

Morphometric And Drainage Characteristics of Selected Sub-Basins in The Lower Benue Basin, Nigeria

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Abstract

This study analysed the morphometric and drainage characteristics of six selected sub-basins of the Lower Benue Basin, Nigeria, namely Katsina-Ala, Mada, Farin Ruwa, Dep, Mu and Shemankar, to assess their drainage organisation, geomorphic development and implications for runoff response and flood management. Digital Elevation Model (DEM) data were processed using Geographic Information System (GIS) techniques to delineate drainage networks and derive linear, areal, relief and hypsometric parameters. Results revealed substantial spatial variation in drainage characteristics. Katsina-Ala was the largest sub-basin (12,139 km²), with 14,861 stream segments, seven stream orders and a total channel length of 1,623.83 km, while Shemankar was the smallest (298.41 km²), with 369 streams and five orders. Drainage density varied markedly from 0.134 km/km² in Katsina-Ala to 4.697 km/km² in Dep, with Shemankar also recording a relatively high value of 2.475 km/km². Form factor (0.16–0.27), elongation ratio (0.45–0.58) and circularity ratio (0.24–0.39) indicate predominantly elongated basin forms. Dep recorded the highest ruggedness number (10.01) and shortest overland-flow length (0.11 km), indicating high potential for rapid runoff concentration, whereas Katsina-Ala exhibited lower runoff concentration potential. The findings demonstrate considerable morphometric heterogeneity and provide a useful basis for sub-basin-specific flood and water-resource management.

Keywords: Morphometric Analysis, Drainage Characteristics, Lower Benue Basin, GIS and Digital Elevation Model (DEM)

Introduction

Drainage basins serve as the fundamental geomorphic and hydrological units for understanding surface-water movement, landscape evolution, and flood dynamics [1-3]. Morphometric analysis, the quantitative evaluation of earth surface forms and channel network geometry, provides a mathematical framework to analyze the operational parameters of river systems. By systematically evaluating linear, areal, and relief properties, hydrologists can deduce underlying geological controls, lithological variations, tectonic influence, and runoff behavior within a watershed, particularly in regions where continuous stream-gauging networks are limited or absent [4-6].

In tropical river catchments, understanding sub-basin morphometry is essential for sustainable water resource development, soil erosion abatement, and regional flood risk management [7]. The Lower Benue Basin in Nigeria represents

a major hydrological engine for West Africa, characterized by complex drainage networks that traverse diverse geological formations ranging from Precambrian basement complex rocks to Cretaceous sedimentary strata [8]. The hydrological regime across this basin is governed by strong seasonal precipitation patterns, rendering its tributary sub-basins vulnerable to extreme hydrological events, soil erosion, and flash flooding [9].

Despite the strategic importance of the Lower Benue Basin, detailed, comparative quantitative assessments of its major tributary sub-basins, specifically the Katsina-Ala, Mada, Farin Ruwa, Dep, Mu, and Shemankar, remain critical for catchment-scale spatial planning. Empirical literature across Nigeria indicates that while regional drainage systems generally display dendritic configurations conforming to Horton's laws, localized variations in structural arrangement, relief, and drainage density dictate distinct runoff generation mechanics and flood peak arrival times [10-12]. Sub-basins characterized by high drainage densities and high relief often produce rapid concentration times and high peak discharges, whereas elongated basins with lower

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drainage densities promote extended infiltration and attenuated hydrographs [13,14].

Advances in Remote Sensing (RS) and Geographic Information Systems (GIS) techniques, integrated with Digital Elevation Models (DEMs), have enhanced the precision of quantitative drainage network extraction across extensive river networks [15,16]. Applying these geospatial methodologies to the Lower Benue sub-basins provides crucial baseline insights into structural controls, landscape development, and watershed hydrologic behavior. Therefore, this study evaluates the linear, areal, relief, and hypsometric characteristics of six major sub-basins in the Lower Benue Catchment, Katsina-Ala, Mada, Farin Ruwa, Dep, Mu, and Shemankar, to elucidate their comparative hydrological behavior, structural development, and management implications.

Materials and Methods

Study Area

Lower River Benue Basin also called Lower Benue Trough lies between Latitudes 6° 13'N and 10° 00'N and Longitudes 7° 00'E and 10° 40'E (Figures 1 and 2) with a basin area of about 77, 379.32km² and a population of 1,356, 225 people (NPC/FRN, 2007). Most parts of the Lower River Benue Basin fall within the boundaries of Benue state with the remaining portions of the Basin falling within Kogi, Nasarawa, Taraba and Plateau States. The major settlements within the Basin include Gboko, Katsina-Ala, Makurdi, Obagaji, Tunga, Lafia, Awe, Abejokoro, okoja, Ibi, and Abinisi (Figure 1).

