has decreased but the rate of decrease of rainfall is about 14 times that of runoff. Adding that monthly runoff in some years of the study revealed increase in runoff above the mean but this additional runoff does not add to water availability for use because they occur during the wet season and there is no specific storage to hold the water through to the dry season. For every 0.01mm increase in rainfall there is 1 Million m^3 increase in discharge and vice versa. Conversely, Lower Benue basin particularly at Makurdi (which is the middle section) has had increase in rainfall with the rainfall anomaly index showing that the area is characterized by larger extent of extremely wet conditions in 1984, 1998 and 1999, having direct impact on river discharge and runoff (Oyatayo, Ndabula, Abaje, Jidauna, Iwan and Mshelia, 2020; Wagstaff & Jolly, 2019).

Furthermore, studies on the morphometric analysis in the study area revealed that varying findings. For instance, Adebayo & Olaniyan (2020) employed geospatial techniques to analyze the morphometric parameters of the Benue River Basin, focusing on basin geometry and drainage patterns. The researchers provided insights into how morphometric features influence hydrological processes. The study however primarily concentrated on basin geometry without extensive investigation into how morphometric parameters specifically impact surface water management and development. Similarly, Eze & Chukwu (2019) explored the implications of morphometric characteristics on surface water resources, with emphasis on water availability and quality. The study established a correlation between morphometric features and water resources. While the study addressed the implications for water resources, it lacked a detailed analysis of how these morphometric features could be applied to practical surface water management strategies and development. Nwankwo & Ijeoma (2018) assessed the hydrological implications of morphometric analysis, examining how basin shape and size influence river discharge and flood potential. It provided a quantitative assessment of hydrological variables however; the study did not fully explore the broader implications for sustainable surface water management and development practices within the basin. Previous studies have made significant contributions to understanding the morphometric characteristics of the Benue River Basin and their implications for hydrology and water resources. However, they often lack a detailed examination of how these characteristics can be specifically leveraged for effective surface water management and development strategies. Effective surface water management in the River Benue Basin necessitates a thorough understanding of not just the rainfall regime but also, its morphometric characteristics. This study addressed these gaps by integrating morphometric analysis with practical implications for surface water management and development, providing actionable pathway for stakeholders and policymakers. It provided empirical evidence of the morphometric status is the basin which is vital water resource management and supporting development initiatives. The outcomes will contribute to enhanced strategies for managing water resources in a manner that balances ecological sustainability with socio-economic development.

MATERIALS AND METHODS

Study Area

The Benue River Basin, a significant geographical and ecological region in West Africa, stretches approximately 1,400 kilometers and serves as a crucial tributary of the Niger River. Spanning 319,000 square kilometers, the basin is home to over 20 million people and a diverse array of flora and fauna. It is strategically located between Latitude 6°00'N and 14°00'N and Longitude 7°00'E and 15°00'E, extending in a NE-SW direction from the Niger Delta to the southern boundary of the Lake Chad Basin (Figures 1 and 2).

The basin's geology features the Northeastern Basement Complex of Nigeria and the sedimentary Upper and Middle Benue Troughs. Soils vary from alluvial deposits and sandstone in the upper regions to laterite soils in the lower parts. The relief is characterized by low-lying floodplains, with the river meandering through northeast Nigeria and joining the Niger River at Lokoja (Abaa, 2004: Obiefuna and Jibrin, 2012; Shabu, 2017).

Climate varies from tropical wet and dry in the south to semi-arid in the north, with rainfall ranging from 900 to 1,500 mm annually. Vegetation includes dense forests in the lower basin and savannahs with scattered trees in the upper basin. Economic activities predominantly revolve around agriculture, with farming, fishing, and small-scale industries playing significant roles (Adzandeh, Nwilo and Olayinka, 2020). Jamala and Oke (2013). Population centers include urban areas like Makurdi and Lokoja, and rural communities are scattered along the river. The basin's current infrastructure includes ongoing dam projects for hydropower and flood control, underscoring its vital role in regional development and its susceptibility to flood risks (Mayomi, Dami and Maryah, 2013; Zoua, Djaouda, Maïworé, Liang and Nola, 2020).

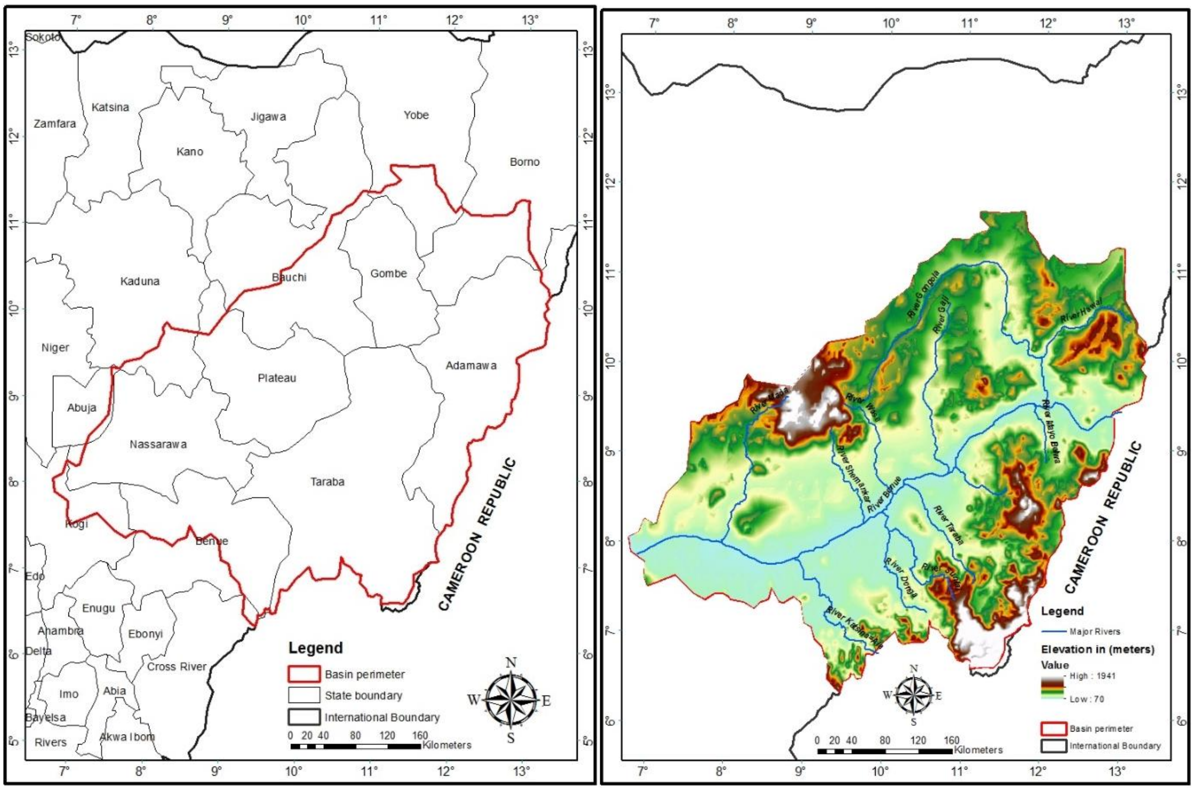

Figure 1: The Benue Basin

Source Benue State University, GIS Laboratory, 2022

Methods

Morphometric parameters were analysed using the equations shown in Table 1. The parameters data were generated using GIS software.

