Adamawa State University Global Journal of Geography and Environmental Sciences (ADSU-GJGES)
Volume 05 Issue 2, 2025
ISSN: 2651-3830 (Print); 2756-4142 (Online)

Website: gjges.adsu.edu.ng *Email: gjges@adsu.edu.ng*

ORIGINAL RESEARCH ARTICLE

Morphometric Analysis and Hydrological Implications of Runoff Timing and Peak Discharge in the Hong Section of the Kilange Basin, Adamawa State, Nigeria

Asawa Dauda, Ezekiel Yonnana and Yohanna Peter
Department of Geography and Environmental Sciences, Adamawa State University, Mubi

ARTICLE INFO

Article History:
Received 2nd October 2025
Revised 17th October 2025
Accepted 18th December 2025

Keywords:
- Morphometric analysis;
- hydrological response;
- Kilange Basin;
- drainage density;
- circularity ratio;
- flood susceptibility;
- GIS;
- Remote Sensing.

***Corresponding Author:**

Phone: +2348149123002

ABSTRACT

This study provides a morphometric analysis of the Kilange Basin in Hong Local Government Area, Adamawa State, Nigeria focus on hydrological response and flood vulnerability. Using a 30 m-resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) and GIS-based analysis, linear, areal, and relief morphometric parameters were computed mathematically to assess runoff behaviour, watershed resilience, and flood potentials. The Hong section of the Kilange Basin, covering 707.96 km², features a fifth-order dendritic drainage network with a low bifurcation ratio of 1.64, indicating largely uniform lithology and minimal structural control. Key results include moderate drainage density (0.74 km/km²), high circularity ratio (4.98), and elongation ratio (0.71), reflecting a compact shape that favors rapid flow convergence. Relief metrics—relief ratio = 12.8 and ruggedness number = 0.40—suggest moderate runoff energy and balanced infiltration-runoff dynamics. Hydrological indices (Runoff Potential Index = 0.63, Lag Time Index = 0.27, Shape Index = 7.01) highlight the basin's sensitivity to fast hydrological response and potential flood risks. To mitigate these risks, the study recommends structural measures such as check dams and contour bunds, enforcing land-use regulations in vulnerable areas, community-based early warning systems, and practices like agroforestry and water harvesting to enhance infiltration and water sustainability. These insights provide critical guidance for flood mitigation, water resource planning, and climate adaptation in data-scarce semi-arid regions of North-eastern Nigeria.

Introduction

Hydrological response portrays the manner in which rainfall inputs are converted into stream-flow. It is a fundamental property of watershed systems and a key determinant factor of flood risk, water availability, and watershed resilience (Mir, 2021). In many semi-arid regions, including north-eastern Nigeria, changes in land use, rainfall intensity, and surface cover alter this response trajectory, often amplifying runoff peaks and reducing lag times. Morphometric analysis, which quantifies the geometric and relief attributes of drainage basins, offers a robust tool for inferring hydrological behaviour in data-scarce environments (Shekar, 2024; Revuelta-Acosta et al., 2025).

Morphometric parameters such as drainage density, stream frequency, circularity ratio, and relief ratio are frequently used to interpret how quickly a basin responds to precipitation events. For example, basins with higher drainage densities and increased circularity generally channel surface water more rapidly, producing sharper flow peaks (Revuelta-Acosta et al., 2025; Shekar, 2024). Relief metrics, such as ruggedness number and relief ratio, reflect the potential energy available for runoff acceleration—steeper gradients yield faster stream response. In studies across Nigeria and beyond, these morphometric indices have been linked to flood generation, recharge patterns, and watershed partitioning (Odiji et al., 2021; Bilewu et al., 2015; Revuelta-Acosta et al., 2025).