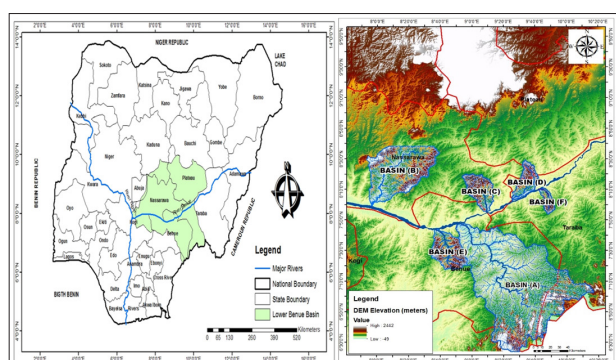


Figure 1: Nigeria showing States within Lower Benue Basin

Source: Benue State University, Cartography and GIS Studio, 2021

The Lower River Benue Basin is predominantly underlain by sedimentary formations, including sandstones, shales, siltstones, limestone and alluvial deposits associated with the Benue Trough. The geological formations include the Asu River Group, Keana Sandstone and Lafia Sandstone, with evidence of folding and varying degrees of metamorphism. The soils largely reflect the underlying geology and comprise hydromorphic soils developed on alluvial deposits along river channels and floodplains, and red ferrasols developed on sedimentary rocks away from the immediate river banks. The basin has generally low relief, with most areas below 300 m above sea level, although elevations rise to 300–900 m in parts of Lokoja and Plateau State. The River Benue constitutes the principal drainage system, supported by major tributaries such as the Katsina-Ala, Mkomon, Konshisha,

Apa and other smaller rivers. Extensive floodplains, wetlands, swamps and ponds occur throughout the basin. The combination of low-lying terrain, extensive floodplains and drainage characteristics increases susceptibility to flooding, particularly where drainage is inadequate or obstructed. At the same time, alluvial soils and floodplains support productive agriculture, especially rice, vegetables and other dry-season crops.

The basin experiences a tropical wet-and-dry climate, controlled mainly by the seasonal movement of the Inter-Tropical Discontinuity and the alternating influence of tropical maritime and tropical continental air masses. The rainy season generally extends from April to October, with annual rainfall varying spatially across the basin and peak rainfall usually occurring between August and September. Temperatures remain generally high throughout the year, while relative humidity increases considerably during the rainy season. Evidence of increasing temperatures and the occurrence of extreme rainfall and flooding indicates the influence of climate variability and change on the basin. Vegetation is predominantly Guinea Savanna, characterised by grasses and scattered trees, with gallery forests occurring along major watercourses. However, agricultural expansion, urbanisation, fuelwood extraction and other human activities have substantially reduced natural vegetation cover, thereby increasing runoff and erosion and potentially intensifying flood risks. Economic activities are dominated by agriculture, particularly subsistence crop production, supplemented by fishing, livestock rearing, artisanal mining and small- and medium-scale agro-processing enterprises. Major crops include yam, rice, cassava, maize, beans, potatoes, soybean, sorghum, millet and cocoyam. These physical and socio-economic characteristics collectively shape the basin's exposure and vulnerability to flooding and other environmental hazards.

Methods

Selection of Sub-basins across the Lower Benue Basin

To ensure adequate spatial coverage and representation of the diverse physiographic and hydrological conditions of the Lower Benue Basin, six sub-basins were purposively selected for detailed analysis. The selection was guided by the availability of hydrological and rainfall data, spatial distribution within the Lower Benue Basin, drainage connectivity, and the contrasting morphometric and physiographic characteristics of the sub-basins. The selected sub-basins are Katsina-Ala, Mada, Farin Ruwa, Dep, Mu, and Shemankar River Basins.

- **Katsina-Ala River Basin** represents a major upstream tributary system within the Lower Benue Basin.
- **Mada River Basin** was selected to represent a basin with intermediate morphometric and physiographic characteristics.
- **Farin Ruwa River Basin** represents a relatively smaller and more elevated sub-basin
- **Dep River Basin** was selected because of its distinctive morphometric characteristics, particularly its very high drainage density
- **Mu River Basin**, located within the southern part of the study area, represents a basin with a well-organised drainage network
- **Shemankar River Basin** was selected to represent a comparatively small sub-basin.