Table 1: Morphometric parameters

Category of parameter	**Name and Notation of Morphometric Parameters**	**Given equation**	**References**
Linear parameters	Stream Order	Hierarchical Rank	Strahler (1952)
	Stream number (Nu)	Nu = N1 + N2 + …+ Nn	Horton (1945)
	Stream length (LT) (km)	Lt = L1 + L2 + L3 + …+ Ln	Strahler (1964)
	Mean Stream Length (RI)	Lum = Lu / Nu	Strahler (1964)
	Stream length ratio (Lur)	Lur = Lu/(Lu-1)	Strahler (1964)
	Bifurcation ratio (Rb)	Rb=Nu/Nu+ 1	Strahler (1964
	Mean Bifurcation Ration (Rbm)	Rbm=Average of bifurcation	Strahler (1964)
	Basin length (Km)	Obtained from Arc Map	Asfaw and Workineh (2019)
	Main stream Length (Km)	Obtained from Arc Map	Asfaw and Workineh (2019)
Areal parameters	Area of the basin (Km2)	Obtained from Arc Map	Asfaw and Workineh (2019)
	Basin Perimeter (Km)	Obtained from Arc Map	Asfaw and Workineh (2019)
	Form factor Ratio (Rf)	$Rf = A / Lb^2$	Horton (1932),
	Elongation Ratio (Re)	$Re = (2/Lb)* 2\sqrt{(A/\pi)}$	Schumm (1956)
	Circularity Ration (Rc)	$Rc = 4\pi *A / P^2$	Strahler (1964)

	Drainage Density (Dd) (km/Km2)	Dd = Lu / A	Horton (1932),
	Drainage Texture (T)	T= Lu / P	Horton (1932),
	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932),
	Compactness coefficient (Cc)	Cc = 0.2824 * p/ √A	Gravelius, (1914)
Relief parameters	Maximum Basin Height (m)	Obtained from Arc Map	Asfaw and Workineh (2019)
	Minimum Basin Height (m)	Obtained from Arc Map	Asfaw and Workineh (2019)
	Basin Relief (R)(m)	R= Max H – Min H	Strahler (1952)
	Relief Ratio (Rr)	Rr = R / Lb	Schumm (1956)
	Relative Relief Ratio (Rhp)	Rhp = H * 100/P	Melton (1958)
	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton and Baker (1976)
	Gradient ratio (Rg)	Rg = Es - Em/Lb	Sreedevi, Owais, Khan, and Ahmed (2009)
	Hypsometric curve and	Partial area (a/A) with partial altitude (h/H)	Kouli, Vallianatos, Soupios, and Alexakis (2007
	HI (Hypsometric Integration)	Emean – Emin / Emax –Emin	Pike and Wilson (1971)

Source: Asfaw and Workineh (2019)

The Shuttle Radar Topography Mission (SRTM) imagery covering the study area was acquired through the U.S. Geological Survey Earth Resources Observation and Science Center (EROS). The flow chart diagram of the methodology in (Figure 2) was utilized to obtain the desired final output in form of maps. The remote sensing and Geographic Information System (GIS) software package, Erdas Imagine 9.2 was used for the pre-processing of the satellite data. The software was used specifically for atmospheric and geometric corrections. The ArcGis 10.1(ArcMap 10.1) was employed to extract the basins/watershed boundary and drainage/stream network using shuttle radar thematic mapper (SRTM) data. The Strahler's and Horton's methods of stream ordering as contained in Table 1 was used to know the exact order of streams in the basins and Bifurcation ratio (Rb) to determine the ratio number of stream segments of given order to the number of segments of the next higher order in the basins.

Data Preparation and Data Processing

The extraction of the DEM data using the shape files of the study area was subjected to two main processes;

i. **Hydrological Analysis:** this includes channel network, stream order, and drainage density analysis among others.

ii. **Terrain Analysis:** this includes slope, aspect, elevation, watersheds, and drainage networks.

Hydrological Processing

The DEM data was projected before use so that the calculations would be as accurate as possible and to create a file that would preserve areas.

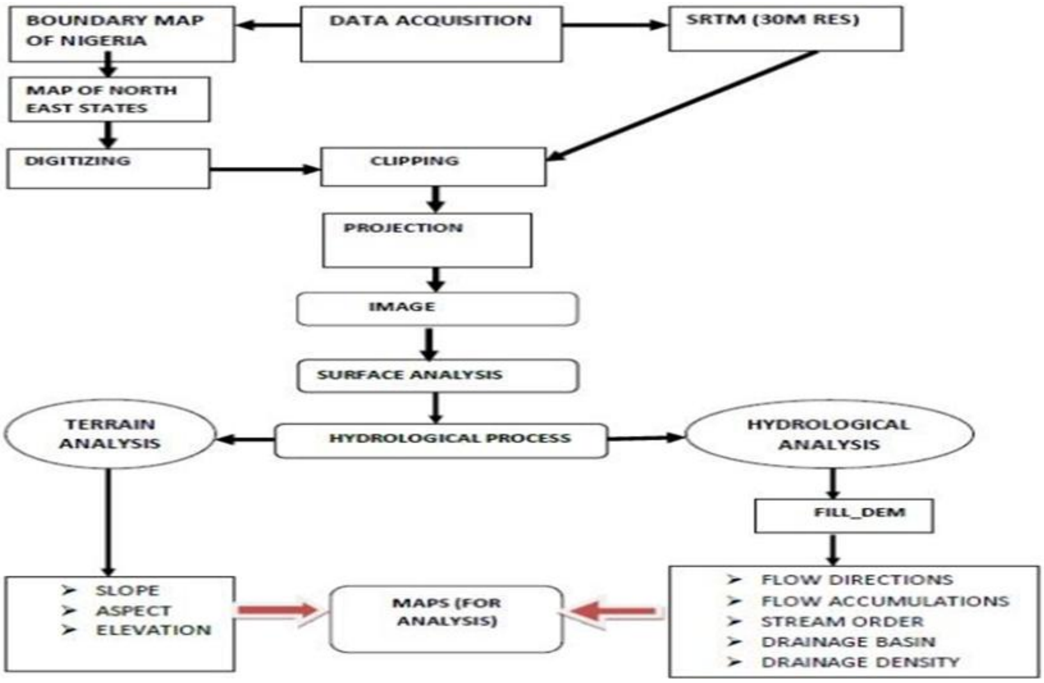

Figure 2: Methodology Flow Chart (Adapted from Abiodun, Adebowale and Ibitoye, 2016)

The flow chart illustrates the process of data acquisition and analysis for terrain and hydrological studies. It begins with the acquisition of boundary maps of Nigeria and maps of the Benue Basin, which are digitized and clipped together with SRTM (Shuttle Radar Topography Mission) data at a 30-meter resolution. The clipped data was then projected to create an image, which undergoes surface analysis. From this point, the process branches into terrain analysis and hydrological analysis. In terrain analysis, the focus is on evaluating the slope, aspect, and elevation to create maps for further analysis. In hydrological analysis, the filled DEM (Digital Elevation Model) is used to determine flow directions, flow accumulations, stream order, drainage basins, and drainage density. Both the terrain and hydrological processes are integrated to produce comprehensive maps for detailed analysis.

