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ASSESSMENT OF THE IMPLICATIONS OF MORPHOMETRIC FEATURES ON HYDRO-GEOMORPHIC PROCESSES OF THE DONGA RIVER BASIN IN TARABA STATE, NIGERIA

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ABSTRACT

This paper analysed the morphometric parameters of the Donga River Basin in Taraba State, Nigeria, to understand the key factors influencing hydro-geomorphic processes. Data used for morphometric analysis were derived from the Shuttle Radar Topographic Mission Digital Elevation Model, obtained from the United States Geological Survey website. Water stage/discharge data were obtained from the Upper Benue River Basin Development Authority, Yola, Adamawa State, Nigeria. Channel width was determined in the field at the confluence of each succeeding Sub-Basin and from a 2020 satellite image. Twenty-one (21) morphometric parameters of area, linear, and relief aspects were generated and calculated using various formulas from the literature. These morphometric parameters were subjected to correlation and principal component analysis in SPSS version 23. The result of the analysis revealed that the study area comprises one hundred and one (101) sub-basins that discharge water and sediments into the main Donga River channel. Water stage/discharge data from five gauging stations on the River Donga (Gembu, Abong, Manya, Donga Town, and Bantaje) showed an increase in downstream flow with channel width. High-level multi-correlation exists between the morphometric parameters and six (6) variables with eigenvalues greater than one (>1), which were factored out and explain 77.154% of the total variance in morphometric attributes. They are: index of basin area (32.922%), slope/relief (16.972%), stream network (13.327%), basin shape (8.235%), and terrain ruggedness (5.699%). These influences slope processes, discharge, erosion, sediment transport, deposition, and the morphology of the study area. Measures for basin planning and management were strongly recommended.

Keywords: Morphometric, Basin area, Drainage density, Slope, Basin shape

INTRODUCTION

Drainage basin morphometry is the topographic expression of a catchment in terms of area, length, and relief. It is important in hydrology, fluvial geomorphology and other facets of environmental studies, which help to ascertain the characteristics of flooding, discharge, erosion, sediment yield, basin evolution and land forms (Jimoh & Ajao, 2009; Jimoh & Iroye, 2010; Ifabiya, 2017; Parvez & Inayathulla, 2019; Anil & Sasi, 2024; Rathod & Khadri, 2024).

Morphometric parameters can be used to analyze groundwater potentials and locate suitable sites for the construction of check dams and artificial recharge structures (Avinash *et al.,* 2011; Mishra *et al.,* 2019). It is the ideal unit for interpreting and analyzing fluvial landforms in an open system (Smith & Sandwell, 2003). Morphometric studies provide insight into the nature of topographic features, climate, hydrology, geology, and lithological characteristics of the basin (Nageswara *et al.,* 2010; Mane *et al.,* 2019; Esimo & Hayicho, 2024). Drainage basin morphometric analysis was previously conducted using topographical maps and data obtained from field survey (Eze & Efiong, 2010;

Sreedevi *et al*., 2012). This has generated considerable controversy over the exact location, size, position, and even morphometric attributes of the drainage basin (Damilola, 2016). However, the emergence of remote sensing and GIS techniques has paved the way for accurate delineation and analysis of basin morphometric attributes (Waikar & Nilawar, 2014; Singh *et al.,* 2014; Hassan & Kabir, 2019; Mazumdar *et al.,* 2023).

The need to link channel forms and processes to the wider context of the drainage basin was highlighted by Charlton (2008). Anil and Sasi (2024) noted that drainage basin morphometric analysis is critical to understanding the dynamics of the fluvial system, associated processes, and landforms. River Donga has been affected by natural and anthropogenic factors, which may have led to erosion, flooding, channel adjustments, and devastating impacts on land use and land cover (Ijafiya *et al.,* 2023). Thus, this study was conducted at the sub-basin scale with the view to identifying the key morphometric variables that influence fluvial forms and processes, to inform decisions on basin planning and management.

MATERIALS AND METHODS

Study Area

The Donga River Basin is a major fluvial system that originates on the Mambilla Plateau in Taraba State, Nigeria. It is located between latitude 6° 30’ 0’’ and 8° 0’ 0’’ north of the Equator and between longitude 10° 0’ 0’’ and 11° 30’ 0’’ east of the Greenwich Meridian, with an area of 13,228 km2. The study area spans about 383.61km from Sardauna to Bantaje in Wukari LGA of Taraba State (Figure 1).

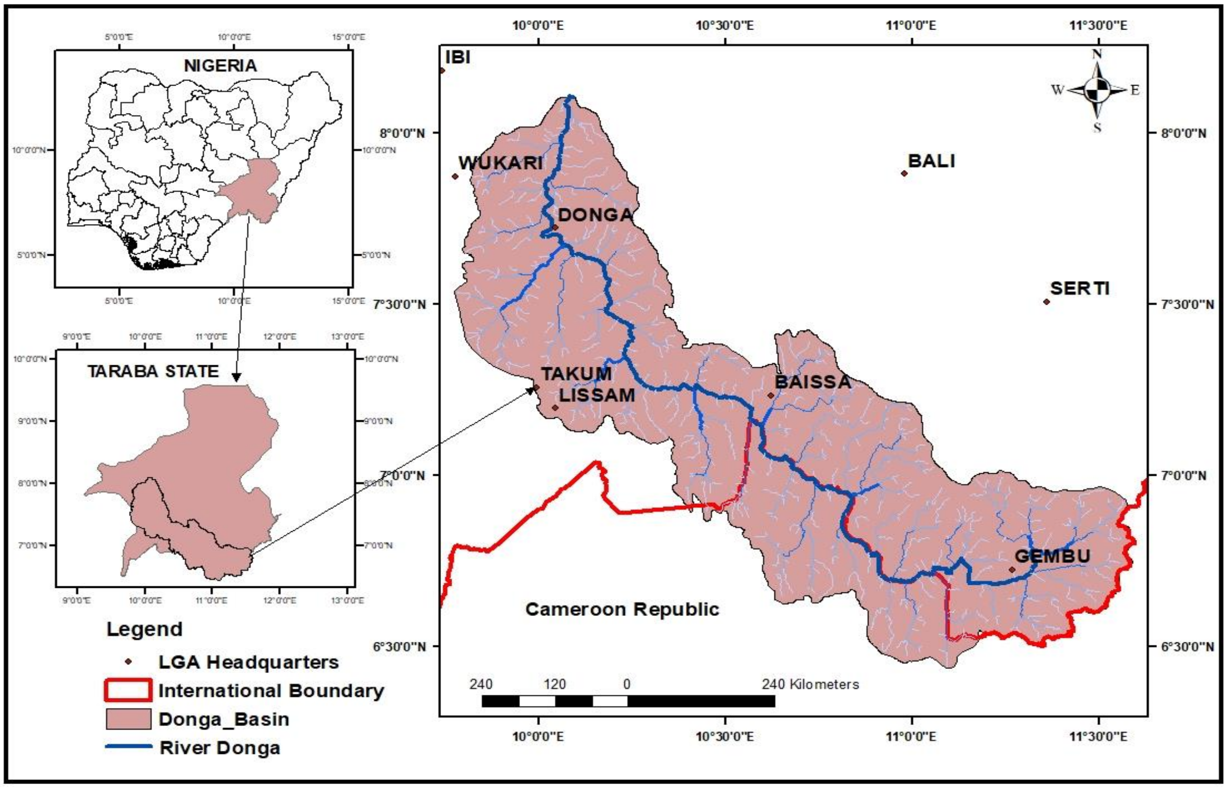

Figure 1: Map the Study Area
Source Extracted from Digital Elevation Model (DEM)

Two distinct climatic regions prevailed in the study area: the Alpine climate on the Mambilla Plateau and the Savannah climate in the surrounding lower areas. The rainy season lasts from April to October, and the dry season from November to March (Adebayo & Umar, 2005). The area has high rainfall, up to 2000mm in the north and 1600mm in the south. The surrounding lowlands have a mean total rainfall of 1511.2 mm and 1468.9mm (Gabriel & Zemba, 2017). On the Plateau, maximum temperature ranges from 20^0 C to 31^0 C; while minimum temperature falls between 11^0 C and 200 °C—the low surrounding recorded maximum temperature up to 320 °C in April (Enock, 2014).

