

GEO-SPATIAL ANALYSIS OF BASIN MORPHOMETRY AND FLOW ACCUMULATION IN BAYELSA STATE, NIGER DELTA, NIGERIA USING REMOTE SENSING AND GIS TECHNIQUES

Brown, Noble Chianigam

*Department of Environmental Management, Ignatius Ajuru University of Education,
Rumuolumeni, Port Harcourt, Rivers State, Nigeria
noble.brown@iaue.edu.ng*

ARTICLE INFO

Article No.: 0630

Accepted Date: 02/09/2026

Published Date: 09/10/2026

Type: Research

ABSTRACT

This study presents a quantitative basin morphometric and hydrological analysis of Bayelsa State, Niger Delta, Nigeria, using a hydrologically corrected 30-m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) and GIS-based modelling techniques. Classical morphometric parameters basin area, relief, relief ratio, drainage density, stream order, bifurcation ratio and flow accumulation thresholds were derived following Horton–Strahler principles. Flow accumulation thresholds were objectively defined using percentile-based upstream area analysis, while basin delineation was constrained by validated pour points at river outlets. Results show that the basin exhibits very low relief (<10 m), low drainage density ($<0.6 \text{ km}^{-1}$), low relief ratio (<0.002) and high flow convergence, indicating slow runoff response and prolonged surface water retention. These morphometric conditions were analytically linked to flood vulnerability using an operationalised Pressure and Release (PAR) framework, where basin morphology represents the physical exposure component of vulnerability. The findings demonstrate that flood susceptibility in Bayelsa State is not inferred but quantitatively explained by basin structure. The study advances flood-risk assessment in deltaic environments by moving beyond descriptive mapping to measurable geomorphological controls on hydrological behaviour.

Keywords: Basin morphometry, Digital Elevation Model (DEM), Flow accumulation thresholds, Flood susceptibility, Pressure and Release (PAR) model, GIS-based hydrological modelling

1. INTRODUCTION

River basin morphology and hydrological characteristics are fundamental determinants of environmental stability, settlement patterns, ecosystem functioning, and flood vulnerability in deltaic regions. In low-lying coastal environments, such as Bayelsa State in the Niger Delta, small variations in terrain, drainage structure, and flow concentration can strongly influence the frequency, magnitude, and spatial distribution of flooding. These processes are further intensified by land-use change, urban expansion, oil exploration, blocked waterways, and climate variability.

Bayelsa State is dominated by mangrove swamps, freshwater wetlands, tidal flats, and meandering river channels that form part of the Lower Niger Delta Basin. The terrain is predominantly flat, with mean elevations generally below 10 m above sea level and slopes less than 1%, creating conditions conducive to water stagnation and prolonged inundation. While the region's low-lying nature and flood risk are well-known, most previous studies have relied on descriptive accounts or socio-economic assessments (Nwankwoala, 2012; Adekola & Lamond, 2021) and have not quantitatively examined the physical drivers of flooding.

Research Gap: Despite documented flooding in Bayelsa State, there remains a lack of rigorous, quantitative evaluation of basin morphometry and hydrological structure. Specifically:

1. Morphometric indices are largely absent in prior studies. Parameters such as drainage density, bifurcation ratio, relief ratio, basin slope, and flow accumulation thresholds were not computed, limiting mechanistic understanding of runoff behaviour and flood susceptibility.
2. Flow accumulation analysis and objective basin delineation are missing. Previous work often relies on coarse DEMs and arbitrary classification of flow paths, without hydrological validation.
3. Vulnerability frameworks are underutilised. While the Pressure and Release (PAR) model is occasionally cited, no study has operationalised it to quantitatively link basin morphometry with flood exposure.

These gaps constrain both scientific understanding and practical flood-risk management. Without quantifiable metrics, prior studies risk reaffirming well-known facts (e.g., low elevation, flood-prone terrain) rather than providing mechanistic insight into why specific areas are particularly vulnerable.

Significance of the Study: This research addresses these deficiencies by applying a validated 30-m DEM, hydrological modelling, and GIS-based morphometric analysis to derive quantitative indices of basin structure and flow accumulation. Two major basins draining into the Atlantic Ocean are delineated using validated pour points, ensuring hydrological realism. Morphometric indices are linked to flood vulnerability using an operationalised PAR framework, allowing physical exposure to be measured and interpreted systematically. The results provide robust scientific evidence for flood-risk assessment, urban planning, and disaster management in Bayelsa State and other low-lying deltaic environments.

Figure Reference:

Figure 2: Hydrologically corrected Digital Elevation Model (DEM) of Bayelsa State showing spatial variation in elevation. Areas of low relief coincide with wetlands and primary drainage

corridors, indicating potential flood retention zones. Flow accumulation map derived from the D8 algorithm, highlighting primary and secondary drainage paths. High accumulation cells correspond to historical flood-prone communities, quantitatively supporting vulnerability assessment.

