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SRTM DEM Based Delineation of Natural Flow Route and Morphometric Assessment of Lower Niger Drainage Basin in Nigeria

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---ABSTRACT---

In this study, mapping of natural flow routes and morphometric assessment of lower Niger drainage Basin in Nigeria has been carried out to understand the spatial variations in morphometric parameters and evaluate hydrological, geological and topographical characteristics using SRTM DEM data. River basin delineation, mapping of slope, aspect, flow direction, and drainage routes has been accomplished using Hydrology tool extension of ArcGIS 10.3 Software. Strahler's and Horton's method of stream ordering has been utilized for all stream related calculations. Drainage characteristic such as stream order, stream number, stream length, mean stream length, Bifurcation ratio, drainage density, stream frequency etc, have been calculated in other to understand the hydrological and topographical processes in the catchment. Result revealed 366 sub-catchment within the basin with the smallest and largest sub-basins occupying area of 1km^2 and 25489km^2 respectively. 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 results are invaluable for watershed management, agricultural land-use planning, flood and erosion analysis and control and for sustainable environmental planning and development within the catchment.

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I. INTRODUCTION

Studies on rivers, stream ordering systems and watershed management abound all over the world as a result of the relevance of water to the sustenance of life. An understanding of the concept of a stream, stream order, and stream segment; its delineation, morphology, classification and quantification, functionality and usages is a fundamental requirement in appraising drainage system and the water resources of an area (Abiodun et'al 2018). Mapping of natural flow route is invaluable for various purposes. Apart from flood and erosion mitigation, urban planning and designing of drainage network, it is funder mental for morphormetric assessment of a drainage basin and knowledge of quantitative attributes of a drainage basin is inestimable for watershed management. Other terms use to refer to watershed are catchment areas and drainage basin. A drainage basin is the developmental unit used to effectively manage resources sustainably, *Digital elevation model (DEM) data are elemental in deriving primary topographic attributes which serve as input variables to a variety of hydrologic and geomorphologic studies (*Jonathan et;al 2017).Results from these studies are extremely useful for watershed management. GIS-based evaluation using Shuttle Radar Topographic Mission (SRTM) data has given a precise, fast, and an inexpensive way for analyzing hydrological systems (Smith and Sandwell, 2003; Grohmann, 2004). Geospatial studies revealed that Shuttle Radar Topography Mission digital elevation model SRTM DEM is much better in providing accurate data particularly for drainage morphometry and hydrological studies than Advanced Spaceborne Thermal Emission and Reflection Radiometer digital elevation model (ASTER DEM) (Kabite and Gessesse 2018; Madavi Venkatesh and Anshumali 2019). The Shuttle Radar Topography Mission (SRTM) was co-sponsored by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) (Dowding *et al.*, 2004). SRTM used a radar interferometer to generate a globally consistent digital elevation map for latitudes smaller than 60° (Rodriguez and Martin, 1992; Rosen *et al.*, 2000; Nwilo et'al 2017). Subhash (2011) appraised that the study of the river basin morphometry analysis provides the useful parameter for the assessment of the groundwater potential, surface and groundwater resource management, runoff and geographic characteristics of the drainage system.

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 AN 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). Drainage basin analysis by Morphometric parameters are classified into Linear aspects , Aerial aspects , Relief aspects . These attributes are vital for watershed management. In the present study, attempt has been made to understand the topographical hydrological and geological processes of the lower Niger basin by drawing inference from assessment of flow route pattern and morphormetric analysis.

1.2 Study area

The area under consideration in this study 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. . The area enjoys both wet and dry season with a total annual rainfall between 1000mm-1500mm. Mean annual temperature is 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 and disaggregates into networks of rivulets that terminates in Atlantic ocean in Delta state

