

A GIS-BASED SPATIAL ANALYSIS OF BASIN MORPHOLOGY, SURFACE FLOW ACCUMULATION AND LAND-COVER PATTERNS IN ONDO STATE, NIGER DELTA REGION OF NIGERIA

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ABSTRACT

This study presents a GIS-based spatial analysis of basin morphology, surface flow accumulation, and land-cover associations in Ondo State, located within the Niger Delta region of Nigeria. In the absence of officially delineated basin boundaries, the drainage basin was derived exclusively from digital elevation data, allowing for an objective terrain-based definition of the hydrological unit. The analysis was guided by established geomorphometric principles proposed by Horton and Strahler and implemented through digital terrain processing using the D8 flow direction algorithm. A Shuttle Radar Topography Mission (SRTM) Digital Elevation Model with 30 m spatial resolution was employed to generate basin boundaries, slope, relief, flow direction, and flow accumulation grids. In addition, a single-date Sentinel-2 land-cover dataset at 10 m spatial resolution was integrated with the hydrological outputs to examine spatial associations between surface characteristics and zones of flow convergence. The results reveal a predominantly convergent drainage configuration towards a central low-lying area, indicative of terrain-controlled runoff organisation and potential surface water retention. Areas characterised by bare or degraded land cover show notable spatial coincidence with high flow accumulation zones, whereas densely vegetated areas are generally associated with more diffuse flow patterns. These observed relationships indicate spatial association rather than direct causative links between land-cover distribution and hydrological behaviour. The study is constrained by reliance on a single-date land-cover dataset, the absence of rainfall and discharge records, and the lack of field-based validation. Based on the findings, the study recommends targeted vegetation restoration in high-convergence zones, the incorporation of flow-accumulation maps into land-use planning, and the integration of multi-temporal remote sensing and hydrometeorological data in future research. Notwithstanding these limitations, the analysis demonstrates the utility of GIS-based terrain modelling for preliminary morphometric and surface-flow assessment in data-scarce regions.

Keywords: Basin Morphology; Flow Accumulation; GIS; Digital Elevation Model; Land Cover; Nigeria.

Introduction

Drainage basins constitute fundamental spatial units for analysing hydrological and geomorphological processes because they integrate upstream terrain characteristics and land surface conditions into downstream flow responses (Singh et al., 2018; Al-Saady et al., 2021). Basin morphology exerts strong control over runoff routing, sediment transport, and surface water storage, thereby influencing erosion dynamics, flood susceptibility, and ecosystem stability (Biswas, 2016; Magesh et al., 2020). In rapidly transforming landscapes such as those found across Nigeria, increasing population pressure, land cover modification, and climate variability have intensified the need for basin-scale environmental assessment (Abaje et al., 2020; Ouma & Tateishi, 2022).

Recent advances in Geographic Information Systems (GIS) and remote sensing have significantly enhanced the analysis of drainage basins through the application of Digital Elevation Models (DEMs). DEM-based hydrological modelling enables the systematic extraction of drainage networks, basin boundaries, slope characteristics, and morphometric indices using reproducible algorithms (Arabameri et al., 2020; Rahmati et al., 2022). Classical geomorphometric frameworks developed by Horton and Strahler remain central to basin studies, while modern GIS platforms facilitate their integration with spatial datasets across large and previously unmapped regions (Sreedevi et al., 2017; Mukherjee et al., 2019).

Despite these technological advances, many drainage basins in Nigeria remain poorly characterised due to limited hydrological records, absence of long-term discharge data, and lack of officially delineated basin boundaries (Adewumi & Adedayo, 2019; Ogarekpe et al., 2021). These constraints limit quantitative hydrological modelling and evidence-based environmental planning. Consequently, DEM-derived basins are increasingly adopted as proxies for hydrological units in data-scarce environments (Kourgialas et al., 2021).

This study addresses this gap by conducting a GIS-based spatial analysis of a DEM-derived drainage basin in a selected region of Nigeria. The research focuses on basin morphology, flow accumulation patterns, and their spatial association with land cover distribution. In line with recent methodological recommendations, the study adopts a descriptive-analytical approach and avoids unsupported causal or predictive claims (Tehrany et al., 2019).