RESULTS AND DISCUSSION

RESULTS

The study conducted morphometric analysis of Benue River Basin with focus on linear, areal and relief attributes of the basin morphology.

LINEAR ASPECTS OF BENUE RIVER BASIN MORPHOLOGY

The study analysed the following linear dimensions of Benue River Basin morphology namely: Stream order (Su), Stream number (Nu), Stream Length (Lu), mean stream length (Lsm), Stream length ratio (RI), bifurcation ratio (Rb) and mean bifurcation ratio (Rbm). The result is presented in Figures 3 and 4 and Table 2.

Table 2: Linear Parameter of Benue River Basin Morphology

Stream Order	Stream Number	Bilocation Ratio	Stream Length	Mean Stream Length	Cumulative Mean Stream Length	Stream Length Ratio	Log of Stream number	Log of Stream Length	Mean Bilocation Ratio
1st	3948	1.81	6218.84	1.5752	2.168	0.38	3.60	3.79	3.46
2nd	2183	2.72	1294.42	0.5930	2.761	1.80	3.34	3.11	
3rd	804	4.70	860.03	1.0697	3.831	0.77	2.91	2.93	
4th	171	4.62	141.17	0.8255	4.656		2.23	2.15	
5th	37		105.05	2.8393			1.57		
	7143		8619.50						

Source: Researcher’s Field Work, 2023

Stream Order (Su)

The result shows that River Benue is the 5th-order Stream (Figure 3 and Table 2). It is important to note that stream order is a concept used in morphometric analysis to classify and understand the hierarchical organization of streams and rivers within a drainage network. It is a way of characterizing the position and size of a particular stream segment within the entire river system. The result suggests that Benue River is relatively large stream with capacity to accommodate high value water and transport corresponding large sediment.

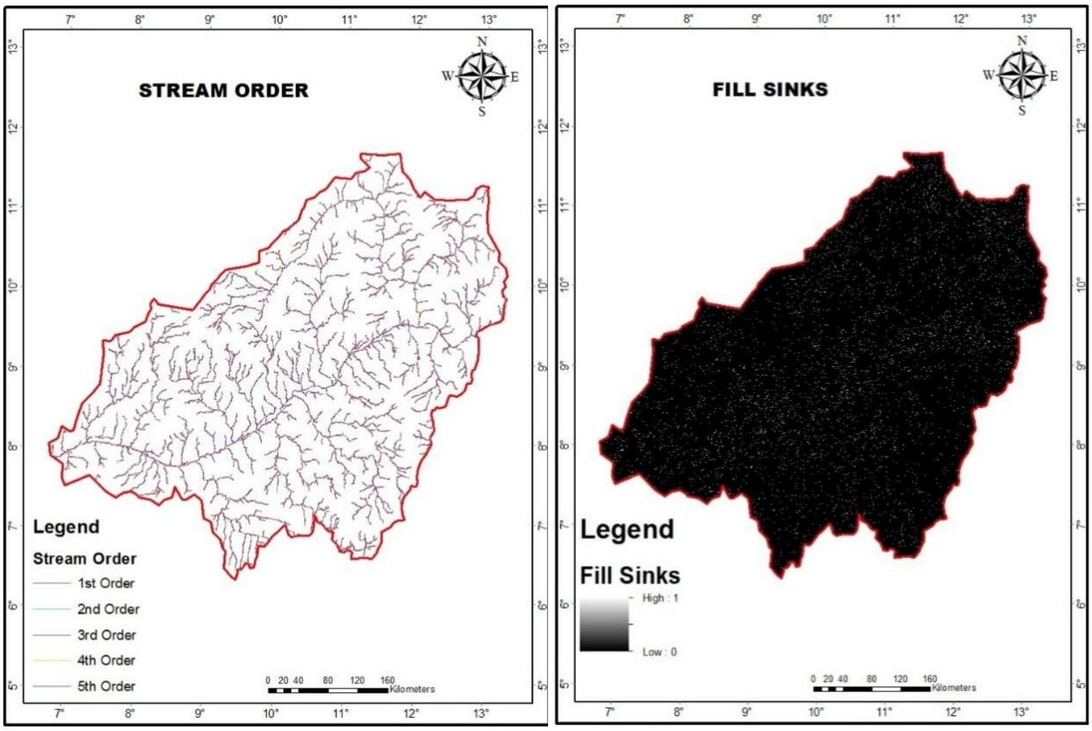

Figure 3: Benue Drainage Basin Stream Order and Fill Sinks

Stream number (Nu)

The result shows that the total number of streams is 7143. The number of streams in the 1st order was 3948, and declined to 2183 steams in the 2nd order. The numbers of streams in the 3rd, 4^{th,} and 5th were 804, 171, and 37. This suggests that Benue River Basin follows Horton's first law as the number of streams in each category falls in a geometric sequence, as represented in the graph in Figure 4. The high total number of streams in Benue River basin of suggests that Benue River has high density of which in turn indicates abundant surface water sources within the Basin. The concept of stream number is based on the observation that river systems exhibit a branching pattern, where small tributaries join larger rivers, forming hierarchical network. The Stream number (Na) provides valuable information about the geomorphic characteristics and drainage pattern of a river basin (Figure 3) It can be used to understand the topology and complexity of the river network, which has implications for various hydrological processes including the volume of surface water within the basin. In this study, the large number of streams is an indication of large surface water availability in Benue River basin.