The six selected sub-basins collectively provide a representative range of basin sizes, elevations, relief characteristics, drainage densities, stream networks, basin shapes, and other morphometric conditions across the Lower Benue Basin. The selection therefore allowed for a comparative assessment of how variations in rainfall and basin parameters influence runoff generation and response. The spatial and physiographic contrasts among the sub-basins also provided a suitable basis for examining the implications of basin morphology for flood generation and hydrological variability within the Lower Benue Basin.

Analysis of Morphometric and drainage characteristics

The morphometric and drainage characteristics of the selected basins were derived from Digital Elevation Model (DEM) data using GIS-based hydrological analysis. The DEM was processed through sink filling, flow direction, flow accumulation, stream-network extraction, stream ordering, and watershed delineation. The extracted drainage networks and basin boundaries were subsequently used to calculate the linear, areal, relief, shape, and hypsometric parameters of each basin. Detail analytical methods is presented in Table 1.

Table 1: Morphometric Parameters with Formulae

S/N	Parameter	Symbol	Formulae	Source
1	Stream Order	Sq	Hierarchical Rank	Strahler (1952)
2	Bifurcation Ratio	Rβ	$R\beta = \frac{N\mu}{N\mu+1}$ Where Rβ= Bifurcation ratio, Nq= Total no. of stream segments of order 'q', Nq + 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, (1956)
4	Stream Length	Lμ	Length of the stream (kilometers)	Horton (1945)
5	Mean Stream Length	Lsm	$L_{sm} = \frac{L}{N\mu}$ Where, Lμ = Total stream length of order 'μ' Nμ = Total no. of stream segments of order 'μ'	Horton (1945)
6	Stream Length Ratio	RL	$RL = \frac{L_{sm}}{L_{sm-1}}$ 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 Length	Lb	$Lb = 1.312 \times A^{0.568}$ (GIS Analysis)	Horton (1945)
9	Basin Area	B	Area from which water drains to a common stream and boundary determined by opposite ridges. (GIS Analysis)	Horton (1945)
10	Drainage Density	Dd	$Dd = \frac{L\mu}{A}$ Where, Dd = Drainage density (Km/Km2) Lμ = Total stream length of all orders and A = Area of the basin (Km2).	Strahler (1952)
11	Stream Frequency	Fs	$F_s = \frac{N\mu}{A}$ Where, Nμ = Total no. of streams of all orders and A = Area of the basin (Km2).	Singh (1998)
12	Drainage Texture	Dt	$D_t = \frac{N\mu}{P}$ Where, Nμ = No. of streams in a given order and P = Perimeter (Kms)	Horton (1945) Pareta & Pareta (2011)
13	Form Factor Ratio	Rf	$R_f = \frac{A}{Lb^2}$ Where, A = Area of the basin and Lb = (Maximum) basin length	Strahler (1952)
14	Elongation Ratio	Re	$Re = \left(\frac{2}{Lb}\right) \left(\frac{A}{\pi}\right)^{0.5}$ Where, A= Area of the basin (Km2) Lb=(Maximum) Basin length (Km)	Horton (1945)
15	Circularity Ratio	Rc	$R_c = \frac{4\pi A}{P^2}$ Where, A = Basin area (Km2) and P= Perimeter of the basin (Km)	Schumn (1956)
16	Constant Channel Maintenance	C	$C = \frac{1}{D}$ Where, D = Drainage density (Km/Km ²)	
17	Length of Overland Flow	Lg	$L_g = \frac{1}{2D}$ Where, D = Drainage density (Km/Km ²)	Horton (1945)
18	Basin Relief	H	$H = Z - z$ Where, Z = Maximum elevation of the basin (m) and z = Minimum elevation of the basin (m)	Rudraiah, Govindaiah & Vittala (2008)
19	Relief Ratio	Rr	$R_r = \frac{H}{Lb}$ Where, H = basin relief (m) and Lb = Basin length (m)	Rakesh , Lohani, Sanjay & Nema (2000)

Results And Discussion

Results

Morphometric Characteristics of Sub- Basins in the Lower Benue Basins

The linear morphometric characteristics of the six sub-basins of the Lower Benue Basin are presented in Tables 2–7 and Figure 2. The results show considerable variation in stream order, stream frequency, stream length, bifurcation ratios and stream-length ratios, reflecting differences in drainage organisation, basin structure and the degree of geomorphic development across the sub-basins.