The area is underlain by basement complex rocks of Migmatite Gneiss, influenced by regional and contact metamorphism. The major soil types identified by Mubi and Adebayo (2005) are ferruginous soils developed from the crystalline acidic rocks of the Basement Complex and humic ferrisols developed from the Basaltic and Biotite rocks of the Basement Complex. The vegetation types range from open grassland in the upper Donga valley to well-developed gallery forests along the rivers and in the foothills, derived savanna, and high rain forest (Bawden & Tuley, 1966).

Data Collection and Analysis

Data on 21 morphometric parameters were generated from the SRTM DEM downloaded from USGS. Water stage data were obtained from the Upper Benue River Basin Development Authority in Yola, Adamawa State, Nigeria. Hydrological analysis, including fill, flow direction, and flow accumulation, was conducted in ArcGIS 10.8. The flow accumulation layer was later reclassified into 0-5000 and 5000 and above, which determines the appearance of rivers in the drainage basins. Afterward, pour points were also generated in the Spatial Analyst tool and snapped to achieve higher flow accumulation. The watershed tool was activated to generate the various sub-basins in raster format, which were later converted to polygons using the conversion tool. Analyses of stream ordering, basin area, basin perimeter, and other morphometric parameters were conducted. The morphometric variables for all the sub-basins were also subjected to Correlation and Principal Component Analysis in SPSS version 23, and the Kaiser-Meyer-Olkin (KMO) value was 0.754. This implies that the sample is adequate for factor analysis. Channel width was determined in the field at the confluence of each succeeding Sub-Basin, from the top of the right bank to the top of the left bank, and from a 2020 satellite image for inaccessible reaches. The parameters were computed using formulas from several sources in the literature, as presented in Table 1.

Table 1: Derivation of Morphometric Attributes of the Study Area

Parameters	Formula	References
Area Aspect		
Basin Area	The area from which water drains to a common stream, and the boundary is determined by the opposite side. ridges.	Strahler (1964)
Basin Perimeter	The outer boundary of the drainage basin is measured in kilometers	Schumm (1956)
Basin Length	The straight line from the mouth of the basin to the farthest point on the basin perimeter.	Schumm (1956)
Form Factor	$F_r = A/L^2$, where Fr =form factor, A = Basin area, L = Basin length.	Boyce and Clark (1964), Horton (1945)
Elongation Ratio	$R_e = 2\,{}^{\sqrt{A}}/_{\pi}/_{L}$ where R_e = Elongated ratio, A= Basin area, L=Basin length, π =3.142	Schumm (1956)
Circulatory Ratio	$R_c = 4\pi A/P^2$ where A= Basin area, π =3.142, P = Perimeter of basin.	Miller (1953)
Stream Frequency	$F_s = Nu/A$, where Fs = Stream frequency, Nu = Number of streams, and A = basin area.	Horton (1945)

Drainage Density	$D_d = L/A$, where L = Total stream length, A = Basin Area.	Horton (1945)
Leminiscate Ratio	$K = L2/4A$ = Where L = Length of the basin and A = Basin area	Schumm (1956)
Constant Channel Maintenance	C= 1/ Dd Where Dd = Drainage Density	Horton (1945)
Drainage Texture	$R_t = N_u/P$, where Rt = Drainage texture, Nu = Number of streams, and P = Drainage perimeter.	Horton (1945), Smith (1950)
Drainage Patter	The pattern of the flow of the streams in the basin	Manoj and Anilkumar (2015)
Linear Aspect		
Total Stream Length	The total length of all the tributaries and the principal drainage	Schumm (1963)
Mean Stream Length	Mean Stream Length	Schumm (1963), Strahler (1964)
Main Stream Length	The Length of the principal drainage	Samson, *et al.* (2016)
Bifurcation Ratio	$R_b = N_u/N_u + 1$, where Rb = Bifurcation ratio; Nu = Number of streams of order U; and Nu + 1 = Number of streams in the next higher order.	Gregory and Walling, (1973), Schumm (1956)
Mean Bifurcation Ratio	Rb = average of bifurcation ratios of all orders	Strahler (1957)
Length of Overland Flow	$L_g = 1/Dd \times 2$, where Lg is the length of overland flow, and Dd is the drainage density.	Horton (1945)
Relief Aspect		
Total Basin Relief	R = H-h, where H = maximum height of the basin, h = minimum height of the basin mouth.	Hadley and Schumm (1961)
Relief Ratio	$R_r = R/L$, where Rr = Relief ratio; R = Relief; L = Length of basin.	Schumm (1963),
Ruggedness Number	$R_n = Bh \times Dd$, where Bh = Basin relief and Dd = Drainage density.	Schumm (1956)
Relative Relief	$R_{hp} = H \times 100/P$	Manoj and Anilkumar (2015).
Gradient Ratio (G_r)	[$G_r = H-h/L_b$]	Manoj and Anilkumar (2015).
Basin Slope	The degree of steepness of the basin	Manoj and Anilkumar (2015).

The choice of these morphometric parameters was based on findings from previous research showing a high correlation among sediment, runoff, discharge, and morphometric attributes of the drainage basin (Ajibade *et al.,* 2010; Jimoh & Iroye, 2010; Ifabiyi, 2017).

RESULTS AND DISCUSSIONS

Results

The result revealed that the study area comprises one hundred and one (101) sub-basins. These sub-basins are coded in different colours and numbered from one (1) at the upper course to one hundred and one (101) at the lower course (Fig. 2 and Table 2).