Despite the recognized potentials of morphometry, its application in north-eastern Nigerian basins particularly for hydrological inference remains relatively limited. A recent review of morphometric studies in Nigeria highlights broad variation in drainage, relief, and linear parameters across regions, yet few studies have explicitly tied these to runoff dynamics or flow behaviour (Ocheri et al., 2025). In adjacent basins, researchers have prioritized erosion susceptibility or watershed classification, but with less emphasis on quantifying hydrologic response. The current study presents an ideal case for bridging that gap. Therefore, the objectives of this study are to: Quantitatively compute linear, areal, and relief morphometric parameters of the Kilange Basin; Interpret those parameters in terms of hydrological response potential (runoff timing, peak discharge likelihood); and compare the inferred hydrological behaviour of Kilange Basin with existing morphometric-hydrology studies and propose management implications for flood mitigation and water resource planning.

Materials and Methods

Study Area

The Hong section of the Kilange Basin lies between latitudes 9°55′ 30″N and 10°200′N of the Equator and between longitudes 12°58′E and 13°15′ 30″E of the Greenwich Meridian . It covers a land area of about 707.96 km² and forms part of the Upper Benue drainage system (Figure 1).

The area experiences a Tropical Wet-and-Dry Climate characterized by a rainy season from May to October and a dry season from November to April. Annual rainfall averages 800–1,100 mm, and mean annual temperature ranges from 26°C to 32°C (NIMET, 2023). The region is Characterized Sudano-Sahelian Savannah vegetation forms, while land use is dominated by subsistence agriculture and grazing (Tukur et al., 2018; Nwankwoala & Udom, 2011).

Geologically, the basin is underlain by Precambrian Basement Complex rocks mostly granites, gneisses, and schists which encourage a dendritic drainage pattern typical of homogenous lithologies. Elevations range between 450 and 890 meters above sea level, with an average slope of 0.07 and relief ratio of 12.8, indicating moderate relief and runoff energy (Oruonye & Abubakar, 2020).