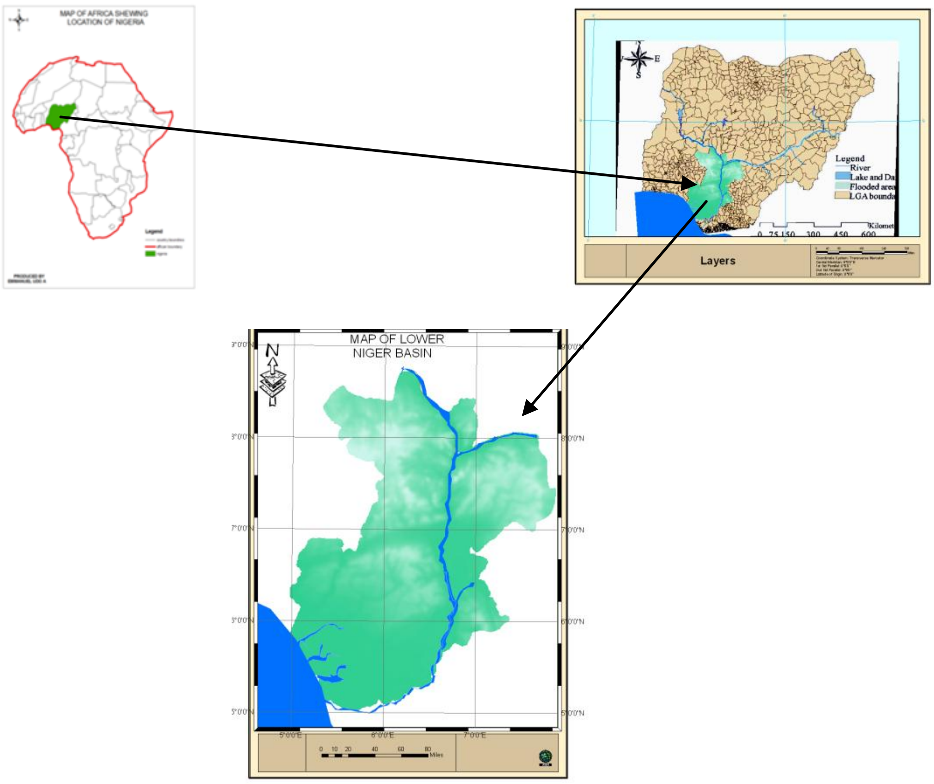


Fig1 Study Area

II. MATERIAL AND METHODS

Digital Elevation Dataset from Shuttle Radar Topographical Mission (SRTM) of one arc second (30m resolution) covering the study area has been downloaded from USGS explorer. Other datasets includes Catchment map of Nigeria, and political map of the catchment area. Software used is Arc-GIS version 10.3. GIS software such as ArcGIS and its extensions have the capacity to processing DEM into runoff routes. At present, the most commonly used method -is "hydrological approach" (Mark 1984; Chukwuocha 2017). In this method, the "drainage area" of each DEM elevation grid (i.e. the number of elevation grids that drain into the grid) is first determined by climbing recursively through the DEM. This process results in a matrix, called the "drainage area transform" that contains the drainage areas for all the grids in the DEM. The information in the drainage area transform is then used to trace the "channel pixels", as identified by those grids with large drainage areas.

Channels are recursively followed upstream until there is no more point that exceeds a minimum threshold. Summary of the methodology adopted is shown in figure2

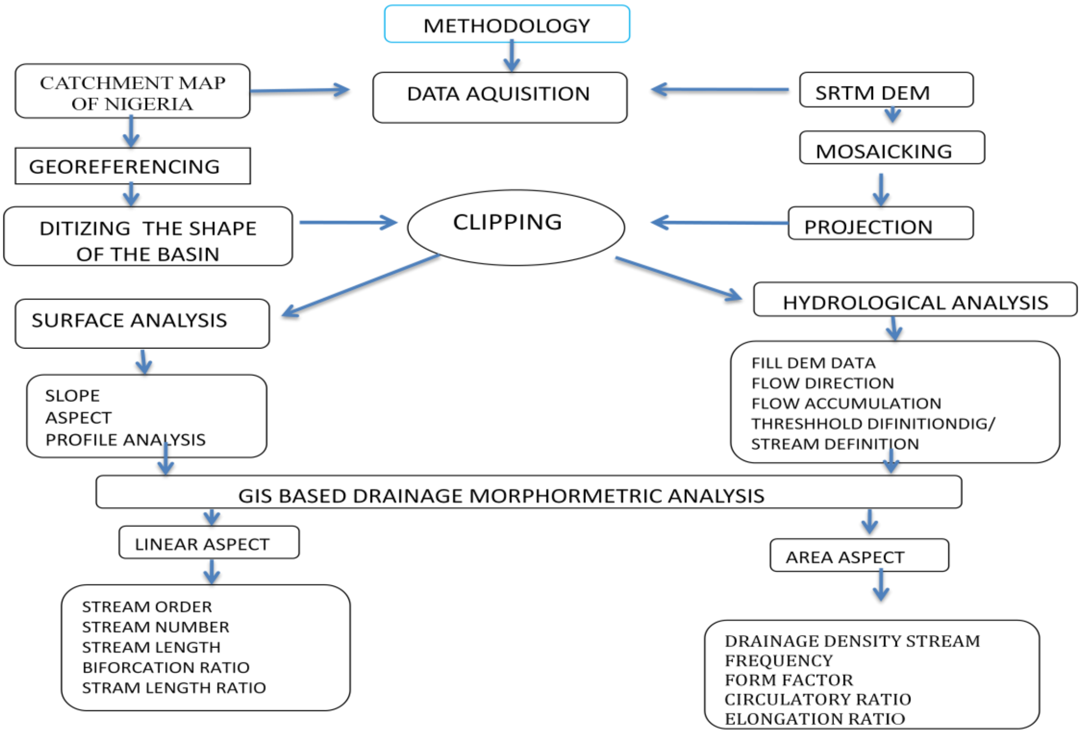


Fig 2 Methodological Flow chart

2.1Data preparation

The ArcGIS 10.3 (ArcMap 10.3) was used to extract the /watershed boundary. The tiles of the elevation raster (DEM) were mosaicked and the shape file of the study area was digitized from the political map of the catchment areas. The digitized shapefile has been used to mask out the study area to the actual boundary limit