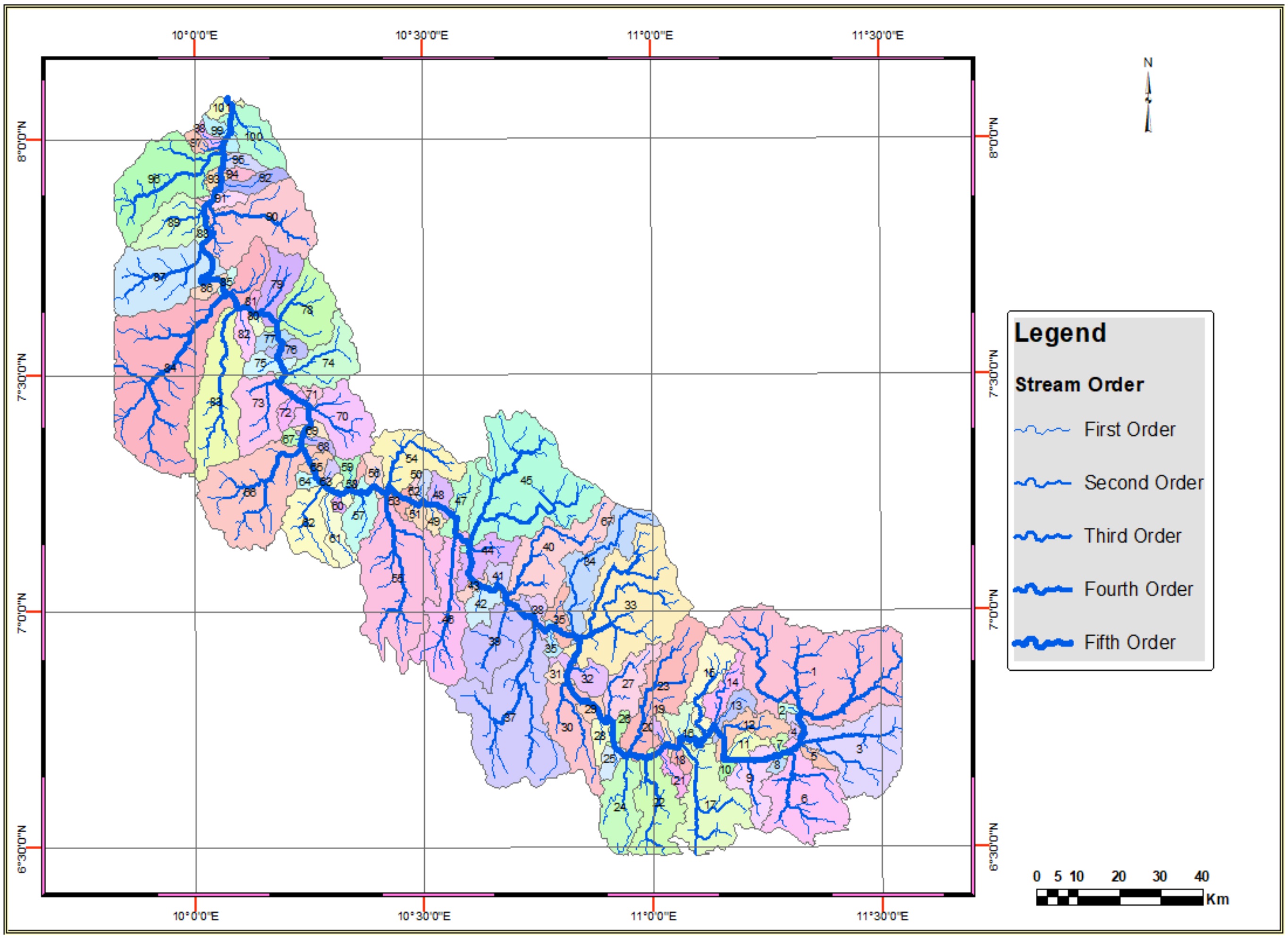

Figure 2: Sub-basin of the Study Area

Table 2. Morphometric Analysis of Sub-Basins of River Donga

Sub-Basins	Basin Area	Basin Perimeter	Basin Length	Form Factor	Elongated Ratio	Circularity Ratio	Stream Frequency	Drainage Density	Liminiscate Ratio	Constant of Channel maintenance	Drainage Texture	Total Stream Length	Mean Stream length	Bifurcation Ratio	Length of overland flow	Total Basin Relief	Relief Ratio	Ruggedness Number	Relative Relief	Gradient Ratio	Basin Slope
1	25.9	28.2	9.6	0.3	0.1	0.4	0.04	0.2	0.2	5	0.03	4.3	4.3	2	0.1	85	8.9	17	648.9	8.9	1.6
2	18.2	24.3	7.8	0.3	0.4	0.3	0.04	0.4	0.2	2.5	0.04	7.1	7.1	2	0.2	60	20.7	27	659.2	7.7	1.3
3	35.2	33.3	12.2	0.2	0.4	0.3	0.03	0.3	0.2	3.3	0.03	4	4	2	0.15	83	5.1	55	544	6.8	1.6
4	25.4	34.4	12.1	0.2	0.3	0.3	0.04	0.4	0.2	2.5	0.09	9.4	4.7	2	0.2	69	5.7	27	505.8	5.7	1.3
5	128.6	56.7	19.7	0.3	0.4	0.5	0.04	0.2	0.08	5	0.09	32.3	16.2	2	0.1	106	5.4	21	296.3	5.4	1.6
6	32.2	31.6	11.9	0.2	0.3	0.4	0.03	0.4	0.2	2.5	0.03	7.8	7.7	2	0.2	75	6.3	30	237.3	6.3	1.9
7	18.5	21.6	8.9	0.3	0.3	0.5	0.05	0.5	0.3	2	0.05	3.1	3.1	2	0.25	75	6.3	37	828.7	8.4	19.2
8	17.1	22.3	6.5	0.4	0.4	0.4	0.06	0.4	0.4	5	0.04	1.3	1.3	2	0.2	39	2.3	15.6	2184	6	1.4
9	55	44.1	17.6	0.2	0.3	0.4	0.02	0.3	0.2	3.3	0.02	15	15	2	0.15	110	6.3	33	279.4	6.3	1.6
10	34.6	33.7	12.4	0	0.3	0.4	0.03	0.4	0.2	2.5	0.03	3.4	3.4	2	0.2	69	5.6	27.6	204.7	5.6	1.9
11	347.5	100.2	29.7	0.4	0.4	0.4	0.07	0.3	0.04	3.3	0.2	90.4	30.1	2	0.15	111	3.7	33.3	212	3.7	1.2
12	15.6	18.3	6.1	0.4	0.6	0.6	0.06	0.4	0.2	2.5	0.05	0.7	0.7	2	0.2	54	8.9	21.6	295.1	8.9	3
13	147.1	57.6	19	0.4	0.4	0.6	0.06	0.1	0.06	10	0.2	40.6	20.3	2	0.05	98	5.2	9.8	261.1	5.2	1.8
14	320.7	84	28.1	0.4	0.4	0.6	0.07	0.2	0.04	5	0.3	71.9	24	3	0.1	119	4.2	23.8	272.6	4.2	2
15	354.3	106	31.2	0.4	0.4	0.4	0.07	0.3	0.04	3.3	0.2	89	29	2.9	0.15	260	0.7	78	344	2.9	2
16	15.5	20	7.4	0.3	0.3	0.5	0.06	0.5	0.2	2	0.05	1.3	1.3	2	0.25	113	15.3	56	1255	15.3	3.9
17	27.9	25.3	10.3	0.3	0.3	0.5	0.03	0.03	0.2	33.3	0.04	0.7	0.7	2	0.02	70	6.7	21	743	5.2	4
18	12.8	17	6.2	0.3	0.4	0.6	0.08	0.1	0.2	10	0.06	1.3	1.3	2	0.05	54	8.7	5.4	1035.3	8.7	1.6
19	116.4	57	19.1	0.3	0.4	0.5	0.04	0.2	0.1	5	0.09	27.9	14	2.6	0.1	104	5.4	20	1198.9	5.4	1.6
20	14	15.5	5.7	0.4	0.4	0.5	0.07	0.2	0.2	5	0.06	2.3	2.3	2	0.1	61	10.7	12.2	1477.4	10.7	1.7
21	194.5	71.2	19.1	0.5	0.5	0.5	0.05	0.2	0.5	5	0.2	48	16	2.8	0.1	481	6.8	96.2	846.9	25.2	16.6
22	29.4	27.2	10.2	0.3	0.3	0.5	0.03	0.1	0.2	10	0.04	3.8	3.8	2	0.5	77	7.5	7.7	750	7.5	1.7
23	869.4	182.2	59.2	0.2	0.3	0.3	0.08	0.3	0.03	3.3	0.4	230.4	76.8	3.1	0.15	646	10.9	2153	415	10.9	3.3
24	35.8	27.7	10.8	0.3	0.4	0.6	0.03	0.1	0.2	10	0.04	3.3	3.3	2	0.05	72	2.01	7.2	722	6.7	1.6
25	45.7	32.5	13	0.3	0.3	0.5	0.02	0.2	0.1	10	0.03	10.2	10.2	2	0.1	87	1.9	8.7	1607.7	6.7	1.7
26	50.1	35.9	13.8	0.3	0.3	0.5	0.02	0.1	0.1	10	0.03	5.97	5.97	2	0.05	82	5.9	8.2	832.2	5.9	1.83
27	171.3	76.1	20.5	0.4	0.4	0.4	0.05	0.2	0.1	5	0.1	40.6	20.3	2.8	0.1	668	8.8	133.6	1051.2	32.6	1.4
28	18.1	30	6.3	0.5	0.4	0.6	0.06	0.09	0.2	11.11	0.03	1.6	1.6	2	0.05	122	19.4	10.98	13250	19.4	4.6
29	35	29.3	10.9	0.3	0.3	0.5	0.03	0.2	0.2	5	0.03	4.8	4.8	2	0.1	81	7.4	6.2	754.3	7.4	2.1
30	21.7	23.7	10	0.2	0.3	0.5	0.05	0.04	0.2	25	0.04	0.9	0.9	2	0.2	248	24.8	9.9	1666.6	24.8	5.9
31	18	19.7	6.9	0.4	0.4	0.6	0.06	0.1	0.2	10	0.05	1.4	1.4	2	0.05	89	12.9	8.9	1213.2	12.9	2.6
32	21	27.2	11.3	0.2	0.3	0.4	0.05	0.2	0.3	5	0.04	4.1	4.1	2	0.1	785	69.5	154	3540	69.5	20.7
33	186.5	69.1	19.5	0.5	0.4	0.5	0.04	0.2	0.1	5	0.1	33.7	16.9	2.6	0.1	282	14.5	56.4	605.8	14.5	7.73
34	198.3	73.8	18.3	0.6	0.5	0.5	0.07	0.2	0.05	5	0.18	46.2	15.4	2.8	0.1	785	42.8	157	1261.5	42.9	18.4