Table 2: Linear Morphometric Characteristics and Horton's Ratios for the Katsina-Ala River 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	7413	2.17	621.84	0.0839	0.180	1.15	3.87	2.79	1.92
2nd	3421	1.72	329.42	0.0963	0.276	1.49	3.53	2.52	
3rd	1989	2.12	286.03	0.1438	0.420	1.19	3.30	2.46	
4th	939	1.67	161.17	0.1716	0.592	1.37	2.97	2.21	
5th	563	1.76	132.17	0.2348	0.827	0.97	2.75	2.12	
6th	320	1.48	73.17	0.2286	1.055	0.41	2.51	1.86	
7th	216		20.05	0.0928	0.685		2.33	1.30	
	14861		1623.83						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026

Table 3: Linear Morphometric Characteristics and Horton's Ratios for the Mada River 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	2419	2.17	521.84	0.2157	0.422	0.96	3.38	2.72	2.10
2nd	1113	1.73	229.42	0.2061	0.628	1.93	3.05	2.36	
3rd	644	1.98	256.03	0.3976	1.026	1.17	2.81	2.41	
4th	326	2.53	151.17	0.4637	1.489	1.88	2.51	2.18	
5th	129	1.08	112.17	0.8695	2.359	0.61	2.11	2.05	
6th	119	2.13	63.17	0.5308	2.890	0.34	2.08	1.80	
7th	56		10.05	0.1795	1.669		1.75	1.00	
	4806		1343.83						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026

Table 4: Linear Morphometric Characteristics and Horton's Ratios for the Farin Ruwa River 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	670	2.23	621.84	0.9281	1.360	0.46	2.83	2.79	2.21
2nd	300	3.16	129.42	0.4314	1.791	2.10	2.48	2.11	
3rd	95	2.16	86.03	0.9056	2.696	0.36	1.98	1.93	
4th	44	1.29	14.17	0.3219	3.018	0.00	1.64	1.15	
5th	34	1.70	0.05	0.0015	3.020	34.08	1.53	-1.28	
6th	20		1.05	0.0526	3.073		1.30	0.02	
	1163		851.50						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026

Table 5: Linear Morphometric Characteristics and Horton's Ratios for the Dep River 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	510	2.16	592.34	1.1615	2.154	0.85	2.71	2.77	2.08
2nd	236	2.07	234.32	0.9929	3.147	0.74	2.37	2.37	
3rd	114	1.04	84.11	0.7378	3.885	0.41	2.06	1.92	
4th	110	3.06	33.04	0.3004	4.185	0.21	2.04	1.52	
5th	36		2422.00	67.2778	4.195		1.56		
	1006		3365.81						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026

Table 6: Linear Morphometric Characteristics and Horton's Ratios for the Mu River Basin

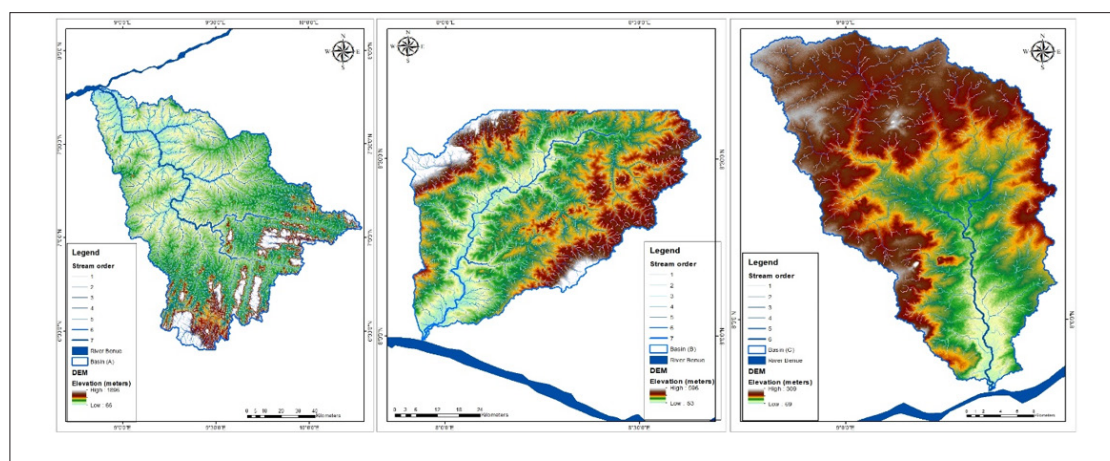
Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Mean Stream Length	cumulative Mean Stream Length	Stream Length Ratio	Log of Stream number	Log of Stream Length	Mean bifurcation Ratio
1st	826	2.15	452.22	0.7528	1.09	0.45	2.92	2.79	1.81
2nd	384	1.74	345.77	0.337	1.427	1.16	2.58	2.11	
3rd	221	1.6	67.33	0.3893	1.816	0.26	2.34	1.93	
4th	138	1.75	15.17	0.1026	1.919	0.46	2.14	1.15	
5th	79		9.44	0.0007	1.911		1.9	1.17	
	1648		851.5						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026