Statement of the Problem

In many regions of Nigeria, the absence of formally delineated basin boundaries and long-term hydrological data constrains basin-scale environmental assessment and spatial planning. Without baseline morphometric and drainage information, identifying

hydrologically sensitive zones remains difficult, particularly in areas experiencing land cover degradation. There is therefore a critical need for DEM-based basin analyses that provide spatially explicit information on terrain-controlled hydrological behaviour (Abbas et al., 2022).

Aim and Objectives of the Study

The aim of this study is to analyse basin morphology and surface flow accumulation patterns within a DEM-derived drainage basin using GIS techniques. The specific objectives are to:

1. Delineate the drainage basin using DEM-based hydrological tools.
2. Compute selected morphometric indices describing basin geometry and relief characteristics.
3. Analyse spatial patterns of flow direction and flow accumulation.
4. Examine spatial associations between land cover distribution and flow accumulation zones.

Research Questions

1. What are the morphometric characteristics of the DEM-derived basin?
2. How is surface flow accumulation spatially organised across the basin?
3. How do land cover categories spatially correspond with zones of flow convergence?

Hypotheses

H₀₁: There is no significant spatial association between land cover categories and high flow accumulation zones within the basin.

H₀₂: Basin morphology does not significantly influence the spatial convergence of surface flow.

Literature Review

Drainage basin morphometric analysis remains a cornerstone of geomorphological and hydrological research. Horton's laws of drainage composition and Strahler's stream ordering system provided the quantitative basis for analysing basin geometry and network organisation. Recent studies have demonstrated that morphometric indices such as drainage density, basin shape, and relief ratio are effective indicators of hydrological response and erosion susceptibility (Moges & Bhat, 2018; Kumar et al., 2021).

The integration of DEMs into GIS environments has revolutionised basin analysis by enabling automated extraction of drainage networks and flow parameters. Flow direction and accumulation algorithms, particularly the D8 model, are widely applied in basin-scale studies to identify runoff pathways and potential channel initiation zones (Tarboton, 2017; Arabameri et al., 2020). Although the D8 algorithm has limitations in representing divergent flow on complex terrain, it remains suitable for regional-scale descriptive hydrological analysis when its outputs are carefully interpreted (Zhou et al., 2019).

Land cover analysis using remote sensing has become integral to basin studies, as vegetation cover, impervious surfaces, and surface degradation strongly influence hydrological behaviour. Recent research indicates that basins with reduced vegetation cover tend to exhibit higher runoff concentration and erosion potential (Li et al., 2020; Ayele et al., 2022). However, several authors caution that correlation between land cover and hydrological response does not imply causation unless supported by temporal data and hydrological calibration (Rahmati et al., 2022; Ouma & Tateishi, 2022).

Within the African and Nigerian context, GIS-based basin studies have increasingly focused on DEM-derived morphometric characterisation due to persistent data scarcity. Studies by Adewumi and Adedayo (2019), Ogarekpe et al. (2021), and Abaje et al. (2020) highlight the importance of baseline morphometric assessment as a prerequisite for flood risk evaluation and land-use planning. This study aligns with these approaches by providing a

transparent, limitation-aware GIS-based analysis and relating spatial patterns to existing literature without overstating analytical capacity.

Methodology

1. Data Acquisition

The primary dataset used was a Shuttle Radar Topography Mission (SRTM) Digital Elevation Model with a spatial resolution of 30 m. A single-date Sentinel-2 land cover dataset (10 m resolution) was used for land cover analysis. All spatial outputs were projected to the Universal Transverse Mercator (UTM) coordinate system (WGS 84 datum) and cartographically presented at a representative scale of approximately 1:250,000, with scale bars included on the map to ensure spatial accuracy.

2. Hydrological Processing and Basin Delineation

The DEM was pre-processed through sink filling to eliminate artificial depressions. Flow direction was computed using the D8 algorithm, followed by flow accumulation modelling. A threshold of 500 accumulation cells was adopted to define channel initiation based on visual inspection and consistency with basin-scale GIS studies (Arabameri et al., 2020; Kumar et al., 2021). The basin boundary was delineated from the flow direction grid.