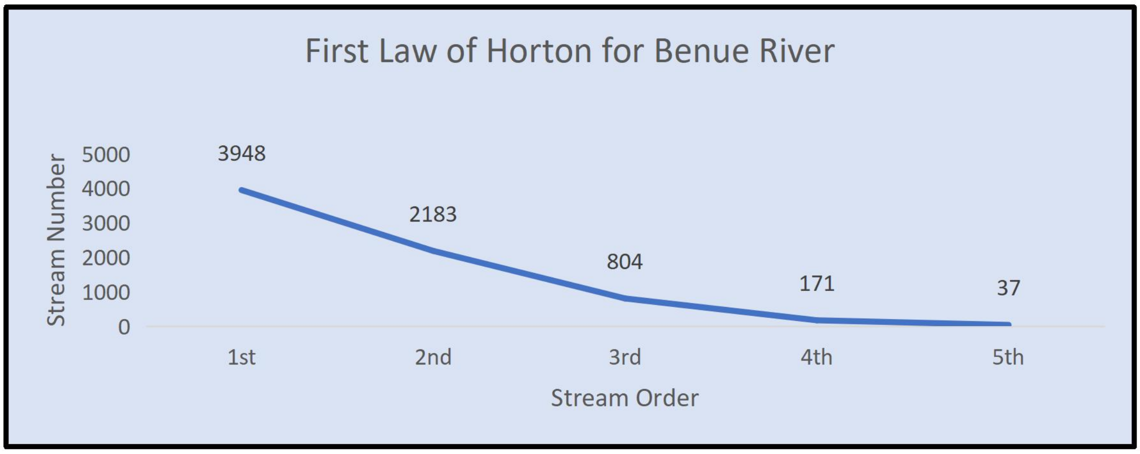

Figure 4: First Law of Horton for Benue River

Stream Length (Lu)

The result of stream length is presented in Table 2 and Figure 5. The result indicates that the 1st order steams accounted for 6,218.84km, while the 2nd, 3rd, 4th and 5th order streams accounted for 1,294.42km, 860.03km, 141.17km and 105.05km respectively. The total length is 8,619.50km long. This result suggests that stream length decreases with increase in stream order which is also in agreement with the first law of Horton. In morphometric analysis of a drainage basin, the stream length is a significant parameter that provides valuable insight in to the hydrological characteristics and behaviour of the basin. The hydrological significance of stream length lies in its influence on various aspects of the basin's hydrological cycle and its overall functioning. For instance, longer stream lengths indicate a more extensive network of interconnected channels, which enhances the hydrological connectivity within the basin. The longer the flow path, the more time water spends within the basin, influencing factors such as residence time and potential for water storage.

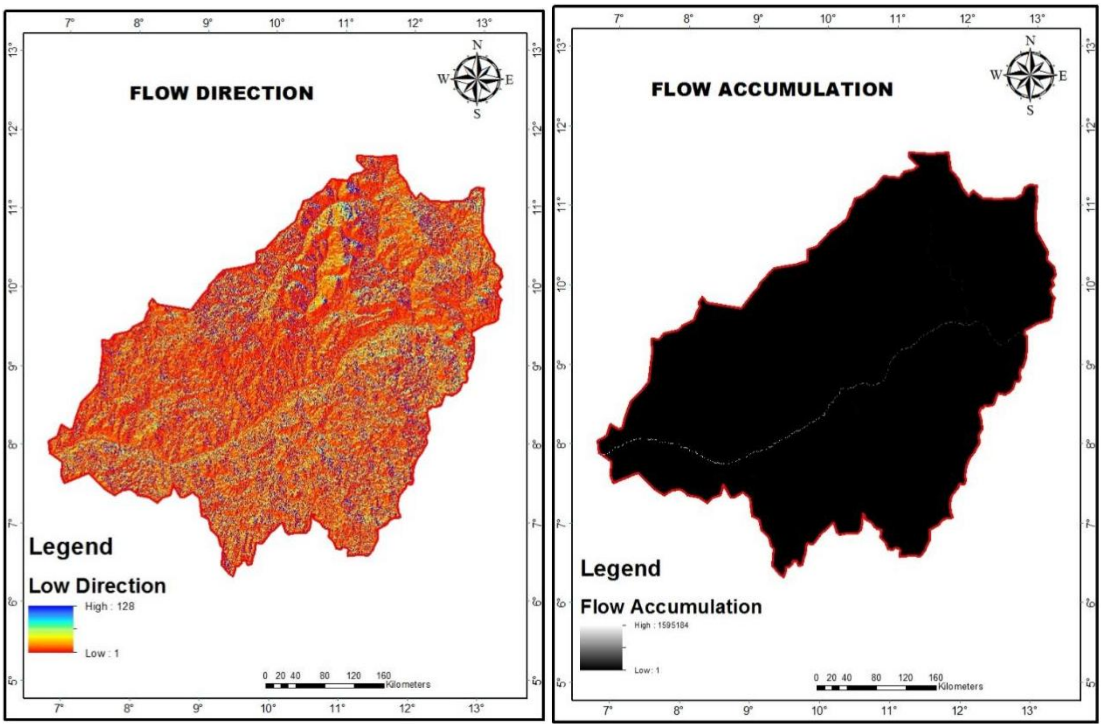

Figure 5: Benue Drainage Basin Flow Direction and Accumulation

Mean Stream Length (Lsm)

The result of the mean stream length is presented in Table 2. The result indicates mean stream length of 1.5752km, 0.5930km, 1.0697lm, 0.8255km, and 2.8393km for 1st, 2nd, 3rd, 4th, and 5th order streams respectively. This suggests that the stream lengths are moderately long. The mean stream length (Lsm) is calculated by dividing the total length of all the streams (main channels and then tributaries) within the drainage basin by the total number of streams in that basin. The mean stream length is a useful metric in morphometric analysis because it helps in understanding the average length of streams present in the basin. This in turn, gives an idea about the basin's shape, complexity and drainage efficiency.

In general, a basin with higher mean stream length tends to have longer, straighter channels and may indicate a more mature and stable drainage pattern. Conversely, a basin with a lower mean stream length may have a more dendritic (tree-like) drainage pattern with shorter and more numerous streams as the case with the Benue River basin (Figure 3).

Stream Length Ratio (RI)

The result of the stream length ratio (Rb) presented in Table 2 indicates that ratios of 0.38, 1.80, and 0.77. The stream, length ratio is defined as the ratio of the total stream length (L) of all the streams of a given order (n) to the length of the main or primary Stream (L1) in the drainage basin. In morphometric analysis of a drainage basin, the stream length ratio is a key parameter used to characterized the shape and development of the river network within the basin. It is also known as the Rb index, and it quantifies the overall complexity and branching pattern of the stream network. It provides insights into the drainage pattern and how the river network has evolved over time. A high Rb value indicates a more complex and mature drainage network with dense branching pattern, Conversely, a low Rb value suggests a less developed and less interconnected river system.

Bifurcation Ratio (Rb)

The result of the bifurcation ratio is presented in Table 4.4. The result shows that the bifurcation ratio ranged from 1.81 – 4.70 between the 1st-order streams and 5th-order. The mean bifurcation ratio is 3.46. The bifurcation ratio (Rb) is defined as the ratio of the number of smaller tributaries (or streams to the number of larger streams in a river network. A low bifurcation ratio (less than 3) indicates a move dendritic pattern with a large number of smaller tributaries, which is common in regions with uniform geology and topography. On the other hand, a high bifurcation ratio (greater than 3) suggests a more elongated pattern.

