Application of geographic information system and remote sensing in assessment of stream order and drainage pattern of selected watersheds in Akwa Ibom, Southern Nigeria

Ahuchaogu, I. I[1], Michael M. E[1],Oisakede E. E[2], Udoumoh, U. I[2], Obineche, C. I[3*]

(1. Department of Agricultural and Food Engineering, University of Uyo, Uyo, 520001 Nigeria;
2. Department of Civil and Water Resources Engineering, University of Delta, Agbor, Delta State,321271 , Nigeria;
3. Department of Agricultural Engineering Technology, Federal College of Land Resources Technology Owerri, Imo State, 460001, Nigeria)

Abstract: A watershed, also referred to as a drainage basin or catchment area, represents a geographical region where surface water converges to a common outlet such as a river, lake, or ocean. Morphometric parameters of watershed can be quantified using geographic information system (GIS) and remote sensing (RS) techniques. This study applies RS and GIS tools to delinate and analyzes three watersheds located in Akwa Ibom State, Nigeria, where limited data currently exist on morphometric characteristic and their implications for watershed management. Shuttle radar topographic mission (SRTM) data, processed with SAGA GIS software, were utilized to generate digital elevation models (DEMs) for boundary delinatin and morphometric analysis. The results reveal that the basin morphology is largely influenced by tectonic activities such as faulting and of thrusting, while the dominance lower-order streams indicates that stream development is primarily controlled by rainfall patterns. The findings highlight the effectiveness of GIS-based morphometric analysis in providing essential hydrological information for watershed planning and sustainable water resource management.

Keywords: Delineation, drainage basin, remote sensing, digital elevation model

Citation: Ahuchaogu, I. I., M. E.Michael, E. E.Oisakede, U. I.Udoumoh, and C. I.Obineche. 2026. Application of geographic information system and remote sensing in assessment of stream order and drainage pattern of selected watersheds in Akwa Ibom, Southern Nigeria. Agricultural Engineering International: CIGR Journal, 28(1): 1-11.

1 Introduction

A watershed is the land area where precipitation and snowmelt drain toward a common outlet, such as a stream, river, or reservoir (Ragi and Mallikarjuna, 2023). Every region, including urban areas, forms part of a watershed system. The hydrological characteristics of a watershed, such as mean annual discharge, flood frequency, groundwater recharge, and stream-flow are greatly influenced by land use and land cover changes. Excessive land modification, deforestation, and urbanization tend to reduce vegetation cover, leading to increased surface runoff, diminished infiltration, and decreased water retention (Ragi and Mallikarjuna, 2023). In the same vein, Clarke (1966) explained that, the morphometry

Received date: 2025-02-25 **Accepted date:** 2025-11-27

***Corresponding author: Obineche, C. I.** Department of Agricultural Engineering Technology, Federal College of Land Resources Technology Owerri, Imo State, Nigeria. Email: ikechiobineche@gmail.com.

involves the measurement and quantitative analysis of the earth's surface configuration and the shape and dimensions of landforms. This analysis encompasses linear, areal, and relief parameters of drainage basins (Nag and Chakraborty, 2003; Ali, 1988). Linear parameters include stream order, stream number, and bifurcation ratio, while areal parameters comprise drainage density, stream frequency, drainage texture, circularity ratio, and length of overland flow. Morphometric analysis provides quantitative insights into basin geometry, aiding the understanding of geological structure, geomorphic evolution, and hydrological behavior (Strahler, 1964). In addition, Modern geospatial technologies have revolutionized morphometric studies by enhancing accuracy and efficiency. Remote sensing, particularly through satellite imagery and digital elevation model (DEM), offers a synoptic view of large areas and facilitates rapid, cost-effective watershed delineation (Shekar and Matthew, 2023). Similarly, geographic information system (GIS) provides a robust framework for managing spatial datasets, enabling the computation, visualization, and interpretation of morphometric parameters with high precision (Shekar et al., 2023; Shekar et al., 2023). Also, by integrating GIS and remote sensing (RS) tools, researchers can better interpret the interactions among geomorphology, hydrology, and environmental factors, thus improving watershed assessment and management. Therefore, this study aims to utilize GIS-based hydrological modeling and Shuttle radar topographic mission (SRTM) DEM data to delineate drainage basins, identify sinks, analyze flow directions and accumulation, and generate stream networks for selected watersheds in Akwa Ibom State, Nigeria.

2 Materials and methods

2.1Study area

Akwa Ibom is one of the oil producing state in Nigeria; it is located in the coastal southern part of the country. It lies on a coordinate between latitudes 4°32′N and 5°33′N, andlongitude7°25′Eand 8°25′E**.** It is within the equatorial rain forest belt, which is a tropical zone forest that houses vegetation of green foliage of trees shrubs and oil trees(Udo-Inyang and Edem, 2012). Figure 1, shows Map of Nigeria indicating the location of the study area while, Figure 2 shows the map of Akwa Ibom State showing the studied watershed (ASTAL,2021). Akwa Ibom state is located in the South geopolitical zone, and is bordered on the east by Cross River State, on the west by Rivers State and Abia State, and on the south by the Atlantic Ocean (Gulf of Guinea) and the southernmost tip of Cross River State, with an area of 7081 km^2.

The rainfall in the area is seasonally, convectional and spatial in distribution. The mean annual rainfall ranges from 1599mm to 3855.9mm. Maximum humidity is recorded in July while minimum humidity occurs in January. Evaporation is high and an annual values range from 1500mm to 1800mm.Its tropical climate was marked by two distinct seasons: the dry season (November – March) and the wet season (April – October). The wet season is usually interrupted by a short dry period in August (ASTAL, 2021). The State also has three distinct vegetation zones: the saline water swamp forest, the fresh water swamp forest and the rain forest tributaries. The landscape of Akwa Ibom is mostly flat. This is because the underlying geology of the state is predominantly coastal plain sediments. The coastal nature of the state makes it the natural deposit of mosaic of marine, deltaic, estuarine, lagoonal and fluvio- lacustrine material.