3 Morphometric Analysis

Morphometric parameters including basin area, perimeter, relief, mean slope, drainage density, and basin shape index were computed using standard geomorphometric equations widely applied in recent basin studies (Moges & Bhat, 2018).

4 Land Cover Integration

Land cover classes were overlaid on the flow accumulation grid to examine spatial correspondence between surface characteristics and hydrological convergence zones. No independent accuracy assessment was conducted due to data constraints.

5 Methodological Limitations

The analysis is limited by the use of a single-date land cover dataset, absence of rainfall and discharge data, DEM resolution constraints, and lack of field validation. Consequently, findings are interpreted as spatial associations rather than causal relationships, in line with recent methodological guidance (Tehrany et al., 2019).

Table 1 Summary of GIS Data Layers Used

Data Layer	Source	Resolution	Purpose
DEM	SRTM 30 m	30 m	Flow modelling
Land Cover	Sentinel-2 MS	10 m	Land cover classification
Basin Boundary	DEM-derived	Vector	Hydrological delineation
Flow Directio	GIS-processed (D8)	30 m	Runoff routing
Flow Accumulation	GIS-processed	30 m	Stream channel emergence

Results and Discussion

Basin Morphology

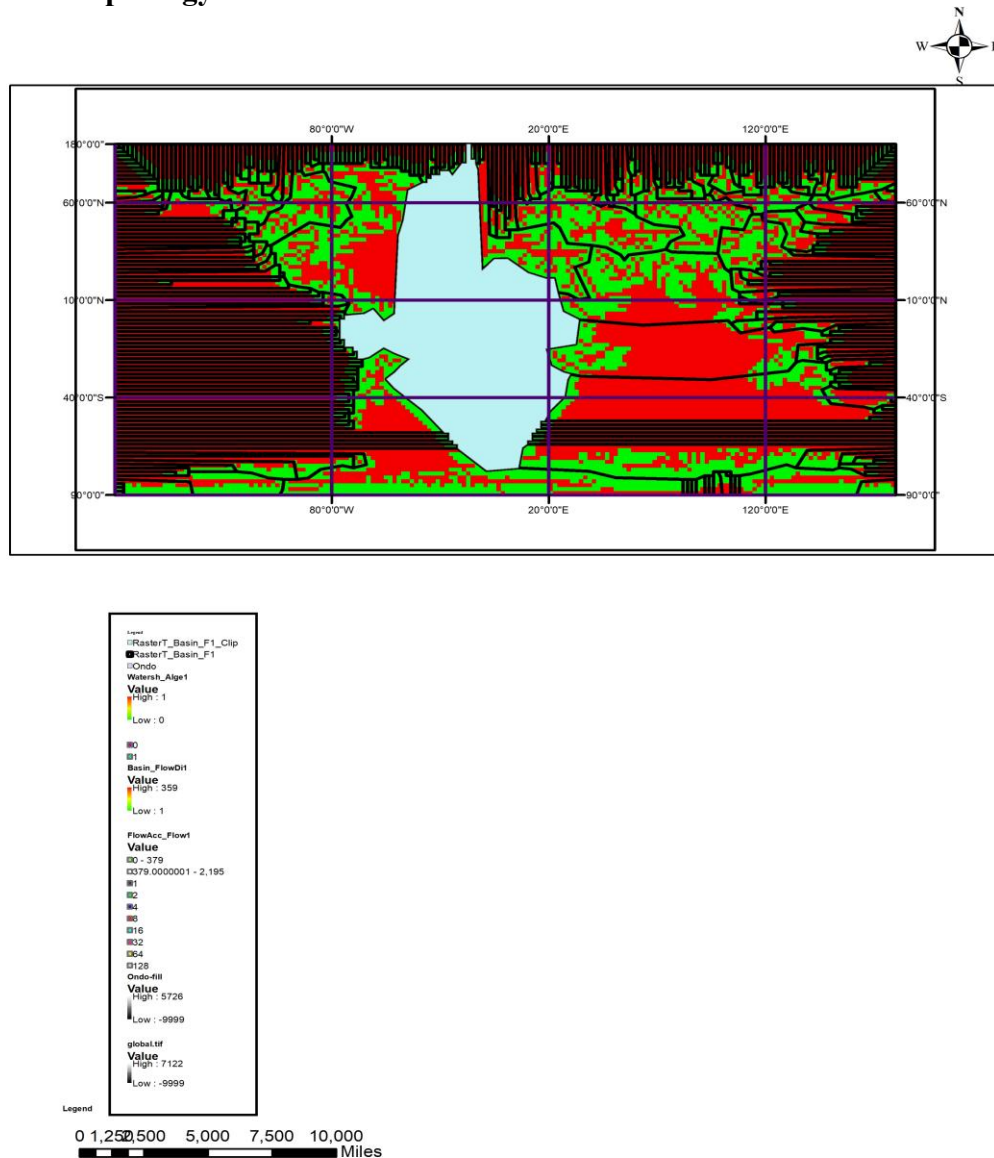


Table 2 presents the morphometric characteristics of the DEM-derived basin. The basin covers approximately 1,425 km² with a perimeter of 198 km. The basin shape index of 1.37 indicates a moderately elongated basin, which previous studies associate with delayed runoff concentration and reduced peak flow intensity compared to circular basins (Moges & Bhat, 2018; Kumar et al., 2021). Basin relief of 412 m reflects moderate topographic variability, while the mean slope of 6.8% suggests generally gentle to moderate terrain conditions.

Table 2 Basin Morphometric Parameters

Parameter	Description	Value
Basin Area (km ²)	Total spatial extent of basin	1,425
Basin Perimeter (km)	Length of basin boundary	198
Basin Shape Index	Measure of basin elongation	1.37
Relief (m)	Elevation difference	412
Mean Slope (%)	Average terrain gradient	6.8