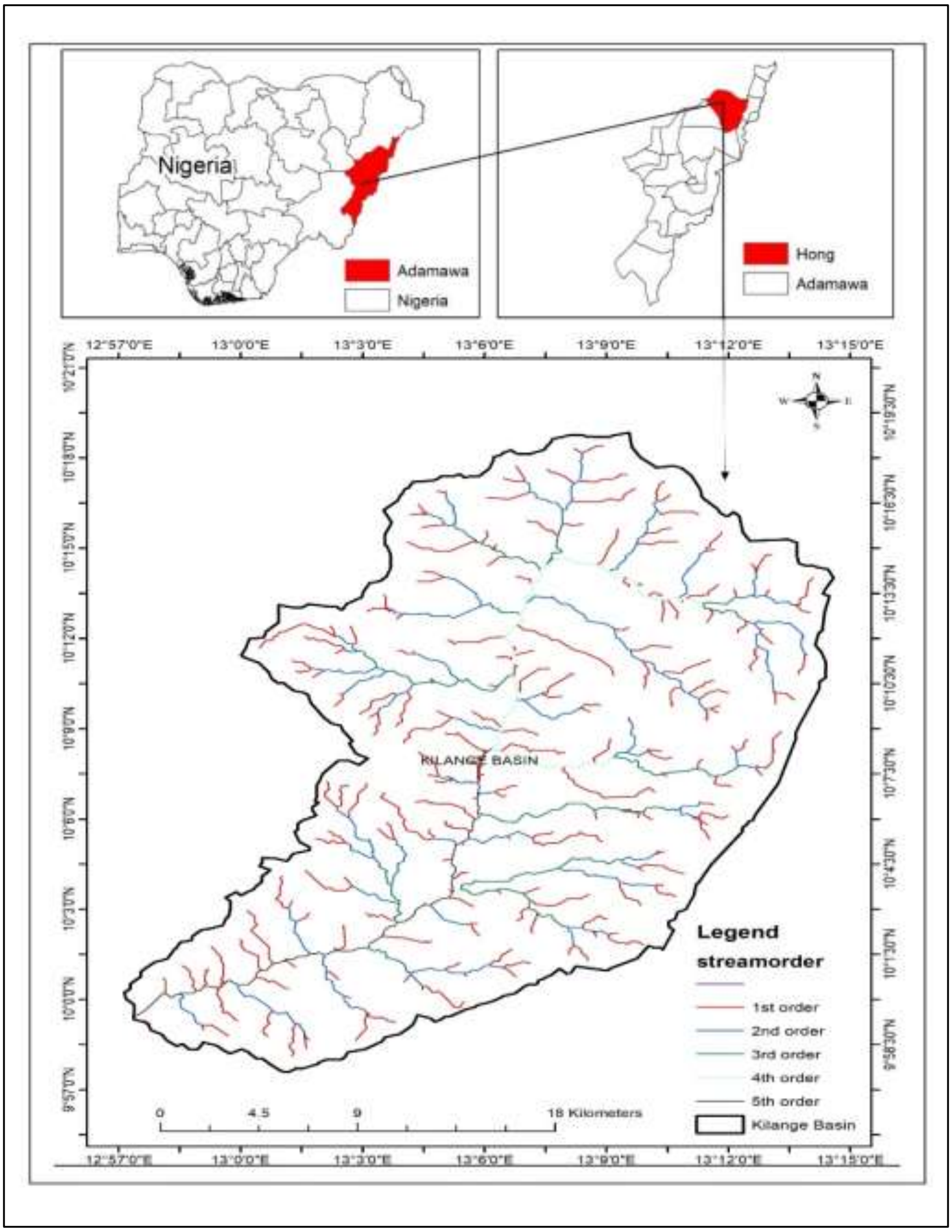

Figure 1: Study Area

Data Sources and Software

The study utilized the Shuttle Radar Topography Mission (SRTM) 30-meter resolution DEM, downloaded from the United States Geological Survey (USGS, 2022). Complementary data, including administrative boundaries and hydrological layers, were sourced from the Adamawa State Ministry of Environment. All spatial analyses were conducted in ArcGIS 10.8 following established geomorphological workflows (Horton, 1945; Strahler, 1964; Schumm, 1956). DEM pre-processing included sink filling, flow direction, flow accumulation, and stream ordering to delineate the Kilange Basin.

Data Processing and Basin Delineation

Hydrological modeling tools in ArcGIS were used to extract the drainage network and delineate the basin boundary through the following steps ensured a spatially accurate representation of stream networks and watershed boundaries:

1. **Sink filling** – to eliminate surface depressions.
2. **Flow direction modelling** – to identify the direction of water flow.
3. **Flow accumulation** – to locate potential stream channels.
4. **Stream definition and ordering** – using the Strahler (1964) hierarchical system.
5. **Basin delineation** – based on topographic divides from DEM data.

Computation of Morphometric Parameters

Morphometric parameters were grouped into three major categories Linear, Areal, and Relief computed using both GIS tools and conventional formulas (Horton, 1945; Strahler, 1964; Schumm, 1956). To enhance clarity, Table 1 summarizes the formulas, hydrological significance, and references used in parameter derivation.

Table 1: Computation of Morphometric Parameters and Their Hydrological Significance

Category	Parameter	Formula	Hydrological Significance	Reference
Linear	Stream Order (U)	Hierarchical classification	Defines flow hierarchy in the basin	Strahler (1964)
	Stream Number (Nu)	Count of streams per order	Reflects drainage texture and surface fragmentation	Horton (1945)
	Mean Bifurcation Ratio (Rb)	Nu / Nu+1	Low Rb (<3) indicates uniform lithology; high Rb shows structural control	Horton (1945)
	Stream Length Ratio (RL)	Lu / Lu+1	Indicates hydrologic maturity and flow uniformity	Schumm (1956)
Areal	Drainage Density (Dd)	Lu / A	Determines runoff efficiency; high Dd → quick runoff	Horton (1945)
	Stream Frequency (Fs)	Nu / A	Indicates drainage texture and infiltration capacity	Strahler (1964)
	Circularity Ratio (Rc)	$4\pi A / P^2$	High Rc → compact basin, faster runoff concentration	Miller (1953)
	Elongation Ratio (Re)	$(2\sqrt{(A/\pi)}) / Lb$	Reflects basin shape; low Re → elongated, high Re → compact	Schumm (1956)
	Infiltration Number (If)	Dd × Fs	Combines infiltration and drainage efficiency	Faniran (1968)
Relief	Relief Ratio (Rhl)	(Hmax – Hmin) / Lb	Indicates potential runoff energy due to slope	Schumm (1956)
	Ruggedness Number (Rn)	Dd × Bh	Reflects terrain roughness and erosion potential	Strahler (1964)
	Average Slope (S)	Derived from DEM	Determines surface flow velocity	USGS (2022)