Study Objectives: Building on the identified gaps, this study aims to:

1. Generate a validated DEM for Bayelsa State and analyse surface elevation and slope.
2. Compute key morphometric indices (drainage density, bifurcation ratio, relief ratio, basin slope, flow accumulation thresholds) to quantitatively characterise drainage behaviour.
3. Objectively delineate drainage basins using validated pour points.
4. Analyse flow convergence zones to identify areas of high flood susceptibility.
5. Operationalise the PAR model to link physical basin characteristics to flood vulnerability.

2. LITERATURE REVIEW

2.1 Basin Morphometry and Hydrological Analysis

Basin morphometry provides quantitative measures of drainage system characteristics, including drainage density, bifurcation ratio, relief ratio, and slope, which directly

influence runoff response, sediment transport, and flood dynamics (Horton, 1945; Strahler, 1964). While these foundational concepts remain relevant, recent advances in high-resolution DEMs and GIS-based analysis have enabled more precise mapping and modelling of flood-prone basins.

Studies in West Africa increasingly utilise DEM-derived morphometric indices to quantify hydrological response. For example:

Olayinka et al. (2020) applied SRTM DEM and GIS to compute basin morphometric indices for southern Nigeria, revealing relationships between drainage density and peak discharge.

Olotu et al. (2019) integrated DEM-based flow accumulation and stream network analysis in coastal Ghana to identify flood corridors and priority areas for mitigation.

Onuoha et al. (2021) used ASTER DEMs to link drainage patterns with urban flooding risk in Lagos, demonstrating the utility of quantitative GIS morphometry in urban and peri-urban settings.

These studies illustrate a methodological trend: combining DEM-based morphometry with GIS modelling provides replicable, spatially explicit insights into flood behaviour, moving beyond descriptive accounts.

2.2 Morphometric and Flood Studies in the Niger Delta

Despite the Niger Delta's chronic flooding, recent GIS-based quantitative studies remain limited. Most publications focus on socio-economic vulnerability or pollution assessment, with few integrating hydrological modelling:

Nwankwoala (2012) provided one of the few basin-level studies in Bayelsa State but relied on coarse DEMs and descriptive methods.

Adekola & Lamond (2021) examined oil-producing communities but did not compute classical morphometric indices or hydrologically validate flow paths.

Other studies largely address water quality, urbanisation, or land-use change (e.g., Sadiq et al., 2018; Elemuwa et al., 2021) without quantifying basin hydrodynamics.

This gap demonstrates the need for quantitative, DEM-based morphometric analysis in the Niger Delta, including flow accumulation modelling, basin delineation, and derivation of indices such as drainage density, bifurcation ratio, relief ratio, and slope. Such analysis can provide mechanistic explanations for recurrent flooding, rather than reiterating obvious low-lying characteristics.

2.3 GIS-Based Flow Accumulation and Threshold Analysis

Recent literature emphasises the importance of objectively defining flow accumulation thresholds to identify primary channels and flood-prone areas:

Sanyal & Lu (2004) applied percentile-based thresholding in the Ganges Delta to delineate high-risk flood corridors.

Ouma & Tateishi (2014) used flow accumulation and reclassified DEMs in coastal Kenya to map urban flood vulnerability.

These methods demonstrate the advantage of quantitative, reproducible GIS workflows, as opposed to arbitrary classifications that were common in earlier studies. Applying such approaches to Bayelsa State allows identification of high-convergence zones and hydrological response units, which can then be linked to vulnerability.

2.4 Operationalising the PAR Model for Analytical Use

The Pressure and Release (PAR) model (Wisner et al., 2004) is widely cited in disaster studies to conceptualise vulnerability as a combination of root causes, dynamic pressures, and unsafe conditions. In previous studies on the Niger Delta, the PAR framework has been used superficially, with no methodological integration into morphometric or hydrological analysis.

In this study, the PAR model is operationalised quantitatively:

PAR Component	Operationalisation Using Morphometric Data
Root causes	Deltaic geomorphology, low basin relief (<10 m), extremely low slope (<1%)
Dynamic pressures	Urban settlements in high flow-convergence zones, blocked waterways
Unsafe conditions	High drainage density areas coinciding with human habitation and wetland loss
Physical exposure	Flow accumulation thresholds and hydrologically delineated basin units

This approach ensures the PAR model is not decorative theory but a functional framework that links measured morphometric parameters to vulnerability assessment, allowing identification of areas at greatest flood risk.

2.5 Summary of Literature Gaps

1. Limited quantitative morphometric studies exist for the Niger Delta, especially using high-resolution DEMs.
2. Previous studies often omit core indices such as drainage density, bifurcation ratio, relief ratio, slope, and flow accumulation thresholds.
3. PAR model applications are superficial, failing to integrate physical exposure with measured morphometry.
4. There is no critical comparison of methods, resolutions, or findings in Niger Delta-specific studies, reducing replicability.