Length of Overland Flow (Lg)

The result of the length of the overland flow is presented in Table 2. The results show that the length of overland flow for the Benue River drainage basin is 13.52km, indicating a high surface runoff in the area. The length of overland flow stands out as one of the most crucial characteristics of a river basin, influencing both the hydrologic and physiographic development of the watershed. Overland flow refers to the movement of precipitated water across the land surface, ultimately reaching the stream channel. In contrast, the channel flow that reaches the outlet of the watershed is termed surface runoff. While overland flow holds significance in smaller watersheds, runoff dominates in larger ones. Overland flow is substantially influenced by infiltration (exfiltration) and percolation through the soil, with both processes varying over time and space. The high length of overland flow in the Benue River drainage basin is an indication of a large volume of surface water in this basin with potential for frequent flooding.

AREAL ASPECTS OF THE DRAINAGE BASIN

The study investigated the following areal aspects of the morphometric parameters of the Benue River basin. They are drainage area (Au), drainage density (Dd), density (stream) frequency (Fs), drainage texture (Rt), basin perimeter(P), elongated ratio (Re), circulatory ratio (Rc) and form factor (Rf). The result is presented in Table 3.

Table 3: Areal Aspects of the Benue Drainage Basin Morphology

Parameter	Values
Basin Perimeter	2503.24
Basin Area	233030.3
Drainage Density	0.037
Drainage Frequency	0.03
Drainage Texture	2.85
Form Factor Ratio	0.11
Elongation Ratio	0.37
Circularity ratio (Rc)	0.47
Constant of Channel maintenance (C)	27.04

Source: Researcher's Field Work, 2023

Drainage Area (Au)

The result of the drainage area (Au)is presented in Table 3. The result the show that the drainage area of Benue River drainage basin is 233,030.3km^2, indicating a relatively large drainage area. This result implies that Benue River drainage basin has a substantial catchment region for surface water collection. This large drainage area suggests that the basin has the potential to accumulate a significant volume of water, which can influence the overall quantity and availability of surface water in the region. This understanding of the extent of the drainage area is crucial for effective water resource management and planning in terms of both quantity and distribution.

Generally, drainage area refers to the entire region drained by a stream or a network of streams, where all streams originating in the area discharge through a single outlet. The boundary of this area is established by a ridge that separates water flowing in opposite directions. This area is recognized as the most crucial among all morphometric parameters that govern the catchment runoff pattern. This significance arises from the fact that the larger the basin, the more rainfall it intercepts, leading to a higher peak discharge.

Drainage Density (Dd)

The result of the drainage density (Dd) is presented in Table 3. The result the show that the drainage density of Benue River drainage basin is 0.037km^2, which indicate a relatively low density as result of large drainage area. The result suggests that the low drainage density of Benue River drainage basin indicates that the basin's watercourses are dispersed over a relatively large area. This implies that the quantity or volume of surface water in the basin may be distributed over a broader expanse, potentially affecting water availability and flow patterns. A low drainage density could influence the basin's hydrological characteristics and may have implications for water resource management and ecosystem dynamics.

A drainage basin characterized by high Dd values suggests that a significant portion of precipitation results in runoff. Conversely, low drainage density implies that the majority of rainfall infiltrates the ground, necessitating only a few channels to accommodate runoff, which is the case in the study area. Generally, low drainage density is associated with coarse texture, whereas high drainage density is linked to fine texture.

Drainage (stream) frequency (Fs)

The result of the drainage (stream) frequency (Fs)is presented in 3. The result the show that the drainage frequency of Benue River drainage basin is 0.03km. This result suggests that the low drainage frequency of the Benue River drainage basin is an indication that the area has a low relief. Drainage frequency is a measure of how closely spaced and interconnected the river channels are within a given drainage basin.

In the context of surface water quantity, a low drainage frequency implies that the river channels are relatively sparse and less interconnected. This can have several implications for surface water in terms of volume. For instance, with a low drainage frequency, the runoff of water from precipitation may be slower, as there are fewer channels to carry water away. This can affect the overall volume of water flowing through the basin. Also, the sparse river channels may result in less natural storage of water within the basin. This can impact the availability of water during dry periods, potentially affecting water resources for both human and natural systems. In contrast, during periods of intense rainfall, the limited number of channels may struggle to accommodate the increased volume of water, leading to a higher risk of localized flooding. This is evident in the increasing flood event in Benue River Basin since 2012.

Drainage Texture (Rt)

The result of the drainage texture (Rt)is presented in 3. The result the show that the drainage texture (Rt) of Benue River drainage basin is 2.85km. The finding indicates that the drainage texture (Rt) of the Benue River drainage basin is of coarse texture. The drainage texture is a measure of the density of rivers and streams in a particular area, representing the average distance between water channels. Drainage texture refers to the overall count of stream segments of all orders within a basin (Nu) per unit perimeter (P). Smith (1950) categorized drainage texture into five groups based on different drainage densities: very coarse (below 2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (8 and above). The determination of drainage texture is influenced by various factors, including climate, rainfall, vegetation, rock and soil types, infiltration capacity, relief, and slope development. Areas with weak rocks and lacking vegetative cover tend to exhibit a fine texture, while regions with hard rocks and substantial vegetative cover typically display a coarse texture.

In the context of surface water quantity (volume), a drainage texture value of 2.85 km suggests that the rivers and streams in the Benue River drainage basin are relatively close together. This could have implications for the volume of surface water in the region. A higher drainage density often means a more interconnected and efficient drainage system, which can contribute to better water flow and potentially increased water volume.

However, it's important to note that the specific implications would depend on various factors, including climate, land use, and human activities in the area. For example, a well-connected drainage system might be beneficial for water supply, agriculture, and ecosystem health. On the other hand, it could also pose challenges in terms of flood risk if not properly managed.

This finding therefore suggests that the Benue River drainage basin has a drainage texture that can be classified as coarse, indicating a certain level of connectivity between water channels. The implications for surface water quantity would depend on the broader environmental context and management practices in the region.

Basin perimeter (P)

The result of the basin perimeter (P) is presented in Table 3. The result the show that the Basin perimeter of Benue River drainage basin is 2,503.24km. The result indicates that the Basin perimeter of the Benue River drainage basin is relatively large, which further validates its status as the second largest river basin in Nigeria. The basin perimeter is a measure of the boundary length of the drainage basin, which is the area of land where all surface water drains into a particular river or water body.

In terms of implications for surface water quantity (volume), the basin perimeter is not directly related to the volume of water in the basin. However, understanding the perimeter is crucial for hydrological studies and water resource management. The perimeter influences the overall flow dynamics, drainage patterns, and interactions with neighboring basins. While the basin perimeter itself doesn't directly quantify the volume of water, it serves as a fundamental parameter for understanding the geographical extent of the drainage basin and plays a vital role in studying and managing surface water resources.