35	29	27.3	9.2	0.3	0.4	0.5	0.04	0.1	0.2	10	0.04	2.6	2.6	2	0.05	773	84	77.3	3391	84	17.53
36	347.5	112.5	41.9	0.2	0.3	0.3	0.07	0.2	0.06	5	0.2	76.9	26.3	2.9	0.1	631	15.1	127.2	669.3	15	16.2
37	15.2	18.5	6.9	0.3	0.4	0.6	0.07	0.2	0.2	5	0.05	3.6	3.6	2	0.1	705	102.2	141	4686.5	102.2	18.31
38	20.1	20.4	6.9	0.4	0.4	0.6	0.05	0.1	0.2	10	0.05	1.2	1.2	2	0.05	250	36.2	25	1980.4	36.2	8.2
39	11.3	21.2	8.9	0.1	0.2	0.3	0.09	0.3	0.4	3.3	0.05	2.9	2.9	2	0.15	411	46.2	123.3	2758.3	46.2	11.5
40	30.1	31.5	10.9	0.3	0.3	0.4	0.03	0.2	0.2	5	0.3	6.3	6.3	2	0.1	755	69.3	151	2914	69.3	18.5
41	201.8	76.2	23.5	0.4	0.4	0.4	0.09	0.3	0.06	3.3	0.2	54.5	18.2	2.9	0.15	741	31.5	222.3	1200.8	31.5	16.8
42	37.3	31.5	11.3	0.3	0.3	0.5	0.03	0.2	0.02	5	0.03	5.3	5.3	2	0.1	768	67.9	153.6	2990.5	67.9	18.9
43	10.4	19.1	7.2	0.2	0.3	0.4	0.09	0.05	0.3	20	0.05	0.5	0.5	2	0.25	70	9.7	3.5	1387.4	9.7	3.13
44	20.6	25.2	8.9	0.3	0.3	0.6	0.05	0.3	0.2	3.3	0.04	5.3	5.3	2	0.15	128	14.4	38.4	1281.7	14.4	11.23
45	10.3	13.9	4.9	0.4	0.4	0.7	0.1	0.5	0.2	2	0.07	5.3	5.5	2	0.25	764	152.2	38.2	6568	152.2	18.6
46	20.8	24.7	8.2	0.3	0.4	0.4	0.02	0.02	0.2	50	0.04	0.5	0.5	2	0.01	389	47.4	74.8	6639.7	47.4	2.9
47	47.1	34.6	12.3	0.3	0.4	0.5	0.02	0.12	0.13	8.3	0.03	5.6	5.6	2	0.06	129	10.5	1075	942.2	10.5	6.96
48	24.4	22.4	7.4	0.4	0.4	0.6	0.04	0.13	0.2	7.7	0.04	3.2	3.2	2	0.07	169	22.8	21.9	1620.5	22.8	7.49
49	23.2	22.7	7.8	0.4	0.4	0.6	0.04	0.13	0.2	7.7	0.04	3.2	3.2	2	0.07	169	22.8	21.9	1620.5	22.8	7.5
50	88.9	61.4	20.5	0.2	0.3	0.3	0.01	0.15	0.12	6.7	0.02	13.3	13.3	2	0.08	176	22.6	74.2	1634.4	22.6	8.9
51	442	105.2	31.8	0.04	0.13	0.5	0.07	0.3	0.04	3.3	0.3	112.8	28.2	2.9	0.15	514	626.4	154.2	627.6	21.3	17.9
52	624.7	149.1	176.6	0.05	0.09	0.4	0.08	0.3	0.14	3.3	0.3	176.6	44.2	3	0.15	1016	5.6	304.8	820.9	5.7	9.21
53	93.8	49.5	20	0.2	0.3	0.5	0.05	0.2	0.11	5	0.1	20	10	2.7	0.1	761	38.1	152.2	1868.6	38.1	18.8
54	161.5	74	20.1	0.4	0.4	0.3	0.08	0.3	0.6	3.3	0.2	40.5	20.3	2.8	0.15	1054	14.2	316.2	250	52.4	20.12
55	86.5	65.1	18.3	0.3	0.3	0.3	0.02	0.3	0.1	3.3	0.03	23.4	11.7	3	0.15	1043	57	312.9	1844	57	20.3
56	102.4	62.6	19.6	0.3	0.3	0.3	0.05	0.1	0.1	10	0.08	14.6	7.3	2.6	0.05	305	15.6	30.5	822	15.6	10.8
57	33.8	29.8	8.6	0.5	0.4	0.5	0.08	0.4	0.1	2.5	0.1	3.5	1.8	2.5	0.2	166	18	49.8	1386.3	18	7.21
58	21.2	27.7	9.2	0.3	0.3	0.4	0.2	0.3	0.2	3.3	0.1	5.9	3	2.3	0.15	166	18	49.8	1386.3	18	7.21
59	270.6	116.4	35	0.2	0.3	0.3	0.09	0.3	0.1	3.3	0.2	76.6	25.5	2.9	0.15	1070	30.6	321	10979	30.6	10.04
60	287.4	118.1	35.6	0.2	0.3	0.3	0.06	0.3	0.06	3.3	0.1	76.3	25.4	2.9	0.15	888	24.9	266.4	944	24.9	17.3
61	853.8	169.7	28.8	1	0.6	0.4	0.08	0.3	0.02	3.3	0.4	234.4	58.6	3	0.15	642	22.3	192.6	1124.9	22.3	14
62	59.9	42	12.3	0.4	0.4	0.4	0.02	0.1	0.1	10	0.02	7.2	7.2	2	0.05	404	32.9	40.4	1483	32.9	14.11
63	30.6	34	10.5	0.3	0.3	0.3	0.07	0.2	0.2	5	0.06	6.1	3	3	0.1	619	81.2	123.8	2508.5	81.2	20.6
64	227.8	121.1	35	0.2	0.3	0.2	0.07	0.3	0.08	3.3	0.1	69.2	34.6	2.7	0.15	1283	43.9	384.9	1267.3	43.9	18.7
65	51.9	45.3	15.5	0.2	0.3	0.3	0.3	1	0.15	1	0.4	70.8	35.4	2.7	0.5	608	39	39.2	1885.2	39	16.52
66	22.6	29.9	9.1	0.3	0.3	0.3	0.4	0.2	0.2	5	0.03	5.5	5.5	2	0.1	566	62.2	113.2	1892.9	62.2	17.9
67	531.3	144.2	43.8	0.3	0.03	0.3	0.07	0.3	0.04	3.3	0.3	147	36.8	3	0.15	1059	24.1	317	848.1	24.1	20
68	574.8	133.7	39	0.4	0.4	0.4	0.08	0.3	0.02	3.3	0.3	158	39.5	2.95	0.15	424	14	127.2	425.6	14	20.12
69	22.2	23.2	5.8	0.7	0.5	0.5	0.04	0.1	0.13	10	0.04	1.5	1.5	2	0.05	603	104	60.3	3719.8	104	16.9
70	214.2	82.8	24	0.4	0.4	0.4	0.01	0.2	0.06	5	0.2	42.2	21.1	2	0.1	880	56.8	176	1342.9	56.8	19.67
71	70.6	50	15.5	0.3	0.3	0.4	0.04	0.2	0.1	5	0.06	12.2	6.1	2.5	0.1	1044	69.6	208.8	2604	69.6	20.2

