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Quantitative Analysis of the Relief Aspects of Do River Basin, Southeastern Nigeria

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Abstract: Morphometric analysis of a drainage basin expresses fully the state of dynamic balance that has been attained due to dealings between matter and energy.

This study was carried out to analyze the relief parameters of the Do River basin. Data were obtained from the digitalized map of the basin and calculation using relevant formula. The Principle Component Analysis (PCA) was employed to determine the contributions of the parameters to the morphometry of the basin.

Results showed that the basin has a relief of 340m, an average basin slope of 0 - > 40% and a ruggedness number of 0.27. Further results showed that the relief disposition, terrain configuration and variations in the slope of the basin, all have major contributions to the drainage development and erosion properties of the basin. Discussions on the findings of the relief parameters analyzed and their contributions to the basin were also undertaken.

Keywords: Do River, quantitative, morphometric, relief, GIS, principal component.

I. INTRODUCTION

With the increase in population and industrialization, the interest for water has gone to an expansive degree that most times, sustainability is undermined.

This can be easily seen as water resources around the globe which drainage basins are key examples of, are being mismanaged. In order to achieve sustainability, drainage basin management is necessary as it plays an important part, since the study of the basin offers important information on the geology and hydrology, as well in its management[1],[2].

A drainage basin as a key strategic geomorphic and hydrological unit, shows the result of the complex interplay of the earth's surface topography, climate, and hydrological processes. This can be a micro basin (few hectares) to macro basin (millions of hectares) with its network that depicts the entire three-dimensional geometry and evolutionary processes[3].

The morphometric analysis of any drainage basin requires measurement of linear features, areal aspects, gradient of channel network and contributing ground slopes of the drainage basin [4],[5].

It is an indicator of hydrogeologic processes and landform structure which also helps to demarcate the drainage system changes that happened due to anthropogenic activities or natural disturbances. Morphometric analysis is one of the most important tool and technique to determine and evaluate the drainage basin responses to climate change, drainage characteristics, flash flood hazard and hydrologic processes [6],[7],[8],[9].

It also helps identify factors that are critical in mitigating a drainage basin's hydrological issue, environmental change, drainage characteristics, flood risk and unsustainable water consumption [10].

Various researchers have carried out studies on drainage basin morphometry in many parts of Nigeria and these have provided insights to drainage morphometric systems of some selected basins in Nigeria [11].

However, employing geospatial techniques in morphometric analyses have replaced traditional measurement methods such as field observation and topographic maps [12].

The integration of remote sensing with the Geographic Information System (GIS) techniques have proven to be the most effective, convenient and accurate way to perform these analyses as it allows for discovering the geomorphology characteristics of many basins that are either unmapped or inaccessible [13].

This study, therefore aimed to analyze the relief morphometric aspects of the Do River basin utilizing GIS techniques to show the relationship existing between drainage development, surface morphometry, subsurface geology, permability and erosion properties of the basin which is very vital in the basin management.

