GIS and Remote Sensing Based Assessment of Hydro-Geomorphological Parameters of Lower Niger Basin in Nigeria

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ABSTRACT
Conservation of natural resources is of prime importance for environmental protection and sustainable development therefore it requires the use of state-of-the-art technologies for effective management. Good understanding of hydro-morphological characters of a river basin, is needed for its effective management. Remote sensing and GIS have emerged as most powerful tools for development and management of regional hydrological models for solving various hydrological problems. Therefore, in this study, hydro-morphological assessment of Lower Niger Basin has been carried out to understand its hydrological, geological and topographical attributes by analyzing ASTER DEM in geographic information system environment. ASTER data was used for preparation of digital elevation model and GIS was used for evaluation of linear, areal and relief aspect of morphometric parameters. Basic terrain, hydrological models and quantitative attributes of the basin such as 3-D Landscape, 2.5-D surface, sub-catchments, flow direction, channel networks, drainage density, stream orders, stream frequency etc has been processed using the elevation raster in GIS environment. Ground truthing and accuracy assessment has been carried out to ensure the reliability of the result. Based on Strahler's method of stream ordering, the river basin is designated as 4th order basin, with 1st order streams mostly dominating. The overall stream network revealed a hierarchy of 1st, 2nd, 3rd order streams with river Niger positioned as 4th order streams in the hierarchy. This study reveals a total number of 188 streams draining an area of 70959.175square kilometers of land. Further investigation revealed that there are three (3) fourth order streams, thirteen (13) third order streams, twenty-six (26) second order streams, and one hundred and thirty-six (136) first order streams. Further morphometric assessments revealed that the basin has a drainage density of 0.0665km^{-1}, stream frequency of 2.452 x 10^{-3}, circulatory ratio of 0.310, elongation ratio of 0.40, Form factor of 0.128 and basin length of 745.976km. These geometric attributes attest that the basin is drainage course textured, elongated in shape and of low discharge potential. These digital derivatives are invaluable for proper management of the river basin and also attest that Remote Sensing and GIS can be effectively utilized as a viable tool to study river basins and their associated morphometry.

KEY WORDS; ***ASTER data, Morphometric Analysis, River basin, GIS, Remote Sensing***

1.0 INTRODUCTION

Conservation of natural resources is of prime importance for environmental protection and sustainable development. Notwithstanding that Lower Niger Basin is one of the most important catchments in Nigeria, its hydrology is not well known. Morphometry analysis of a river basin provides useful parameters for assessment of surface and underground ground water potential, surface and ground water resource management, assessment of erosion and flood potential and provides for good understanding of geographic characteristics of the drainage system (Subhash 2011). Knowledge of these parameters, enable effective watershed management, conservation of natural resources and for environmental protection and sustainability. The use of conventional technique for such analysis is cumbersome, time consuming and cost ineffective therefore the need to adopt the most promising approach that provides quality result. Remote sensing and GIS have emerged as most powerful tools for development of regional hydrological models for solving various hydrological problems (Sayeed et al 2017). Using remote sensing and GIS techniques, more precise data generation for morphometric analysis can be done. Morphometric analysis of a drainage basin is a quantitative description of a basin and an important aspect to know the character of the basin (Strahler 1964). Cleark (1996) reported that Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. Morphometric parameters define the topographical, geological and hydrological condition of a basin (Angillieri 2012; Kabite and Gessesse 2018; Madavi and Anshumali 2019; Ahuchaogu et al 2021). Morphometric analysis of watershed covers the drainage networks and parameters such as drainage area, gradient, relief and is invaluable for prediction of floods, soil erosion and sediment yields (Sangeetha et al 2019). The drainage basin is the fundamental unit in fluvial geomorphology within which the relationships between landforms and the processes that modify them have been studied. The study of the geometry of the basin and the way in which it changes in response to processes has become a major part of modern geomorphology (Sumantra 2016). Hydrology deals with surface and ground water flow whereas geomorphology is the science of landforms. Remote Sensing is a very effective tool in the study of River Basins and their morphology as well as their management because of its ability to provide timely and precise data of extensive area that cannot be accessed through conventional ground method. DEM is a raster or cellular method of terrain analysis in which each cell carries a value which represent the elevation it occupies in geographic space. This is a raster representation, in which each grid cell records the elevation of the Earth's surface. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data has given a fast, and inexpensive way for analyzing hydrological systems (Smith and Sandwell, 2003; Grohmann, 2004). It provides fast and inexpensive data in the sense that the data is readily available in digital topographical database online and can be easily accessed. In this present study Linear. areal and relief morphometry has been assessed as the fundamental parameters to understand the hydrological, geological and topographical characteristics of the basin for effective management.

