

# DEM-BASED GIS ANALYSIS OF HYDROLOGICAL BEHAVIOUR IN THE ENUGU BASIN, SOUTH-EASTERN NIGERIA

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## ABSTRACT

This study applied Digital Elevation Model (DEM) based Geographic Information System (GIS) hydrological modelling to analyse terrain-controlled hydrological behaviour within the Enugu Basin, southeastern Nigeria. Unlike earlier studies that relied largely on descriptive geomorphology, this research employs reproducible GIS procedures to quantify drainage organisation, flow convergence and terrain influence on runoff processes. A 30-m resolution Shuttle Radar Topography Mission (SRTM) DEM was processed in ArcGIS 10.8 using sink filling, Deterministic Eight-node (D8) flow-direction, flow-accumulation and watershed delineation algorithms. The results reveal structurally controlled drainage patterns, distinct runoff convergence zones and a strong topographic control on hydrological response across the basin. Flow-accumulation outputs highlight potential runoff concentration corridors rather than direct erosion magnitudes, consistent with established hydrological theory. These patterns indicate areas of heightened hydrological vulnerability linked primarily to terrain configuration and drainage connectivity, corroborating previous studies in southeastern Nigeria. The findings demonstrate that DEM-derived hydrological layers provide an objective basis for identifying erosion-prone zones, guiding flood-risk screening and informing land-use suitability assessments in data-scarce environments. The study further underscores the need to integrate DEM-based hydrological modelling into environmental planning, erosion-control strategies and watershed-scale management frameworks within the Enugu Basin. It also highlights the importance of field validation, institutional capacity building and the future adoption of higher-resolution elevation data to improve micro-scale runoff characterisation. Overall, the research confirms the analytical value of DEM-based GIS hydrological modelling as a cost-effective and scientifically robust approach for sustainable land-use planning and environmental management in developing regions.

**Keywords:** Digital elevation model, GIS hydrology, flow accumulation, terrain analysis, Enugu Basin.

## Introduction

Understanding basin-scale hydrological behaviour is fundamental to effective watershed management, erosion control and flood mitigation. Advances in Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) have transformed hydrological analysis from largely descriptive approaches to quantitatively reproducible modelling frameworks (Lindsay, 2019; Teng et al., 2020). DEM-derived hydrological parameters such as flow direction, flow accumulation and watershed boundaries provide objective measures of terrain control on surface runoff dynamics.

In southeastern Nigeria, rapid urban expansion, deforestation and increasing rainfall variability have intensified surface runoff and erosion hazards, particularly within structurally complex sedimentary basins such as the Enugu Basin. While several studies have examined gully erosion and morphometric characteristics of drainage basins in the region (Eze & Efiog, 2010; Aghamelu & Okogbue, 2011), many rely on limited morphometric indices or qualitative field observations. Few studies apply fully reproducible DEM-based hydrological modelling workflows capable of objectively identifying runoff convergence zones and drainage connectivity.

A further limitation in previous research is the tendency to reference broad environmental or climatic classifications without integrating them analytically into hydrological modelling. Contemporary hydrological scholarship emphasises that terrain configuration, rather than general climatic zonation alone, exerts primary control on drainage organisation at basin scale (Beven & Kirkby, 2018; Tarboton et al., 2022).

Against this background, this study addresses the following research problem: How does terrain structure, as represented by DEM-derived hydrological parameters, control surface hydrological behaviour within the Enugu Basin? By applying standardised GIS hydrological algorithms, the study aims to provide a methodologically transparent and empirically grounded assessment that complements existing regional geomorphological studies.

## Statement of the Problem

Despite persistent erosion and flood-related challenges in the Enugu Basin, hydrological assessments remain largely descriptive and lack reproducible spatial modelling. The absence of DEM-based hydrological analyses limits the ability of planners and environmental managers to identify runoff convergence corridors and terrain-induced hydrological sensitivities. This methodological gap constrains evidence-based land-use planning and erosion-control interventions in the basin.

