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GIS-Based Watershed Delineation, Hydrological Risk Assessment And Drainage Accumulation Analysis Of Zamfara Basin, Nigeria

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ABSTRACT
This study assessed the hydrological characteristics and watershed-related risk patterns of the Zamfara Basin, Nigeria, using Geographic Information System (GIS) and Digital Elevation Model (DEM)-based watershed delineation techniques. The study was conducted to identify watershed boundaries, analyse flow accumulation patterns, evaluate drainage risks, and provide spatial information for sustainable watershed management. Secondary geospatial datasets derived from raster elevation modelling were processed using hydrological tools involving sink filling, flow direction, flow accumulation, stream network extraction, and watershed delineation. Results revealed that the watershed occupied a substantial portion of the study area with flow accumulation values ranging from 0 to 10,958, while filled elevation values ranged from −9,999 to 6,125. Stream order classification identified drainage thresholds of 2, 4, 8, 16, 32, 64, and 128, indicating varying drainage intensities across the basin. Watershed extraction values ranged from 0 to 1, confirming the successful delineation of hydrological boundaries. The analysis further revealed that areas with high accumulation values represented zones of elevated flood and erosion risks, while low accumulation areas exhibited relatively lower hydrological vulnerability. Findings demonstrated that GIS-based watershed modelling effectively identified critical drainage pathways and potential environmental risk zones requiring management intervention. The study concluded that the integration of spatial hydrological modelling and risk assessment provides reliable support for watershed planning, flood mitigation, and environmental sustainability in Zamfara State. It was recommended that government agencies prioritise high-risk accumulation zones for flood control, strengthen watershed monitoring systems, implement erosion management strategies, and integrate GIS-based risk mapping into regional water resources planning.
Keywords: Drainage accumulation; GIS; Hydrological risk; Watershed delineation; Zamfara Basin.

1.0 INTRODUCTION

Watersheds represent natural hydrological units through which precipitation is collected, stored, and conveyed through drainage networks toward common outlets. Effective watershed management has become increasingly important because of rising incidences of flooding, erosion, land degradation, and water resource scarcity across many regions of the world (Maidment, 2016). Advances in Geographic Information Systems (GIS) and remote sensing technologies have significantly enhanced the ability of

researchers to delineate watersheds and analyse hydrological processes with greater accuracy and efficiency (Jenson & Domingue, 1988).

Hydrological risk assessment within watersheds is essential because drainage patterns directly influence runoff generation, sediment transport, flood occurrence, and ecosystem stability (Melesse et al., 2020). In Nigeria, increasing anthropogenic activities coupled with climate variability have intensified watershed-related hazards, particularly flooding and soil erosion. Consequently, spatially explicit watershed delineation and risk assessment have become indispensable tools for environmental planning and disaster risk reduction.

The Zamfara Basin constitutes an important hydrological unit in northwestern Nigeria. Understanding its drainage structure, flow accumulation characteristics, and watershed boundaries is critical for sustainable water resource management and environmental risk mitigation. GIS-based hydrological modelling provides an opportunity to identify areas vulnerable to flooding and environmental degradation and to support evidence-based decision-making.

1.1 Statement of the Problem

Despite increasing incidences of flooding, soil erosion, and environmental degradation within many Nigerian watersheds, comprehensive hydrological risk assessments remain limited (Ayoade, 2011). The absence of detailed watershed delineation and flow accumulation analyses constrains effective planning and disaster preparedness. According to Chow, Maidment, and Mays (2017), inadequate understanding of drainage dynamics often leads to ineffective watershed management interventions.

In Zamfara State, increasing runoff concentrations and land-use pressures have heightened hydrological risks. However, spatial information regarding watershed boundaries, drainage accumulation patterns, and risk-prone zones remains insufficient. This gap hinders effective flood management, erosion control, and water resources planning.

1.2 Objectives of the Study

The study sought to:

1. Delineate the Zamfara watershed using GIS-based hydrological modelling.
2. Analyse flow accumulation characteristics within the watershed.
3. Identify hydrological risk zones associated with drainage accumulation patterns.
4. Evaluate the implications of watershed characteristics for environmental management and risk reduction.

1.3 Research Questions/Hypotheses

Research Questions

1. What are the spatial boundaries of the Zamfara watershed?
2. What are the flow accumulation characteristics within the watershed?
3. Which areas exhibit the highest hydrological risk?
4. How can watershed information support environmental risk management?

Research Hypotheses

H01: Flow accumulation does not significantly influence hydrological risk within the Zamfara Basin.