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II. MATERIALS AND METHODS

A. Study Area

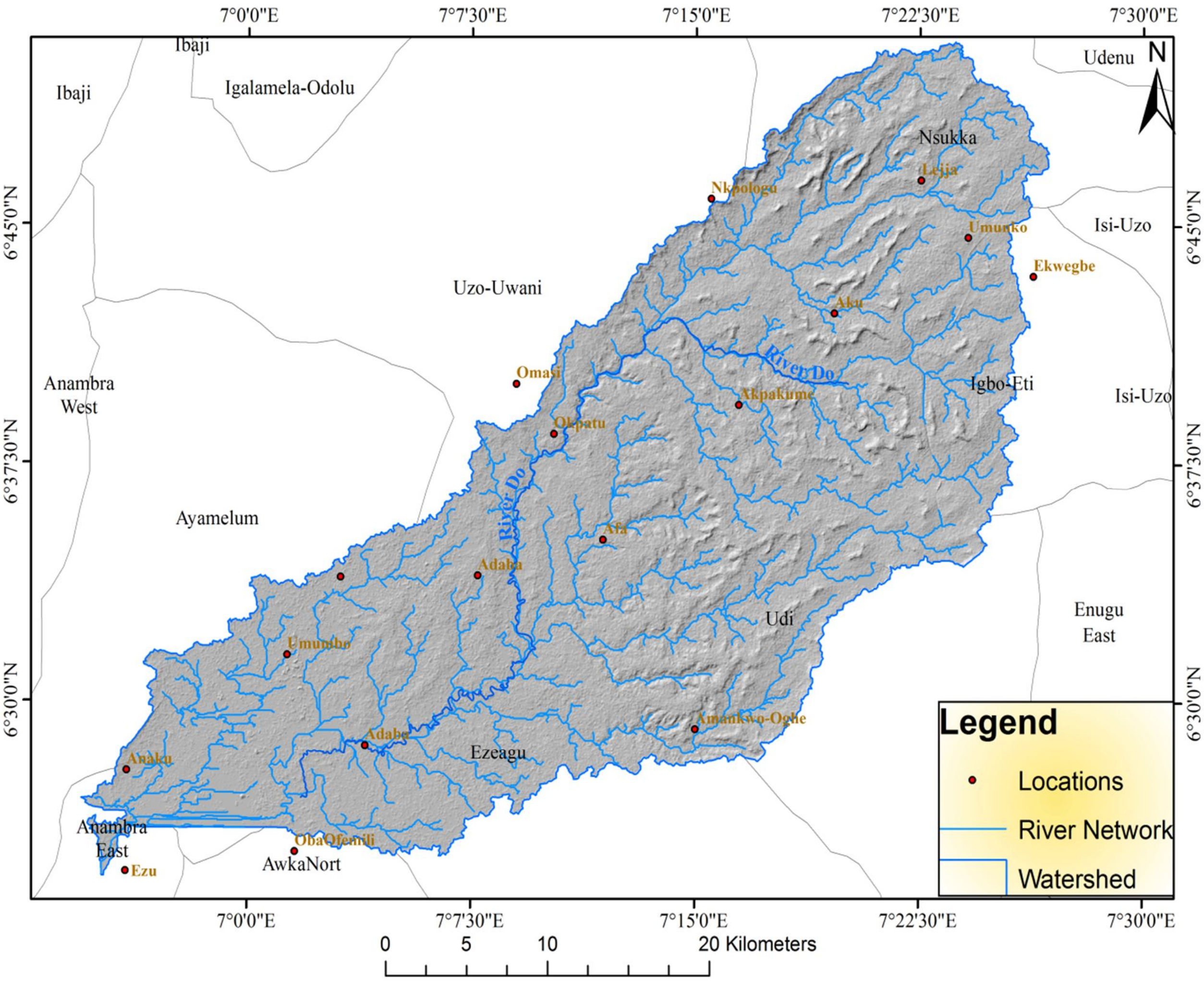

Fig 1: Drainage Map of Do River basin

The Do River basin, a sub-basin of the Mamu River basin is located between Latitudes 6° 24'N and 6° 48'N and Longitudes 6° 48'E and 7° 22'E (Fig 1). It has an area of 1285.71 sq.km which is about 33% percent of land area covered by the Mamu river Basin.

The climate of the basin is tropical wet and dry (Koppen's Aw Climate) with a hot-wet and hot-dry seasons. The mean annual temperature of the area is about 26.1^{0}C, while annual rainfall ranges from 1800mm to 2000mm. The dominant geological composition of the basin is of sedimentary parenthood which mainly consists of Mamu formation, Ajalli sandstone and Nsukka formation that usually containing a sequence of grey shales which are occasionally clay iron, stones and sandstone bed [14].

The soil is mainly of ferruginous and hydromorphic types. The area is drained mainly by Do and Adada Rivers with dendritic drainage patterns. The Do River drains extensive areas of Uzo-Uwani, Nsukka, Isi-Uzo, Ezeagu and Ayamelum Local Government Areas.

The vegetation within the basin is dominated by the derived savanna, except along the water courses where fringing forests of high forest features are common. Typical grass vegetation and fresh water swamp forests are dominant in the upper part of the basin while the lower part of the basin falls within the high forest zone that comprises of tall trees with thick undergrowth and numerous climbers. The typical trees found within the area include palm trees, raffia palm and iroko trees.

The settlement within the basin is rural with a predominant dispersed character even though the basin has a relatively high population density considering the population it hosts. The estimated population of the basin as at 21st March 2022 was 2,114,600 persons[15]. The area is predominantly agrarian with some engaged in hunting and fishing.