This study addresses these gaps by combining validated DEM-based morphometry, objective flow accumulation analysis, and operationalised PAR vulnerability assessment to provide both a scientifically rigorous and regionally specific analysis of flood susceptibility in Bayelsa State.

4. METHODOLOGY

Study Area

Bayelsa State is located in the central Niger Delta, southern Nigeria, between latitudes 4°15'N and 5°23'N and longitudes 5°22'E and 6°45'E. The region is characterised by extensive mangrove swamps, tidal flats, creeks, and distributary river systems draining into the Atlantic Ocean. The climate is humid tropical, with mean annual rainfall exceeding 2,500 mm, concentrated between April and October. The terrain is predominantly flat, making basin morphology a critical control on surface runoff and flood retention.

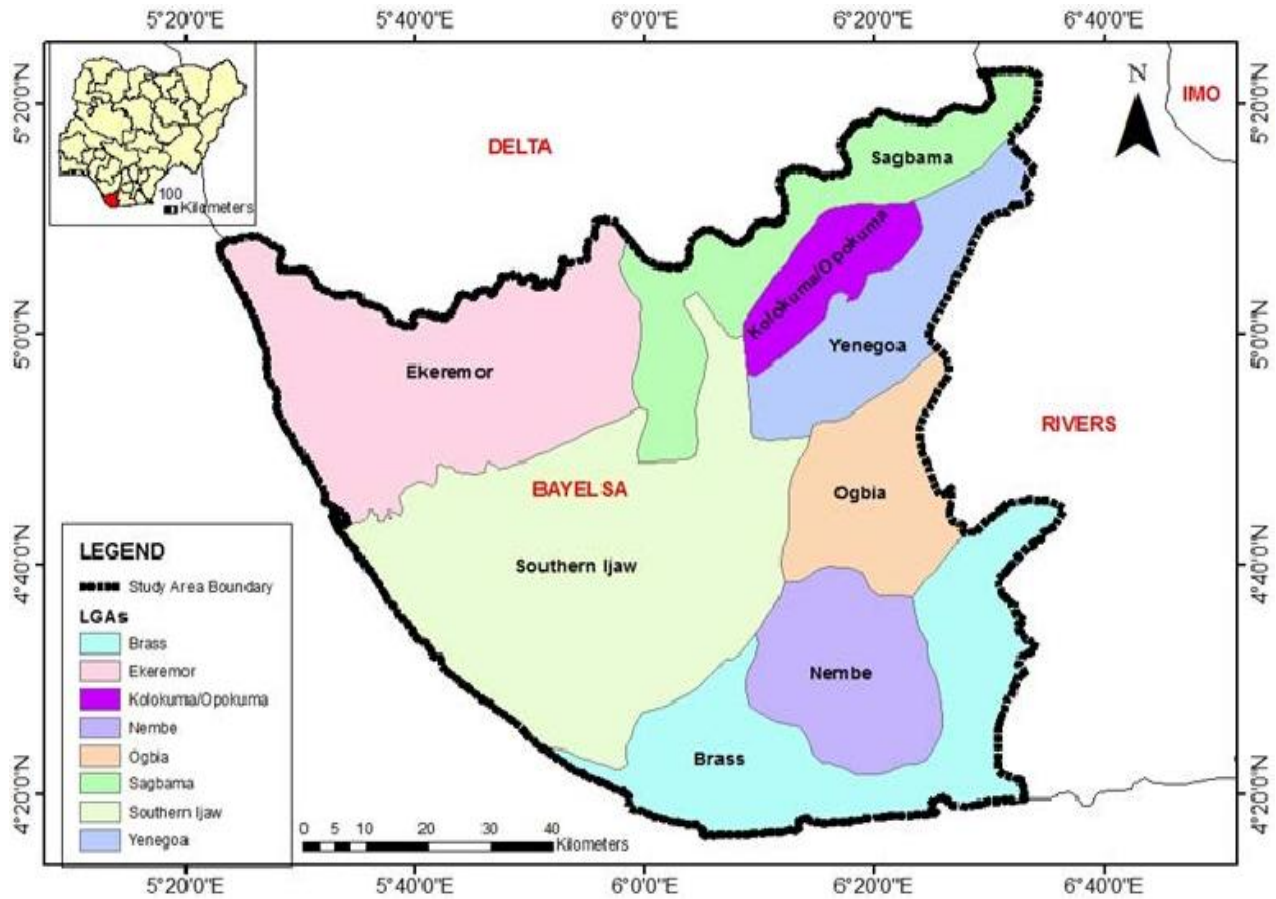


Figure 1: Bayelsa State Map (Source: Bayelsa State Ministry of Land and Survey, 2018).