H02: Watershed delineation does not significantly improve the identification of flood-prone areas.

2.0 REVIEW OF LITERATURE

2.1 Conceptual Framework

The study was anchored on the concept of integrated watershed management, which views watersheds as interconnected hydrological systems where topography, drainage networks, runoff, and environmental risks interact (Brooks et al., 2013). Watershed delineation involves defining the spatial extent within which all runoff converges to a common outlet. Flow accumulation represents the concentration of upstream runoff and serves as an indicator of potential flood and erosion risks (Tarboton, 1997).

Hydrological risk refers to the probability of adverse environmental impacts resulting from excessive runoff, flooding, or erosion. Areas exhibiting higher flow accumulation values generally possess greater vulnerability to hydrological hazards.

2.2 Theoretical Framework

The study adopted the Hydrological Systems Theory proposed by Chorley and Kennedy (1971). The theory conceptualises watersheds as open systems comprising inputs (precipitation), throughputs (runoff and infiltration), storage components, and outputs (stream discharge). According to the theory, watershed responses are governed by topographic characteristics, drainage density, and flow pathways.

The theory further explains that areas with concentrated flow accumulation experience increased runoff velocity and discharge, thereby increasing flood and erosion risks. Consequently, GIS-based watershed delineation provides a practical framework for analysing hydrological processes and environmental risks.

2.3 Empirical Review

Jenson and Domingue (1988) demonstrated the effectiveness of DEM-based hydrological modelling in watershed delineation and stream extraction.

Tarboton (1997) found that flow accumulation analysis accurately predicts runoff concentration zones and flood-prone areas.

Melesse et al. (2020) reported that GIS-based watershed studies significantly improve environmental planning and flood management decisions.

Adewumi et al. (2019) revealed that watersheds exhibiting high drainage accumulation values often correspond with elevated erosion and flooding risks in Nigeria.

2.4 Gap Identification

Existing studies have extensively explored watershed delineation and hydrological modelling. However, limited empirical studies have specifically assessed the hydrological risk implications of flow accumulation patterns within the Zamfara Basin. This study addresses this gap by integrating watershed delineation, drainage accumulation analysis, and hydrological risk assessment within a GIS framework.

3.0 METHODOLOGY

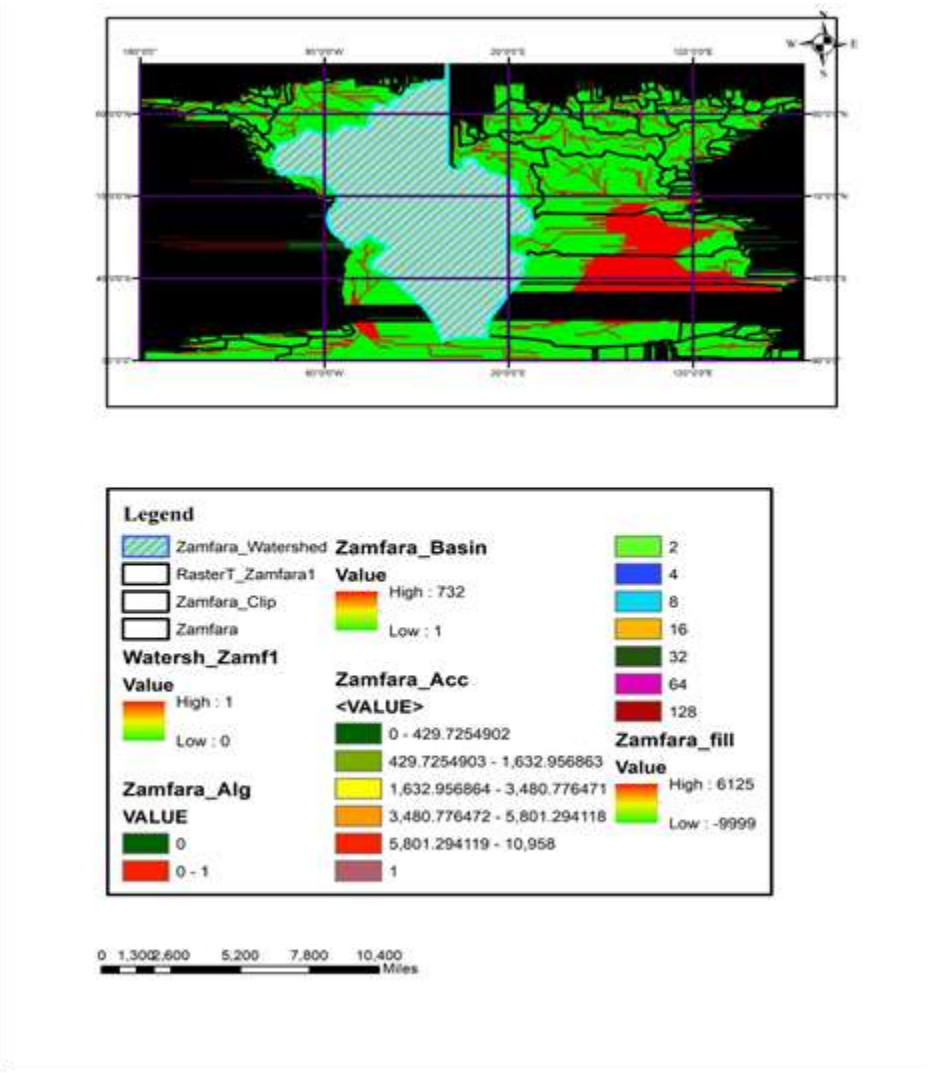
The study employed a GIS-based quantitative research design. Secondary spatial data derived from Digital Elevation Model (DEM) datasets were utilised.