2.2 Data processing

This research downloaded the DEM for the study area in Raster format with a resolution of 30m from the website (https://earthexplorer.usgs.gov). The downloaded DEM were projected to convert its coordinates from the geological coordinates to universal transverse mercator (UTM) coordinates under the classification of the world geodetic system (WGS) of the year 1984 using the "Project" tool in ArcGIS10.8 software. Six DEM tiles of Akwa Ibom state were downloaded covering the entire study area and beyond. The tiles of the DEM were mosaicked using the "Mosaic" tool in ARGGIS 10.8 software into a single DEM data covering the entire study area. The DEM data come with inherent errors called Sinks. It is important to use a DEM with no depressions or sinks. The sinks in the elevation grid from the DEM layer were removed using the "Fill function" of the Hydrology toolbox, Sinks in elevation data are most commonly due to errors in the data. These errors are often caused by sampling effects and the rounding of elevations to integer numbers. Subsequent hydrological analysis was then carried out using this DEM. DEM denote height information of a continuous surface, hill shading, digital surface shaded relief, slope, basin area, stream order, among others.

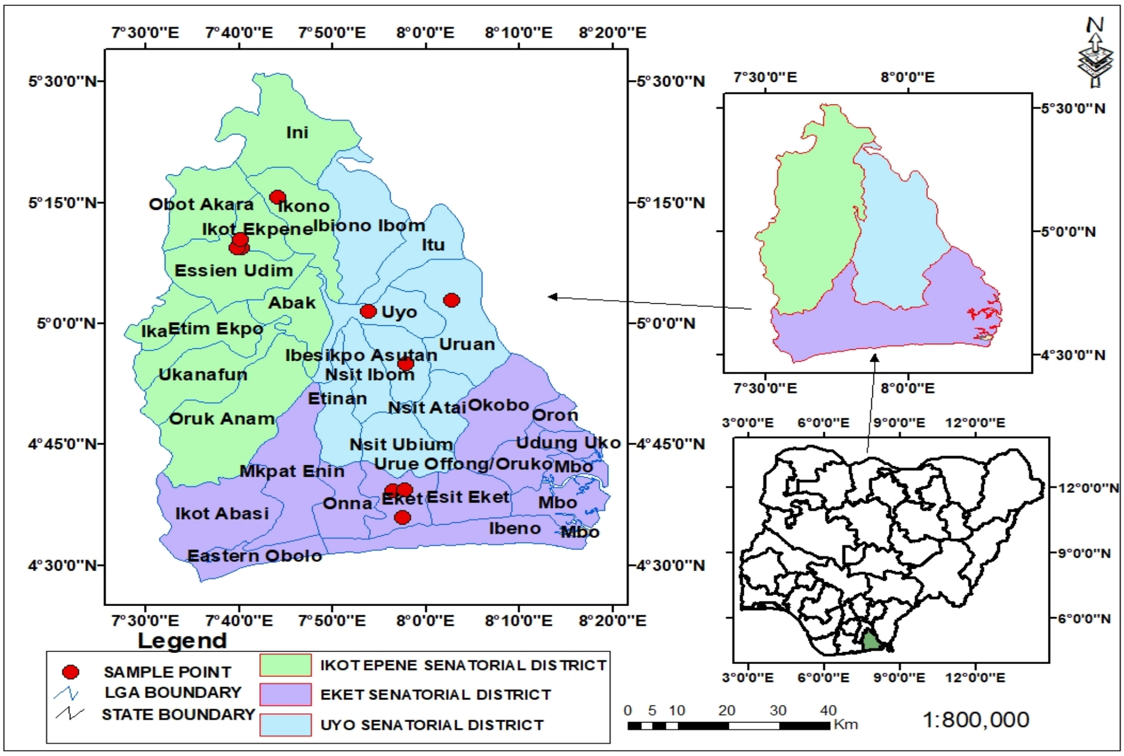

Figure 1 Map of Nigeria showing Akwa Ibom State(Source: ASTAL,2021)

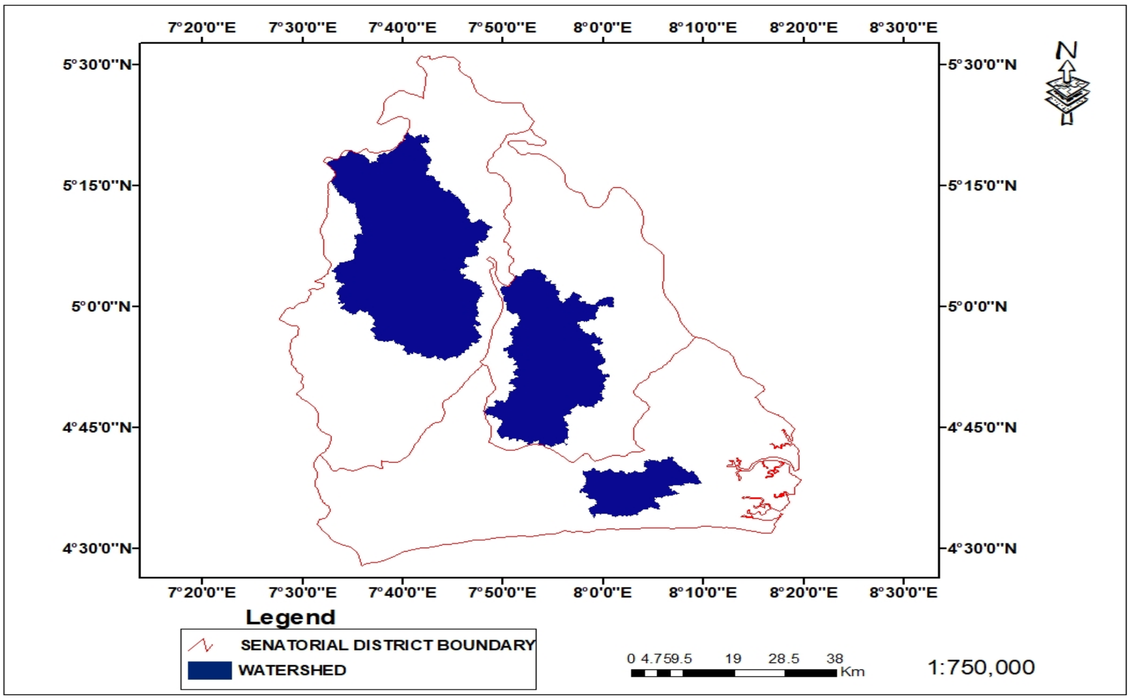

Figure 2 Akwa Ibom map showing the watershed area (Source: ASTAL,2021)