## Aim and Objectives of the Study

The aim of this study is to analyse terrain-controlled hydrological behaviour in the Enugu Basin using DEM-based GIS modelling. The specific objectives are to:

1. Delineate the Enugu Basin and its drainage structure using DEM-derived hydrological algorithms.
2. Analyse flow-direction and flow-accumulation patterns to identify runoff convergence zones.
3. Examine how terrain configuration influences hydrological connectivity and surface runoff behaviour.
4. Discuss the implications of the observed hydrological patterns for erosion risk and land-use planning.

## Literature Review

### Digital Elevation Models and GIS-Based Hydrological Modelling

Digital Elevation Models provide the foundational data for modern hydrological analysis by representing terrain as a continuous surface from which hydrological parameters can be derived (Wilson & Gallant, 2000). The Deterministic Eight-node (D8) algorithm remains one of the most widely applied flow-direction models, assigning flow from each grid cell to its steepest downslope neighbour (O’Callaghan & Mark, 1984). Although alternative algorithms exist, D8 remains appropriate for basin-scale screening in data-limited environments (Tarboton et al., 2022).

Flow accumulation quantifies the number of upstream cells contributing flow to each location, thereby identifying relative runoff convergence zones rather than absolute discharge volumes (Lindsay, 2019). Recent studies emphasise that accumulation values must be interpreted relative to DEM resolution and analysis scale, not as direct indicators of erosion magnitude (Teng et al., 2020).

Hydrological enforcement through sink filling is a critical preprocessing step, ensuring drainage continuity and preventing artificial flow termination caused by DEM artefacts (Jenson & Domingue, 1988; Schwanghart & Scherler, 2017).

### Terrain Control and Basin Hydrological Behaviour

Hydrological systems theory recognises terrain configuration as a primary control on drainage organisation, runoff velocity and connectivity (Beven & Kirkby, 2018). Steep or structurally controlled landscapes tend to exhibit rapid hydrological response and concentrated flow paths, increasing susceptibility to erosion where protective vegetation is removed. Recent basin-scale studies in tropical environments demonstrate that DEM-derived flow-accumulation patterns correspond closely with observed erosion corridors and channel initiation zones (Liu et al., 2021; Akinyemi et al., 2023).