1.1 STUDY AREA

The basin under investigation measures 70959.175 square kilometers and geographically located between latitudes 5°.00`N and 8°.45`N, then longitudes 5°.00`E and 7°.45`E. It cuts across four major sub-catchments which which include kogi, Edo, Amambra and Delta catchments. Annual rainfall falls between 1000mm-1500mm with Mean annual temperature of about 27.7oc and a relative humidity of 30% in dry season and 70% in wet season. Average daily wind speed is 89.9km/hr. wind speed is usually at its peak in March and April. The basin is drained by two major rivers (River Niger and river Benue) which joined at Northern part of the basin before flowing towards south dividing the basin into nearly two equal wings (Ahuchaogu et al 2021). In the southern part the river disaggregates into networks of rivulets that terminates in Atlantic Ocean in Delta state

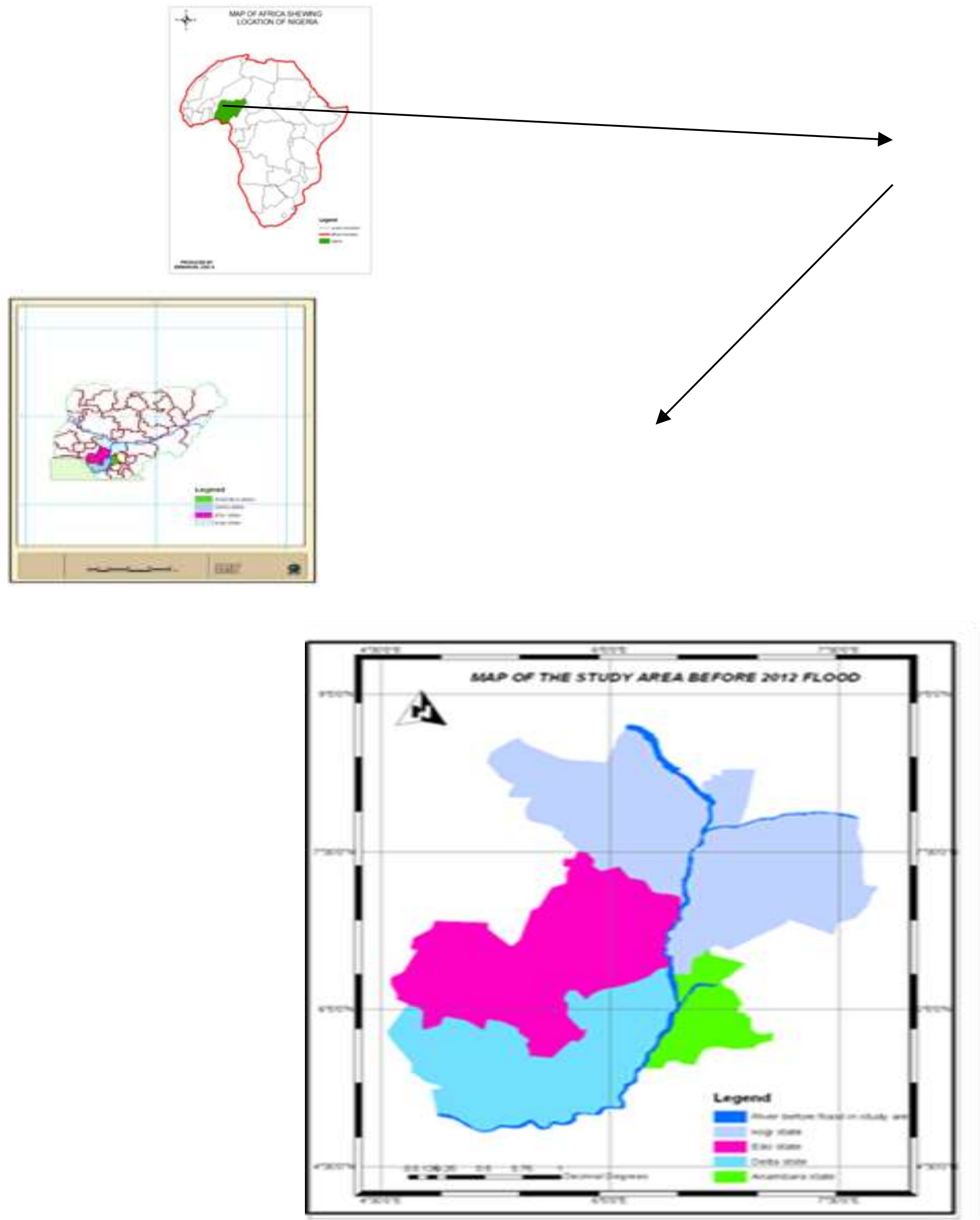


Figure 1 Location map

2.0 MATERIAL AND METHODS

In this study, Advance space borne thermal emission and reflection Data (ASTER DEM) of one arc second (30m resolution) covering the study area was utilized. This dataset is originally, georeferenced into the horizontal datum of WGS84 and then it is referenced into the vertical datum of EGM96 geoids. Other datasets include Catchment map of Nigeria, and political map of the catchment area. software used is Arc-GIS version 10.4 and surfer11