72	13.8	20	4.5	0.6	0.5	0.4	0.07	0.2	0.2	5	0.05	3.4	3.4	2	0.1	392	87.1	78.4	8290	87.1	17
73	125.3	68.1	22.2	0.3	0.3	0.3	0.04	0.2	0.09	5	0.07	31.1	15.55	2.7	0.1	1281	57.7	256.2	2428	57.7	22.72
74	30.5	24.8	6	0.8	0.6	0.6	0.03	0.04	0.1	25	0.04	1.1	1.1	2	0.02	960	160	38.4	4943	160	23.31
75	72.2	54.3	18.4	0.2	0.3	0.3	0.07	0.3	0.12	3.3	0.09	22.8	11.4	2.7	0.15	646	35.1	193.8	3257	35.1	16.13
76	33.1	77.1	24.8	0.2	0.3	0.3	0.07	0.3	0.09	3.3	0.12	40.7	13.6	2.8	0.15	716	28	214.8	2385	28	14.17
77	48.9	47.4	15.1	0.2	0.3	0.3	0.02	0.2	0.2	5	0.02	11.4	11.4	2	0.1	519	34.4	103.8	3746	34.4	78.35
78	7.5	16.7	5.6	0.2	0.3	0.3	0.13	0.2	0.4	5	0.06	1.3	1.3	2	0.1	433	77.3	86.6	10083	77.3	16.89
79	13.9	20.4	8.2	0.2	0.3	0.4	0.07	0.3	0.3	3.3	0.05	3.8	3.8	2	0.15	744	89.6	223.2	7039	89.6	20.75
80	23.4	28.3	9.3	0.3	0.3	0.4	0.08	0.2	0.2	5	0.07	4.9	4.9	2	0.1	1023	110	204.6	5197	110	23.79
81	60.9	46.5	9.4	0.7	0.5	0.4	0.05	0.1	0.1	10	0.06	8.2	8.2	2.5	0.05	635	67.6	63.5	3303	67.6	19
82	21.8	31.9	12.1	0.1	0.2	0.3	0.05	0.2	0.3	5	0.03	4.8	4.8	2	0.1	776	64.1	155.2	4636	64.1	20.03
83	41.8	36	12.2	0.3	0.3	0.4	0.02	0.2	0.1	5	0.03	10.2	10.2	2	0.1	414	33.9	82.8	4552	33.9	17.21
84	16.3	22	6.9	0.3	0.4	0.4	0.06	0.2	0.2	5	0.05	3.6	2.6	2	0.1	417	25.6	83.4	7586	25.6	14.19
85	357.3	105.3	30.2	0.03	0.4	0.4	0.05	0.2	0.04	5	0.17	83.2	27.7	3	0.1	548	1.5	109.6	1709	1.5	15.89
86	286.5	10.1	36.8	0.2	0.3	0.3	0.05	0.3	0.06	3.3	0.12	80.2	26.7	3.9	0.15	1286	34.9	3858	17215	34.9	18.16
87	90.6	66	16.5	0.3	0.4	0.3	0.06	0.2	0.09	5	0.08	22.3	11.2	2.6	0.1	490	7.4	98	2563.6	7.4	16.84
88	37.8	32	12	0.3	0.3	0.5	0.03	0.2	0.2	5	0.03	7	7	2	0.1	1025	85.4	205	4343	8.4	21.2
89	24	29.3	11.2	0.2	0.3	0.4	0.04	0.2	0.2	5	0.03	5.9	5.9	2	0.1	389	34.7	77.8	5597	34.7	17.8
90	13.3	16.3	5.5	0.4	0.4	0.06	0.08	0.1	0.2	10	0.06	1.2	1.2	2	0.05	530	96.4	53	1088.9	96.4	14.67
91	20.3	25	9	0.3	0.3	0.4	0.05	0.2	0.2	5	0.04	4	4	2	0.1	608	67.6	121.6	5832	67.6	19
92	33.8	29.2	10.3	0.3	0.4	0.5	0.03	0.2	0.2	5	0.03	5.1	5.1	2	0.1	911	88.4	182.2	5202	88.4	22.1
93	13.6	16.8	5.8	0.4	0.4	0.6	0.07	0.01	0.04	10	0.06	0.2	0.2	2	0.05	510	87.9	5.1	10327	87.9	18.48
94	586.2	140.8	39.8	0.4	0.4	0.4	0.06	0.3	0.03	3.3	0.3	144.4	36	2.9	0.15	1320	9.4	396	1108.6	9.4	22.38
95	194.3	85.4	27.9	0.2	0.3	0.3	0.05	0.3	0.07	3.3	0.11	48.6	16.2	2.8	0.15	1245	44.6	373.5	1764.6	44.1	22.3
96	216.7	88.5	20.7	0.5	0.5	0.3	0.08	0.2	0.05	5	0.2	52.6	17.5	3	0.1	1098	53	219.6	1950	53	18.2
97	39.1	44.4	13.7	0.2	0.3	0.2	0.03	0.2	0.18	5	0.02	9.2	9.2	2	0.1	873	63.7	174.6	3475	63.7	18.14
98	314.5	102.8	25.7	0.5	0.4	0.4	0.07	0.3	0.04	3.3	0.2	85.4	28.5	2.9	0.15	542	21.1	1806.6	1740	21.1	17.71
99	118.2	73.2	19.7	0.3	0.4	0.3	0.04	0.2	0.08	5	0.07	24.5	12.3	2.6	0.1	595	30.2	119	2490	30.2	17.46
100	293.8	114.4	25.2	0.5	0.4	0.2	0.07	0.3	0.04	3.3	0.18	78.8	26.3	4.1	0.15	962	38.2	288.6	1589	38.2	20.5
101	169	68.6	24.1	0.3	0.3	0.5	0.04	0.3	0.07	3.3	0.1	45.9	23	2.8	0.15	26	1.1	78	423.2	1.1	21.21

Source: Fieldwork and Analysis 2020

The result of Principal Component Analysis revealed that the total variance explained by the morphometric parameters accounts for 77.154%, and six (6) components have eigenvalues greater than one (>1) (Fig. 3).