2.3Estimation of watersheds morphometric parameter using GIS and RS

Mapping out the watershed for the study area and other morphometric parameters which are the three geopolitical zones of Akwa Ibom state, were estimated from Advance Space Technology Application Laboratory (ASTAL), following the method cited by Strahler(1964), Dodson and Li(1999), and Bilewu et al.(2015). The DEM from the shuttle radar topography mission (SRTM) was used, which is a global research shuttle own by the United States Geological Survey that provides a geological, topographic and meteorological database for the Earth in a medium resolution digital format represented by DEM. The SRTM data for the world were processed into geographic "tiles," and each of them represents one degree by one degree of latitude and longitude and is represented by geographic coordinates.

2.4 Watershed delineation

Watershed delineation can be used to develop water resource management plans, including flood control and water supplies strategies. The features of a drainage system can be quantified with the use of morphometric analysis. Using this data, we can pinpoint problem regions prone to erosion and floods. The following procedure was adopted in the use of the software to delineate the watershed from the imagery obtained from the SRTM. Figure 5 gives a flowchart for the watershed delineation.

2.4.1 Determination of flow direction and flow accumulation

To understand the hydrologic characteristics of a surface requires knowing the flow direction from each raster pixel. With a surface as its input, this application generates a raster with the flow directions for each individual cell. A cell in an elevation raster will get the flow if it is lower than its neighbor. When many of a cell's neighbors have the lowest values, the flow is estimated in an elevation raster by eliminating the cell's sink. To delineate the major watershed of the three geopolitical zones of the study area, the boundary map of the senatorial district was used to subset the Filled DEM using the "Clip" function in the data management tool in ARCGIS 10.8. Each senatorial district DEM was used to generate the flow direction using the "flow direction function". To determine the flow direction is the first step in delineating watershed. The Eight- direction (D8) flow method models follow an approach presented in Jenson and Domingue (1988) was used to compute the flow direction from each cell to its steepest down slope neighbor. The code for direction of flow, the elevation values and the flow direction from the center are as presented in Figure 3a, 3b and 3c.

The Flow accumulation is computed using the flow direction as an input data. Flow accumulation is the number of upstream cells which drain through a certain cell. Flow accumulation grid illustrates the number of pixels which drains into a given pixel base on the flow direction. The flow accumulation was used to delineate sub-basins and subsequently the whole watershed. Flow accumulation tool in ArcGIS toolbox was used to calculate flow accumulation.

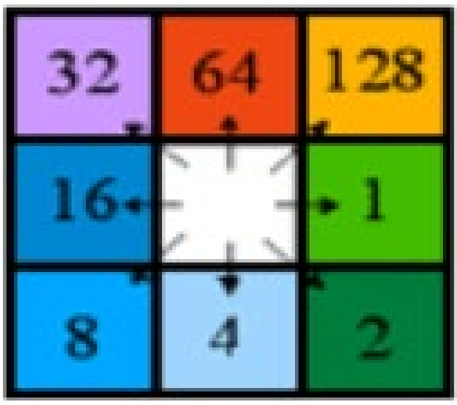

Figure 3(a) The code for direction of flow

Below is the representation of elevation data and the flow direction.

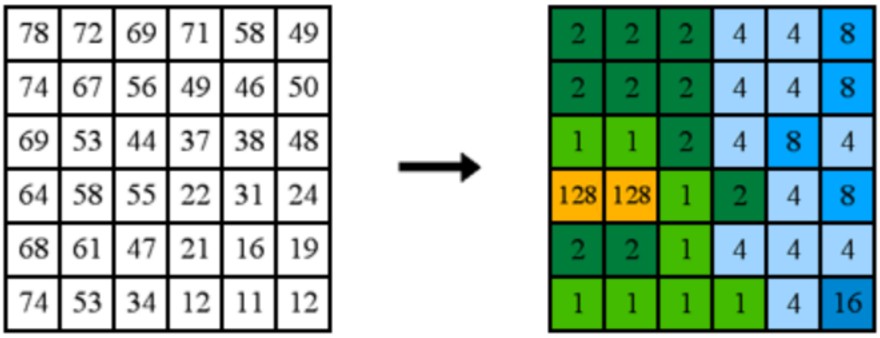

Figure 3(b) Elevation value Figure 3(c) Flow direction from each cell

Figure 3 The code for direction of flow

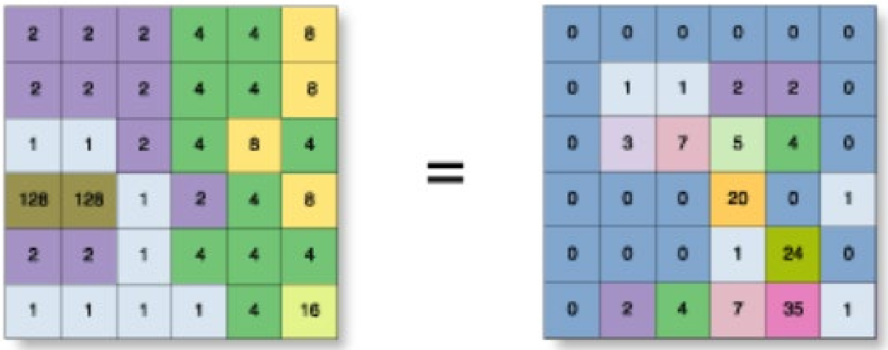

Figure 4 Flow direction resulting in flow accumulation

2.5 Watershed boundary delineation

To delineate the watersheds, the DEM was done by computing the flow direction and pour point as input, using the Watershed tool in ArcGIS 10.8 software. To determine the contributing area, a raster representing the direction of flow must first be created with the flow direction tool. The pour points for the watershed would be the junctions of a stream network derived from flow accumulation threshold.