B. Data Collection

Data for this study were obtained from 1:50,000 topographic maps (covering Udi SE and SW). The maps were scanned, geo-referenced, before the region of interest was extracted. The drainage basin was mapped out after which it was digitalized and the watershed lines inserted to ascertain the actual extent of the basin using ArcGis 10.2 and QGIS 2.12.2 softwares. Also, Digital Elevation Model (DEM) with a 30 meter resolution was used as well as Landsat imagery covering the study area. The extracted basin data achieved from the available landset imagery of the study area was further subjected to the relevant morphometric analysis.

Data were also obtained from published and unpublished sources as relevant formula and equations were equally employed to calculate other parameters which were not measured with GIS.

C. Statistical Analysis

The Principal Component Analysis (PCA) was employed in this study. PCA is a powerful multivariate technique often employed to expose the underlying dependent structure of variables through clustering of the variables, thus ensuring easy explanation of the phenomena. The new set of components usually achieved through rotation produce a set of principal components that are orthogonal (uncorrelated) . The first principal component is the linear combination of the original morphometric variables that contribute most to the total variance and followed by the second not correlated with the first and so on. The PCA is calculated using the formular:

$$Zij = ai1x1j + ai_2 x\, 2_j + \ ...\ aim\, x\, mj\ ... \qquad (1)$$

Where Z represents the co-efficient of the component, a is the weight of the component, x is the measured value of the variable, i, corresponds to the component number, j represents the ample number and m represents the total number of variables[16],[17]. As a universal rule only components with an eigenvalue of 1.00 and more are extracted as well as component loadings of $-/+0.70$ or more known as the Component Defining Variables (CDV) are commonly utilized for further analyses.

III. RESULTS AND DISCUSSION

A. Results

Data obtained from GIS software, as well as, other methods were employed to generate the relief morphometric properties and their values which are coded, labeled and described (Table 1).

Table 1: Description. Labelling and Coding of Parameters

Variable Code	Variable Name	Derivation Procedure	Symbol	Value
X_1	Relief Ratio	$R_r = \frac{H}{L_b}$;	R_r	4.37
X_2	Basin Relief	GIS Software	H	340
X_3	Relative Relief Ratio	$R_{hp} = H*\frac{100}{p}$	Rhp	136.70
X_4	Dissection Index	GIS Software	D_i	0.80
X_5	Average Slope	GIS Software	B_s	0 - > 40%
X_6	Ruggedness Number	$R_n = Dd * \frac{H}{1000}$	R_n	0.27
X_7	Melton's Ruggedness Number	$MR_n = H/A^{0.5}$	MR_n	9.48
X_8	Gradient Ratio	$R_g = H/L_b$	R_g	4.37
X_9	Watershed Slope	$S_w = H/ L_b$	S_w	4.37

Where;
L_b (basin length) = 77.80km
P (basin perimeter) = 248.72km
A (area) = 1285.71 sq.km
D_d (drainage density) = 0.81km^{-1}

The values obtained from the morphometric analysis were further subjected to statistical analysis. In the correlation analysis of the relief parameters the result shows that a very low association between some variables mostly exists (Table 2) e.g. X1 (R_r) and X_4 (D_{is}) (0.178), X_2 (H) and X_8 (R_g) (0.105), and X_2 (H) and X_9 (S_w) (0.039), X_3 (Rhp) and X_8 (0.066) then X_8 (R_g) and X_9(S_w) (0.058) as well as very weak and insignificant negative correlation and strong correlation. Strong correlation between variables were observed as well. E.g X_1 (R_r) and X_7 (MR_n) (0.876), X_3 (Rhp) and X_7 (MR_n) (0.746), and X_5 (B_s) and X_6 (R_n) (0.713). The correlation result were subjected to PCA.

Table 2: Correlation of Relief Aspects

Var	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1.000	.652	.662	.178	.679	.623	.876	.395	.288
X_2	.652	1.000	.789	.017	.230	.256	.632	.105	.039
X_3	.662	.789	1.000	.101	.312	.252	.746	.066	.224
X_4	.178	.017	.101	1.000	.127	.528	.232	-.203	.323
X_5	.679	.230	.312	.127	1.000	.713	.563	.450	.471
X_6	.623	.256	.252	.528	.713	1.000	.479	.133	.386
X_7	.876	.632	.746	.232	.563	.479	1.000	.344	.479
X_8	.395	.105	.066	-.203	.450	.133	.344	1.000	.058
X_9	.288	.039	.224	.323	.471	.386	.479	.058	1.000

From the total explained variance shown in Table 3, it can be seen that only three components together account for the 79.58% of the contributions of the relief paramteres influencing hydrological processes in the basin.