2.2 Sink filling and flow direction grid

The first step in processing flow routes from DDEM is to fill all void in the DEM data. A sink cell does not have associated drainage value. Drainage value indicates the outward flow direction from each cell of the DEM. Failure to fill the sinks, result to abnormal termination of flow routing. The Watershed process solves this problem by first locating and filling the depressions. This depression filled DEM is fundamental in computation of the flow direction and flow accumulation. The depression in the DEM has been filled using the fill tool and was fundamental to the creation of flow direction map of the Basin.

2.3 Flow direction

A Flow Direction Grid was created from the DEM as the next step in processing data from the DEM using Arc-Hydro extension. The Flow Direction function takes a DEM grid and computes the corresponding flow direction grid. 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 (flow direction) from that cell as is illustrated in figure3. Flow direction grid has been created using flow direction tool. For every 3x3 cell neighborhood, the grid processor finds the lowest neighboring cell from the centre. Each number in the matrix below corresponds to a flow direction that is, if the centre cell flows due north, its value will be 64; if it flows northeast, its value will be 128, etc. 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.

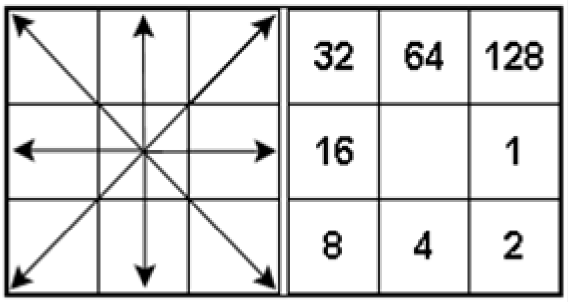


Figure3 The Flow Direction Grid Numbering Scheme

2.4 Flow Accumulation Grid:

After the Flow Direction Grid was accomplished, the accumulation of each cell of the grid was computed.

The flow direction grid was fundamental to the computation of flow accumulation grid. The *Flow Accumulation* tool calculates the flow into each cell by identifying the upstream cells that flow into each down-slope cell. In other words, each cell of flow accumulation value is determined by the number of upstream cells flowing into it based on landscape topography. Simply, it's the number of cells draining into a given cell along flow network. Cells that lie on drainage networks have substantially higher values than cells on hill slopes. This results into grid of flow route in the basin.

2.5 Stream Definition Grid:

The Flow Accumulation Grid was processed to create the Stream Definition Grid. Progressively, the flow accumulation grid has been subjected to stream definition (visualization) and segmentation algorithms. The stream definition is based on a specified threshold that is usually applied to reveal the stream length. It tries to determine the number of accumulating cells that define a stream cell. Progressively the stream segments were vectorised as a thematic layer so as to permit overlay analysis with other environmental datasets

2.6 Slope delineation;

Slope is defined as the maximum rate of change in value from each cell to its neighbors. The DEM data was procesed to slope map of the study area using spatial analysis tool. Higher slope degree results in rapid runoff and increased erosion rate (potential soil loss) with less ground water recharge Potential. The degree of slope in lower Niger basin varies from

$< 1.0^0$ to $> 89^0$. The slope values are higher at the northern part of the basin and lower at the southern part closer to Atlantic Ocean

2.7 Aspect Delineation

Aspect is generally refers to the direction to which a mountain slope faces. The aspect of a slope can make very significant influences on its local climate because the sun's rays are in the west at the hottest time of day in the afternoon, and so in most cases a west-facing slope will be warmer than sheltered east-facing slope(Praveen et al 2017). Aspect (Fig12) depicts the slope direction and is measured clockwise from 0° to 360°. It shows the direction of surface water flow. The aspect and slope is invaluable tools for erosion and flood analysis and can also be applied for suitability analysis of areas for agricultural practice.

2.8 LINEAR MORPHOMETRY

2.8.1 Stream order (u)

Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). The streams having no tributaries are considered as first order streams. Then two first order streams join and form second order streams and so on. In this study the drainage net work was digitized in layers, categorized into orders, and symbolized (figure8) .

2.8.2 Stream number:

The stream number (Nu) is defined as a number of streams in each order (Horton 1945). It is inversely proportional to stream order. In this study the number of streams in the various orders were calculated using ''Calculate Geometry Module'' of Arc-GIS

2.8.3 Stream lenght (Lu)

The total length of the stream is Sum of the lengths of each stream order**.** Horton (1945) noted that the total length of stream segments decreases with an increase in the stream order. The total stream lengths of various orders have been measured with the help of calculate geometry module of ArcGIS. Mean stream lengths has been calculated by dividing total sum of the stream length of a given order by the total number of streams in that order; Lsm=Lu/Nu. As per Strahler, (1964), mean stream length increases with successive increasing orders. It is related to the size of the drainage network

2.8.4 Bifurcation ratio (Rb)

The Bifurcation ratio may be defined as the ratio between the numbers of stream segments of any given order to the number of the next higher order. If Rb of a river basin is low ,there is a higher chance of flooding, as the water will be concentrated in one channel rather than spread out (**Sayeed et'al 2017).** In line with the above definition, bifurcation ratio has been calculated using the formular; Rb = Nu/Nu+ 1.