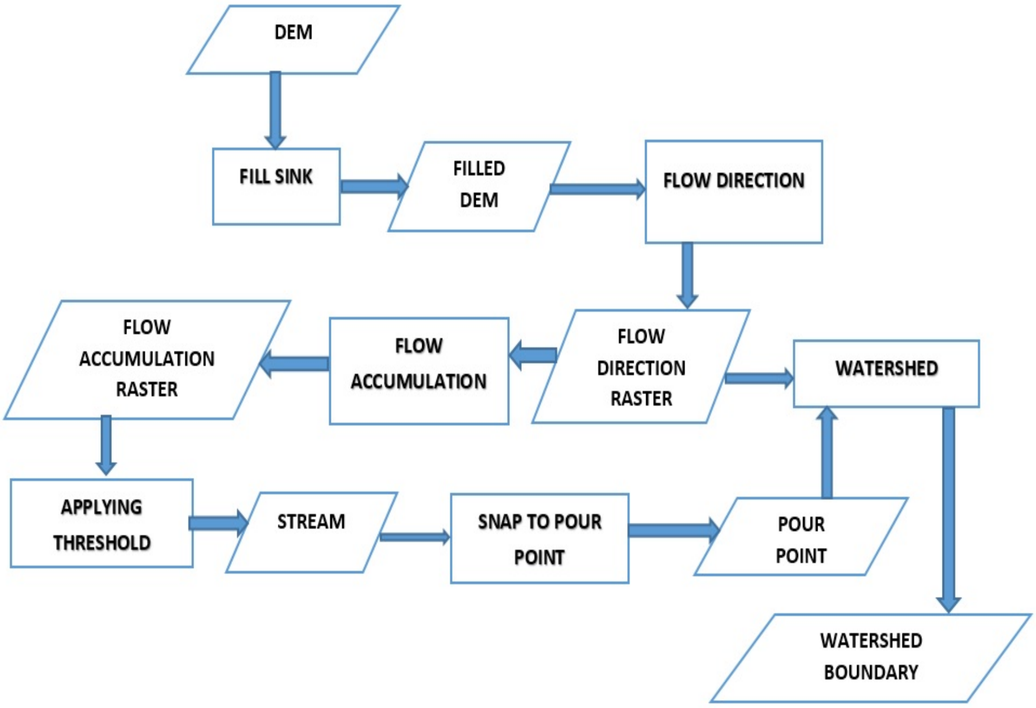

Figure 5 Watershed delineation methodology

3 Result and discussion

3.1 DEM and terrain characteristics

The filled DEM for Akwa Ibom State reveals significant topographic variation. Higher elevations dominate the northern and eastern regions, decreasing progressively toward the south and southwest, with values ranging from approximately 148 m to –2 m. This terrain gradient controls the general flow direction and hydrologic connectivity across the basins. The DEM outputs processed using SRTM data in ArcGIS 10.8 enabled watershed delineation and extraction of drainage networks for the three senatorial districts: Uyo, Ikot Ekpene, and Eket.

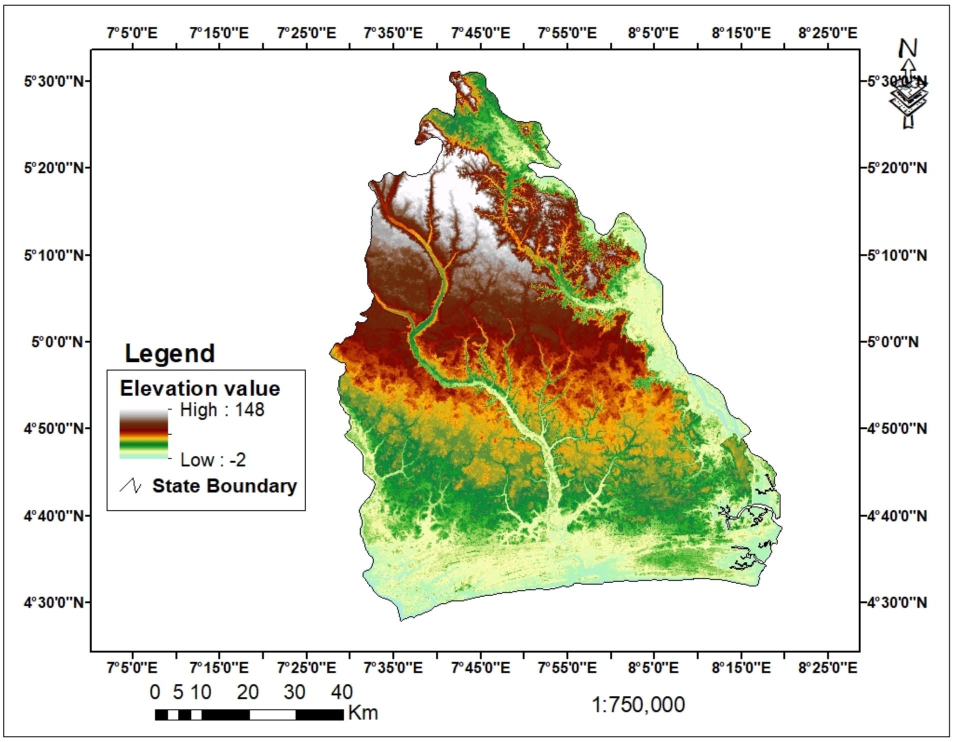

Figure 6 DEM Map of Akwa Ibom State

3.2 Stream order analysis

Stream ordering provides insight into drainage structure and hydrological behavior. The study area contains first-, second-, and third-order streams, with first-order streams being predominant. Ikot Ekpene exhibits the greatest density of first-order streams (25), followed by Uyo (17) and Eket (7). The abundance of lower-order streams indicates a complex and responsive drainage system capable of rapidly generating runoff during rainfall. Notably, Ikot Ekpene also has the greatest cumulative stream length, suggesting a more extensive drainage network.