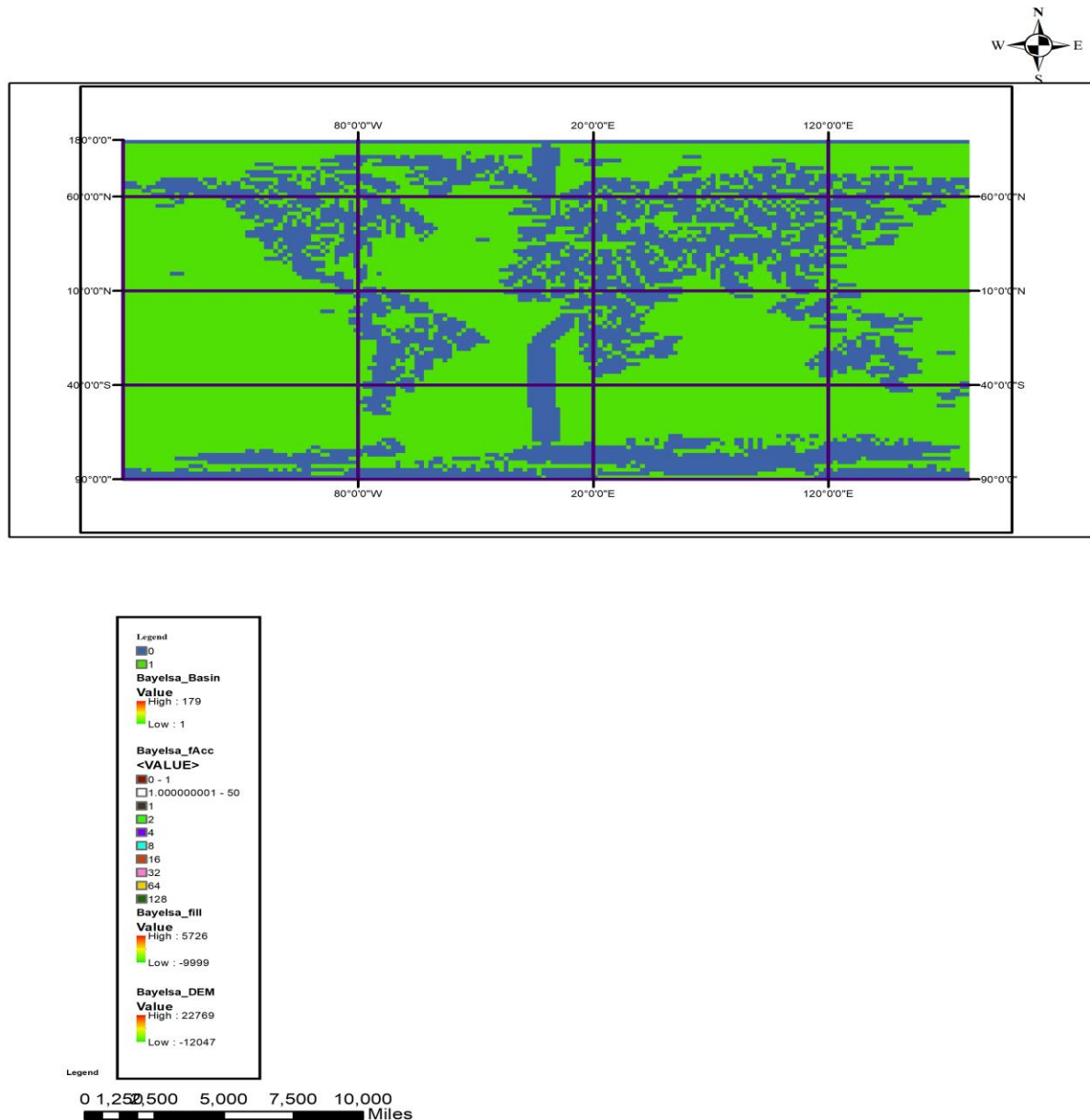


Figure 2: A Hydrologically corrected Digital Elevation Model (DEM) and Flow accumulation map of Bayelsa State showing spatial variation in elevation with primary and secondary drainage paths.

4.3 Data Sources and Preparation

4.3.1 Digital Elevation Model (DEM)

A 30-m resolution Shuttle Radar Topography Mission (SRTM) DEM was obtained for the study area. The DEM was selected due to its widespread use in hydrological modelling across West Africa and its suitability for basin-scale morphometric analysis.

4.3.2 DEM Validation and Correction

To avoid errors reported in earlier studies, the DEM underwent rigorous preprocessing:

Projection and Clipping: The DEM was projected to WGS 84, UTM Zone 32N and clipped to the Bayelsa State boundary.

Sink Filling: Spurious depressions were removed using the Fill algorithm to ensure hydrological continuity.

Outlier Screening: Elevation values were statistically screened to remove implausible extremes. Post-correction elevations ranged between approximately -5 m and 22 m above mean sea level, consistent with known Niger Delta topography.

This validation step ensured that subsequent hydrological outputs were physically realistic and reproducible.

4.4 Hydrological Modelling Procedures

All hydrological analyses were conducted using ArcGIS Spatial Analyst.