2.9 AREAL ASPECT OF MORPHOMETRY

2.9.1 Drainage density (Dd)

this is the ratio of the total stream length in a given basin to the total area of the basin (Strahler 1964). It is high for impervious areas of high precipitation and zero for the permeable basin with high infiltration rate. Drainage density is related to various features of landscape dissection such as valley density, channel head source area, relief, climate and vegetation (Moglen et al. 1998; Praveen et al 2017), soil and rock properties (Kelson and Wells 1989; Praveen et al 2017). The area of the basin and the total length of the streams and rivers in the basin has been calculated using Calculate geometry module of ArcGIS10.2 and the drainage density has been calculated using the formula; Lu/A.

2.9.2 Stream frequency (Fs)

It 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. It is an index of various stages of landscape development and depends on the nature and amount of rainfall, the nature of rock and soil permeability of the region (Magesh et' al 2012; Sumantra et al 2016) In the present study, the total number of streams and rivers in the basin has been measured using Calculate geometry tool in GIS environment. These datasets were combined with the area of the basin to compute the drainage frequency of the basin using the formula; Fs = Nu/A

2.9.3 Form factor

This is defined as the ratio of the basin area to the square of the basin length. It is dimensionless quantity which is used to describe the different shape of basin. The basins with high form factors portrays 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). The value of the form factor varies from 0 (highly elongated shape) to the unity, i.e., 1 (perfect circular shape). In this study Form factor has been computed using the formula; $Ff = A/L^2$.

2.9.4 Circulatory ratio (Rc)

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 the movement of runoff, whereas an elongated basin has the least frequency. This information is very significant in forecasting drainage discharge, particularly in a time of the flood. In this study Circulatory ratio was computer using the formula; $Rc = 4\pi A/P^2$

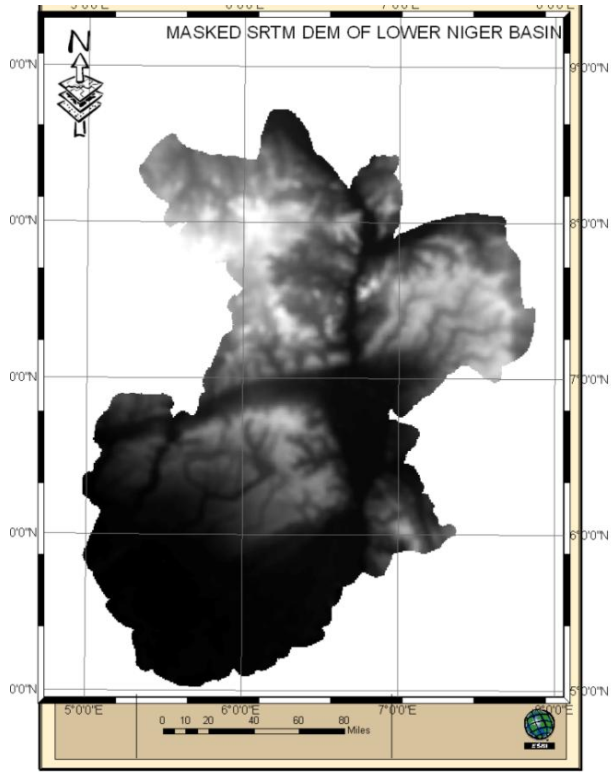
2.9.5 Elongation Ratio (Re)

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Sumantra et al (2016) reported that 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) (Schumms1956). A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997; Praveen et'al 2014). In this sudy elongation ratio has ben computed using the formular. Re = D/L = 1.128HA/L

III. RESULTS AND DISCUSSION

3.1 Result

Figure 4 is the Clipped SRTM DEM of the basin and fig 5 is Flow direction map of Lower Niger basin. Figure6 is flow routes (drainages) of Lower Niger Basin and figure7 is Drainage order map of the basin. Figure8 is the overlay analysis of the drainage on the catchment map of the basin. Figure9 is the digital terrain model of the study area. Fig 10 and fig11 are slope and Aspect maps of the basin respectively. Figure 12 and figure 13 are longitudinal and cross profiles of river Niger channel in the study area Table I contain the overall morphometric attributes of the basin.