The result of the stream order shows the drainage pattern ranges from the first, second and third order as shown in Tables 1-3.

Table 1 Stream order of Eket senatorial district watershed

Stream order	Stream length(km)	Number
First	25.02	7
Second	9.10	2
Third	16.26	4

Table 2 Stream order of Ikot Ekpene senatorial district watershed

Stream order	Stream length(km)	Number
First	156.21	25
Second	69.27	15
Third	42.16	9

Table 3 Stream order of Uyo senatorial district watershed

Stream order	Stream length(km)	Number
First	76.41	17
Second	35.76	9
Third	25.03	7

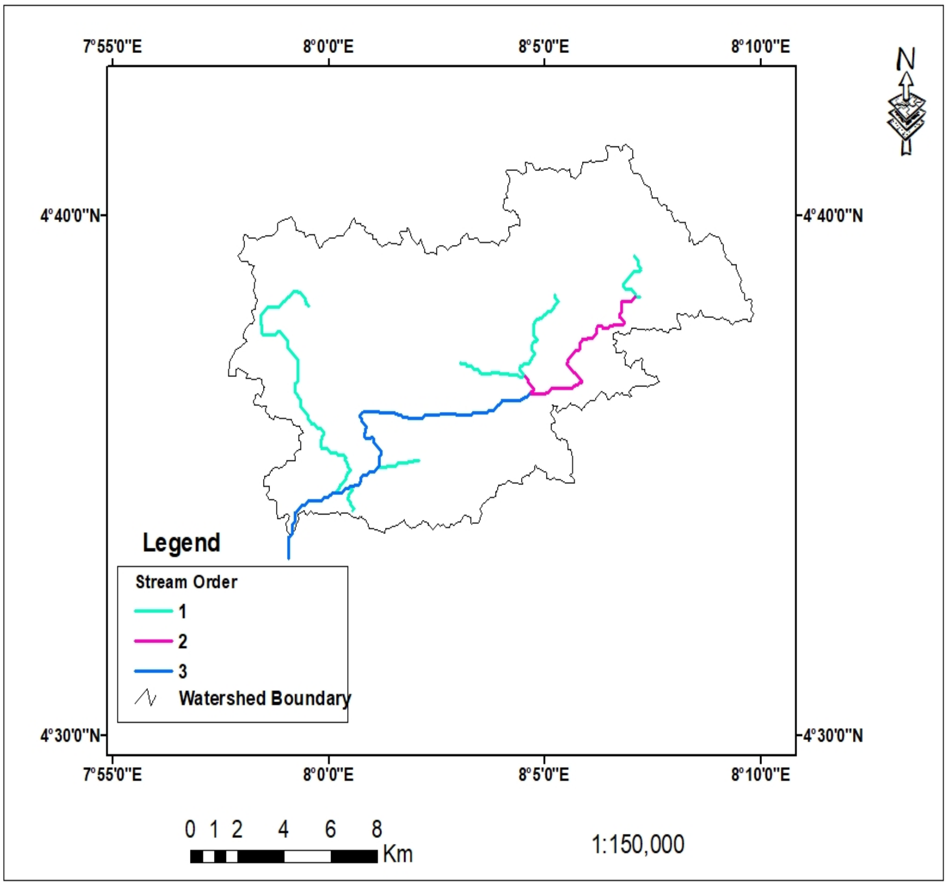

Figure 7 Stream order of Eket senatorial watershed

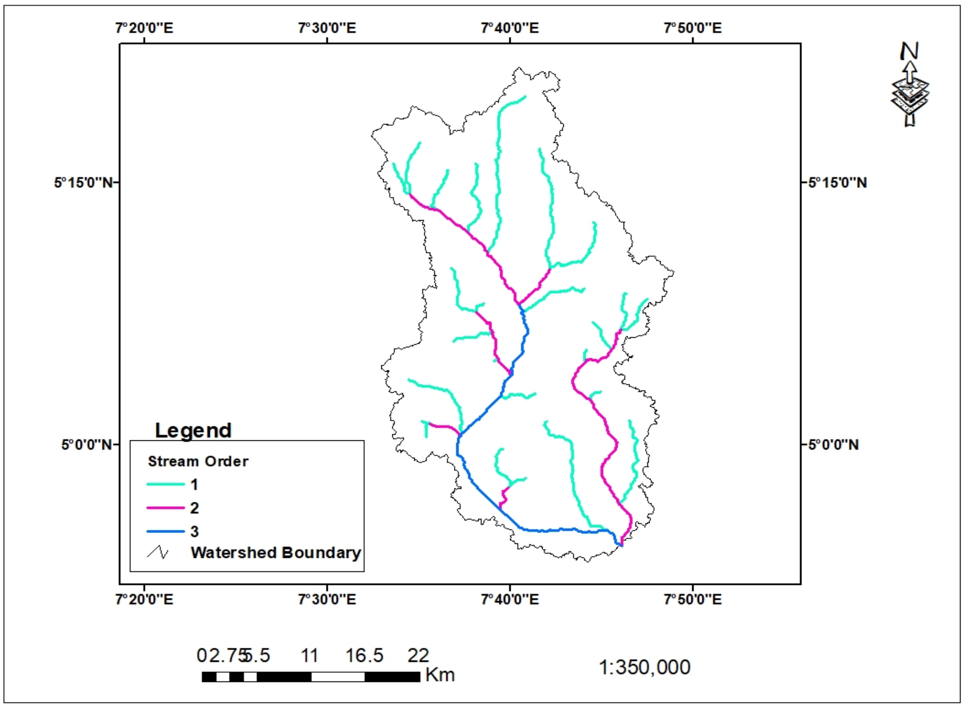

Figure 8 Stream order of Ikot Ekpene senatorial district

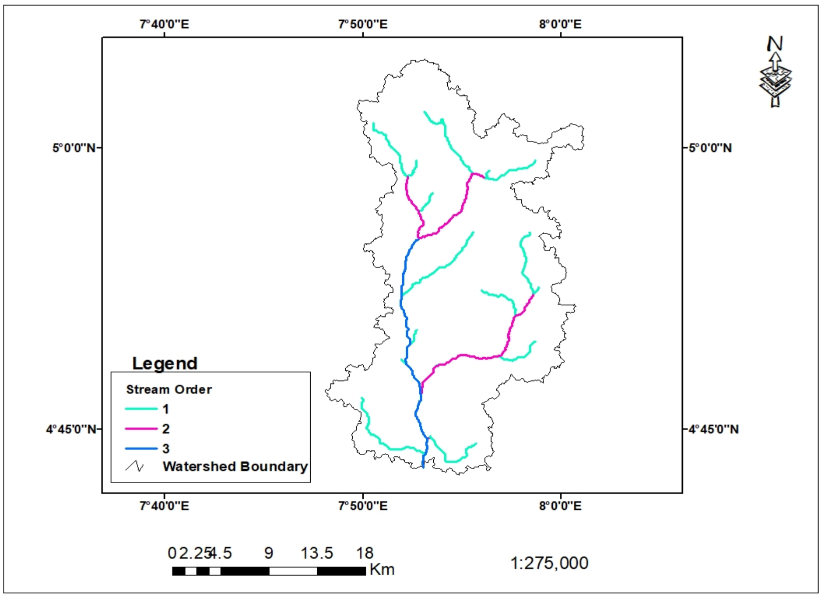

Figure 9 Stream order of Uyo senatorial district

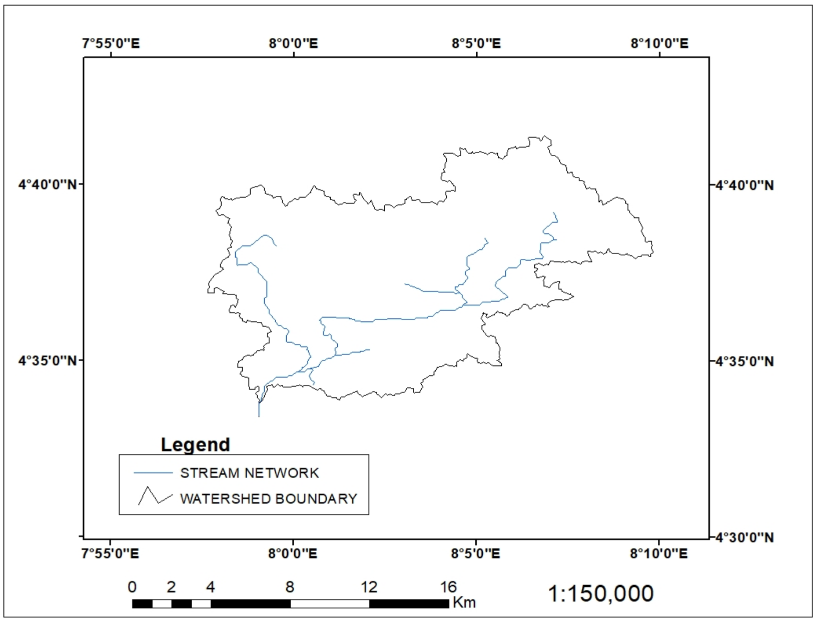

Figure 10 Stream Network for Eket senatorial district

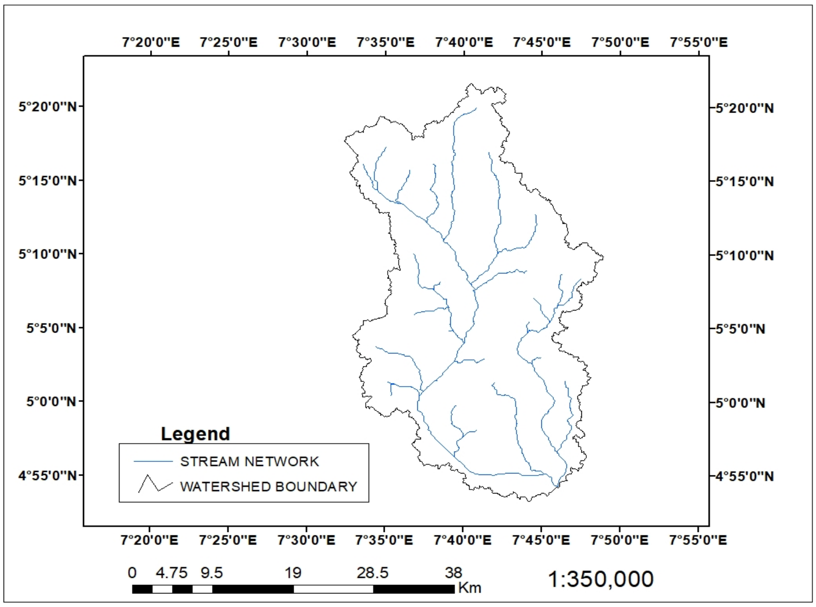