2.1 METHODOLOGY

This study was carried out as per the methodology shown in fig2 below. GIS and strahler's methods of morphometric analysis were utilized for data extraction, analysis and for all stream related calculations within the basin. Digital elevation model is fundamental for morphometric analysis because of its ability to provide hydrological and topographical parameters needed for hydro-morphological studied when processed in GIS environment. The tiles of the elevation raster (DEM) has been mosaicked using data management function of Arc-tool box in ArcGIS 10.4 environment and the generated data was transformed from geographic coordinate system to projected coordinate system World Mercator. Progressively, the catchment map of Nigeria, and political map of the catchment area were harmonized to the same coordinate system. The shape-file of the basin was extracted from the Nigeria catchment map through digitizing and was used to clip out the study area from the DEM to actual boundary limit and shape. The clipped raster was used for surface analysis, hydrological analysis, linear, and areal aspects of morphometric analysis. The void in the DEM was filled and this was fundamental to the creation of flow direction grid of the Basin. A void cell does not have associated drainage value. Drainage value indicates the outward flow direction from each cell of the DEM. Failure to fill the voids, result to abnormal termination of flow routing. The Watershed process solves this problem by first locating and filling the depressions. Flow direction grid holds values in its cells that indicate the direction of the steepest descent from each cell. Flow direction grid was utilized to create flow accumulation grid. Flow accumulation identifies cells of high flow where streams and channels are to be expected. In other wards each cell in the flow accumulation grid contains a value that is determined by the number of upstream cells flowing into it. The Flow Accumulation Grid was processed to create the Stream Definition Grid. A threshold of the volume of flow (number of accumulating cells) that defines a stream in the project area was set. This helped in proper definition of the stream segments. Progressively, Strahler's system of classification was use to categorize the stream segments into the various orders and for other metric assessments.

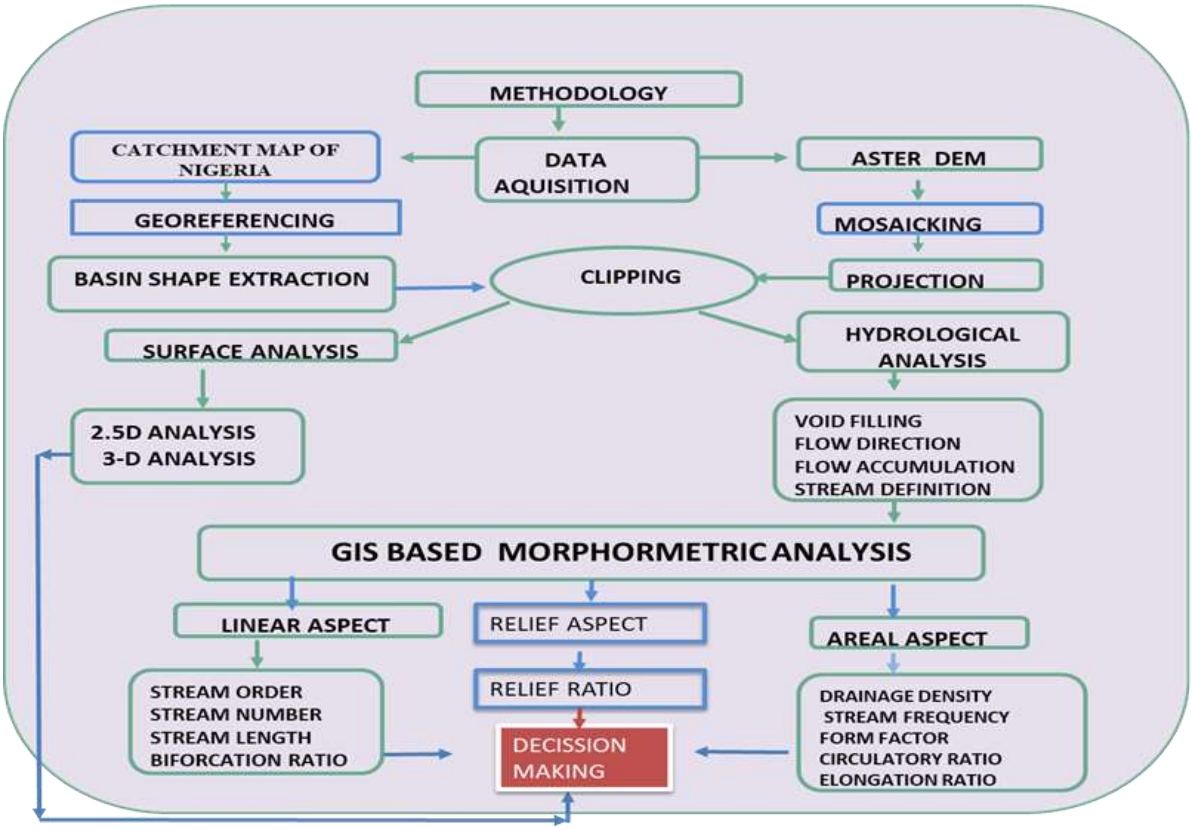
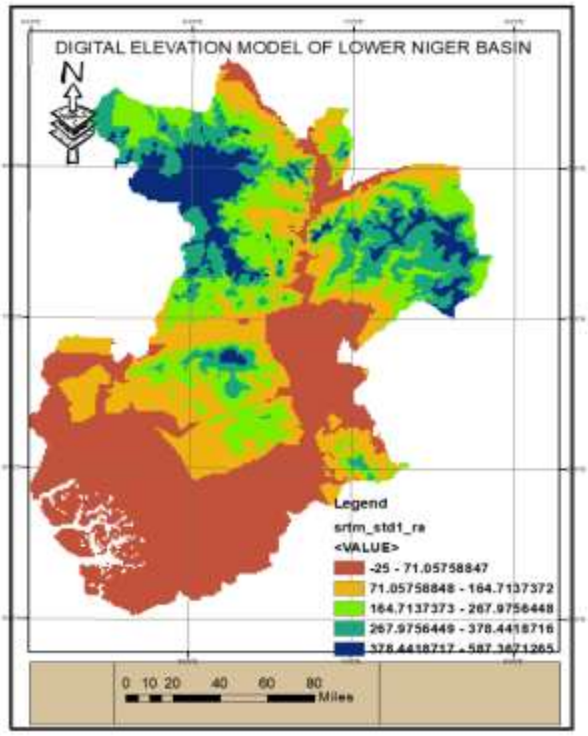


