Drainage Basin Morphology and Terrain Analysis of the Nigerian section of Lake Chad River Basin, Nigeria using GIS and Remote Sensing

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Abstract
The study aims to assess the effectiveness of Remote Sensing and Geographic information systems (GIS) in the mapping and morphological analysis of sub-basins in the Lake Chad Basin. This study evaluated morphometry parameters and terrain characteristics such as aspect, slope, channel networks, drainage density, stream orders, flow direction and accumulation of Lake Chad River Basin using GIS-based techniques. The morphological parameters of the sub-basins have been determined based on Strahler’s and Horton’s methods of stream ordering. The Shuttle radar topography mission (SRTM) data and ArcGIS 10.1 software were utilized for the analysis. The result established that the dominant flow directions of the river sub-basins are in the East and Northeast direction which is the direction of Lake Chad. Based on Strahler’s method of stream ordering, it revealed that the sub-basins have one (1)five order streams, six (6) four order streams, nineteen (19) third order streams, seventy one (71) second order streams and one ninety two (192) first order streams. Morphometric analysis of the sub-watersheds in the basins revealed a predominantly dendritic drainage pattern. In addition, the low drainage density value obtained (0.00202km) revealed that the sub-basins are not well-drained which indicates that the terrain is underlain by highly impermeable sub-surface material with low to moderate relief. The variation in the values of bifurcation ratio (Rb) of the basins varies from (2.70-6.00) with the mean bifurcation ratio (mRb) value of 3.90. This low value indicates that the drainage pattern lacks structural control or disturbances. This study showed that Remote Sensing and GIS can be effectively utilized as a viable tool to study river basins and their associated morphometry.

Keywords: Remote sensing, geographic information systems, Morphometry, Basin, Lake Chad

Introduction

Chad basin is the largest endorheic drainage basin in Africa, centered on Lake Chad. It has no outlet to the sea and contains large area of desert or semi-arid savanna. Nigeria has two sub-basins that drain into Lake Chad namely; The Yedseram/Ngadda sub-basin to the south; The Hadejia/Jama‘are-Komadougu/Yobe sub-basin to the North located in Yobe and Borno states at the northern part of Nigeria. The drainage basin is roughly conterminous with the sedimentary basin of the same name but extends further to the Northeast and Eastern part of Lake Chad basin (Wikipedia). Terrain consists of the physiography, lithology, morphometry, soil geography and to some extends land cover (Meijerink, 1988). The abiotic attributes (relief, geological or geomorphological processes, lithology, soil, etc) and hydrological condition complemented by vegetation/landcover types characterizes the terrain, (Van Zuidam, 1985). Terrain analysis consists of a set of activities that leads to the compilation of terrain characteristics which are used in terrain or land evaluation for various purposes. The term terrain denotes a variety of landscape types such as settlement, water, recreation, enclosed land, woodland, open land etc. Therefore, a complete understanding of a terrain involves knowledge of hydrology, geomorphology, pedology, climatology and ecology, which have a definite functional inter-relationship between them. Terrain evaluation is the primary requisite for regional and national planning, location of engineering structures such as dams, reservoirs, bridges and buildings, alignment of highways, rail, roads, pipelines, tunnels, canals etc. and slope stability studies. In terrain evaluation, segments of lands are assigned quantitative and qualitative grades on the basis of terrain characteristics, as well as on the objective of such evaluation. In this study, the topographical and hydrological analysis of the terrain in the sub-basins of the Lake Chad was evaluated. The main focus here is hydrological and surface analysis of drainage basins morphology in this area using Digital Elevation Model data (DEM). Remote Sensing is a very effective tool in the study of River Basins and their Morphology as well as their management. DEM comprises a large number of measurements of the elevation of the Earth’s surface. This is a raster representation, in which each grid cell records the elevation of the Earth’s surface, and reflects a view of terrain as a field of elevation values. GIS-based
evaluation using Shuttle Radar Topographic Mission (SRTM) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data has given a precise, fast, and an inexpensive way for analyzing hydrological systems (Smith and Sandwell, 2003; Grohmann, 2004). DEM can often be augmented with spot elevations, or GPS measurements. The availability of DEMs is critical for performing geometric and radiometric corrections for terrain on remotely sensed imagery, and allows the generation of contour lines and terrain models, thus providing another source of information for analysis. The digital elevation model (DEM) of the area was generated to deduce the morphometric parameters like drainage basin area, drainage density, drainage order, relief and network diameter in GIS environment. Combination of the remote sensing satellite data and hydrological and spatial analysis in GIS environment is made easy to identify and discriminate the drainage area (Pirasteh et al., 2010). The geographic and geomorphic characteristics of a drainage basin are important for hydrological investigations involving the assessment of groundwater potential, etc. The demand for DEM is growing with increasing use of GIS and with increasing evidence of improvement in information extracted using elevation data (for example, in discriminating wetlands, flood mapping, drainage networks and forest management).