Figure 11 Stream Network for Ikot Ekpene senatorial district

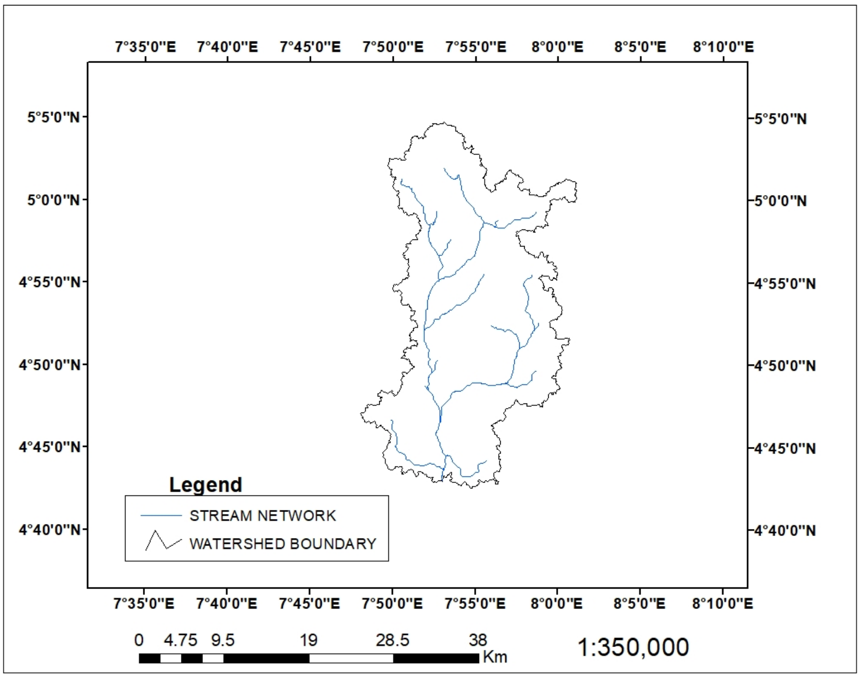

Figure 12 Stream Network for Uyo senatorial district

3.3 Flow direction and hydrological implications

Flow direction maps indicate prominent southward and southwestward flow patterns. Multiple tributaries converge into major rivers such as Qua Iboe River (Eket), Iba Oku Stream (Uyo), Nwaniba River (Uyo), and Udo Anwankwo River (Ikot Ekpene). Basin hydrology is strongly influenced by these tributary networks, which amplify runoff concentration. Additional regional systems such as the Imo River, Cross River, and Kwa Iboe River also significantly shape hydrological dynamics.

The merging of numerous first- and second-order channels into higher-order streams increases discharge potential, making areas with dense tributary networks highly susceptible to flooding. Flood magnitude is further influenced by rainfall variability, soil infiltration characteristics, land use, surface geology, and channel connectivity.