Figure2 Methodological flow chart

3.0 RESULTS AND DISCUSSION

Following the purpose of this study, remote sensing and GIS approach has been combined to assess the hydro-morphological attributes of Lower Niger Basin in Nigeria with the view of understanding the topographical, hydrological and geological concepts of the watershed for effective management. The models derived includes DEM (Figure 3), flow direction map (Figure 4), drainage map (Figure 5) sub-catchment map of the basin (Figures 6), Hydro-geological models (figure7a and b), 3D surface model and surface flow model (Figure8-9), Drainage order map (Figure10). Geological, topographical and hydrological processes on the basin have been interpreted based on in-depth assessment of quantitative attributes of the basin which includes; basin area, basin length, circulatory ratio (Rc), perimeter of the basin, form factor (Ff), stream frequency, drainage density, stream number, stream length, and bifurcation ratio of the basin and these are summarized in Table 1.



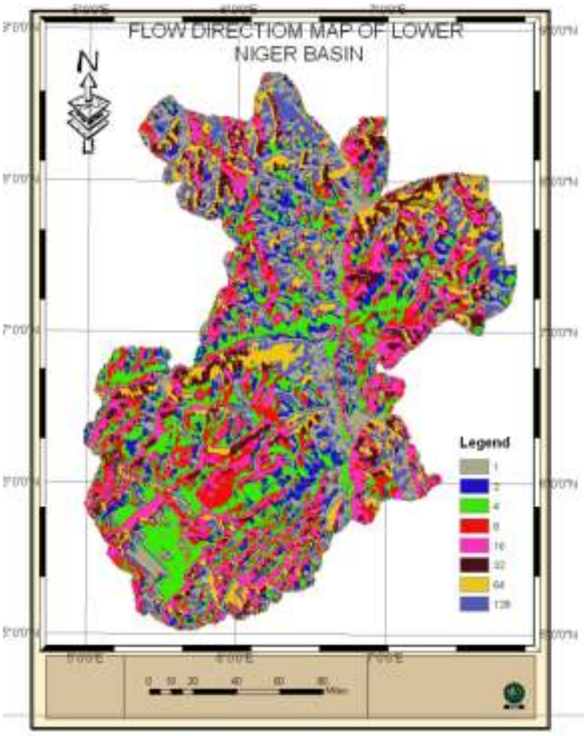


Figure 3 Digital elevation model of the study area   Figure 4 flow direction raster of the basin

Figures 3 is the digital elevation model of the basin. The models show elevation range of - 25m to 587m relative to mean sea level that is, the lowest point in the basin is at -25 m relative to MSL while the highest point is 550 m relative to MSL. Relief ratio is an index for predicting runoff potential of a basin. Total relief (Z –z) of a basin is the difference between the highest and lowest point on the basin. Relief ratio is the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Sayeed et al 2017; Ahuchaogu et al 2022). In the present study, relief ratio has been calculated using the formular; Rh=H/Lb and this recorded a value of 0.77m which signifies low discharge potential. Figure4 is the flow direction model of the basin. This is a crucial step in hydrological modeling as the direction of flow will determine the ultimate destination of the water flowing across the surface of the land. This grid holds values in its cells that indicate the direction of the steepest descend. if the cell flows due north, its value will be 64; if it flows northeast, its value will be 128, also a value of 1, 2, 4, 8, 16, 32 indicates flow towards east, south east, south, south west, west and North west directions respectively. These numbers have no numeric meaning they are simply codes that define a specific directional value, and are determined using the elevation values from the underlying DEM. The flow direction grid has been processed to flow accumulation raster which is fundamental to stream definition grid.