Table 3: Rotated Component Matrix^a of the Relief Aspects of Do River Basin

Variable Label	Variable Code	I	II	III
R_r	X_1	.738	.407	.422
H	X_2	.930	-.030	.011
R_{hp}	X_3	.929	.107	-.013
D_i	X_4	.033	.766	-.416
B_s	X_5	.245	.608	.636
R_n	X_6	.231	.820	.197
MR_n	X_7	.770	.420	.306
R_g	X_8	.077	-.023	.894
S_w	X_9	.087	.698	.113
Eigen Values		2.99	2.47	1.70
% Of Variance		33.24	27.44	18.89
Cumulative %		33.24	60.69	79.58

From Table 3, PC I has high and significant positive loadings on X_1 (R_r) 0.738, X_2 (H) 0.930, X_3 (Rhp) 0.929 and X_7 (MR_n) 0.770. The component has an eigenvalue of 2.99 and explains 33.24% of the variation, which is indicative of relief disposition of the basin. However, the value of 340m is reflective of the basin's moderate relief. This component describes the disposition of the basin relief. PC II contributes 27.44% of the variation with an eigenvalue of 2.47 and has high positive loadings on two variables, X_4 (D_i) 0.766 and X_6 (R_n) 0.820. This component therefore, describes the landform development. The ruggedness number of the basin which is 0.27 indicates that the terrain is very much regular, not rugged and absence of steep slopes.

Finally, PC III achieves an eigenvalue of 1.70 and contributes 18.89% of the variation. It loads highly and significantly on X_8 (R_g) 0.894. This shows describes the <u>variations in slope of the basin</u>. The moderate slope value and gradient ratio show that the basin has a gentle slope.

B. Discussion

1) *Disposition of the Basin Relief*: The basin relief (H) was found to be 340m which implies that the Do basin has a moderate to high relief and is supported by the relief ratio (R_r) of 4.37 which means that basin is an area of moderately high relief with less steep slope underlain by less resistant rocks (Rai *et al*., 2019). This further indicates that the basin is characterized by moderate gravity of water, high infiltration, low runoff conditions and discharge capabilities of the basin which is responsible for the good ground water potentials in the basin. This is supported by the low infiltration value of 0.28 which conforms to the suggestion that the lower the infiltration value, the higher the level of infiltration within the basin and consequently the lower the runoff which gives rise to the development of higher drainage density [18].
2) *Terrain Configuration*: The value of the ruggedness number (R_n) of the Do River Basin was calculated to be 0.27 which indicates the basin's terrain is very much regular, not rugged and has less steep slopes characterized with low drainage density. From the ruggedness number map shown in Fig. 2, it was revealed that the value of the R_n varies in the various sub-watersheds of the basin with areas such as Igbo-Etiti and Nsukka as higher than every other part of the basin (0.45 – 0.60), while the Anaku, Oba-Ofemili, Umubo, Ezeagu areas the lowest point of the basin (0 – 0.05). Furthermore, that the rate of erosion susceptibility which varies in these watersheds, is higher in the upper course of the basin than any other part. This is further supported by the dissection index (D_i) of the basin, calculated to be 0.80. The study of the dissection index reveals that the rate of dissection is high in Nsukka and Igbo-Etiti area (0.68-1.00) of the basin which happens to be the area with the highest elevation as can be seen in the elevation map of the drainage basin (Fig. 3). The dissection index is medium (0.34-0.49) towards Nkpologu and Akpakume area of the basin and low (0-0.14) towards the Anaku, Umumba area of the basin which happens to be the lowest point of the basin as can still be seen on the elevation map of the basin. The dissection index map of the basin is further depicted in Fig. 4.