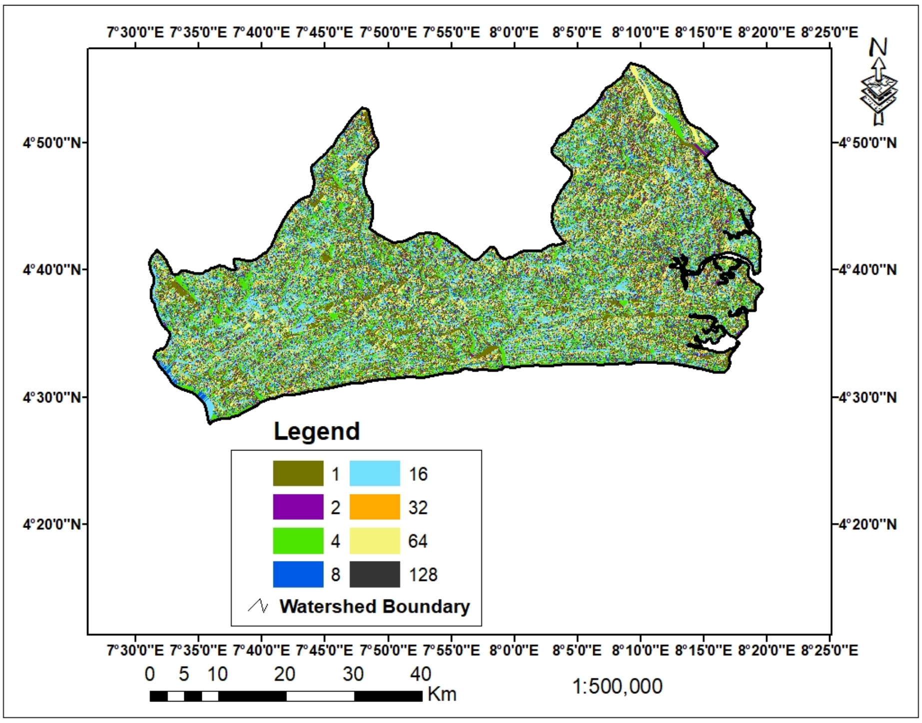

Figure 13 Flow direction for Eket senatorial district

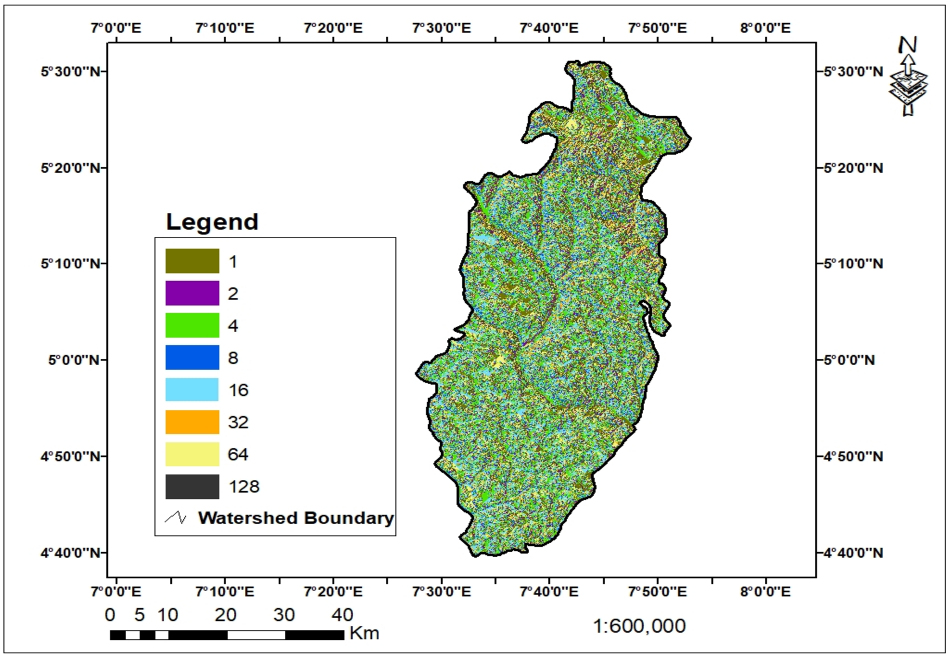

Figure 14 Flow direction for Ikot Ekpene senatorial district

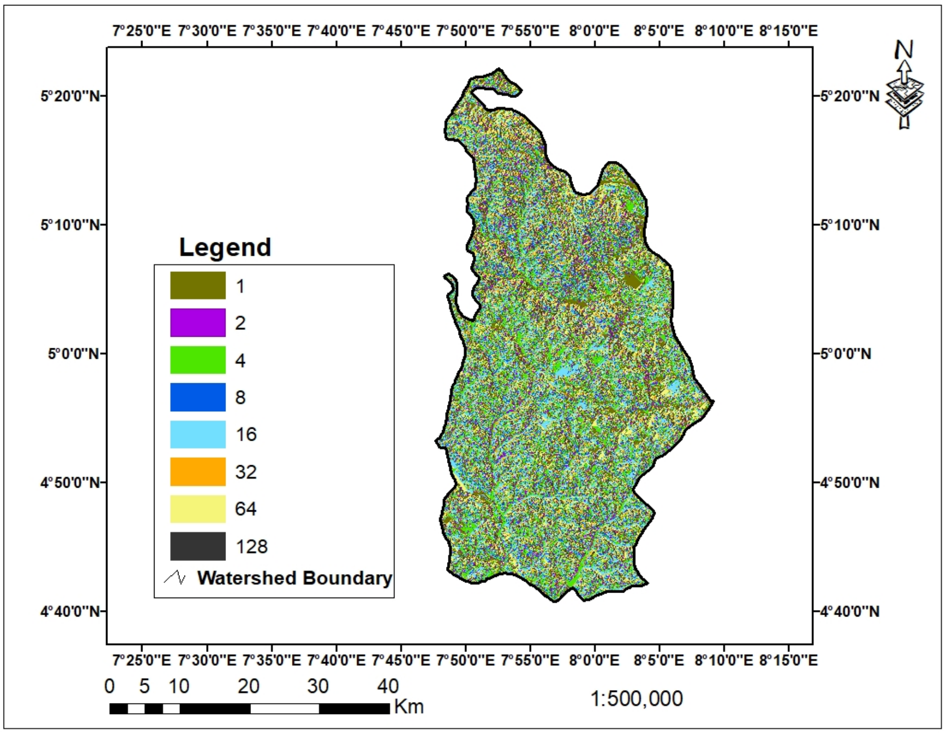

Figure 15 Flow direction for Uyo senatorial district

3.4 Relationship between stream order and flood magnitude

Stream order strongly governs flood behavior in the study area. Lower-order streams contribute substantial runoff to larger rivers, increasing flow velocity and volume during peak rainfall. Flow accumulation maps show thickened drainage lines representing major flood paths originating from the main rivers. These findings highlight the importance of morphometric parameters in identifying flood-prone areas and understanding watershed responses.

4 Conclusion

Morphometric analysis supported by DEM and GIS techniques provides an effective framework for understanding hydrological processes and flood sensitivity within the drainage basins of Akwa Ibom State. The study reveals that the basins are dominated by lower-order streams, which play a critical role in runoff generation and concentration. Terrain slope and stream order configuration significantly influence flow direction, drainage efficiency, and flood vulnerability.

The DEM effectively characterized elevation gradients and hydrologic pathways, while the drainage network analysis highlighted the key role of tributaries feeding major rivers such as Qua Iboe, Nwaniba, and Iba Oku. These rivers exhibit increased flood susceptibility due to contributions from numerous headwater streams.

The findings underscore the value of morphometric analysis in watershed planning, environmental management, and flood mitigation. The results serve as a baseline for hydrological modeling, identification of ecologically sensitive zones, and formulation of sustainable watershed management strategies for Akwa Ibom State.

References

Ali, S. A. 1988. Morphometric Analysis of the Hiyunl River Basin at Rishikesh, Garhwal Himalayas, India.In *Proceedings of the IX Asian Conference on Remote Sensing*,pp. B-9-1B-9-8. angkok, 23-29 November