### Previous Studies in Southeastern Nigeria

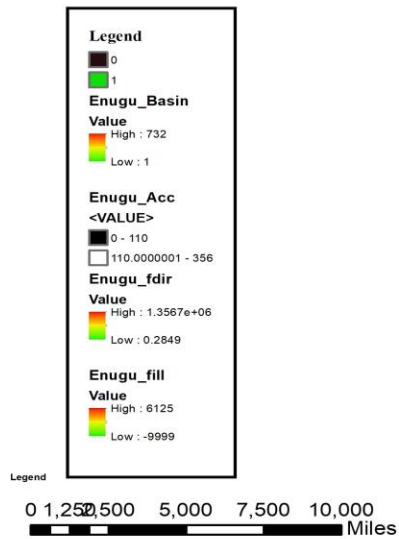
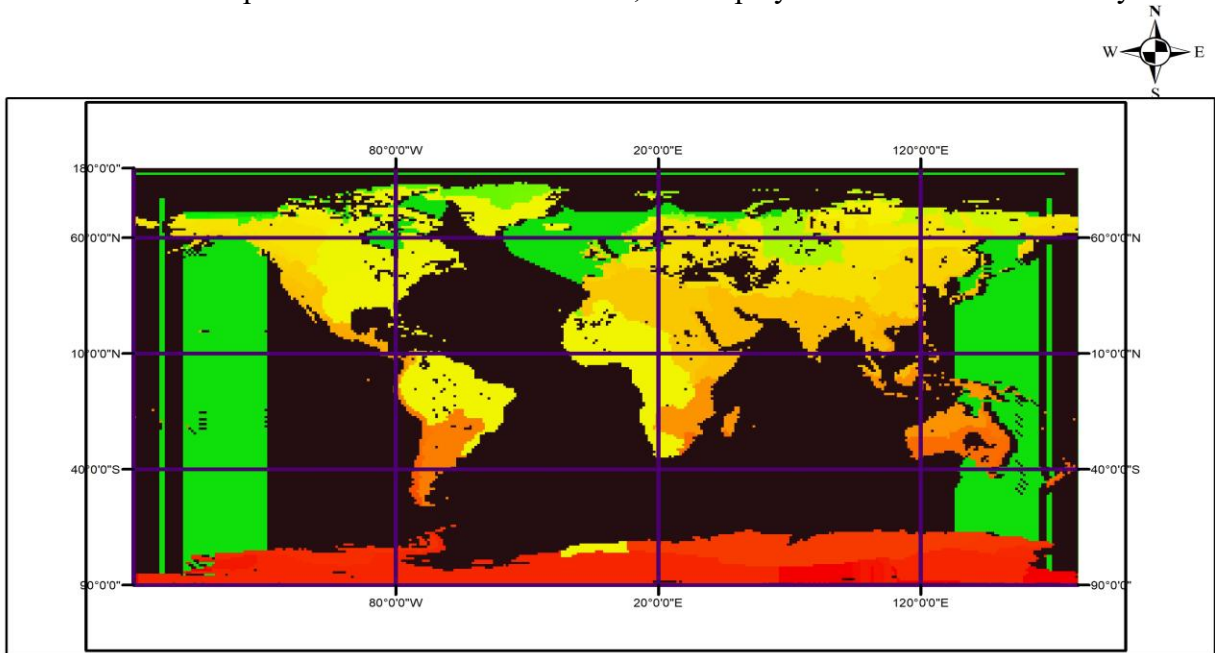
Studies in southeastern Nigeria consistently highlight the influence of lithology, slope and drainage density on erosion development (Eze & Efiog, 2010; Aghamelu & Okogbue, 2011). However, most pre-2015 studies relied on manual morphometric indices. More recent work calls for GIS-based hydrological modelling to support spatially explicit risk identification (Nwankwoala & Amadi, 2020). This study addresses this gap by applying a transparent DEM-based hydrological workflow to the Enugu Basin.

### Methodology

#### Data Sources and Scale

The study utilised a 30-m resolution Shuttle Radar Topography Mission (SRTM) DEM obtained from the USGS EarthExplorer archive. The spatial reference system is WGS 84, projected to UTM Zone 32N. All analyses were conducted in ArcGIS 10.8.

Map scale: Derived map were standardised to a 1:250,000 display scale for basin-level analysis.



**Table 1. Data Sources and Descriptions**

Dataset	Description	Source	Purpose
SRTM DEM	30-m resolution elevation data	USGS	Terrain and hydrological modelling
Enugu Basin Boundary	Basin polygon	GIS extraction	Spatial focus
Flow Direction	D8 flow-direction raster	DEM processing	Drainage pathways
Flow Accumulation	Upstream contributing cells	DEM processing	Runoff convergence
Filled DEM	Sink-corrected DEM	Hydrological enforcement	Drainage continuity

### Hydrological Modelling Procedure

1. Sink Filling: The DEM was hydrologically corrected using the Fill tool to remove artificial depressions.
2. Flow Direction: Flow direction was computed using the D8 algorithm, producing coded directional values (1–128).
3. Flow Accumulation: Flow accumulation was generated to identify relative runoff convergence zones.
4. Basin Delineation: Watershed boundaries were delineated using standard ArcGIS hydrology tools.

## Results and Discussion

### Basin-Scale Hydrological Setting

The Enugu Basin exhibits undulating to rugged terrain consistent with its sedimentary and structural setting. This terrain configuration exerts strong control on drainage organisation, in agreement with Beven and Kirkby (2018).

**Table 2. Environmental and Terrain Characteristics of the Enugu Basin**

Variable	Description	Hydrological Implication
Climate	Humid Tropical Zone	High rainfall input
Relief	Undulating-rugged	Rapid runoff response
Vegetation	Moist forest remnant	Reduced protection where disturbed
Soils	Ferrallitic	Erosion-prone when exposed

### Flow Direction Patterns

The flow-direction raster shows coherent drainage pathways aligned with basin structure. As expected, D8 flow-direction values represent directional codes rather than slope magnitude, confirming organised drainage rather than chaotic flow. Similar structural control has been documented by Eze and Efiog (2010).