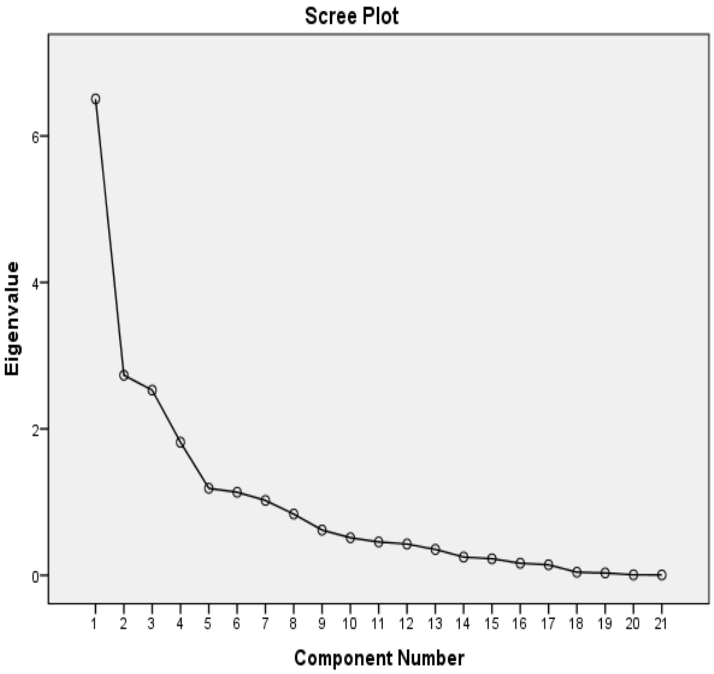

Figure 3: Eigenvalue of all the components analyzed.
Source: Authors' Analysis

Examination of this curve shows that it has an elbow shape. This distribution favors the six explanatory variables with eigenvalues >1. Individually, components with eigenvalues <1 may not be significant in the explanation; collectively, they can be significant for system characteristics and sustainability.

The rotated component matrix was used to identify the six explanatory variables with eigenvalue >1. To achieve this, a threshold value of 0.5, considered a high component loading, is used to identify components based on their size and significance in the principal component loadings (Table 3).

Table 3: Rotated Component Matrix^{a}

	Component					
	1	2	3	4	5	6
Basin Area	**.968**	.051	-.005	.010	.033	.005
Basin Perimeter	**.942**	.038	.158	-.039	-.154	-.084
Basin Length	**.747**	-.008	.011	-.368	.039	-.015
Form Factor	.108	-.113	-.009	**.912**	-.033	.047
Elongated Ratio	-.049	-.097	-.058	**.909**	.010	-.097
Circularity Ratio	-.195	-.169	-.593	.346	-.044	.306
Stream Frequency	.047	**.631**	-.003	.051	.084	.274
Drainage Density	.146	**.888**	.055	-.106	-.028	-.088
Leminiscate Ratio	-.672	.160	-.132	-.182	.042	.057
Constant of channel maintenance	-.185	-.582	-.307	.074	.112	.218
Drainage Texture	**.848**	.321	-.047	.086	-.012	.159
Total Stream Length	**.962**	.158	.006	-.009	.055	.017
Mean Stream Length	**.940**	.198	.051	-.031	.056	-.066
Bifurcation Ratio	**.744**	.150	.269	.015	.222	-.143
Length of overland flow	.041	**.813**	-.128	-.162	-.021	-.069
Total Basin Relief	.359	-.015	.750	-.029	.287	.229
Relief Ratio	.030	-.010	.191	-.107	-.012	**.840**
Ruggedness Number	.364	.036	.074	-.095	**.799**	-.174
Relative Relief	-.243	-.078	.226	.055	**.791**	.227
Gradient Ratio	-.289	-.054	**.560**	.278	.215	**.549**
Basin Slope	.033	-.001	**.806**	.015	.044	.217

Source: Extracted from Principal Component Analysis in SPSS Version 23

From Table 3, five (5) factors influenced hydro-geomorphic processes:

i. Basin area (32.922%);
ii. Basin Slope/Relief (16.972%);
iii. Stream Network (13.327%);
iv. Basin shape (8.235%); and
v. V.Terrain Ruggedness (5.699%).

Discussions

Factor 1: Index of basin area; this variable strongly influences hydro-geomorphic processes, especially discharge in the study area. Discharge significantly influences channel morphological characteristics, such as channel width, depth, width-to-depth ratio, pattern, slope, meander wavelength, and sedimentation, at the watershed scale (Knighton, 1984; Tukur & Mubi, 2002; Ijafiya & Iroye, 2017; Ijafiya *et al.,* 2023b). Observation of water stage data, which is used in this study as a surrogate for discharge, because of its high correlation with discharge from five gauging stations of River Donga (Gembu, Abong, Manya, Donga Town and Bantaje), revealed a downstream increase in the year 2020 (Fig. 4). This is because the number and size of the sub-basin are proportional to discharge of the study area. The result herein is consistent with the work of Jimoh and Iroye (2010), who found that basin area has a profound influence on the discharge of River Asa, Ilorin, Kwara State, Nigeria. Ifabiyi (2017) also found that basin area is one of the major factors responsible for hydro-geomorphic processes at the upper Kaduna Catchment, Nigeria.

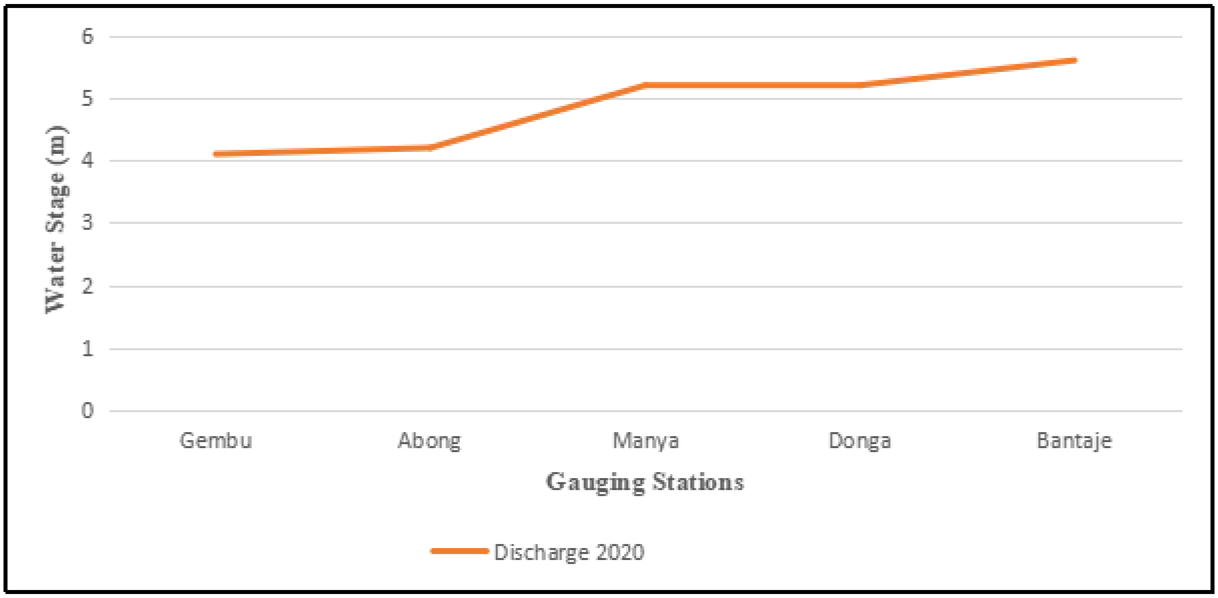

Figure 4: Spatial Variation of Water Stage at Gauge Stations of River Donga
Source: Upper Benue River basin Development Authority, Yola

The spatial dimension of channel width analysis in 2020 revealed a constant undulating pattern in the upper reaches, which gradually increased from the middle to the downstream, as shown in Fig. 5.