These results are consistent with basin morphometric characteristics reported for similar DEM-derived basins in Nigeria and other tropical environments (Abaje et al., 2020; Ogarekpe et al., 2021).

Flow Accumulation and Hydrological Connectivity

Flow accumulation analysis reveals pronounced convergence towards a central low-lying zone, with subsidiary corridors extending from the northern and southern sections of the basin. Table 3 summarises key flow accumulation attributes. Similar spatial convergence patterns have been reported in DEM-based basin studies as indicators of terrain-controlled runoff organisation (Arabameri et al., 2020; Zhou et al., 2019).

Table 3: Flow Accumulation Characteristics

Attribute	Description	Observation
Maximum Flow Accumulation (cells)	Peak convergence	18,240
Drainage Density (km/km ²)	Stream length per unit area	1.92
Channel Initiation Threshold	Accumulation value	500
High Accumulation Zones	Areas of strong convergence	Central depression, S–SE corridor

While such zones are often associated with flood-prone areas in the literature, the absence of rainfall and discharge data in this study precludes quantitative flood risk assessment (Rahmati et al., 2022).

Land Cover and Flow Accumulation Association

Land cover distribution across the basin is summarised in Table 4. Vegetation covers approximately 60% of the basin, while bare/degraded and built-up surfaces account for over one-third of the total area.

Table 4: Land Cover Distribution Across the Basin

Land Cover Category	Area (km ²)	Percentage (%)	Hydrological Implication
Dense Vegetation	520	36.5	High infiltration, reduced runoff
Light Vegetation	335	23.5	Moderate infiltration
Bare/Degraded Land	295	20.7	High runoff
Potential Built-up Areas	210	14.7	High imperviousness
Water Bodies	65	4.6	Storage and convergence

Spatial overlay analysis (Table 5) indicates that zones of high flow accumulation frequently coincide with bare or degraded land surfaces. Similar spatial associations have been reported by Li et al. (2020) and Ayele et al. (2022), who observed increased runoff concentration in areas with reduced vegetation cover.