**Table 3. Flow-Direction Characteristics**

Attribute	Observation	Interpretation
Directional coherence	High	Structurally guided drainage
Dominant trend	SE-ward	Basin structural influence

### Flow Accumulation and Runoff Convergence

Flow-accumulation values range from low background values to higher relative concentrations along valley corridors. These values represent relative convergence zones, not discharge volumes. Comparable interpretations are reported by Lindsay (2019) and Liu et al. (2021).

**Table 4. Flow-Accumulation Summary**

Metric	Value Range	Significance
Low accumulation	<100 cells	Hillslope runoff
Moderate accumulation	100–300 cells	Channel initiation zones
High accumulation	>300 cells	Runoff convergence corridors

### Filled DEM and Drainage Connectivity

Sink filling eliminated artificial depressions, improving drainage continuity and basin delineation accuracy. This step is critical for reliable hydrological modelling, as noted by Schwanghart and Scherler (2017).

**Table 5. Effects of DEM Sink Filling**

Parameter	Pre-fill	Post-fil	Implication
Artificial sinks	Present	Removed	Improved flow routing
Drainage continuity	Disrupted	Continuous	Reliable modelling

### Implications for Environmental Management

The identified runoff convergence corridors correspond with zones historically affected by erosion in southeastern Nigeria (Aghamelu & Okogbue, 2011; Nwankwoala & Amadi, 2020). These areas warrant priority in erosion-control and land-use planning.

**Table 6. Environmental and Hydrological Implications for Land-Use Planning**

Issue	Hydrological Evidence	Planning Response
Erosion risk	High flow convergence	Soil conservation
Flood Susceptibility	Connected drainage paths	Development control
Infrastructure siting	Terrain constraint	Avoid convergence zones

### Conclusion

This study demonstrates that DEM-based GIS hydrological modelling provides a robust and reproducible framework for analysing basin-scale hydrological behaviour in the Enugu Basin. Terrain configuration and drainage connectivity, rather than generalized environmental zonation, primarily control surface hydrological response. The findings align with both regional and global hydrological literature and provide an objective basis for erosion-control and land-use planning in southeastern Nigeria.

### Recommendations

1.State and local planning authorities should formally adopt DEM-based GIS hydrological modelling as a standard analytical tool for basin-scale environmental assessment. The flow-accumulation and drainage-connectivity outputs generated in this study demonstrate the capacity of such models to objectively identify runoff convergence corridors that are unsuitable for intensive development.

2. Areas identified as high flow-accumulation corridors should be prioritised for erosion-control interventions, including slope stabilisation, controlled drainage channels, re-vegetation, and contour-based land management. This recommendation is directly supported by the observed concentration of surface runoff along structurally controlled drainage paths.
3. Land-use zoning frameworks within the Enugu Basin should incorporate DEM-derived hydrological layers to restrict residential, industrial and infrastructural development within identified runoff convergence and drainage concentration zones. Such integration will reduce exposure to erosion and flash-flood hazards.
4. Government agencies and research institutions should conduct targeted field surveys to validate the runoff convergence zones identified by the flow-accumulation analysis. Ground verification will strengthen the reliability of DEM-based modelling and support adaptive watershed management strategies.
5. Environmental management interventions should be planned at the watershed scale rather than along administrative boundaries. The basin delineation outputs from this study provide a scientifically defensible framework for coordinating erosion control, drainage management and land-use decisions across the Enugu Basin.
6. While the 30-m SRTM DEM is adequate for basin-scale analysis, future studies and planning exercises should utilise higher-resolution DEMs (e.g. LiDAR or photogrammetric datasets) where available. Improved spatial resolution will enhance the identification of micro-scale runoff pathways and erosion-prone slopes.
7. Training programmes should be established for environmental officers, urban planners and watershed managers in GIS-based hydrological modelling techniques. Building institutional capacity will ensure the sustained application of scientifically robust terrain analysis in environmental decision-making within the Enugu Basin.

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