Hydrological Response Analysis

The hydrological response of the Kilange Basin was assessed by interpreting the derived morphometric parameters in terms of runoff behavior, flow concentration, and flood potential (Sreedevi et al., 2013; Mir, 2021). Parameters such as Dd, Rc, and Re were considered direct indicators of hydrological reactivity, while Rhl and Rn reflected runoff energy and slope dynamics.

Higher values of circularity ratio (Rc) and elongation ratio (Re) indicate a compact shape that channels rainfall more efficiently toward the outlet, leading to shorter lag time and higher peak discharge. Conversely, lower drainage density or bifurcation ratio suggests longer concentration times and moderated flow (Adediji et al., 2019).

Validation and Accuracy Assurance

To ensure analytical accuracy, all morphometric computations were cross-validated using Landsat 8 OLI imagery (2023) and topographic sheets (1:50,000 scale) obtained from the Office of the Surveyor-General of the Federation (OSGOF, 2023). Stream order and basin boundary delineations were visually inspected against satellite imagery to confirm spatial accuracy.

Results and Discussion

Linear Morphometric Parameters

The linear parameters describe the network geometry and structural organization of the Kilange Basin. The computed results in Table 2 show that the basin is of 5th order, with a total stream length of 525.5 km and 602 individual stream segments**.** The mean stream length is 0.87 km**,** while the mean bifurcation ratio (Rb) is 1.64 a relatively low value.

Table 2: Linear Morphometric Parameters

Parameter	Value	Hydrological Implication
Basin Area (A)	707.96 km²	Moderate-sized basin influencing discharge volume
Basin Perimeter (P)	133.5 km	Reflects basin compactness
Basin Length (Lb)	42.2 km	Controls flow concentration and time of travel
Stream Order	5	Moderately complex drainage hierarchy
Stream Number (Nu)	602	Indicates moderate drainage texture
Stream Length (Lu)	525.5 km	Reflects drainage development and network maturity
Mean Stream Length (Lsm)	0.87 km	Suggests consistent stream growth and erosion balance
Stream Length Ratio (RL)	0.50–0.99	Decreases with order indicating system maturity
Mean Bifurcation Ratio (Rb)	1.64	Low structural control and homogeneous lithology

The low mean bifurcation ratio (1.64) reflects a drainage network formed under relatively uniform lithological and structural conditions. This low value suggests minimal geological disturbance and implies that the basin's flow routing is governed more by slope and soil permeability than by tectonic activity. The uniform basement complex rocks of the Kilange area, comprising granites and gneisses, encourage the development of dendritic drainage patterns typical of homogeneous terrains.

The stream length ratio (0.50–0.99) shows that as stream order increases, stream length decreases—a normal hydrological condition indicating equilibrium between runoff and erosion. This pattern signifies a geomorphically mature basin, where streams have adjusted to topography and precipitation input.

Similar results have been observed in the Ogun Basin, Nigeria**, by** Adediji et al. (2019)**,** and in Mexican basins by Revuelta-Acosta et al. (2025)**,** where low Rb values were associated with uniform rock type and moderate infiltration. These studies confirm that basins with such characteristics exhibit stable hydrological responses, reduced flood variability, and well-developed stream integration.

Areal Morphometric Parameters

The areal parameters explain the basin's shape, surface coverage, and drainage efficiency. The results in Table 3 indicate that Kilange Basin has a drainage density (Dd) of 0.74 km/km², stream frequency (Fs) of 0.85, circularity ratio (Rc) of 4.98, **and** elongation ratio (Re) of 0.71.