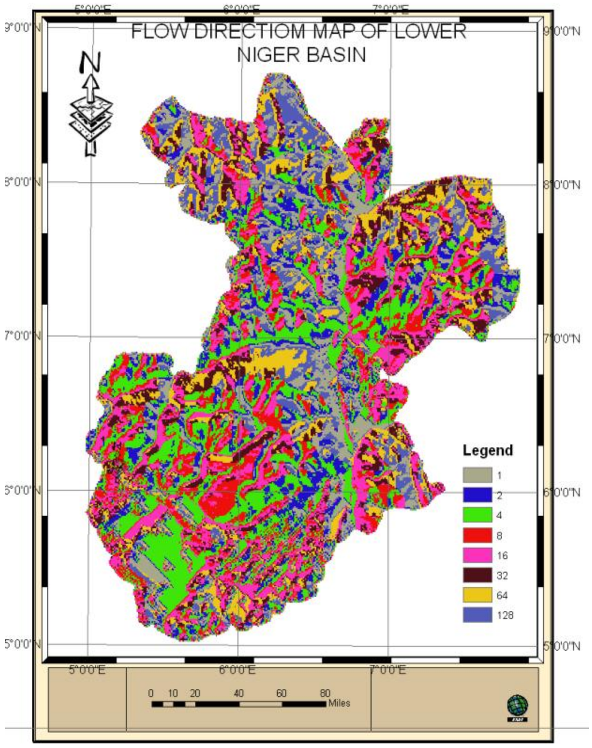


Figure4 Clipped SRTM DEM of Lower Niger Basin

Figure5 Flow direction map of Lower Niger basin

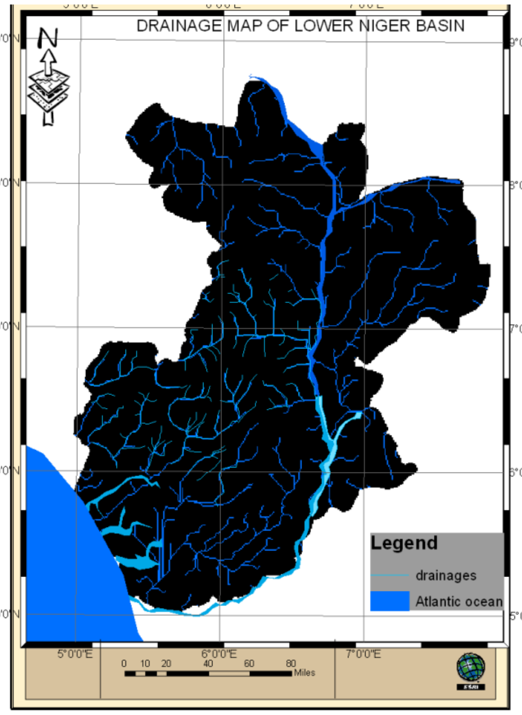


Figure6 flow routes of Lower Niger Basin

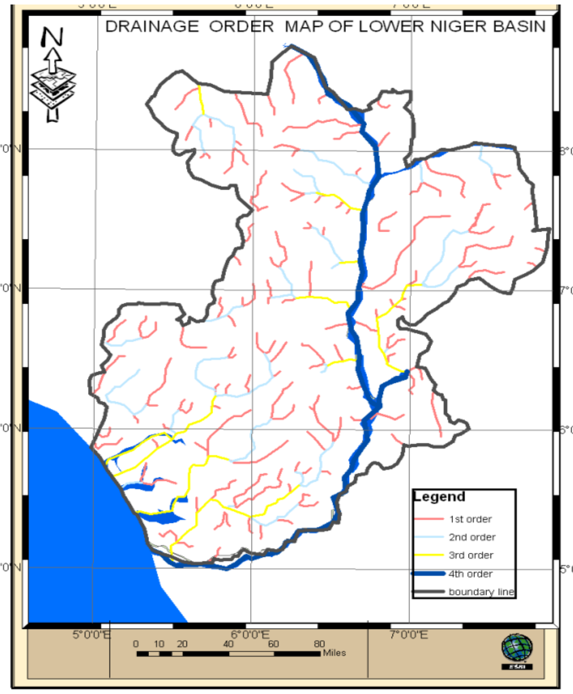


Figure7 Drainage order map of Lower Niger Basin

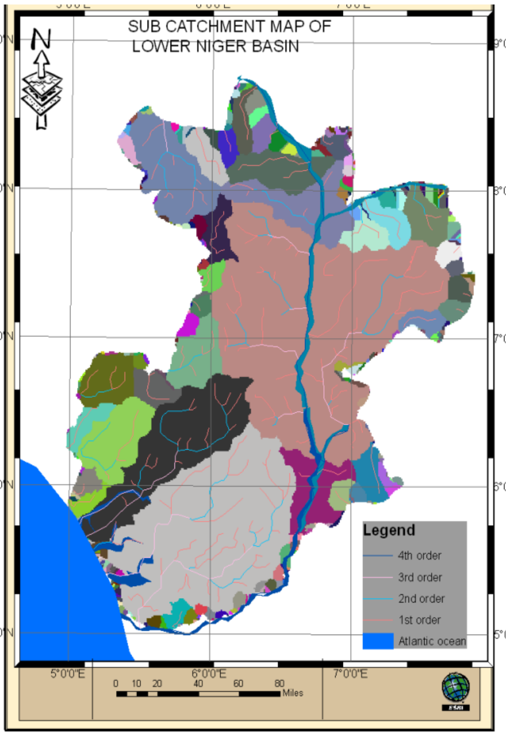


Figure8 overlay analysis of drainages and sub-catchement map of Lower Niger Basin