Table 7: Linear Morphometric Characteristics and Horton's Ratios for the Shemankar River 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	190	2.41	521.84	2.7465	4.258	0.55	2.28	2.72	1.80
2nd	79	1.52	119.42	1.5116	5.770	0.97	1.90	2.08	
3rd	52	1.86	76.03	1.4621	7.232	0.27	1.72	1.88	
4th	28	1.40	11.17	0.3988	7.631	1.26	1.45	1.05	
5th	20		10.05	0.5026	8.133		1.30	1.00	
	369		738.50						

Source: Computed from Satellite imagery from USGS Earth Explorer, 2026



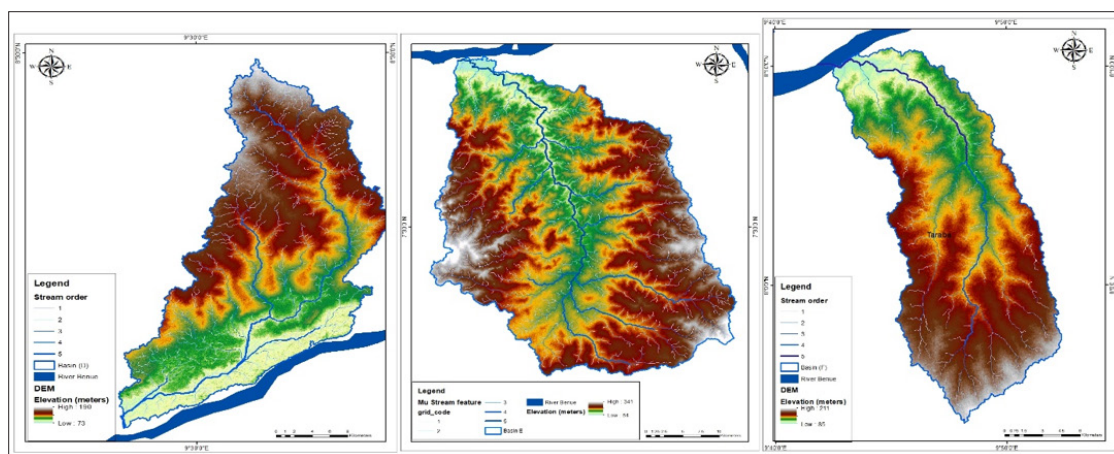


Figure 2: Katsina-Ala, Mada, Farin Ruwa, Dep, Mu and Shemankar River Basins Morphology

The Katsina-Ala River Basin exhibits the most extensive drainage network, with 14,861 stream segments distributed across seven orders and a total stream length of 1,623.83 km. The number of streams declines progressively from 7,413 first-order streams to 216 seventh-order streams, which is consistent with Horton's law of stream numbers. The bifurcation ratios range from 1.48 to 2.17, with an overall pattern indicating relatively low to moderate branching. Such values suggest that the drainage network is not strongly controlled by structural disturbances and that geological structure exerts only a limited influence on the arrangement of channels. The cumulative mean stream length increases from 0.180 km for first-order streams to 1.055 km at sixth order, indicating progressive enlargement of channel dimensions with increasing stream order. The relatively large number of first-order channels and extensive total stream length imply a highly developed drainage network capable of efficiently collecting runoff from the basin. The Mada Basin similarly follows the expected hierarchical decline in stream number, from 2,419 first-order to 56 seventh-order streams, with a total of 4,806 streams and 1,343.83 km of channel length. Its bifurcation ratios range between 1.08 and 2.53, although the relatively high value at the fourth order suggests some local structural or lithological influence on drainage branching.

The Farin Ruwa, Dep, Mu and Shemankar basins display comparatively smaller and more varied drainage networks. Farin Ruwa contains 1,163 streams with a total stream length of 851.50 km, extending to the sixth order. Its bifurcation ratio varies considerably from 1.05 to 3.16, with the high second-order value indicating greater branching at that level and potentially stronger local geological or topographic controls. The Dep Basin, with 1,006 streams and a total stream length of 3,365.81 km, is particularly distinctive because its fifth-order stream length is exceptionally large (2,422 km), producing a very high mean stream length of 67.28 km at that order. This suggests the presence of a relatively dominant higher-order channel system and should be interpreted in relation to the basin's geomorphology and channel extraction characteristics. The Mu Basin contains 1,648 streams and 851.50 km of total stream length, with bifurcation ratios between 1.60 and 2.15, indicating a relatively orderly drainage hierarchy and limited structural distortion. The Shemankar Basin is the smallest in terms of stream number, with 369 streams and 738.50 km of channel length across five orders. Its bifurcation ratios range from 1.40 to 2.41, while cumulative mean stream length increases markedly from 4.258 km at first order to 8.133 km at fifth order, indicating rapid enlargement of channels with increasing order.