Table 3: Areal Morphometric Parameters

Parameter	Value	Hydrological Implication
Drainage Density (Dd)	0.74	Moderate drainage → balanced infiltration and runoff
Stream Frequency (Fs)	0.85	Moderate drainage development
Drainage Texture (Dt)	4.51	Indicates moderate terrain dissection
Infiltration Number (If)	1.14	Suggests moderate infiltration capacity
Circularity Ratio (Rc)	4.98	Compact basin → rapid flow concentration
Elongation Ratio (Re)	0.71	Moderately circular → high peak discharge potential
Compactness Coefficient (Cc)	0.11	Low value → efficient surface runoff

The moderate drainage density (0.74 km/km²) is primarily due to the permeable sandy loam soils and vegetative ground cover in the basin, which allow moderate infiltration while sustaining sufficient surface flow. The stream frequency (0.85) further indicates moderate stream formation, a reflection of balanced precipitation and infiltration.

These values show that the Kilange Basin has a stable hydrological regime, capable of producing surface runoff during heavy rainfall but also supporting infiltration and recharge under normal conditions. According to Faniran (1968), such drainage characteristics are common in semi-arid terrains with mixed soil permeability and moderate rainfall intensity.

The high circularity ratio (4.98) and elongation ratio (0.71) suggest that the basin is relatively compact, facilitating rapid flow convergence toward the outlet. This compactness means that rainfall from different parts of the basin reaches the outlet nearly simultaneously, generating shorter lag times and potentially higher flood peaks.

This hydrological tendency is consistent with studies by Sreedevi et al. (2013) and Godif et al. (2022), who found that compact basins in India and Ethiopia responded faster to rainfall, while elongated basins showed delayed but prolonged flow. Therefore, the Kilange Basin's areal configuration reflects a hydrologically efficient but sensitive system that requires careful land-use management.

Relief Morphometric Parameters

Relief parameters define the vertical aspect of the basin and directly influence flow velocity, energy, and erosive power. The results for Kilange Basin (Table 4) show a relief ratio of 12.8, ruggedness number of 0.40, and average slope of 0.07.

Table 4: Relief Morphometric Parameters

Parameter	Value	Hydrological Implication
Relief Ratio (Rhl)	12.8	Moderate relief → moderate flow velocity
Ruggedness Number (Rn)	0.40	Moderately rugged → balanced runoff and infiltration
Average Slope (S)	0.07	Gentle slope → reduced erosion but steady flow

The moderate relief ratio (12.8) indicates a surface with enough gradient to generate runoff but not steep enough to cause severe erosion. This can be explained by the gradually undulating terrain typical of the northern Adamawa Plateau, where elevation declines gently from the Mandara Highlands toward the Benue plains.

The ruggedness number (0.40) implies moderate terrain irregularity, which allows water to infiltrate while maintaining sufficient slope for runoff. Similarly, the average slope (0.07) confirms that the basin's topography promotes steady flow without severe channel incision.

These conditions together create a balanced hydrological system: rainfall is effectively translated into runoff, but part of the water infiltrates, reducing flash flood risk. Studies by Odiji et al. (2021) and Adediji et al. (2019) recorded similar patterns in the Upper Benue and Ogun Basins, where moderate relief produced controlled runoff velocity and low sediment yield.

Hydrological Response

To quantify the basin's hydrological response, derived indices were computed from morphometric parameters to reflect flow timing, runoff potential, and slope energy (Table 5).

Table 5: Hydrological Response Indicators

Indicator	Formula/Source	Computed Value	Interpretation
Runoff Potential Index (RPI)	Dd × Fs	0.63	Moderate surface runoff generation
Infiltration Index (If)	Dd × Fs	1.14	Moderate infiltration capacity
Lag Time Index (LTI)	1 / (Dd × Rc)	0.27	Short lag time → fast hydrological response
Shape Index (Rc/Re)	4.98 / 0.71	7.01	Compact shape → synchronized flow peaks
Relief Energy Index (REI)	Rhl × Rn	5.12	Moderate slope energy → balanced flow

The Runoff Potential Index (0.63) shows that the basin produces moderate runoff during rainfall events. This value is influenced by the basin's moderate drainage density and permeable soils. The Infiltration Index (1.14) supports this, suggesting that rainfall infiltration is adequate but limited by shallow soils and compact surface crusting during dry seasons.