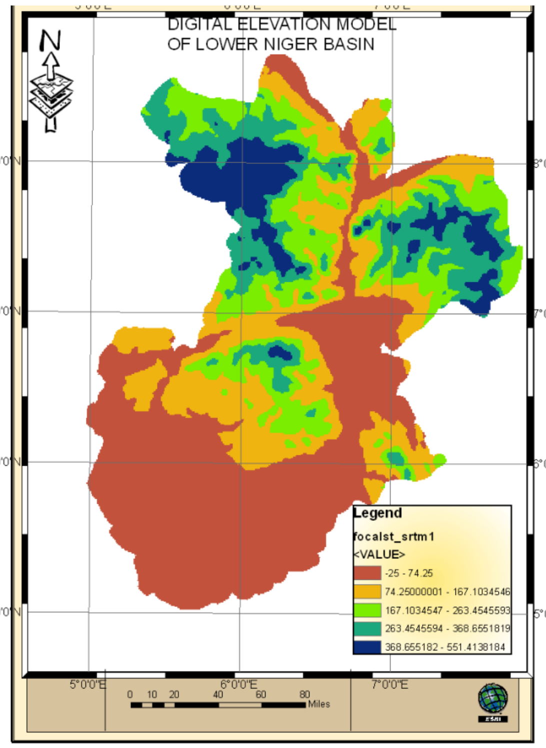


Figure9 digital terrain of Lower Niger Basin

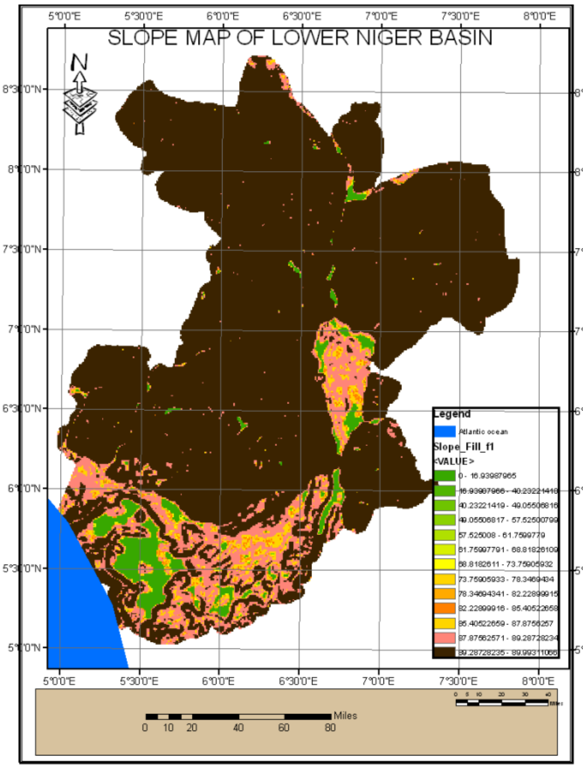


Figure10 Slope map Lower Niger Basin

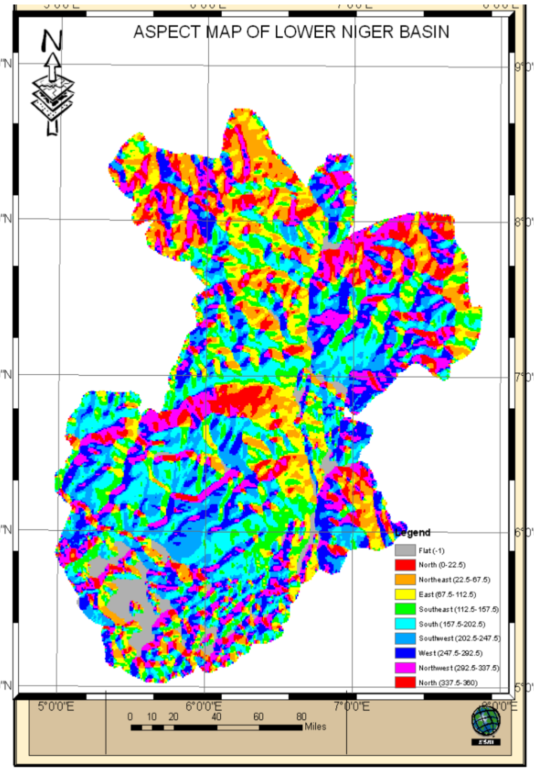


Figure11 Aspect map of Lower Niger Basin

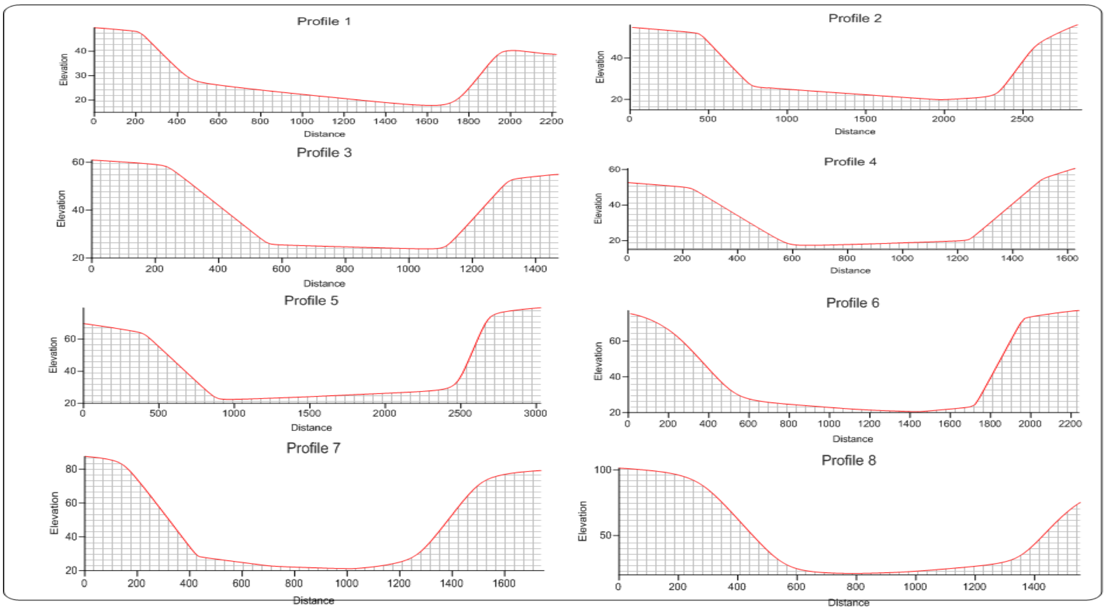


Figure12 cross sections of the flow channel along river Niger in the study area

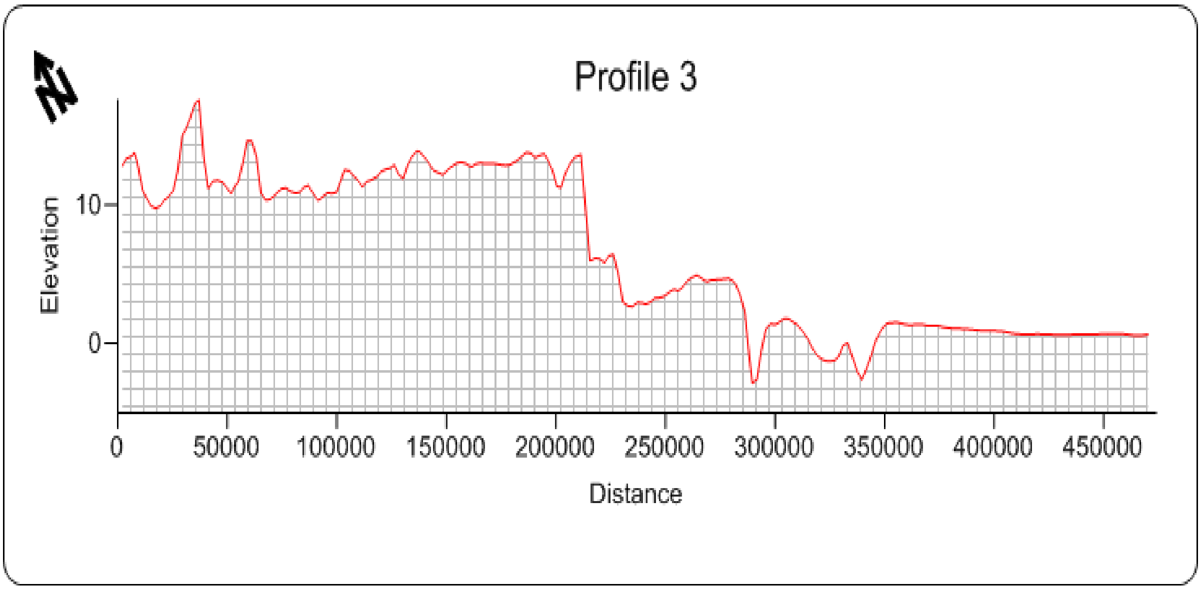


Figure13 Longitudinal profile of river Niger in the study area

Table 1 Morphometric attributes of Lower Niger basin

Basin Area			70959.175sq km		
Basin Lenght			745.976km		
Circulatory Ratio (Rc)			0.319		
Perimeter of Basin			1671947km		
Form Factor (Ff)			0.128		
Elongation Ratio (Re)			0.040		
Stream Frequency			2.452×10^{-3}		
Drainage Density			$0.0665\ km^{-1}$		
Stream Order	**Stream Number(Nu)**	**Stream Length**	**Mean Stream Length (Lsm)**	**Bifurcation Ratio(Rb)**	**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	3	650737	216912.3		1.003936