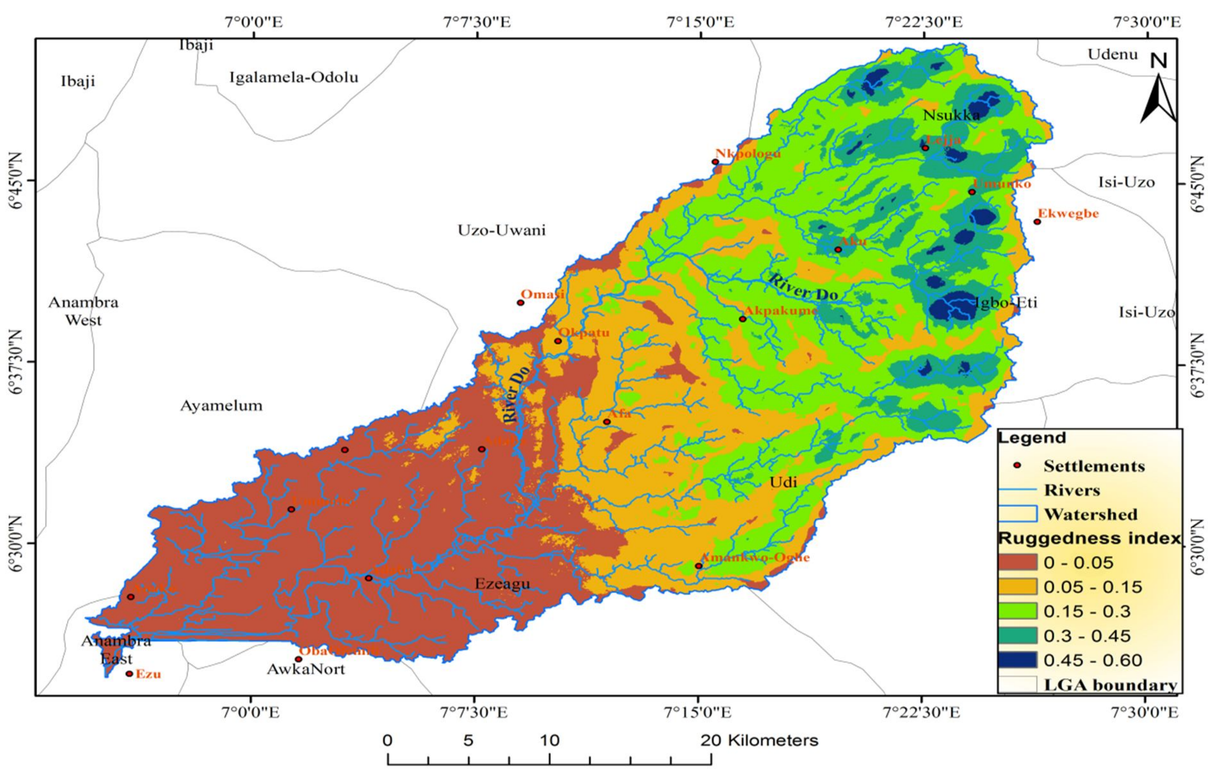

Fig. 2: Ruggedness Index Map of Do River Basin

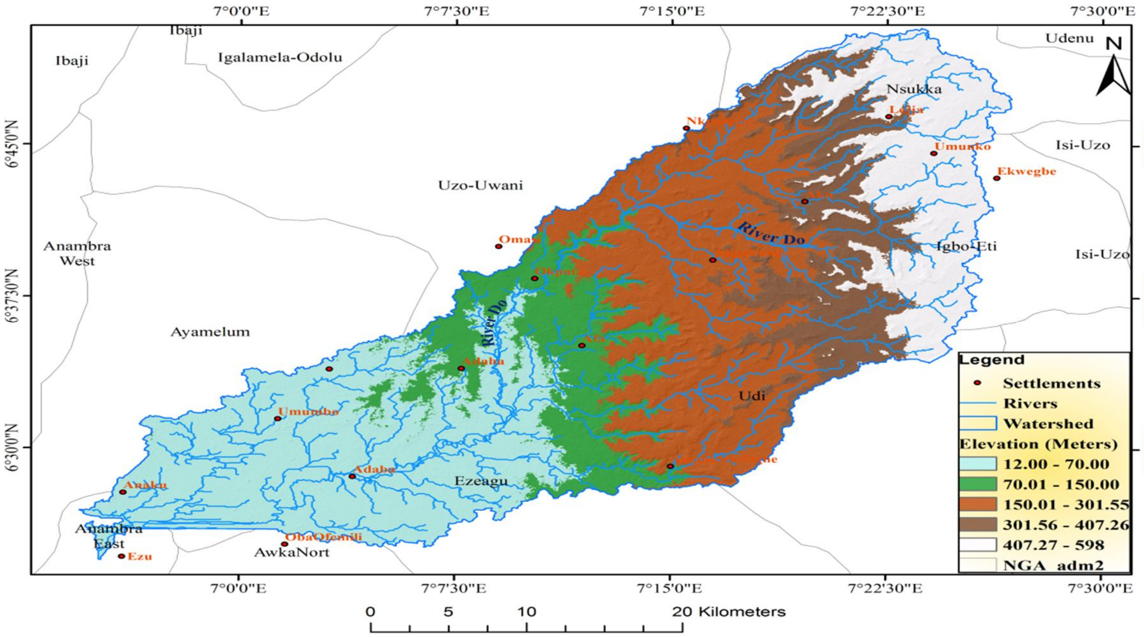

Fig.3: Elevation Map of Do River basin

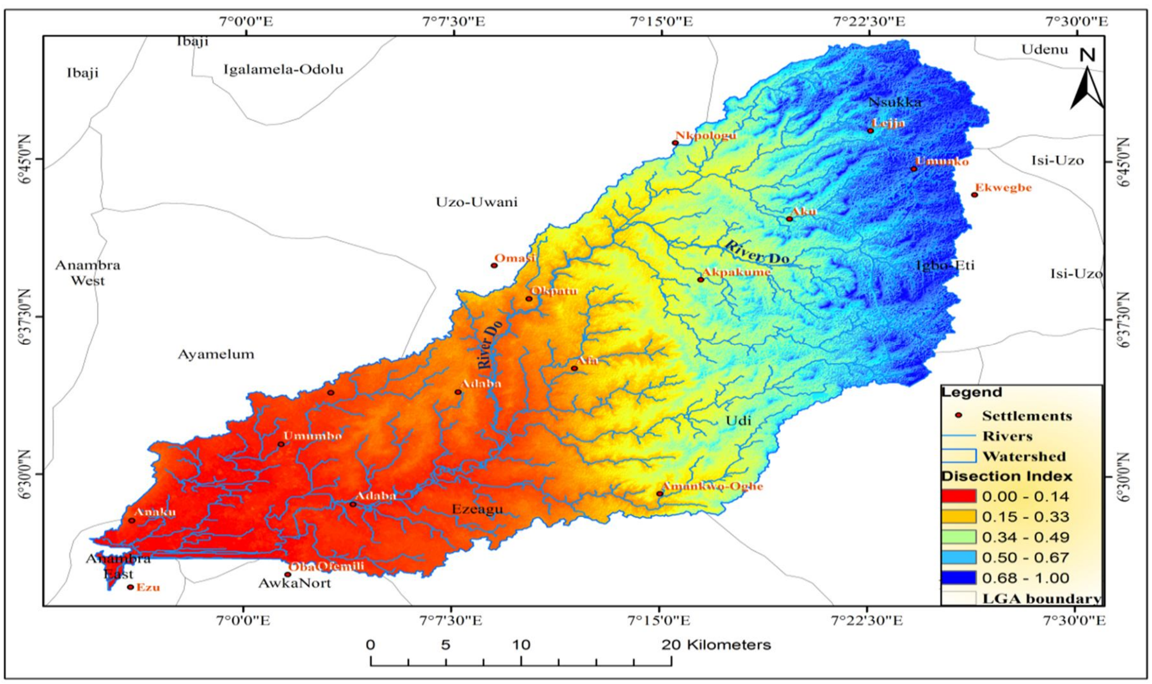

Fig. 4: Dissection Index Map of Do River Basin

3) *Variations in Slope of the Basin*: Slope of the area was calculated in percent gradient using ArcGIS 3D analysis tool. The drainage basin map of Do River shows that areas with higher slope and thus steeper terrain in the basin to be around Nsukka and Igbo-Etiti areas (>40%) where the basin originates and areas of lower slope (0-10%) which is also indicative of flatness of the terrain to be around Anaku, Oba-Ofemili and Umumba areas of the basin. This can be seen in the average slope map of the basin shown in Fig. 5. Areas of higher degree of slope are characterized with rapid runoff and increased erosion rate with less ground water recharge potential which conforms with the assertion made in *(2)*.