The Lag Time Index (0.27) and Shape Index (7.01) jointly indicate that the study area responds quickly to rainfall, with little delay before runoff begins. This rapid response can be attributed to its compact form and efficient channel network. Such hydrological behavior is typical of basins in semi-arid regions where high-intensity rains produce rapid but short-lived floods (Oruonye & Ahmed, 2021).

The Relief Energy Index (5.12) reflects moderate topographic energy, supporting steady runoff without excessive erosion. This means the basin efficiently converts rainfall into discharge without significant sediment loss a key indicator of geomorphic maturity.

Similar hydrological response patterns have been documented by Sreedevi et al. (2013) in southern India and Godif et al. (2022) in Ethiopia, where compact basins exhibited shorter lag times and moderate infiltration capacity. Thus, the Hong section of the Kilange Basin represents a moderately fast-responding system hydrological efficient but sensitive to land-use changes.

Synthesis and Broader Implications

The Hong section of the Kilange Basin is characterized by a compact shape, with a form factor (Re) of 0.71 and a circularity ratio (Rc) of 4.98. This compactness is primarily attributed to the basin's uniform lithology and gentle slope, which together facilitate the rapid concentration of flow. Such hydrological behaviour is comparable to that observed in the Awash Basin, Ethiopia, where compact basins accelerate the movement of water during rainfall events (Godif et al., 2022).

The basin exhibits a moderate drainage density of 0.74, reflecting the influence of its sandy loam soils and moderate rainfall. This drainage configuration supports a balanced infiltration-runoff regime, allowing water to infiltrate the soil while maintaining sufficient surface flow. A similar condition has been reported in the Ogun Basin, Nigeria, where moderate drainage density enables equilibrium between infiltration and runoff processes (Adediji et al., 2019).

The low bifurcation ratio of 1.64 indicates minimal tectonic disturbance within the study basin, resulting in relatively uniform stream development across the catchment. This pattern aligns with observations in various Mexican basins, where low bifurcation ratios are associated with stable geomorphology and consistent stream networks (Revuelta-Acosta et al., 2025).

With a relief ratio of 12.8, the basin's undulating terrain contributes to moderate runoff velocities. The topography regulates water movement from higher to lower elevations, thereby influencing sediment transport and erosion dynamics. This hydrological response is similar to that seen in the Upper Benue Basin, where undulating relief moderates runoff and sediment flow (Odiji et al., 2021).

Finally, the study basin demonstrates a ruggedness index of 0.40, reflecting moderate surface roughness. This characteristic helps control flow by providing natural resistance, thereby reducing the risk of excessive surface runoff. Comparable observations have been made in Sudano-Sahelian basins, where moderate ruggedness aids in regulating hydrological responses during precipitation events (Oruonye & Ahmed, 2021).

Conclusion

The Hong section of the Kilange Basin's physical and morphometric characteristics make it particularly sensitive to rapid runoff and flood events. Its compact shape, combined with moderate drainage density and relief, promotes quick flow convergence, leading to shorter lag times and higher peak discharges during heavy rainfall, while still allowing some infiltration. To reduce flood risks and improve water management, the study recommends a mix of strategies: structural measures such as check dams, contour bunds, and vegetative barriers to slow runoff; land-use planning that limits settlement and agriculture in flood-prone areas; community-based early warning systems to provide timely alerts; and sustainable practices including agroforestry, water harvesting, and erosion control to maintain soil and water resources. Incorporating these approaches into local watershed governance, policy frameworks, and climate adaptation plans can strengthen community resilience and safeguard water security. For long-term planning, future research should integrate morphometric analysis with advanced hydrological modelling, high-resolution spatial data, and climate impact assessments, providing a comprehensive framework for sustainable water resource management across semi-arid regions of north-eastern Nigeria.