In general, the six sub-basins demonstrate a dendritic to moderately structurally influenced drainage organisation, with most bifurcation ratios falling within relatively low-to-moderate ranges. The progressive reduction in stream number with increasing order and corresponding increase in mean stream length generally conform to Horton's principles, suggesting systematic drainage development across the Lower Benue Basin. However, the marked fluctuations in stream-length ratios and bifurcation ratios in some basins, particularly Farin Ruwa and Dep, indicate local variations in lithology, relief, slope and geological structure. These differences are hydrologically important because basins with numerous low-order tributaries and dense drainage networks can respond rapidly to rainfall, whereas basins characterised by longer higher-order channels may exhibit greater channel storage and a more delayed runoff response. Thus, the linear morphometric characteristics provide an important basis for explaining the observed differences in runoff generation and temporal response among the Lower Benue sub-basins.

Hypsometric Parameters of the Selected Sub-Basins

Table 8 presents the hypsometric characteristics of the six selected sub-basins in the Lower Benue River Catchment.

Table 8: Morphometric and Hypsometric Parameters of Selected Sub-Basins

Parameter	Katsina-Ala River Basin	Mada River Basin	Farin Ruwa River Basin	Dep River Basin	Mu River Basin	Shemankar River Basin
Average elevation	981.00	324.50	189.00	131.50	202.5	148
Max Hight (meters)	1896	596	309	190	341	211

Min High (meters)	66	53	69	73	64	85
Basin perimeter	797.29	344.99	186.88	192.05	208.22	105.64
Basin Area	12139	3696.11	986.34	716.59	1338.95	298.41
Drainage Density	0.134	0.364	0.863	4.697	0.636	2.475
Length of Overland Flow	3.74	1.38	0.58	0.11	0.79	0.20
Drainage Frequency	1.22	1.30	1.18	1.40	1.23	1.24
Drainage Texture	18.64	13.93	6.22	5.24	7.91	3.49
Basin Length	274.00	139.45	65.85	54.92	78.33	33.39
Form Factor Ratio	0.16	0.19	0.23	0.24	0.22	0.27
Elongation Ratio	0.45	0.49	0.54	0.55	0.53	0.58
Constant of Channel maintenance (C)	7.48	2.75	1.16	0.21	1.57	0.40
Basin Relative Relief	1830.00	543.00	240.00	117.00	277	117.00
Relief Ratio	6.68	3.89	3.64	2.13	3.54	3.50
Circularity ratio (Rc)	0.24	0.39	0.35	0.24	0.39	0.34
Ruggedness number	0.89	1.42	3.15	10.01	2.25	8.67
Hypsometric integral (Hi)	0.50	0.50	0.50	0.50	0.5	0.50
Dissection index (Di)	0.97	0.91	0.78	0.62	0.81	0.62

Source: Satellite imagery from USGS Earth Explorer, 2020

The results reveal substantial differences in basin size, elevation, drainage development and relief. The Katsina-Ala Basin is by far the largest, covering 12,139 km², with the highest average elevation (981 m), maximum elevation (1,896 m) and basin relative relief (1,830 m). In contrast, the Shemankar Basin is the smallest (298.41 km²) and has a relatively low average elevation of 148 m. Drainage density varies markedly, from only 0.134 km/km² in Katsina-Ala to 4.697 km/km² in Dep, while the length of overland flow shows the reverse pattern, ranging from 3.74 km in Katsina-Ala to only 0.11 km in Dep. This indicates that Dep has a highly developed and closely spaced drainage network with rapid concentration of surface runoff, whereas Katsina-Ala has a relatively sparse drainage network and longer pathways for overland flow. The high drainage density of Dep and Shemankar (2.475 km/km²) is further reflected in their high ruggedness numbers of 10.01 and 8.67, respectively, suggesting greater susceptibility to rapid runoff and erosion. Katsina-Ala, despite its considerable relief, has the lowest ruggedness number (0.89), reflecting the effect of its very large basin area.