Study Area
The two sub basins that drain into Lake Chad in Nigeria are located in Borno and Yobe States, which falls within Latitudes 10° N to 14° N and Longitudes 10°E to 15°E. These two sub-basins are named locally as The Yedseram/Ngadda sub-basin to the south and The Hadejia/Jama'are-Komadougou/Yobe sub-basin in the North (Fig.1). Lake Chad is a freshwater lake in the Sahelian zone of west-central Africa at the conjunction of Chad, Cameroon, Nigeria and Niger. It is situated in an interior basin formerly occupied by a much larger ancient sea that is sometimes called Mega-Chad. Lake Chad is a terminal depression with the seven basin countries grouped around it, of which four are in direct contact with the lake namely: Nigeria, Niger, Chad and Cameroon. The Yedseram River and its tributaries rise in the Mandara hills and it 'loses' most of its water while flowing northwards through a 7km-wide floodplain. Further downstream, together with the Ngadda River, it forms an 80km² swamp and does not maintain a definable water course to the lake. The Komadougou/Yobe River is the border between Nigeria and Niger over the last 300 km. Upstream of the confluence of the Hadejia and Jama'are rivers is where the Hadejia-Nguru wetlands (Fadamas) start. These cover a total area of about 6000 km² and a water surface area of about 2000km². However, the dam construction and increasing water abstraction for irrigation purposes upstream since the 1980s contributed to the fact that large areas of the floodplains are becoming increasingly drier.

![Figure 1: Map showing basins in Yobe and Borno States](image-url)
Materials and Methods
The Shuttle Radar Topography Mission (SRTM) imagery covering the study area was acquired through the U.S. Geological Survey Earth Resources Observation and Science Center (EROS) [http://earthexplorer.usgs.gov/](http://earthexplorer.usgs.gov/). The flow chart diagram of the methodology in (Fig. 2) was utilized to obtain the desired final output in form of maps. The remote sensing and Geographic Information System (GIS) software package, Erdas Imagine 9.2 was used for the preprocessing of the satellite data. The software was used specifically for atmospheric and geometric corrections. The ArcGis 10.1(ArcMap 10.1) was employed to extract the basins/watershed boundary and drainage/stream network using shuttle radar thematic mapper (SRTM) data. The Borno and Yobe states shapefile where the basins studied are located were clipped with DEM using ArcMap 10.1. The Strahler’s and Horton’s method of stream ordering was used to know the exact order of streams in the basins and bifurcation ratio (Rb) was used to determine the ratio number of stream segments of given order to the number of segments of the next higher order in the basins. It is considered as an index of relief and dissection, (Horton, 1945 and Schumm, 1956).

Data Preparation and Data Processing
The extraction of the DEM data using the shape files of the study area was subjected to two main processes (Fig.3);

1. **Hydrological Analysis**: this includes fill, flow directions, flow accumulation, channel network, stream order, and drainage density analysis etc.
2. **Terrain Analysis**: this includes slope, aspect, elevation, watersheds, and drainage networks.

Hydrological Processing
DEM data was projected before use so that the calculations will be as accurate as possible and to create a file that will preserve areas. The input raster is DEM and the output coordinate is WGS 1984 UTM zone 33N because the study area falls in the Northeastern part of Nigeria.
**Result and Discussion**

**Flow Direction**
This is one of the basic parameters of hydrological process. The Flow direction tool of ArcGIS 10.1 was used to determine the direction of flow to the individual cells. One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This was done with the Flow Direction tool. The input and output raster showing the direction of flow out of each cell creates a raster of flow direction from each cell to its steepest down slope neighbor. The areas of each value represent areas of similar aspect. The cells flow to their nearest neighbor along 1 of 8 compass directions labeled East =1, SE =2, S =4, SW=8, W=16, NW= 32, N=64, NE=128 Northeast and North which are the directions to Lake Chad, (Fig. 4).
Flow Accumulation

Flow accumulation gives the total area (number of cells times multiplied by the area of each cell) that is upslope and/or upstream of any given cell. 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. The input raster here is the flow direction generated. This results into grid of stream segments in the sub-basins.
Figure 5: Flow Accumulation map of Rivers in Yobe and Borno Basins