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Furthermore, the gradient ratio (R_g) which is a vital indicator of channel slope also allows the evaluation of the runoff volume. The R_g value of the Do River basin was found 4.37 which shows a gentle relief and main stream flow through a moderate terrain. It can be interpreted that for every 4.37 units of horizontal distance, there is 1unit vertical change either up or down. This is further supported by the watershed slope (S_w) value of the Do River basin (4.37) which affirms the indication of the value of the gradient ratio as it reflects a gentle rate of change in elevation with respect to the length of the principal flow channel.

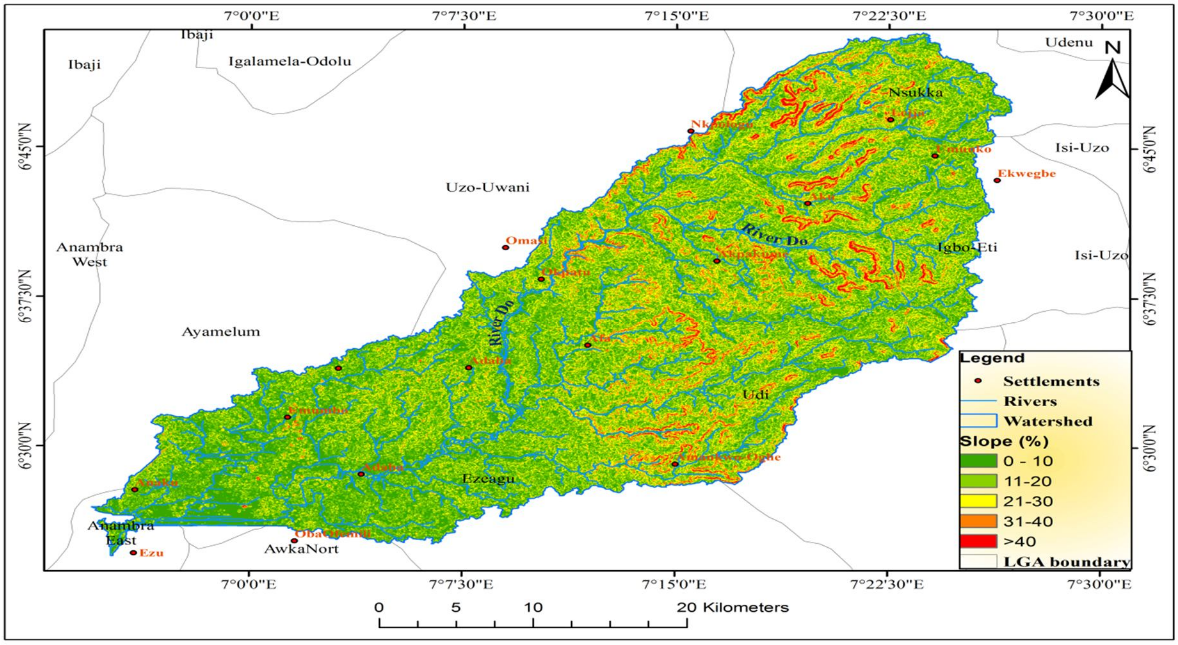

Fig. 5: Average Slope Map of Do River Basin

IV. CONCLUSION

Based on this finding, it is very necessary that any plan for sustainable water resources management and land use within the Do River basin, should incorporate findings from this study. The study shows that three-quarter of the land area of the basin is characterized by a gentle slope which is indicative of low runoff and higher underground water recharge potential in the basin except at the upper course around Nsukka and Igbo-Etiti area with steep slope as high as > 40°, experiences high runoff and some level of erosional activities and low ground water recharge disposition. This therefore calls for a proper regional planning to ensure that the potentials of the basin are sustainably exploited ensuring that the susceptibility of some parts of the basin to erosion is not increased while measures to reduce already existing impacts of sediment yield and transportation on a relative low relief adopted.

Furthermore, the results of the statistical analysis show contributions of the disposition of the basin relief, terrain configuration and variations in the slope of the basin to the relief aspect of the basin's morphometry. The findings of the analysis of the relief aspects of Do River basin should also trigger the revitalization of the dilapidated Omor – Adani irrigation project for the irrigation of rice and cassava farms and as well other water supply facilities should the high water storage of the basin be considered. This will help ameliorate the bad living condition of inhabitants in the basin as they are afflicted with numerous water borne diseases.

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