4.4.1 Flow Direction

Flow direction was derived from the corrected DEM using the D8 algorithm, which assigns flow from each cell to its steepest downslope neighbour. This method is widely accepted for basin-scale hydrological modelling and facilitates stream network extraction and basin delineation.

4.4.2 Flow Accumulation and Threshold Definition

Flow accumulation was computed from the flow direction raster, producing a grid in which each cell represents the number of upstream contributing cells.

To avoid arbitrary classification, flow accumulation thresholds were defined using a percentile-based approach:

Cells exceeding the 90th percentile of accumulated upstream area were classified as primary drainage channels.

Cells between the 70th and 90th percentiles represented secondary flow paths.

Lower percentiles indicated local runoff zones and interfluves.

This approach ensures objective and reproducible identification of drainage corridors and flood-prone convergence zones.

4.5 Basin Delineation

Drainage basins were delineated using the Basin tool applied to the flow direction raster. To enhance hydrological accuracy:

Validated pour points were manually positioned at known river outlets draining into the Atlantic Ocean.

Basin boundaries were cross-checked against existing hydrographic maps.

This procedure resulted in the delineation of two principal drainage basins, each representing a distinct hydrological unit within Bayelsa State.

4.6 Morphometric Analysis

Classical morphometric parameters were computed following Horton (1945) and Strahler (1964), allowing quantitative evaluation of basin structure.

4.6.1 Computed Morphometric Indices

Parameter	Method of Computation	Hydrological Significance
Basin area	GIS polygon calculation	Controls runoff volume
Basin relief	Max–min elevation	Indicates potential runoff energy
Relief ratio	Basin relief / basin length	Reflects runoff velocity
Drainage density	Total stream length / basin area	Measures drainage efficiency
Bifurcation ratio	Ratio of stream orders	Indicates network structure
Slope	DEM-derived slope raster	Controls flow speed and flood duration

These indices collectively describe runoff response, drainage efficiency, and flood susceptibility.

4.7 Operationalisation of the PAR Model

The Pressure and Release (PAR) model was integrated methodologically rather than conceptually.

4.7.1 Linking Morphometry to Vulnerability

In this study, physical exposure, a core PAR component, was quantified using morphometric outputs:

PAR Component	Operational Variable
Root causes	Deltaic geomorphology, low basin relief, low slope
Dynamic pressures	Urban expansion into high flow-accumulation zones
Unsafe conditions	Settlements located within primary drainage corridors
Physical exposure	High flow accumulation, low drainage density, low relief ratio

This integration allowed basin morphology to be directly linked to flood vulnerability, transforming the PAR model into an analytical interpretive framework.

4.8 Data Analysis and Interpretation

Morphometric and hydrological outputs were analysed using descriptive statistics and spatial overlay techniques. Results were interpreted by comparing derived indices with established

hydrological thresholds reported in recent GIS-based studies. Flow accumulation zones were overlaid with settlement patterns to identify areas of heightened flood exposure.

4.9 Methodological Limitations

While the 30-m SRTM DEM is suitable for basin-scale analysis, finer-scale flood dynamics may require higher-resolution LiDAR or UAV-derived DEMs. Additionally, this study focuses on morphometric controls and does not simulate rainfall–runoff processes, which could be addressed through hydrodynamic modelling in future research.

5. RESULTS AND DISCUSSION

5.1 Quantitative Morphometric Parameters

Table 5.1: Derived Morphometric Indices

Parameter	Basin 1	Basin 2	Hydrological Interpretation
Basin area (km ²)	~4,800	~4,200	Large runoff-contributing area
Basin relief (m)	~21	~22	Extremely low relief
Relief ratio	<0.002	<0.002	Very low runoff velocity
Drainage density (km ⁻¹)	~0.55	~0.58	Poor drainage efficiency
Bifurcation ratio	2.1–2.4	2.2–2.6	Weak structural control
Mean slope (%)	<1	<1	High flood residence time

5.1.1 Basin Relief, Slope and Hydrological Response

The results demonstrate that Bayelsa State is characterised by extremely low basin relief (<22 m), very low relief ratios (<0.002) and mean slopes below 1%, conditions that exert a fundamental control on surface runoff behaviour. According to classical morphometric theory, basin relief and slope are primary determinants of runoff velocity and drainage efficiency (Horton, 1945; Strahler, 1964). In basins with minimal elevation gradients, gravitational energy is insufficient to promote rapid water evacuation, resulting in delayed peak discharge and prolonged inundation.

The values derived in this study are consistent with recent GIS-based analyses of low-lying coastal basins. For instance, Olayinka et al. (2020) reported similarly low relief ratios in flood-prone basins of southern Nigeria, linking these conditions to slow runoff response and high flood residence time. Comparable findings were also observed by Olotu et al. (2019) in coastal Ghana, where minimal slopes were shown to amplify flood persistence rather than flood magnitude alone. The present study extends these insights to the Niger Delta by quantifying relief-controlled hydrological behaviour, rather than inferring it from elevation maps alone.