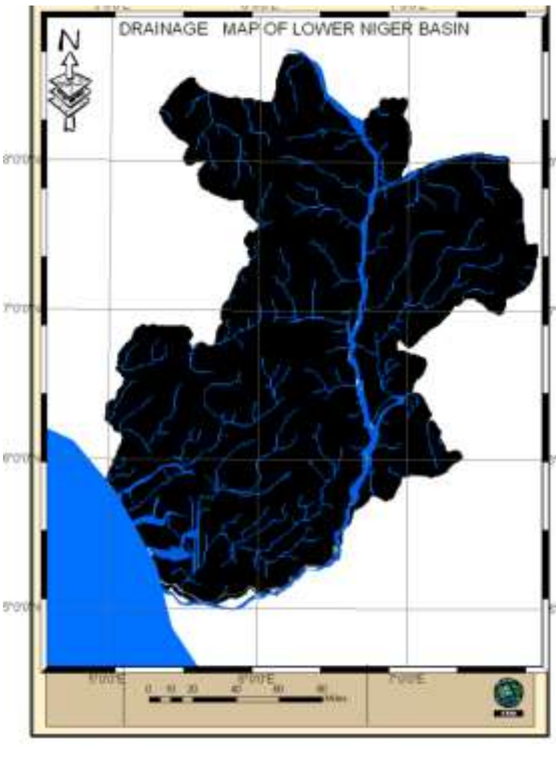


Figure **5 drainage map of the Basin**

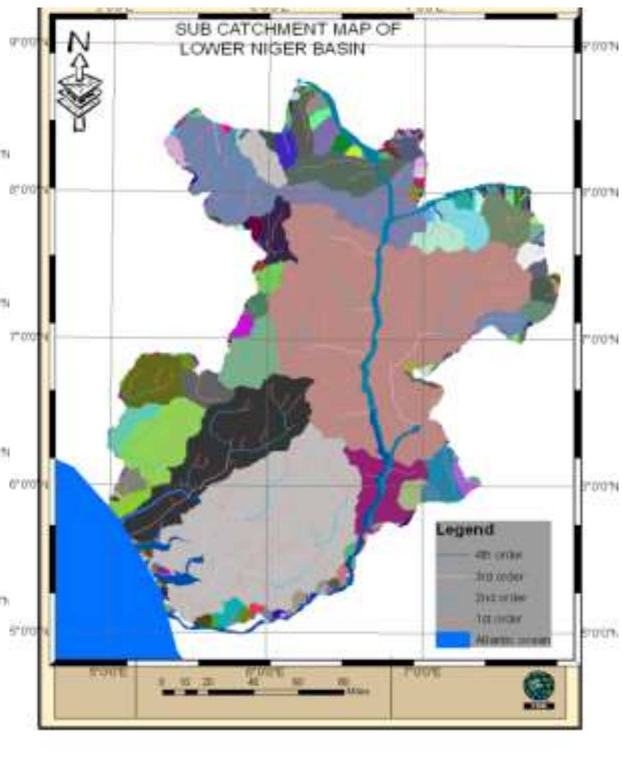


Figure **6 sub-catchment map of the basin**

The drainage channel network (figure5) defines all stream and rivers within the basin. A drainage channel is a linear connection of land units that accumulate the most runoff in an area. A close study revealed that majority of the drainages at the northern and central part of the basin originates from the river Niger while those at the southern parts originate from the

Atlantic Ocean. Generally, the channel networks in the study area are predominantly dendritic drainage pattern. The morphology of the drainage channel network is important because it can be used to interpret the lithological or geological conditions of the basin and its influence on the hydrology of the watershed. This study reveals a total number of 174 streams and total stream lengths of 4719124 kilometers draining an area of 70959.175 square kilometers of land; Figure6 is the sub-catchment map of the basin. A sub-catchment map disaggregates a river basin into smaller land units. A sub-catchment is the basic unit of any landscape in drainage analysis. When an urban area is planned the drainage of the area should be planned in consideration of the layout of the sub-catchment. The design should anticipate the capture of runoff from the landscape before it builds up enough to create flood or to erode the landscape. This study revealed that there are 79 sub-catchment within the basin with the smallest and largest sub-catchment occupying area of 1km^2 and 25489km$^{2.5}$ respectively.

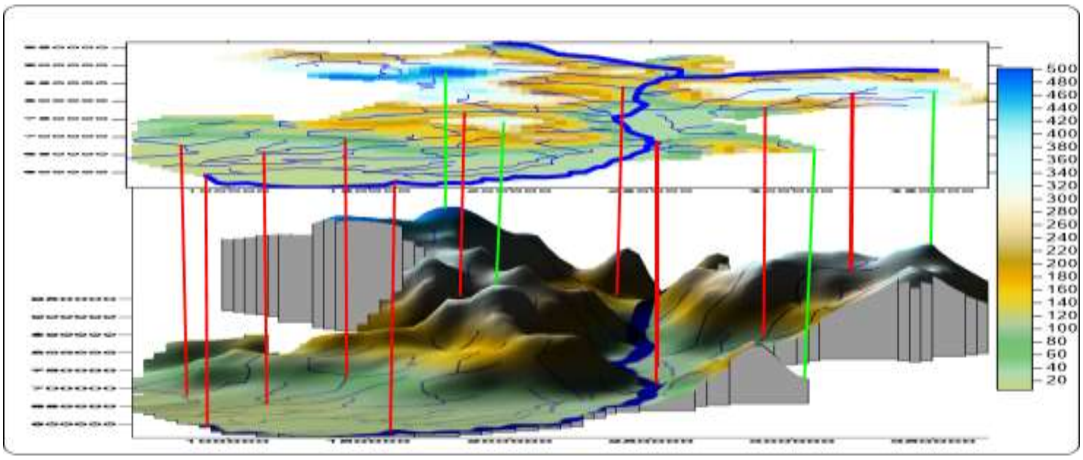


Figure 7a A stack of hydro-terrain model on 3-D surface of the basin (rotated view)