**Stream Order**

The Strahler’s method of stream order was used to know the exact order of streams in the basins in the study area, (Strahler, 1964). The study revealed that there are five stream order basins. The total number of fifth stream order in the basin is 1, which is the largest river that flows into the Lake Chad, there are six (6) fourth stream order which serve as tributaries to the fifth stream order and seventeen (17) third stream order which also serves as tributaries to the second stream order. Similarly, seventy one (71) second stream order serve as tributaries to the first order streams which has one ninety two (192). It was observed that the lower the order, the higher the number of streams in the order.
Figure 6: Stream Orders of Lake Chad Basin in Nigeria

**Bifurcation ratio (Rb)**

The variations in the values of the bifurcation ratios (Rb) of the basins varies from (2.70-6.00) with the mean bifurcation ratios (mRb) value of 3.90 which is under the range of 3.0 to 5.0 for basins. This low value (3.90mRb) indicates that the drainage pattern lacks structural control and disturbances (Strahler, 1964; Vittala et al., 2004; Chopra et al., 2005)

**Drainage Density**

The drainage density formula = \( \frac{\sum L}{\sum A} \)

Where, \( \sum L \) is the total length of streams in a basin;
\( \sum A \) is the total area of the basin

Stream length is defined as mean lengths of stream segments of each of the successive orders.

TOTAL LENGTH = 23186.15km

Total area of the basins in square metre = 115016000 km²

Drainage density = \( \frac{23186.15}{115016000} \) = 0.00202km

The drainage density value in this basin is very low (0.00202km) which indicates that the basin is underlain by a highly permeable subsurface material with low to moderate relief, a characteristic of a coarse drainage texture. This low drainage density value is also indicative of relatively long overland flow of surface water.
Channel Networks

The drainage channel network includes all stream and rivers in which water is concentrated and flows within a confined channel. While it is often difficult to clearly identify the starting point of a drainage channel, it is often one of the recognizable features of a catchment. The drainage network is characterized by streams and rivers of various sizes and having perennial, intermittent and ephemeral flow regimes. 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. However, the channel networks in the study area, as shown by the result of the processed DEM are predominantly dendritic drainage pattern, which was well formed by interlinking of the streams with its tributaries branching and rebranching freely in all directions, (Fig.7). This drainage pattern is diagnostic of relatively homogeneous materials such as horizontally bedded sedimentary rock and granite and lack of structural control.

Figure 7: Map Showing Channel Networks in Lake Chad Basin.
Slope

This is the gradient or rate of maximum change in value from each cell to its neighbor (Burrough, 1986). The slope tool in ArcMap calculates the maximum rate of change in value from each cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. 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 slope of the terrain is gentle slope which is highlighted in the map as light green and yellow most especially around the east and southeastern part of the study area, (fig.9). It also shows relative high slope value around the southern and southwestern part of the area where the rivers that drain into Lake Chad originate. (fig.8)

Aspect

The result of the aspect map produced (fig.6) indicates that the direction of slope of the terrain that fall within the two sub basins which drains into lake Chad is North-South dip direction and also the terrain is progressively flattened as we moved closer to the lake Chad as shown in the value assigned i.e. -1. It can be observed that East-facing slopes largely occur in the sub basins. Hence, these slopes have a higher moisture content and lower evaporation rate.
Conclusion

Drainage morphology analysis is essential to any hydrological study. Hence, the determination of stream networks behavior and their interrelation with each other is of great importance in many water resources studies. Remote sensing satellite data and GIS technologies have been proved substantially to be an effective tool in drainage delineation. In this study, Remote sensing satellite data (SRTM) and GIS tools for drainage analysis has been employed to evaluate several drainage parameters. Therefore, the morphometric analysis of the Lake Chad sub basins (i.e., Bornu and Yobe) was delineated. The study revealed that the sub basins have five (5) stream order basins. Specifically, the total number of the streams in first order is one ninety two (192), with the second order having seventy one (71), third order (19), fourth order (6) and fifth order (1) respectively. The dominant flow directions of rivers in the basins are to the northwestern part of the study area i.e., direction to the Lake Chad basin. The morphometric analysis of the sub-watersheds in the basin revealed a predominantly dendritic drainage pattern which is formed by interlinking of the streams. As a result of this, the sub basins indicate there is homogeneity in the lithology. In addition, the variation in the values of the bifurcation ratios (Rb) of the basins varies from (2.70-6) having a mean bifurcation ratio (mRb) value of 3.90. However, this low value (3.90mRb) indicates that the drainage pattern of the basins lacks structural control or disturbances (Strahler 1964; Vittala et al., 2004; Chopra et al., 2005). The very low drainage density value of the basins (0.00202km/km²) implies that the basins are underlain by a highly permeable sub-surface material, with low to moderate relief, a characteristic of a coarse drainage texture.
References


https://en.wikipedia.org/wiki/ChadBasin