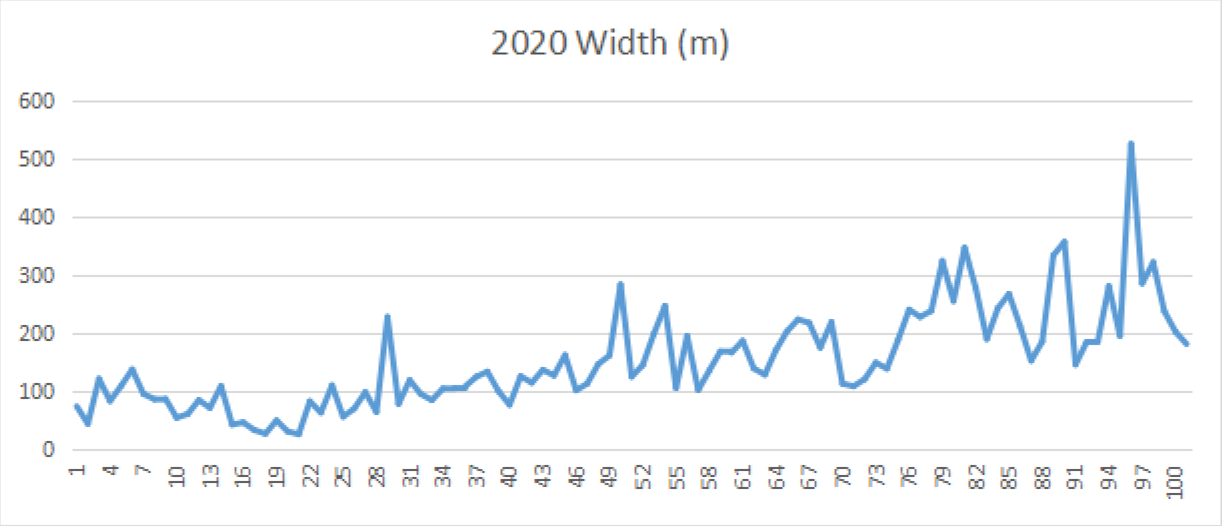

Figure 5: Spatial Variation of Channel Width of River Donga
Source: Satellite Image Analysis, 2020

The observed downstream increase in water stage and channel width in the study area is in consonance with previous findings, such as Knighton (1981), who links an increase in the width dimension with distance downstream of a river channel. Ojo (2010) reported such an undulating pattern in the upper reaches of the River Asa, which suddenly increased with distance downstream. Factor 2: index of stream network, especially Drainage density. This variable provides information on landscape dissection, runoff potentials and infiltration capacity of the studied sub-basins. The total number of streams in the entire study area is 833, comprising 1st-, 2nd-, 3rd-, 4th-, and 5th-order streams in accordance with Strahler’s classification; the stream intervals in the basins are 0.3km/km2, and the drainage pattern is dendritic (Fig. 6).

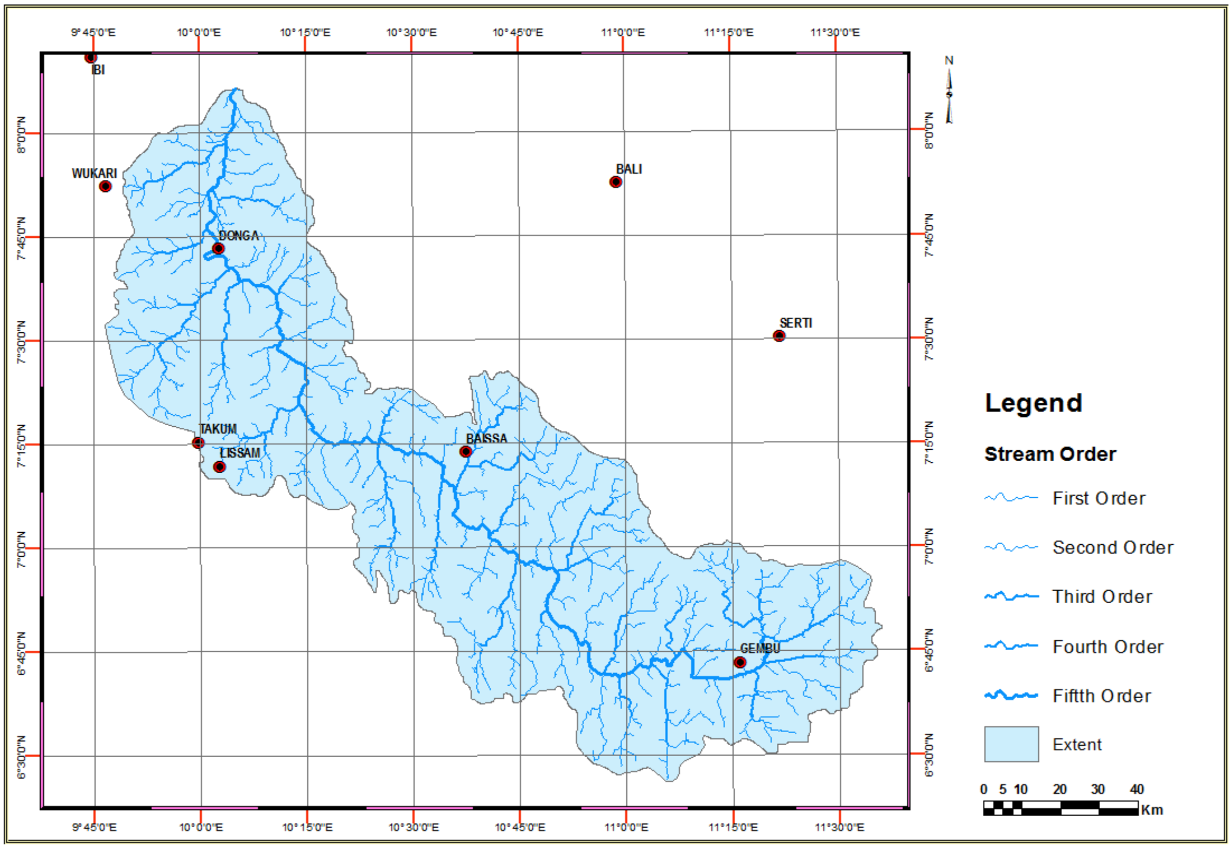

Figure 6: Stream Order of Donga Basin
Source Analyzed from DEM Data

The values of drainage density of the individual sub-basins ranged from 0.1 to 1.00, which are considered to be low; collectively, their effects on fluvial processes in the study area are enormous. The implication of such a value of drainage density at the sub-basin scale is that most of the runoff will infiltrate into the ground. This appeared to be contrary to what is observed in other highland areas of the world. Strahler (1964) noted that high drainage density is associated with an area of high relief and vice versa. The observation herein could be a result of the rolling nature of the Mambila Plateau, low slopes on the tableland and valley of the Plateau, the presence of vegetation, and soil characteristics. The low slope values in the upper course may explain why the study area's sub-basins have low drainage density (Fig. 7).