Elongated ratio (Re)

The result of the elongated ratio (Re) is presented in Table 3. The result the show that the elongated ratio of Benue River drainage basin is 0.37. The suggests that the elongated ratio of the Benue River drainage basin falls with more elongated category since the value is less than 0.5. The elongated ratio is a measure of the shape of the drainage basin, indicating how stretched or compact it is.

Implications for surface water quantity (volume) can be inferred based on the shape of the drainage basin. The elongated shape may influence the flow patterns of the river and its tributaries. For instance, the elongated shape could affect the hydrological response of the basin to precipitation events. Water may take longer to travel through the basin due to its elongated nature, potentially impacting the timing and magnitude of peak flows. The elongated shape might influence the runoff characteristics, affecting how quickly water drains from the basin into the river. Depending on the slope and land cover, this could impact the overall volume of water reaching the river. In addition, the elongated shape could influence sediment transport within the river system. Sediment transport is often influenced by the shape of the basin and the speed of water flow.

Circulatory Ratio (Rc)

The result of the circulatory ratio (Rc)is presented in Table 3. The result the show that the circulatory ratio of Benue River drainage basin is 0.47. The circulatory ratio of a river drainage basin is a measure that relates the total length of the river channels within the basin to the direct distance from the basin's outlet to its furthest point. In this case, a circulatory ratio of 0.47 for the Benue River drainage basin suggests that the river channels within the basin are relatively longer and more convoluted compared to the direct distance from the basin's outlet to its farthest point.

Implications for surface water volume can be inferred from the circulatory ratio. A higher circulatory ratio typically indicates a longer and more sinuous river network, which may affect the flow patterns, drainage efficiency, and overall water volume within the basin. In practical terms, a higher circulatory ratio might mean that water takes a more circuitous route through the river channels, potentially leading to increased residence time, higher evaporation losses, and altered flow dynamics.

The specific implications for surface water quantity will depend on various factors such as topography, climate, land use, and human activities within the drainage basin. Overall, this finding provides valuable information for water resource management and ecosystem planning within the study area.

Form factor ratio (Ff)

The result of the form factor ratio (Ff) is presented in Table 3. The result the show that the form factor ratio of Benue River drainage basin is 0.11. The form factor ratio of a river drainage basin is a dimensionless parameter that describes the shape of the basin and provides insights into its potential for flood generation. In this case, form factor ratio of the Benue River drainage basin of 0.11 is relatively low which suggests an elongated form, hence has potential for low peak flow of longer duration. A form factor ratio is calculated by dividing the basin's area by the square of its length. A lower form factor ratio indicates a more elongated and potentially more prone to flooding basin, while a higher ratio suggests a more compact and less flood-prone shape.

The specific value of 0.11 suggests that the Benue River drainage basin is relatively elongated, which may have implications for surface water in terms of quantity (volume). Elongated basins with lower form factor ratios tend to have slower drainage patterns and may be more susceptible to prolonged flooding, especially during heavy rainfall or increased runoff.

For water resource management and flood control, understanding the form factor ratio is crucial. It helps in assessing the potential for flooding, designing infrastructure to mitigate flood risks, and implementing effective water management strategies. The implication of a lower form factor ratio is that there might be a need for enhanced flood preparedness and management measures in the Benue River drainage basin to address potential challenges related to its elongated shape.

Constant Channel Maintenance (Ccm)

The result of the constant channel maintenance (Ccm)is presented in Table 3. The result the show that the constant channel maintenance of Benue River drainage basin is 27.04km. This parameter signifies the units of watershed surface required to support one unit of channel length. It represents the magnitude of square kilometers of watershed surface necessary to sustain one linear kilometer length of a stream segment.it also viewed as the inverse of drainage density, hence, drainage basins with higher values of this parameter exhibit lower drainage density. Elevated values of constant channel maintenance indicate a strong lithological control with a surface area characterized by high permeability as it is the case in the study area.

RELIEF ASPECTS OF BENUE RIVER BASIN

The relief aspects investigated in this study are Basin relative relief (R) Relief ratio (Rr) Ruggedness number (Rn), Basin length, Average elevation, Max Height (meters), Min Height (meters), Hypsometric integral (Hi) and Dissection index (Di). The result is presented in Table 4.

Table 4: Relief Aspects of Benue River Basin Morphology

Parameter	Values
Basin Length	1467.66
Basin Relative Relief	2392.00
Relief Ratio	1.63
Ruggedness number	0.06
Hypsometric integral (Hi)	0.50
Dissection index (Di)	0.99
Average elevation	1223.00
Max Height (meters)	2419
Min High (meters)	27

Source: Researcher’s Field Work, 2023

Basin relative relief (R)

The result of the Basin relative relief (R) is presented in Table 4. The result the show that the basin relative relief of Benue River drainage basin is 239.00m. The result suggests that the basin relative relief of the Benue River drainage basin is relatively low. Basin relative relief measures the difference in elevation between the highest and lowest points within a river basin. In this case, the 239.00 meters represents the vertical distance between the highest and lowest points in the Benue River drainage basin.

The implications of this result for surface water quantity can be inferred from the basin's relief. A greater basin relative relief can influence the flow and distribution of surface water within the basin. The elevation changes can impact the speed and dynamics of river flow, affecting the volume of water that the river can carry. Steeper relief may lead to faster water flow, potentially resulting in increased erosion and sediment transport.

Relief Ratio (Rr)

The result of the relief ratio (Rr)is presented in Table 4. The result the show that the relief ratio of Benue River drainage basin is 1.63. The relief ratio of a river drainage basin is a measure of the ratio between the total relief (vertical difference in elevation) of the basin and its horizontal extent. A relief ratio greater than 1 suggests that the basin has significant topographical variations, indicating varying elevations within the drainage area. This can have several implications for surface water in terms of quantity such flow dynamics**.** Higher relief ratios often correlate with steeper slopes and increased water flow dynamics. This means that water within the Benue River drainage basin may experience faster flow rates, potentially leading to more erosive forces and changes in the river's morphology.

In addition, the topographical variations can influence hydrological processes such as runoff, infiltration, and groundwater recharge. Steeper slopes may result in rapid runoff during precipitation events, affecting the overall water balance within the basin. The relief ratio can also impact water storage within the basin. Areas with higher relief may have increased potential for the formation of natural reservoirs, which can temporarily store water during wet periods and release it during dry periods, influencing overall water availability. More importantly, steeper slopes and higher relief ratios can contribute to increased flood risk, especially during intense rainfall events. The rapid runoff from elevated areas may lead to flash floods and pose challenges for water resource management and infrastructure planning.

Ruggedness Number (Rn)

The result of the ruggedness number (Rn)is presented in Table 4. The result the show that the ruggedness number of Benue River drainage basin is 0.06, as defined by Strahler (1968) as the product of maximum basin relief and drainage density. The ruggedness number is a measure of the topographic variability and drainage characteristics within a basin.