The form factor ratios (0.16–0.27) and elongation ratios (0.45–0.58) indicate that all six basins are predominantly elongated rather than circular. The low form factor values, particularly in Katsina-Ala (0.16) and Mada (0.19), suggest relatively longer concentration times and less synchronised runoff, whereas the higher values in Shemankar (0.27) and Dep (0.24) indicate comparatively greater potential for rapid concentration of runoff. Similarly, the low circularity ratios (0.24–0.39) reinforce the elongated nature and relatively youthful-to-mature stages of basin development. The hypsometric integral of 0.50 across all basins indicates a broadly similar intermediate stage of landscape development, while the dissection index varies from 0.62 in Dep and Shemankar to 0.97 in Katsina-Ala, indicating stronger vertical dissection and relief contrasts in Katsina-Ala. Overall, the results demonstrate that Dep and Shemankar are characterised by high drainage density, short overland-flow lengths and high ruggedness, conditions conducive

to rapid runoff generation, whereas Katsina-Ala, with its low drainage density, extensive area and elongated form, is likely to exhibit a comparatively slower and more attenuated hydrological response.

Discussion

The morphometric analysis reveals considerable spatial variation in drainage-network organisation, basin geometry, relief and terrain characteristics among the six Lower Benue sub-basins. The predominance of first-order streams and progressive decline in stream numbers with increasing order are consistent with, who found that Nigerian drainage basins generally range from third- to seventh-order systems and are predominantly dendritic. Similarly, identified a seventh-order dendritic network in the Upper Benue River watershed, while reported a fourth-order dendritic system in the Yewa Basin [17,18]. The present study identifies seventh-order systems in Katsina-Ala and Mada, sixth-order in Farin Ruwa, and fifth-order systems in Dep, Mu and Shemankar, confirming the hierarchical organisation of drainage networks and the applicability of Horton's Law of Stream Numbers [19]. further demonstrated the usefulness of GIS- and DEM-based morphometric analysis for characterising drainage systems and supporting water-resource assessment.

The Mu Basin provides an important local comparison with. Both studies identify a dendritic and predominantly elongated basin, although the present analysis records a fifth-order network, form factor of 0.16 and circularity ratio of 0.39, compared with the fourth-order network, form factor of 0.22 and circularity ratio of 0.27 reported by. The differences may arise from variations in basin delineation, DEM resolution, drainage extraction and stream-order classification. Nevertheless, both studies indicate relatively low drainage density and an elongated basin configuration, supporting the interpretation of comparatively high infiltration, lower runoff potential and less rapid runoff concentration in Mu. The contrasting bifurcation

ratios-1.81 in the present study compared with 4.62 reported by also demonstrate the sensitivity of morphometric parameters to methodological procedures and caution against interpreting bifurcation ratio independently of other basin characteristics.

Bifurcation ratios across the present basins range from 1.80 in Shemankar to 2.21 in Farin Ruwa, indicating generally limited structural control. These values broadly fall within the Nigerian range synthesised by and are comparable with the mean value of 2.03 reported by for the Yewa Basin. The relatively low values suggest predominantly dendritic drainage with limited influence of major structural disturbances. However, the substantial difference between the present Mu value and that of reinforces the need to consider stream-order classification and data resolution when comparing bifurcation ratios.

Drainage density exhibits the strongest spatial contrast among the six basins, ranging from 0.134 km/km² in Katsina-Ala to 4.697 km/km² in Dep, with Mada (0.364 km/km²), Mu (0.636 km/km²), Farin Ruwa (0.863 km/km²) and Shemankar (2.475 km/km²) occupying intermediate positions. The Mu value is reasonably close to the 0.40 km/km² reported by Ocheri et al. (2024), supporting its relatively low drainage density and greater infiltration opportunity. Comparable relationships were reported by Abayomi and Lanre (2023), who obtained 0.256 km/km² for the Yewa Basin, and Hassan and Ruma (2024), who recorded 0.41 km/km² for the Hadejia sub-basin. Both studies associated low drainage density and elongated basin form with greater infiltration and groundwater-recharge potential. In contrast, the high drainage density of Dep indicates a highly dissected terrain with greater drainage efficiency and potentially faster runoff concentration. The broad range of drainage densities observed is also consistent with the national variability documented by [11].

Basin-shape parameters further indicate that the six sub-basins are predominantly elongated. Form factors range from 0.16 in Katsina-Ala to 0.27 in Shemankar, while elongation ratios range from 0.45 to 0.58. These results agree with, who characterised Mu as elongated, and with, who reported a form factor of 0.42, circularity ratio of 0.27 and elongation ratio of 0.73 for the broader River Benue Basin. Similarly, Abayomi and Lanre (2023) obtained a form factor of 0.243 and elongation ratio of 0.556 for Yewa. Although the main River Benue Basin is relatively less elongated than the present sub-basins, the consistently low circularity values demonstrate that elongated and non-circular configurations are important characteristics within the Benue drainage system.