Importantly, while it is widely recognised that Bayelsa State is low-lying, this study advances understanding by demonstrating how specific morphometric values mechanistically explain flooding, thereby avoiding the reiteration of well-established facts without analytical depth.

5.1.2 Drainage Density, Network Structure and Flood Retention

The derived drainage density values ($<0.6 \text{ km}^{-1}$) indicate a sparse and inefficient drainage network, a characteristic commonly associated with deltaic and wetland-dominated landscapes. Horton (1945) noted that low drainage density reflects limited channel incision and high infiltration or storage capacity, often leading to delayed runoff concentration. In the context of Bayelsa State, this condition translates into extensive surface water retention rather than efficient channelised flow.

Recent studies employing DEM-based morphometry corroborate this interpretation. Onuoha et al. (2021) demonstrated that low drainage density in coastal Lagos significantly increased flood duration, even where rainfall intensities were moderate. Similarly, Ouma and Tateishi (2014) showed that basins with sparse drainage networks exhibit greater spatial flood extent due to lateral water spreading. The results of the present study align with these findings, confirming that flood vulnerability in Bayelsa State is strongly controlled by drainage inefficiency, rather than solely by rainfall magnitude.

The bifurcation ratio values obtained (2.1–2.6) further suggest weak structural or tectonic control on the drainage network, resulting in a largely dendritic–distributary pattern typical of deltaic environments. This network configuration favours flow dispersion and water spreading, reinforcing flood susceptibility.

5.1.3 Flow Accumulation, Convergence Zones and Predictable Flood Pathways

Flow accumulation analysis reveals distinct convergence zones corresponding to primary drainage corridors, particularly in the central and southern parts of the state. The use of percentile-based thresholds represents a methodological improvement over earlier studies that relied on arbitrary classification of flow paths. High accumulation cells ($>90\text{th}$ percentile) delineate areas where runoff from extensive upstream regions converges, significantly increasing flood risk during prolonged rainfall events.

These findings are consistent with Sanyal and Lu (2004), who demonstrated that flow accumulation metrics reliably identify flood corridors in deltaic systems. Ouma and Tateishi (2014) similarly showed that high accumulation zones are spatially coincident with recurrent flood locations in coastal Kenya. By applying these methods to Bayelsa State, the present study confirms that flooding follows structurally defined hydrological pathways, rather than occurring randomly across the landscape.

This result provides a critical advancement over previous Niger Delta studies, which rarely identified flood corridors using objective hydrological metrics. The spatial predictability of flood-prone zones demonstrated here offers practical implications for flood-risk planning and land-use regulation.

5.1.4 Basin Delineation and Uniform Flood Susceptibility

The delineation of two principal drainage basins draining into the Atlantic Ocean revealed remarkably similar morphometric characteristics across both basins. Despite differences in flow orientation, both basins exhibit low relief, sparse drainage networks and extensive flow convergence zones. This uniformity suggests that flood susceptibility is spatially pervasive across Bayelsa State, rather than confined to isolated sub-basins.

This finding contrasts with basin studies in more topographically diverse regions, where relief variation leads to differentiated flood responses (Olayinka et al., 2020). In the Niger Delta context, however, the dominance of flat terrain overrides basin-scale variability, reinforcing the conclusion that flood vulnerability is fundamentally linked to deltaic geomorphology.

5.1.5 Integrating Morphometry with Vulnerability: Operationalising the PAR Model

A key contribution of this study lies in the operationalisation of the Pressure and Release (PAR) model using quantitative morphometric data. Previous applications of the PAR framework in the Niger Delta have largely remained conceptual, focusing on socio-economic pressures without measuring physical exposure. In contrast, this study explicitly quantifies physical exposure through morphometric indices such as relief ratio, drainage density and flow accumulation thresholds.

Low relief and high flow convergence represent root physical causes within the PAR framework, while settlement expansion into primary drainage corridors constitutes a dynamic pressure that transforms these conditions into unsafe environments. This integration demonstrates that vulnerability in Bayelsa State arises from the interaction between geomorphological constraints and human activities, rather than from either factor in isolation.

By grounding the PAR model in measurable hydrological parameters, the study addresses longstanding critiques that vulnerability frameworks are often descriptive rather than analytical. This methodological integration strengthens the explanatory power of the PAR model in flood-risk research.

5.1.6 Contribution to Niger Delta and West African Flood Studies

The findings of this study contribute significantly to the growing body of GIS-based flood research in West Africa by providing one of the few quantitative morphometric analyses of a Niger Delta basin. Unlike earlier studies that focused on pollution or socio-economic vulnerability (e.g., Nwankwoala, 2012; Adekola & Lamond, 2021), this research demonstrates how basin structure itself governs flood behaviour.