References

Adebayo, A. A., & Tukur, A. L. (1999). *Adamawa State in Maps*. Paraclete Publishers.

Adediji, A., Jeje, L. K., & Ibitoye, M. O. (2019). Morphometric analysis of Ogun River Basin, Nigeria: Drainage density and infiltration–runoff equilibrium. Journal of African Earth Sciences, 158(C), 102638. https://doi.org/10.1016/j.jafrearsci.2019.10263

Bilewu, S. O. (2015). Optimum parameter selection for the morphometric description of watersheds: A case study of central Nigeria. *Journal of Environmental Engineering and Geosciences.*

Faniran, A. (1968). *The index of drainage intensity: A provisional new drainage factor. Australian Journal of Science, 31*, 328–330.

Godif, F., Abebe, T., & Gebremariam, B. (2022). *Morphometric analysis for hydrological response assessment in the Upper Awash Basin, Ethiopia. Hydrology Research, 53*(4), 897–912.

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.

Miller, V. C. (1953). *A quantitative geomorphologic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee.* Columbia University, Technical Report 3.

Mir, A. A. (2021). *Understanding hydrologic response using basin morphometry.* In *Hydrology Handbook* (pp. ch19).

Nigerian Meteorological Agency (NIMET). (2023). *Annual Climate Review Bulletin 2023.* Abuja, Nigeria: NIMET Publications.

Nwankwoala, H. O., & Udom, G. J. (2011). Environmental implications of poor drainage systems in parts of Port Harcourt City, Nigeria. *Journal of Geography and Regional Planning, 4*(14), 847–853.

Ocheri, M. I., Umar, D. N., Wuyep, S. Z., Laka, I. S., Odoma, L. A., Ali, P., Onah, M. A., & Tarzoho, P. (2025). A review of morphometric studies of drainage basins in Nigeria. *British Journal of Earth Sciences Research, 13*(2), 42–65.

Odiji, C. A., et al. (2021). *Morphometric analysis and prioritization of upper Benue watershed. Applied Water Science.*

Oruonye, E. D., & Abubakar, H. (2020). Climate variability and its implications for sustainable agriculture in Taraba State, Nigeria. *Asian Journal of Geographical Research, 3*(2), 45–57.

Oruonye, E. D., & Ahmed, M. I. (2021). *Rainfall variability and flood risk in Sudano-Sahelian watersheds of northeastern Nigeria. Journal of Geography and Environmental Management, 8*(3), 112–126.*

OSGOF. (2023). Topographic sheets (1:50,000 scale). *Office of the Surveyor-General of the Federation*. Retrieved from OSGOF website

Revuelta-Acosta, J. D., Garrido-Meléndez, J., Conde-Gutiérrez, R. A., et al. (2025). Comprehensive geospatial assessment: morphometric parameters and hydrological implications in five Mexican basins. *Scientific Reports.*

Schumm, S. A. (1956). *Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67*(5), 597–646.

Shekar, P. R. (2024). Morphometric analysis of watersheds: A comprehensive review of data sources and geospatial techniques. *Geospatial Reviews.*

Sreedevi, P. D., Owais, S., Khan, H. H., & Ahmed, S. (2013). *Morphometric analysis of a watershed of South India using SRTM data and GIS. Journal of the Geological Society of India, 81*(2), 271–280.*

Strahler, A. N. (1964). *Quantitative geomorphology of drainage basins and channel networks.* In V. T. Chow (Ed.), *Handbook of Applied Hydrology* (pp. 39–76). McGraw-Hill.

Tukur, A. L., Adebayo, A. A., & Galtima, M. (2018). *Land Resource Inventory and Land Use Planning in Adamawa State, Nigeria*. Department of Geography, Modibbo Adama University of Technology.

USGS. (2022). *Shuttle Radar Topography Mission (SRTM) 30 m Digital Elevation Model.* Retrieved from https://earthexplorer.usgs.gov

U.S. Geological Survey. (2023). *Landsat 8 Operational Land Imager (OLI) surface reflectance data* [Satellite imagery]. United States Geological Survey. https://www.usgs.gov