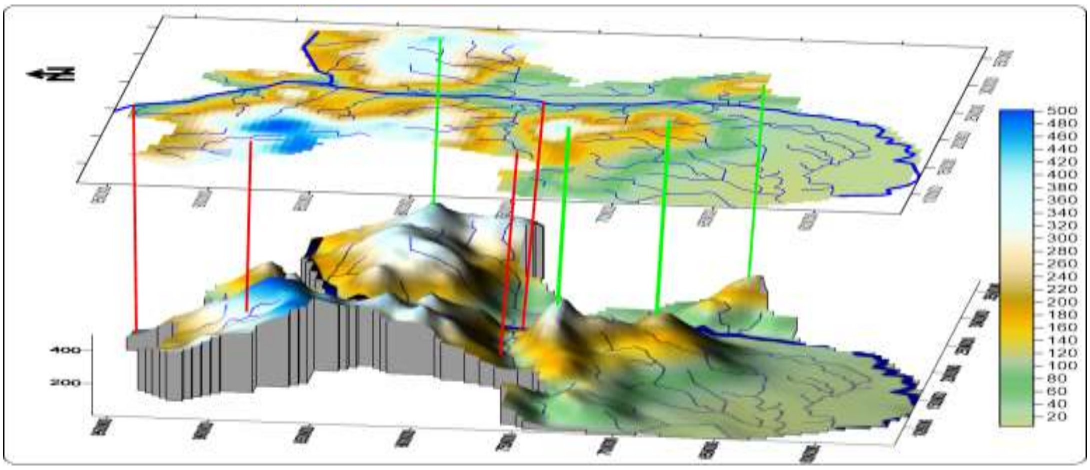


Figure 7b A stack of hydro-terrain model on 3-D surface of the basin (rotated view)

Figures 6a and 6b are stacks of hydro- terrain on the 3-D surface of the basin rotated in different viewing direction. The red lines connect the drainage features on the 2.5-D hydro-terrain (upper layer) to their corresponding spatial locations on the 3-D surface below. The green lines connect identified terrain features between the two surfaces. A cursory examination of the 3-D surface shows that generally, there is hierarchy in the topography with reference to height and ruggedness of the relief. The northern part of the basin is undulating high land while the southern part is flat. The surface analysis also reveals a wide river Niger valley which divides the basin into eastern and western wings. Analysis revealed that the domains of the river segments are either in the valley or the lowest regions in the basin. Hydrological character of a given area is a function of the surface in which it flows. In other words one of the forces that determine the landform pattern of a particular area is the interaction between the flowing water and geology this is because water tries to find it routes through easily erodible path.