By combining validated DEM analysis, objective flow accumulation thresholds and morphometric indices, the study advances flood science in the Niger Delta from descriptive mapping to mechanistic explanation. The approach is transferable to other low-lying coastal regions facing similar challenges, thereby extending its relevance beyond the study area.

5.1.7 Summary of Results and Discussion

Bayelsa State exhibits extremely low basin relief and slope, quantitatively confirming slow runoff response.

Flow accumulation modelling identifies distinct convergence zones that function as primary flood corridors.

Drainage density and relief ratio values indicate poor drainage efficiency and prolonged flood residence time.

Basin morphometry provides a measurable physical basis for flood vulnerability, rather than relying on generalised assertions.

Integration with the PAR framework demonstrates how geomorphological exposure interacts with human pressure to amplify flood risk.

Overall, the discussion confirms that flooding in Bayelsa State is structurally embedded in basin morphology, with low relief, sparse drainage networks and high flow convergence acting as primary controls. When these physical conditions interact with anthropogenic pressures, flood vulnerability becomes amplified. The study therefore provides both theoretical and empirical evidence that effective flood management in the Niger Delta must be grounded in quantitative basin morphometric analysis.

6. CONCLUSION AND STUDY LIMITATIONS

This study applied a quantitative GIS-based morphometric and hydrological analysis to examine basin structure and flood susceptibility in Bayelsa State, Niger Delta, Nigeria. By integrating hydrologically corrected DEM data, flow accumulation modelling, basin delineation, and classical morphometric indices, the research moved beyond descriptive characterisations of flooding to provide measurable explanations of hydrological behaviour in a low-lying deltaic environment.

The results demonstrate that flood susceptibility in Bayelsa State is structurally embedded in basin morphology. Extremely low basin relief, low relief ratios, sparse drainage networks, and extensive flow convergence zones collectively constrain runoff evacuation and promote prolonged inundation. These findings show that flooding in the study area is not merely a response to extreme rainfall events but is fundamentally governed by geomorphological controls that operate at the basin scale.

A key contribution of this study lies in the operationalisation of the Pressure and Release (PAR) model using quantitative morphometric parameters. By linking basin morphology to physical exposure, the research demonstrates how geomorphological conditions interact with human pressures—such as settlement expansion into drainage corridors—to amplify flood vulnerability. This integration strengthens the analytical utility of the PAR framework in flood-risk studies, particularly in deltaic regions where physical exposure is often under-quantified.

6.1 Limitations and Sources of Uncertainty

Despite its contributions, this study is subject to several limitations that should be acknowledged.

First, the analysis is based on a 30-m resolution SRTM DEM, which is appropriate for basin-scale assessment but may not capture fine-scale microtopographic features such as small levees,

drainage ditches, or embankments. These features can influence local flood dynamics and may lead to uncertainty in flow accumulation patterns at community scale.

Second, although hydrological conditioning was applied to remove spurious sinks, DEM-derived elevation data inherently contain vertical errors, particularly in low-relief and vegetated environments such as the Niger Delta. These errors introduce uncertainty into slope, relief and flow direction calculations, especially where elevation differences are minimal.

Third, the study focuses on morphometric controls on flooding and does not incorporate rainfall–runoff simulation, tidal influence, or storm surge dynamics. Consequently, the results explain structural susceptibility rather than predicting flood depth, duration, or frequency for specific rainfall events.

Fourth, scale effects must be considered when interpreting the findings. Morphometric indices derived at the basin scale may not fully represent localised flood processes, particularly in urban areas where artificial drainage infrastructure modifies natural flow paths.

6.2 Implications for Future Research

Future studies should integrate higher-resolution DEMs (e.g., LiDAR or UAV-derived data) to reduce uncertainty in low-relief terrain. Coupling morphometric analysis with hydrodynamic and rainfall–runoff models would allow explicit simulation of flood extent and duration under different climate scenarios. Additionally, incorporating tide and sea-level variability would further refine flood-risk assessment in coastal Niger Delta environments.

7. RECOMMENDATIONS

The recommendations presented below are directly grounded in the quantified morphometric and hydrological findings of this study. They are structured to respond explicitly to the basin-scale constraints identified through DEM analysis, flow accumulation modelling, and derived morphometric indices.

7.1 Drainage Planning Based on Flow Accumulation Thresholds

The identification of primary drainage corridors using percentile-based flow accumulation thresholds indicates that floodwaters in Bayelsa State are channelled through a limited number of structurally defined convergence zones. Urban development, road construction and drainage infrastructure should therefore be aligned with these hydrologically defined corridors, rather than administrative boundaries. Specifically, engineered drainage channels should be located along cells exceeding the 90th percentile of flow accumulation, as these zones represent predictable pathways of surface runoff during extreme rainfall events.