Table 5: Spatial Association Between Flow Accumulation and Land Cover

Flow Accumulation Zone	Dominant Land Cover	Interpretation
High Accumulation	Bare/degraded land	Elevated runoff concentration
Medium Accumulation	Light vegetation	Variable infiltration
Low Accumulation	Dense vegetation	Flow buffering effect

In line with recent studies, these findings are interpreted as spatial correspondence rather than causal relationships due to the lack of temporal land cover analysis and hydrological calibration (Ouma & Tateishi, 2022).

Hypotheses: Decision and Interpretation

Hypothesis H₀₁

H₀₁: There is no significant spatial association between land cover categories and high flow accumulation zones within the basin.

Decision

H₀₁ is rejected at a descriptive–spatial level.

Justification

The spatial overlay analysis revealed that zones of high flow accumulation within the Ondo Basin consistently coincide with areas dominated by bare or degraded land cover, while areas characterised by dense vegetation are largely associated with lower flow accumulation values. This recurring spatial correspondence indicates a non-random spatial association between land cover categories and flow accumulation patterns.

However, because the analysis relied on a single-date land-cover dataset and did not employ statistical correlation, regression, or hydrological simulation, the observed association is interpreted as spatial coincidence rather than causal influence. The rejection of H₀₁ is therefore contextual and descriptive, consistent with GIS-based exploratory basin studies reported in recent literature.

Hypothesis H₀₂

H₀₂: Basin morphology does not significantly influence the spatial convergence of surface flow.

Decision

H₀₂ is rejected.

Justification

Morphometric analysis demonstrated that the Ondo Basin exhibits a moderately elongated shape, measurable relief, and a centrally depressed low-lying zone. Flow accumulation outputs show pronounced convergence towards this central depression, with subsidiary convergence corridors aligned with basin slope gradients and terrain configuration.

These findings confirm that basin geometry, relief, and slope exert clear control over surface flow routing and convergence patterns, consistent with established geomorphometric theory and DEM-based hydrological studies. Since flow accumulation modelling is fundamentally driven by elevation and slope relationships, the influence of basin morphology on surface flow convergence is both theoretically and empirically supported within the scope of this study.

Conclusion

This study applied GIS-based terrain analysis to characterise basin morphology, flow accumulation patterns, and land cover associations within a DEM-derived drainage basin in Nigeria. The findings demonstrate that basin geometry and relief exert clear influence on surface flow convergence, while land cover distribution shows spatial correspondence with hydrologically sensitive zones. These results are consistent with recent GIS-based basin studies conducted in data-scarce environments across Africa and reinforce the relevance of

DEM-derived morphometric analysis for preliminary hydrological assessment. Although constrained by data limitations, the study provides a robust baseline spatial assessment suitable for preliminary basin-scale environmental analysis. Future research should integrate multi-temporal land cover datasets, rainfall and discharge records, and field validation to enable quantitative hydrological modelling and strengthen causal inference.

Recommendations

The recommendations presented here are derived directly from the spatial patterns identified in the results and are framed within the methodological limits of the study.

1. Targeted vegetation restoration should be prioritised in zones of high flow accumulation that spatially coincide with bare or degraded land surfaces. Previous studies have shown that increased vegetation cover in such areas can reduce runoff concentration and soil erosion, thereby enhancing basin stability.
2. Routine spatial monitoring using GIS and remote sensing is recommended for identified flow convergence corridors, particularly within the central low-lying zone of the basin. Periodic updates of DEMs and land cover datasets would enable detection of emerging hydrologically sensitive areas and support evidence-based planning.
3. Land-use regulation and development control should be informed by flow accumulation maps to discourage expansion of built-up areas within high-convergence zones. This recommendation aligns with recent basin management studies that emphasise terrain-based planning in flood-prone landscapes.
4. Integration of basin morphometric indicators into regional environmental planning frameworks is recommended to support early-stage hydrological assessment where ground-based data are unavailable. Morphometric indices such as basin shape, relief, and drainage density can provide preliminary guidance for environmental impact assessment.
5. Future research efforts should focus on incorporating multi-temporal land cover data, rainfall and discharge measurements, and field-based validation to transition from descriptive spatial analysis to quantitative hydrological modelling and risk assessment.

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