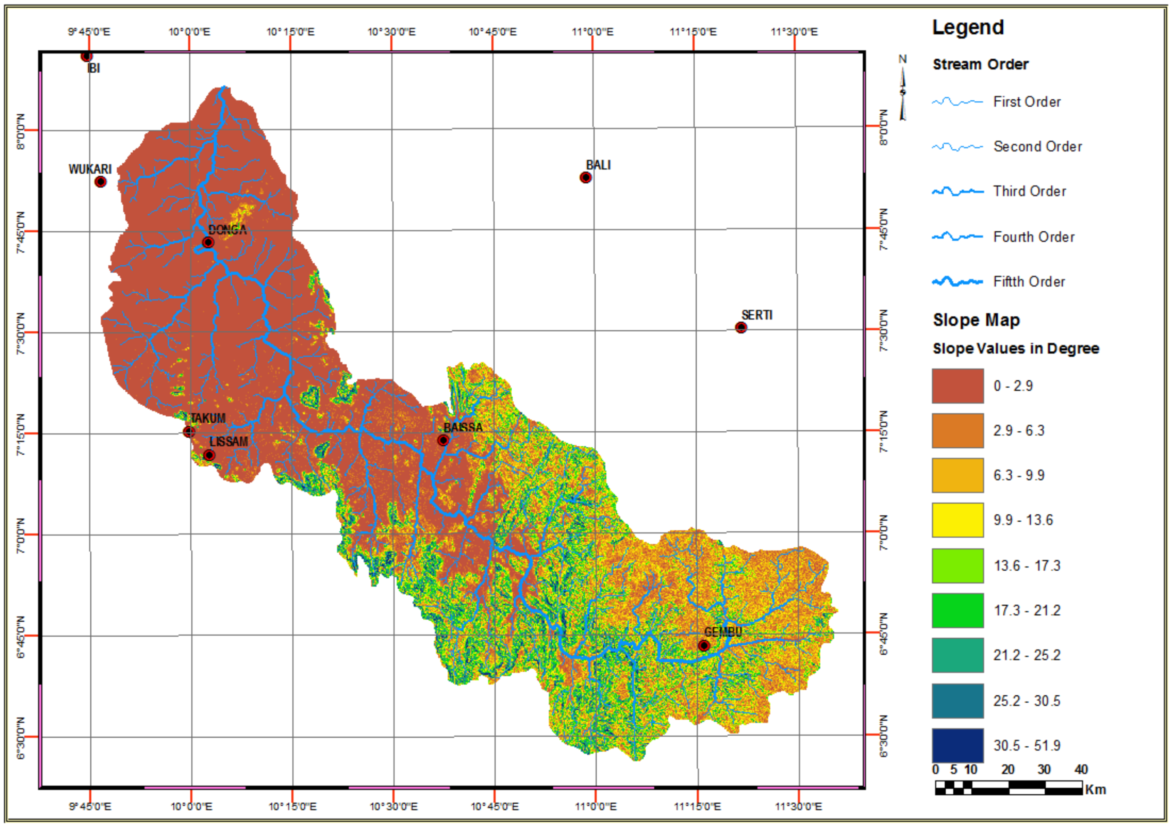

Figure 7: Slope of Donga Basin
Source: Analyzed from DEM Data

The implication of these low slope values is that the tableland of the Mambilla Plateau provided a platform equivalent to what is obtained in areas with low relief, allowing the development of sub-basins with low drainage density. The soils of the study area are made up of textural classes that fall within the categories of sandy, sandy loam, sandy clay loam and loamy sandy. This allows for high infiltration of rainwater in the study area. The finding herein is consonant with the observation made by Mubi and Adebayo (2005), who reported a high percentage of sand on the Mambilla Plateau, with Dorofi at 66%, Banga at 63.2%, and Mayo Ndaga at 59.1%. The infiltrated and percolated water from the sub-basins eventually reaches the main Donga River Channel as a result of interception by the underlying Basement Complex Formation via throughflow, interflow, and baseflow; this, according to Graziano et al. (2022), is known as riverbank seepage. The emergence of the infiltrated and percolated water in the river channel, coupled with high rainfall experienced (2000mm) on the Plateau, results in elevated water stage, an increase in discharge and flooding, causing impacts on riparian land uses/ land cover (Ijafiya, 2023a).

Factor 3: index of basin slope/Relief; this is significant at each stage of river development and has impacts on the processes of erosion, transportation and deposition. It is on this note that Mubi and Adebayo (2005) stated that "on steep slopes of the Mambilla Plateau, the velocity of overland flow is relatively high and infiltration rates lower than on comparatively gentler slopes". **Factor 4:** index of basin shape; most sub-basins are elongated, with ratios ranging from 0.1 to 0.6; some fall within the category of highly elongated rivers commonly found in regions of high relief and steep ground (Strahler, 1964). The implication of such a basin shape is that water and sediment have a very long lag time before they can get to the main channel. It also implies that runoff is not quickly removed from the sub-basins, which could make them susceptible to flooding and erosion of the adjacent river channel. Bhatt *et al. (2020) noted that an elongated ratio of 0.61 made the Pahuj catchment of central India prone to headward* erosion.

Factor 5: index of terrain ruggedness; the ruggedness number for the study area ranged from 17 to 3858; this falls within the category of level to extremely rugged terrain based on the terrain ruggedness index classification of Riley et al. (1991). The implication is that the terrain consists of steep slopes and high relief, making it prone to erosion. This can cause the easy generation of sediment from slopes through various processes of mass wasting, slope wash, landslides, and free fall under the influence of gravity. The materials collected in the river channel are transported and deposited in an area of low gradient. The highly rugged nature of the terrain could be the reason for the high rate of erosion, meander migration, numerous meanders, point bars, alternate bars and cutoffs found at the upper course (Plates 1 and 2).

Plate 1: Ruggedness Nature of the Mambilla Plateau with Point Bar and Meander at Gembu on 19/3/2020
Source: Field Work, 2020

Plate 2: Ruggedness Nature of the Mambilla Plateau with Alternate Bars at Ngwayi near Titong on 19/3/2020
Source: Field Work, 2020

The findings of this research are in agreement with the observations of Kabite and Gessesse (2018) that the highly rugged nature of the Dhidhessa River Basin in Ethiopia is responsible for high soil erosion in the study area.

CONCLUSION

In order to understand the effects of sub-basins on hydro-geomorphic processes of the Donga River Basin, Taraba State, Nigeria, twenty-one (21) morphometric parameters were generated from DEM and subjected to correlation and principal component analysis. The result revealed that only five parameters with eigenvalues greater than 1 (>1) were retained to account for 77.154% of the total variance in morphometric parameters. They are: basin area index, stream network, basin slope/relief, basin shape, and terrain ruggedness. These factors cause spatial variation in discharge, erosion, flooding, transportation, and channel morphology. The need for basin planning through reforestation and restoration of riparian buffer zones is highly recommended.

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