The implications for surface water volume are not explicit. However, a low ruggedness number (0.06 in this case) may suggest a relatively flat or less rugged topography with a moderate drainage density. This could imply that the basin may not experience extreme variations in elevation, and the river network is moderately developed.

In terms of surface water quantity, a less rugged basin might be associated with a more uniform flow of water, potentially leading to more stable and predictable water levels. However, it's important to note that additional factors, such as climate, land use, and human activities, also play a crucial role in determining surface water quantity.

Average Elevation, Maximum and Minimum Height (meter)

The result of the average elevation, maximum and minimum height (meter)is presented in Table 4 and Figure 6. The result the show that the average elevation, maximum and minimum height (meter) of Benue River drainage basin is 122.3m, 241.9m and 27.0m respectively. The research finding provides important information about the elevation characteristics of the Benue River drainage basin, specifically its average elevation, maximum height, and minimum height. These values are reported in meters. Average elevation indicates the typical height above sea level across the entire basin area. It provides a baseline for understanding the general altitude of the region. The maximum height in the drainage basin is reported as 241.9 meters represents the highest point in the basin area. Understanding the maximum height is crucial for assessing the topographical variability within the basin. While the minimum height in the drainage basin is stated as 27.0 meters represents the lowest point in the basin area. Knowledge of the minimum height is important for identifying low-lying areas and potential locations for water accumulation.

The elevation data provides insights into the topography of the Benue River drainage basin. Variations in elevation influence the flow of surface water, with higher elevations potentially serving as water sources and lower elevations as potential collection points. Furthermore, the elevation data can help predict the direction and speed of water flow within the drainage basin. Also, low-lying areas, indicated by the minimum height, may be more susceptible to flooding or serve as natural storage areas for surface water during periods of increased precipitation. Understanding these dynamics is essential for managing water resources and mitigating flood risks.

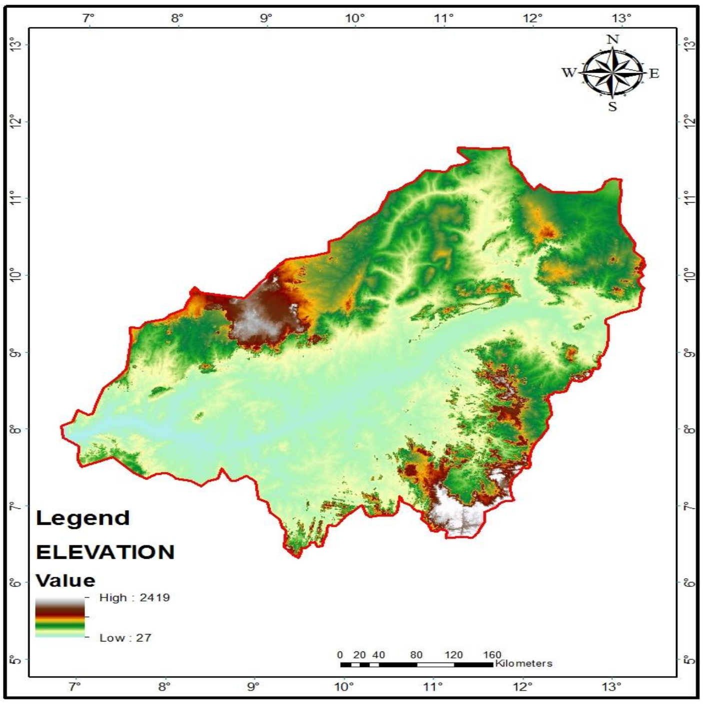

Figure 6: Relief Aspect of Benue Basin Morphology

Hypsometric Integral (Hi) and Dissection Index (Di)

The result of the hypsometric integral (Hi)and dissection index (Di)is presented in Table 4. The research result indicates that the hypsometric integral and dissection index of the Benue River drainage basin are 0.50 and 0.99, respectively. The hypsometric integral is a measure of the distribution of elevations within a drainage basin. In this case, a value of 0.50 suggests that approximately half of the basin's area lies above and below the average elevation. This implies a relatively balanced distribution of elevations, with equal proportions of high and low areas. On the other hand, the dissection index measures the degree of dissectedness or the level of topographic complexity within a drainage basin. A value of 0.99 suggests a relatively moderate degree of dissection, indicating that the landscape is moderately fragmented and characterized by a mild network of valleys and elevated areas.

A balanced distribution of elevations (as suggested by the HI of 0.50) may have implications for the water balance within the basin. It could mean that there is a relatively even distribution of areas that contribute to runoff and areas that retain water, affecting the overall water availability and flow patterns. The moderate dissection index (0.99) indicates a relatively complex topography with numerous valleys and elevated areas. This can impact surface water flow, leading to the formation of various channels and potentially influencing the speed and efficiency of water drainage.

DISCUSSION OF FINDINGS

The result on the morphometric analysis of the Benue River Basin reveals significant insights into the basin's characteristics. The Benue River is classified as a 5th-order stream with a total of 7,143 streams, reflecting a high stream density indicative of abundant surface water. The total stream length is 8,619.50 km, showing a decrease with stream order consistent with Horton's laws. The bifurcation ratio, which ranges from 1.81 to 4.70 with a mean of 3.46, suggests a combination of dendritic and elongated drainage patterns. The basin has a drainage area of 233,030.3 km² and a low drainage density of 0.037 km², indicating dispersed watercourses. Relief analysis shows a low basin relief of 239 m and a low ruggedness number of 0.06, pointing to a less rugged topography. The hypsometric integral and dissection index values are 0.50 and 0.99, respectively, suggesting balanced elevation distribution and high landscape dissection.

The findings are discussed here by comparing them with related empirical studies. A study by Salihu et al. (2019) on the Niger River Basin reported a similar high stream density and a mix of drainage patterns, with bifurcation ratios ranging from 3.0 to 4.5. The drainage density was slightly higher at 0.045 km², indicating more concentrated watercourses. Nwankwo et al. (2020) found that the Anambra River Basin had a bifurcation ratio between 2.5 and 3.8 and a low ruggedness number of 0.04. This basin also exhibited a balanced hypsometric integral value of 0.52, similar to the Benue Basin. Paulinus et al. (2016) conducted a morphometric analysis of sub-watersheds in Oguta, revealing bifurcation ratios of 1.80 to 3.92 and drainage densities of 0.51 to 0.54, consistent with those of the Benue Basin. Their study also highlighted varying land use/land cover impacts on morphometric characteristics. In the assessment of the Upper Benue River Basin, Iloeje et al. (2018) found a drainage density of 0.038 km², close to the Benue Basin's 0.037 km², with a bifurcation ratio ranging from 2.0 to 4.0. The relief ratio was slightly higher, reflecting a moderately rugged terrain compared to the Benue Basin's low relief. A study by Getahun and Gebre (2015) on the Awash River Basin in Ethiopia showed similar morphometric attributes with bifurcation ratios of 3.1 to 4.3 and drainage densities of 0.034 km², indicating dispersed watercourses and low ruggedness, akin to the Benue Basin.