The elongated basin forms generally imply longer flow paths and less synchronised arrival of runoff at basin outlets, potentially reducing peak-flow concentration. This interpretation agrees with, who associated elongated basin morphology with lower runoff concentration and greater infiltration or groundwater-recharge opportunities. However, the present results demonstrate that basin shape should not be interpreted independently of drainage density and relief. Dep, for example, is relatively elongated but has the highest drainage density (4.697 km/km²), shortest overland flow length (0.11 km) and highest ruggedness number (10.01), conditions that may favour rapid runoff concentration despite its elongated form.

Relief characteristics further distinguish the sub-basins. Katsina-Ala has the highest average elevation (981 m), maximum elevation (1,896 m), relative relief (1,830 m) and relief ratio (6.68), whereas Dep records the highest ruggedness number (10.01). Hassan and Ruma (2024) similarly demonstrated the importance of relief and slope in interpreting infiltration and runoff processes, while Yiyeh et al. (2024) emphasised the relevance of relief and other morphometric parameters to surface-water development and flood management in the River Benue Basin. The present findings suggest that high relief in Katsina-Ala may increase runoff velocity once flow is generated, whereas the combination of high drainage density and ruggedness in Dep may enhance rapid runoff concentration and conveyance. Thus, elevation, relief and drainage density interact to produce different runoff responses among the sub-basins.

The hypsometric integral of 0.50 obtained for all six basins requires cautious interpretation. Although it falls within the Nigerian range of 0.22–0.99 reported by, its uniformity is unusual given the marked differences in relief, elevation and drainage characteristics among the basins. For example, reported a value of 0.22 for the Upper Benue watershed and associated it with an old geomorphic stage. The difference highlights the sensitivity of hypsometric interpretation to basin scale and DEM processing. The uniform value of 0.50 should therefore be verified against the original DEM and hypsometric curves before firm conclusions are drawn regarding geomorphic development.

Overall, the findings have important implications for water-resource and flood management. demonstrated the relevance of morphometric characteristics to surface-water development in the Benue Basin, while highlighted their practical value for water-resource assessment and utilisation. The strong contrasts between Katsina-Ala and Dep indicate that identical rainfall events may produce substantially different runoff magnitudes and response times across the sub-basins. This is also consistent with, whose integration of HEC-RAS and GIS in the Ogbese Catchment demonstrated the value of combining catchment characteristics with hydraulic modelling for flood-vulnerability assessment.

In general, the evidence from supports the conclusion that the six Lower Benue sub-basins are morphometrically heterogeneous. Their contrasting combinations of drainage density, basin shape, relief, overland flow length, ruggedness and drainage-network organisation create different physical controls on runoff generation and concentration. Morphometric characteristics therefore provide a useful basis for understanding spatial differences in runoff response and for prioritising subsequent hydrological modelling, flood-risk assessment and water-resource planning in the Lower Benue Basin [10,20-23].

Conclusion and Recommendations

The study concludes that the six selected sub-basins of the Lower Benue Basin exhibit substantial spatial variation in drainage organisation, basin geometry, relief and hydrological characteristics. The drainage networks generally conform to Horton's law and are predominantly dendritic, with mean bifurcation ratios ranging from 1.80 to 2.21, indicating generally limited structural control. Basin shape parameters, including form factor (0.16–0.27), elongation ratio (0.45–0.58) and circularity ratio (0.24–0.39), indicate predominantly elongated basins. However, marked differences in drainage density and terrain characteristics imply contrasting

runoff responses. Dep recorded the highest drainage density (4.697 km/km²), shortest overland-flow length (0.11 km) and highest ruggedness number (10.01), while Shemankar also recorded high drainage density (2.475 km/km²) and ruggedness (8.67), indicating greater potential for rapid runoff concentration, erosion and flooding. In contrast, Katsina-Ala, with its very large area (12,139 km²), low drainage density (0.134 km/km²), long overland-flow length (3.74 km) and low ruggedness (0.89), is likely to have a comparatively slower and more attenuated runoff response.

The study therefore recommends sub-basin-specific watershed and flood-management strategies, with priority attention given to Dep and Shemankar for flood monitoring, erosion control, drainage improvement and vegetation restoration. Protection of riparian zones, floodplains and natural drainage corridors should be strengthened, while land-use planning should incorporate morphometric and flood-susceptibility information. Rainfall and streamflow monitoring should also be improved and integrated with GIS and remote sensing to support flood forecasting and early-warning systems. Furthermore, future studies should combine morphometric parameters with rainfall, runoff, soil and land-use data to quantify peak discharge, runoff volume and lag time. The uniform hypsometric integral value of 0.50 across all six basins should also be independently verified using the original DEM data and hypsometric curves before firm conclusions are drawn about their geomorphic development.

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