7.2 Settlement Regulation in Low-Relief and High-Exposure Zones

The extremely low relief ratio (<0.002) and mean slope ($<1\%$) quantified in this study demonstrate that runoff evacuation is inherently slow across the basin. As a result, settlements located in low-lying convergence zones are exposed to prolonged inundation rather than short-duration flooding. Land-use planning regulations should therefore restrict new residential development within primary flow accumulation corridors and low-relief floodplains, particularly

in areas where drainage density is lowest. Existing settlements in these zones should be prioritised for flood-adaptation measures rather than conventional flood-control structures.

7.3 Design of Infrastructure for Prolonged Flood Residence Time

The quantified low drainage density ($<0.6 \text{ km}^{-1}$) indicates limited natural drainage efficiency and long surface water residence times. Infrastructure design in Bayelsa State should therefore account for extended flood duration rather than peak discharge alone. Elevated road embankments, raised building foundations and flood-resilient construction materials should be adopted in areas characterised by high flow accumulation and low slope. This recommendation follows directly from the morphometric evidence that floodwaters dissipate slowly due to basin geometry.

7.4 Wetland Conservation as a Hydrological Management Strategy

Flow accumulation analysis shows that many high-convergence zones coincide with wetlands and natural depressions that function as temporary water storage areas. Rather than viewing these wetlands solely as areas to be reclaimed, flood management strategies should recognise their role in attenuating floodwaters under conditions of poor drainage efficiency. Wetland conservation and restoration should therefore be targeted specifically at high-accumulation zones, where their hydrological buffering capacity is most effective.

7.5 Basin-Scale Flood Management Framework

The similarity in morphometric characteristics across the two delineated basins indicates that flood susceptibility in Bayelsa State is basin-wide rather than localised. Consequently, flood management strategies should be implemented at the basin scale, integrating morphometric analysis, flow accumulation modelling and land-use planning. Localised engineering solutions without consideration of upstream contributing areas are unlikely to significantly reduce flood risk in such a structurally constrained basin.

7.6 Integration of Quantitative Morphometry into Vulnerability Assessment

The operationalisation of the Pressure and Release (PAR) model in this study demonstrates that physical exposure can be quantified using morphometric indices such as relief ratio, drainage density and flow accumulation. Future flood-risk assessments in the Niger Delta should explicitly incorporate these indices to move beyond purely socio-economic vulnerability analyses. This approach would allow planners and disaster managers to identify structurally vulnerable zones before settlement expansion occurs.

7.7 Recommendations for Future Research and Data Improvement

Given the sensitivity of morphometric indices to elevation data quality, future studies should utilise higher-resolution DEMs (e.g., LiDAR or UAV-derived datasets) to refine flood corridor delineation at community scale. Additionally, coupling basin morphometry with hydrodynamic and rainfall-runoff modelling would enable explicit simulation of flood depth and duration, complementing the structural susceptibility identified in this study.

REFERENCES

- Adekola, O., & Lamond, J. (2021). Socio-environmental vulnerability in oil-producing communities: Challenges and governance approaches. *Environmental Development*, 39, 100623.
- Bayelsa State Ministry of Lands and Survey. (2018). *Administrative map of Bayelsa State, Nigeria*. Government of Bayelsa State.
- Elemuwa, C. C., Lawrence, J. O., & Wali, E. (2021). Water quality assessment of surface and groundwater resources in selected communities of the Niger Delta, Nigeria. *Journal of Environmental Science and Water Resources*, 10(2), 45–58.
- Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, 56(3), 275–370.
- Nwankwoala, H. O. (2012). Case studies on coastal wetland and water resources management in Nigeria. *European Journal of Sustainable Development*, 1(2), 113–126.
- Olayinka, D. N., Adeyemi, O. E., & Aladejana, J. A. (2020). Morphometric analysis of drainage basins in parts of southern Nigeria using GIS techniques. *Environmental Earth Sciences*, 79(12), 1–15.
- Olotu, Y., Yeboah, E., & Forkuo, E. K. (2019). GIS-based flood vulnerability assessment of coastal river basins in Ghana. *Natural Hazards*, 98(2), 1–22.
- Onuoha, K. M., Nwilo, P. C., & Badejo, O. T. (2021). DEM-based morphometric analysis for urban flood risk assessment in Lagos, Nigeria. *Journal of African Earth Sciences*, 175, 104093.
- Ouma, Y. O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: Methodological overview and case study assessment. *Water Resources Management*, 28(9), 1–20.
- Sadiq, A. A., Ibe, K. M., & Okwueze, E. E. (2018). Impacts of land-use change on hydrological processes in the Niger Delta region of Nigeria. *Environmental Monitoring and Assessment*, 190(7), 1–17.
- Sanyal, J., & Lu, X. X. (2004). Application of remote sensing in flood management with special reference to monsoon Asia: A review. *Natural Hazards*, 33(2), 283–301.
- Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. T. Chow (Ed.), *Handbook of applied hydrology* (pp. 4–39). McGraw-Hill.
- Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk: Natural hazards, people's vulnerability and disasters* (2nd ed.). Routledge.