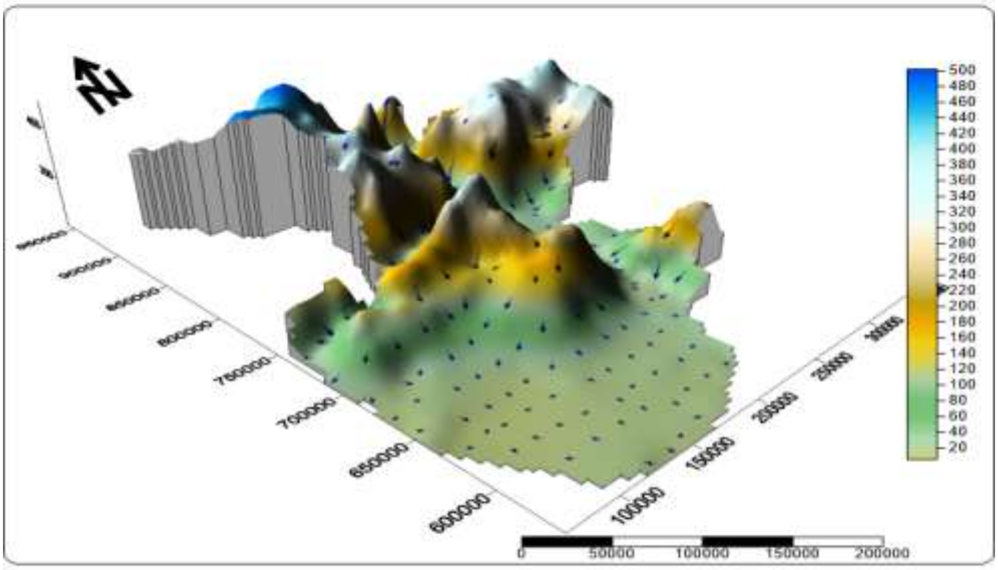


Figure 8 Overlay analysis of surface flow vectors on 3-D model of the study area

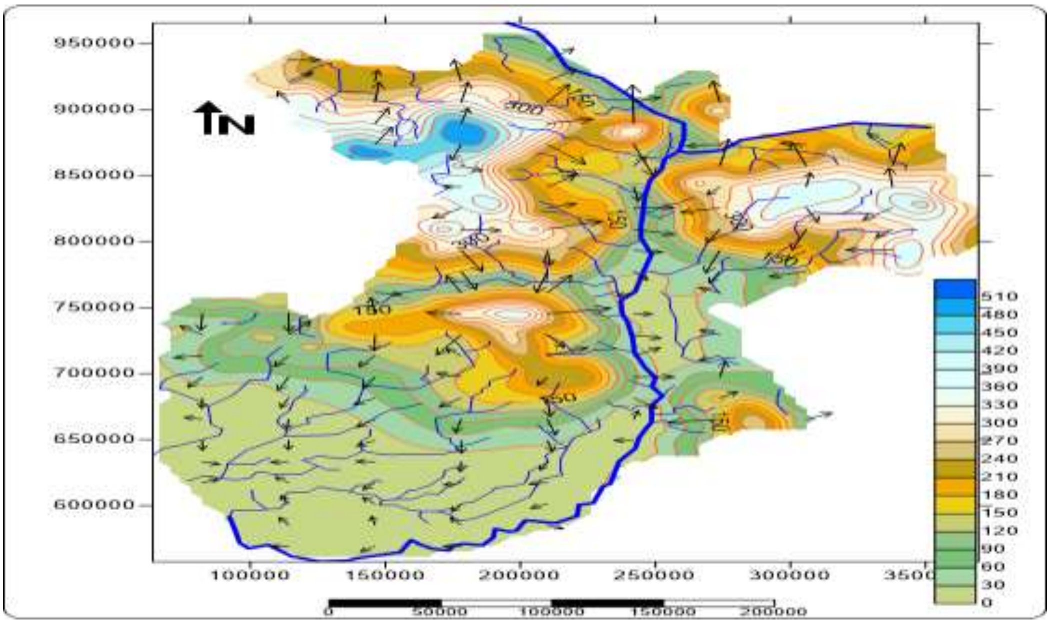


Figure 9 Overlay analysis of surface flow vectors on hydro-terrain of the study area

Figures8 is overlay analysis of the flow vectors on the 3-D surface model and fig9 is the overlay analysis of the same flow vectors on the hydro terrain. As can be seen in fig9, the surface flow vectors are seeking for the natural flow routes. (Natural drainage system). These natural flow routes are fundamental in efficient urban drainage design. The aim of effective drainage design is to ensure that the natural and constructed drainages networks form a drainage system that serve to convey runoff in ways that eliminate the danger of either erosion or flooding within the environment. When an urban area is planned the drainage of the area should be planned in consideration of the layout of the sub-catchment. The design should anticipate the capture of runoff from the landscape before it builds up enough to create a flood or to erode the landscape (chukwuocha 2015). These constructed drainages should convey runoff to the natural drainages. Principle of Flow efficiency requires that there should be three levels of the drainage network. The primary level (stream segment) would drain the entire sub-catchment. The secondary level would drain the blocks of the layout design and empty them into the primary drains. The tertiary level would collect the runoffs of each plot and empty them into the secondary level drains. Therefore these natural flow paths must be physically located in space before any physical construction else erosion or flood may spring up.