ASTAL. 2021. Advanced Space Technology Laboratory.Uyo,Nigeria:Federal Ministry of Science and Technology.

Bilewu, S.O., B. Sule, and A. Ayanshola. 2015. Optimum Parameter Selection for the Morphometric Description of Watersheds: A Case Study of Central Nigeria. *Journal of Ecological Engineering*, 16(4): 29-35.

Clarke, J. I. 1966. Morphometry from Maps. In *Essays in Geomorphology*, ed. G. H. Dury, ch. pp 235-274.New York, USA: Elsevier Publishing Company.

Dodson, R. D., and X. Li. 1999. The Accuracy and Efficiency of GIS- based Floodplain Determinations. In *19th ESRI International proceedings of User Conference*, Abstract, San Diego, CA: ESRI 281-440-3787, July 1999

Jenson, S. K., and J. O. Domingue.1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis. *Photogrammetric Engineering and remote Sensing*, 54(11): 1593-1600.

Nag, S. K., and S. Chakraborty. 2003. Influences of rock types and structures in the development of drainage network in hardrock area. *Journal of Indian Society- Remote Sensing*, 31(1):25-35.

Ragi, R., and V. Mallikarjuna. 2023. Watershed delineation and morphometric analysis using GIS and remote sensing. *E3S Web of Conferences*, 399: 02002.

Shekar, P. R., and A. Mathew. 2023. Detection of land use/land cover changes in a watershed: A case study of the Murredu watershed in Telangana state, India. *Watershed Ecology and the Environment*, 5: 46-55.

Shekar, P. R.,A. Mathew, H. G. Abdo, H. Almohamad, A. A. A. Dughairi, and M. Al-Mutiry. 2023. Prioritizing sub-based watersheds for soil erosion using geospatial techniques based on morphometric and hypsometric analysis: a case study of the Indian Wyra basin. *Applied Water Science*,13(7):160.

Strahler, A. N. 1964. Quantitative Geomorphology of Drainage Basins and Channel Networks. In*Handbook of Applied Hydrology*, ed. V. T. Chow, ch. 4-11:, 439-476. New York, USA:McGraw-Hill Book Company.

Udo-Inyang, U. C., and I. D. Edem.2012. Analysis of rainfall trends in Akwa Ibom State, Nigeria. *Journal of Environment and Earth Science*,2(8): 60-70.