3.2 Discussion of result

The drainage channel network (figure 6) includes all stream and rivers in which water is concentrated. A cursory study revealed that majority of the stream are tributaries to river Niger while others are rivulets to benin river , Escavo river and river focados that terminates at Atlantic ocean. The channel networks in the study area, are predominantly dendritic drainage pattern **,**which was well formed by interlinking of the streams with its tributaries branching and rebranching freely in all directions. The morphology of the drainage channel network is important because it can be used to interpret the geological conditions responsible for certain patterns and what controls the texture of the patterns which in turn has an influence on the hydrology of the drainage basin. 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. The drainage order map (fig7) shows that the basin is a 4^{th} order basin. It further revealed that the basin has three (3) four order streams, thirteen (13) third order streams, twenty six(26) second order streams and one hundred and thirty two (132) first order streams. Fig 8 is the overlay analysis of the drainage on the sub-catchment map. This is invaluable for agricultural planning, and also for investigation of the source of stream pollution.. This study revealed that there are 79 sub-catchment within the basin with the smallest and largest sub-basins occupying area of $1km^2$ and *25489km* respectively

.A cursory examination of the the digital terrain model (fig9) shows that generally, there is hierarchy in the topography with reference to height and ruggedness of the relief. It shows range of -25m to 552m relative to mean sea level. The northen part of the basin is undulating high land while the southern part is flat.The surface analysis also reveals a wide valley which created a distinct dichotomy between the northern and central relief of the basin. slope of varying degrees (fig10) abound in the sudy area. In slope analysis, the range of values in the output depends on the type of measurement units. For degrees, the range of slope values is 0 to 90 and for percent rise, the range is 0 to essentially infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly large. The lower the slope value, the flatter the terrain while the higher the slope value, the steeper the terrain. The result of the processed data indicates that the basin is located on surface of slope range of 0 to 90 digrees. Aspect (Fig3.2) depicts the slope direction and is measured clockwise from 0° to 360°. It shows the direction of surface water flow. The aspect and slope is invaluable tools for erosion and flood modelling and can also be applied for suitability analysis of areas for agricultural practice.

longitudinal section (figure12) of the river Niger shows high irregular profile and gradual decrease in slope and elevation from the upstream (North) towards the flow outlet (downstream). The irregularities are due to the presence of resistance rock which is intermittent with less resistant rocks along the channel. This type of profile retards flow speed and lowers discharge and flood potential. The cross profiles (fig13) are of gentle steep and open sided form. This represents lateral cutting rather than down cutting erosion. Discharge and flow speed at any point along the course of a river is influenced by the slope and cross section at that point.

Table1 contain the quantitative attributes of the basin. The study revealed that the basin have a circulatory ratio, elongation ratio and form factor of 0.319, 0.128, 0.040 respectively. These attributes shows that the basin elongated in shape, which is an indication of low peak flow of longer duration . The bifurcation ratio (Rb) is defined as the ratio between the number of streams of a given order to the number of streams of the next higher orders (Strahler 1957). It is a dimensionless property which shows the degree of integration prevailing between streams of various orders in a drainage basin. In the present study, the Rb varied from 2.0 5.07. This indicates variations in geological and lithological features of the catchment. In general the bifurcation ratio is low indicating weak structural control. The drainage density and stream frequency of the basin are 0.0665 km^{-1} and 2.452 x 10^3 respectively. These characteristics indicate coarse drainage texture and shows that the basin is made of permeable sub-surface materials with low run off and erosion potential

IV. CONCLUSSION

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. Watershed characterization is inestimable for Conservation of natural resources, sustainable development, management and protection of our environment. Based on these it's facts, state-of-the-arts techniques that produce accurate result must be adopted to ensure a reliable and sustainable result. Morphometric descriptors represent the relatively simple approaches to describe the drainage basin processes. It is used to compare basin characteristics and enable understanding of geological geomorphic and hydrological history of the drainage basin. In this study, we were able to investigate lower Niger basin and delineate quantitative attributes using SRTM DEM data in GIS platform. It is inferred that lower Niger basin falls under 4th order basin and is dominated by lower order streams . Other morphometric attributes of the basin suggests that it is an elongated basin with low discharge potential. The database obtains through analysis of morphometric parameters would be suggested for its proper utilization in the integrated watershed programme aimed at development and management of water resources in the study area. It also attests the reliability of SRTM DEM data in morphormetric assessment of a river basin

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