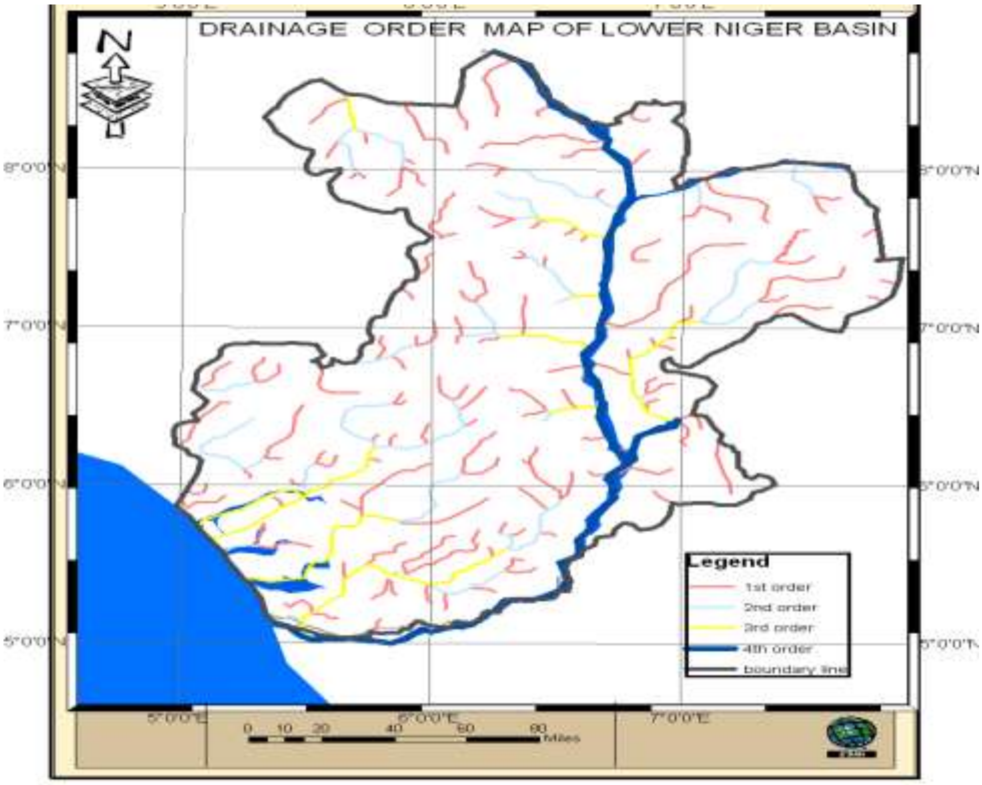


Figure **10 drainage order map of the study area.**

Table1 Morphometric parameters of Lower Niger basin

PARAMETER		FORMULAR		DIMENSION	
Basin Area		GIS Analysis/DEM		70959.175sq km	
Basin Length		GIS Analysis/DEM		745.976km	
Drainage Density		D= ΣLu/Au		0.0665 km^{-1}	
Stream Frequency		F=ΣNu/Au		2.452 x 10^{-3}	
Circulatory Ratio		Rc=4ΠA/P		0.319	
Form Factor		$Ff=A/LP^2$		0.128	
Perimeter of Basin		GIS Analysis/DEM		1671947km	
Elongation Ratio (Re)		Re = D/L = 1.128HA/L		0.040	
Relief ratio		Rh=H/Lb			
STREAM ORDER	**STREAM NUMBER**	**STREAM LENGHT**	**MEAN STREAM LENGTH (Lsm)**	**BIFURCATION RATIO**	**STREAM LENGTH RATIO**
1	132	2508576	19004.36	5.076923	
2	26	911625	35062.5	2	0.363403
3	13	648186	49860.46	4.333333	0.711023
4	5	650737	216912.3		1.003936

Figure 10 show the drainage order map of the basin. Drainage order is a notation use to describe the position occupy by a stream segments within a drainage system. Based on Strahler's scheme of classification, a river segment without a tributary is a first order river. Second order begins where two first orders meet and so on. This study revealed that the basin is a 4^{th} order basin with first order mainly dominating. Table 1 is a summary of the morphometric attributes of the basin. Drainage density is a function of the total length of the stream in a given drainage basin and the area of that drainage basin while stream frequency is the ratio of a total number of channels cumulated for all orders within a given drainage basin and the area of that drainage basin. Drainage density and stream frequency indicates how well a basin is drained by streams and rivers and can be used to predict areas exposed to flooding during extreme weather condition. They are influenced by Geology of basin. Permeable rocks with a high infiltration rate have low drainage density and stream frequency and vice-versa. In this study, the drainage density and stream frequency of the basin were calculated using the relevant parameters extracted in GIS window and this resulted to a value of 0.0665 km^{-1} and 2.452 x 10^{-3} respectively. Miller (1953) appraised that circularity ratio is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin. It is a dimensionless parameter which provides a quantitative index of the shape of the basin (Jha VC (1996). Circular basin has a maximum efficiency of discharge, whereas an elongated basin has the least efficiency. It is a factor for discharge prediction in an ungauged basin, particularly in a time of flood. In this study Circulatory ratio was computed using the formula; $Rc = 4\pi A/P2$ and this resulted to a value of 0.319. Form factor is dimensionless quantity which is used to describe the different shape of basin also. Basins with high form factors portray high peak flows of shorter duration, whereas, elongated drainage basin with low form factors depicts lower peak flow of longer duration (R. E. Horton,1945; Sayeed et al 2017). It is defined as the ratio of the basin area to the square of the basin length. The value of the form factor varies from 0 (highly elongated shape) to the unity, i.e., 1 (perfect circular shape). This study recorded a value of 0.128 for the form factor. Elongation ratio is also a parameter that shows the shape of a basin and is also useful for predicting flow efficiency. It is a meaningful index for classifying drainage basins into varying shapes. The value of elongation ratio varies from 0 to 1 i.e., circular (0.9- 1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5) (Praveen et al 2014). It is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956; Praveen et al 2014).

4.0 CONCLUSION

In contemporary time, the pace of climatic change and rapid urbanization create a complex Eco- system and puts thrust on policy makers concerned with resource management. Therefore modern techniques that produce accurate results must be used in management and conservation of natural resources if millennium development goals must be met and sustained. Remote sensing and GIS has proved to be reliable in capturing and management of large volume of data in geographic space. In this study remote sensing and GIS has been combined for hydro-geomorphological assessment of lower Niger basin in Nigeria. Basic quantitative attributes of the basin such as drainage density, stream frequency, form factor, circulatory ratio, elongation ratio bifurcation ratio relief ratio etc have been mapped in GIS environment in order to understand the topographical, hydrographical and geological processed within the basin. Basic models of reality such as drainage network, surface flow vectors, 2-D and 3-D surface models have also been produced and analyzed in other to investigate their relationship in space. Result revealed that the basin is a 4th order basin with 1st order stream mostly dominating. The overall stream network revealed a hierarchy of 1st, 2nd, 3rd order streams with river Niger positioned as 4th order streams in the hierarchy. This study reveals a total number of 188 streams draining an area of 70959.175 square kilometers of land. Further investigation revealed that there are three (3) fourth order streams, thirteen (13) third order streams, twenty six (26) second order streams, and one hundred and thirty six (136) first order streams. Further morphometric assessments revealed that the basin has a drainage density of 0.0665km-^{1}, stream frequency of 2.452 x 10-3, circulatory ratio of 0.310, elongation ratio of 0.40, Form factor of 0.128 and basin length of 745.976km. These quantitative attributes revealed that the basin is elongated with low discharge potential. The models of reality and metric attributes of the basin presented in this study are invaluable for watershed management. They also show the effectiveness of integrating remote sensing and GIS for hydro-geomorphological analysis of a river basin.

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