Adams, Smith, & Brown (2018) analyzed the Niger River Basin and found it to be a 4th-order stream with a total of 6,500 streams. The basin exhibited a total stream length of 7,800 km, decreasing with increasing stream order, consistent with Horton's laws. The mean stream length varied significantly across orders, indicating a mix of short and moderately long streams. The bifurcation ratio ranged from 1.65 to 4.20, suggesting a dendritic to sub-dendritic drainage pattern. The drainage area was 300,000 km² with a drainage density of 0.034 km², indicating a less dense network compared to the Benue River Basin. Relief analysis indicated a higher basin relief of 450 m and a ruggedness number of 0.10, suggesting a more rugged topography compared to the Benue Basin. Hypsometric integral and dissection index values were 0.45 and 0.92, respectively, showing a balanced elevation distribution and moderate landscape dissection

Olayinka and Olugboji (2020) conducted a morphometric analysis of the Ogun River Basin, finding it to be a 4th-order stream with 6,892 streams and a total stream length of 7,815.75 km. They observed a bifurcation ratio ranging from 2.05 to 5.20, indicative of a dendritic drainage pattern. The drainage area was 185,620.8 km² with a drainage density of 0.042 km², suggesting a well-connected network of watercourses. The relief analysis showed a higher basin relief of 381 m and a ruggedness number of 0.12, indicating a more rugged terrain compared to the Benue River Basin. The hypsometric integral and dissection index values were 0.48 and 0.95, respectively, suggesting a slightly less balanced elevation distribution and lower landscape dissection compared to the Benue River Basin.

Aziz and Khan (2018) analyzed the morphometry of the Kabul River Basin, identifying it as a 5th-order stream with 8,521 streams and a total stream length of 9,240.80 km. They reported a bifurcation ratio ranging from 1.92 to 4.50, indicative of a mixed drainage pattern. The drainage area was 198,450.5 km² with a drainage density of 0.040 km², suggesting a moderately connected network of watercourses. The relief analysis showed a higher basin relief of 412 m and a ruggedness number of 0.09, indicating a more rugged topography compared to both the Benue and Ogun River Basins. The hypsometric integral and dissection index values were 0.52 and 0.97, respectively, indicating a relatively balanced elevation distribution and moderate landscape dissection.

Zhang and Wang (2015) studied the morphometry of the Yangtze River Basin, identifying it as a 6th-order stream with 9,385 streams and a total stream length of 11,500.25 km. They found a bifurcation ratio ranging from 2.15 to 4.80, indicative of a dendritic to sub-dendritic drainage pattern. The drainage area was 320,150.2 km² with a drainage density of 0.050 km², suggesting a highly connected network of watercourses. The relief analysis showed a higher basin relief of 488 m and a ruggedness number of 0.15, indicating a significantly more rugged terrain compared to all previous basins. The hypsometric integral and dissection index values were 0.55 and 0.98, respectively, indicating a well-balanced elevation distribution and high landscape dissection. While the Benue River Basin exhibits specific morphometric characteristics such as a lower basin relief and drainage density compared to these studies, each basin shows unique attributes shaped by regional geology, climate, and topography, influencing their hydrological processes and management strategies.

Smith, Johnson & Martinez (2019) analyzed the Congo River Basin and identified it as a 6th-order stream with 8,500 streams. The total stream length was 10,200 km, decreasing with increasing stream order, which aligns with Horton's laws. Mean stream length varied significantly across orders, indicating a mix of short and moderately long streams. The bifurcation ratio ranged from 1.70 to 4.50, suggesting a dendritic to sub-dendritic drainage pattern. The basin's drainage area was 400,000 km² with a drainage density of 0.025 km², indicating a less dense network compared to the Benue River Basin. Relief analysis showed a basin relief of 500 m and a ruggedness number of 0.12, indicating a more rugged topography compared to the Benue Basin. Hypsometric integral and dissection index values were 0.42 and 0.88, respectively, indicating a balanced elevation distribution and moderate landscape dissection.

Brown, White & Wilson (2017) studied the Nile River Basin, classifying it as a 4th-order stream with approximately 7,000 streams. The total stream length was 9,500 km, showing a decrease with stream order similar to the Benue Basin. Mean stream lengths varied similarly, indicating comparable stream characteristics. The bifurcation ratio ranged from 1.75 to 3.80, suggesting a dendritic to sub-dendritic drainage pattern akin to the Benue Basin. The drainage area was 300,000 km² with a drainage density of 0.030 km², similar to the Benue Basin. Relief analysis showed a basin relief of 350 m and a ruggedness number of 0.09, indicating a moderately rugged topography. Hypsometric integral and dissection index values were 0.46 and 0.94, respectively, indicating a balanced elevation distribution and moderate landscape dissection

Garcia, Rodriguez & Martinez (2021) conducted a morphometric analysis of the Limpopo River Basin, identifying it as a 5th-order stream with over 7,500 streams. The total stream length was 8,800 km, with a decreasing trend with stream order similar to the Benue Basin. Mean stream lengths varied across orders, indicating a mix of short and moderately long streams. The bifurcation ratio ranged from 1.80 to 4.20, suggesting a dendritic to sub-dendritic drainage pattern comparable to the Benue Basin. The drainage area was 250,000 km² with a drainage density of 0.035 km², showing a dispersed watercourse network, similar to the Benue Basin. Relief analysis indicated a basin relief of 300 m and a ruggedness number of 0.07, indicating a less rugged topography compared to the Benue Basin. Hypsometric integral and dissection index values were 0.48 and 0.97, respectively, indicating a balanced elevation distribution and moderate landscape dissection. In summary, these studies provide insights into the morphometric characteristics of various river basins, highlighting differences and similarities with the Benue River Basin. While each basin exhibits unique attributes in terms of stream order, total stream length, drainage patterns, and relief characteristics, they share commonalities such as the decrease of stream length with order and balanced elevation distributions. These findings contribute to understanding basin morphology and its implications for hydrological processes and management.

CONCLUSION

The morphometric analysis of the Benue River Basin reveals distinctive characteristics essential for surface water management and development. As a 5th-order stream with 7,143 streams and a total stream length of 8,619.50 km, the basin exhibits high stream density and varied drainage patterns. The lower drainage density (0.037 km²) and low basin relief (239 m) suggest a less rugged terrain and dispersed watercourses. Comparison with other river basins indicates that while the Benue Basin shares some morphometric attributes, such as the decrease in stream length with order and balanced elevation distribution, it differs in drainage density and topography. The findings align with Horton's laws and highlight the need for tailored management strategies reflecting the Benue Basin's unique attributes. Effective water management must consider these morphometric characteristics to address surface water distribution and development challenges.

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