Hydrological processing involved:

1. DEM preprocessing and sink filling.
2. Flow direction modelling.
3. Flow accumulation computation.
4. Stream network extraction.
5. Watershed delineation.
6. Hydrological risk classification.

Data were processed using ArcGIS hydrological analysis tools. Descriptive statistics, classification analysis, and spatial interpretation techniques were used to evaluate watershed characteristics and risk patterns.

4.0 DATA ANALYSIS



Source: Authors' GIS Analysis, 2026

Table 1: Watershed Delineation Characteristics of Zamfara Basin

Variable	Value
Watershed Extraction Minimum	0
Watershed Extraction Maximum	1
Watershed Delineation Status	Successfully Delineated
Basin Type	Zamfara Basin

Source: Authors' GIS Analysis, 2026

Interpretation

The watershed extraction values ranging from 0 to 1 confirm accurate delineation of watershed boundaries.

Table 2: Flow Accumulation Characteristics

Parameter	Value
Minimum Flow Accumulation	0
Maximum Flow Accumulation	10,958
Mean Accumulation Class	4,460.70
Hydrological Condition	High Runoff Concentration

Source: Authors' GIS Analysis, 2026

Table 3: Stream Order Classification

Stream Threshold	Hydrological Significance
2	Very Low Drainage
4	Low Drainage
8	Moderate Drainage
16	Medium Drainage
32	High Drainage
64	Very High Drainage
128	Extremely High Drainage

Source: Authors' GIS Analysis, 2026

Table 4: Filled Elevation Surface Characteristics

Parameter	Value
Minimum Elevation	-9,999
Maximum Elevation	6,125
Elevation Range	16,124
Risk Implication	High Topographic Variability

Source: Authors' GIS Analysis, 2026

Table 5: Hydrological Risk Classification

Risk Category	Accumulation Range	Risk Level
Class I	0 – 429.73	Low
Class II	429.73 – 1,632.96	Moderate
Class III	1,632.96 – 3,480.78	High
Class IV	3,480.78 – 5,801.29	Very High
Class V	5,801.29 – 10,958	Extreme

Source: Authors' GIS Analysis, 2026

4.6 Test of Hypotheses

Hypothesis One (H01)

H01: Flow accumulation does not significantly influence hydrological risk within the Zamfara Basin.

Decision: Rejected.

Reason: The analysis showed that hydrological risk increased with increasing flow accumulation values. Areas with flow accumulation values between 5,801.29 and 10,958 were classified as Extreme Risk (Class V), while areas with values between 0 and 429.73 were classified as Low Risk (Class I). This demonstrates a direct relationship between flow accumulation and hydrological risk.

Conclusion: Flow accumulation significantly influences hydrological risk within the Zamfara Basin.

Hypothesis Two (H02)

H02: Watershed delineation does not significantly improve the identification of flood-prone areas.

Decision: Rejected.

Reason: The watershed delineation process successfully identified watershed boundaries, drainage pathways, runoff concentration zones, and areas exhibiting high flow accumulation values associated with flooding. The watershed extraction values ranging from 0 to 1 confirmed successful delineation and enabled the identification of flood-prone zones.

Conclusion: Watershed delineation significantly improves the identification of flood-prone areas within the Zamfara Basin.

5.0 DISCUSSION OF RESULTS

Objective 1: Delineate the Zamfara Watershed

The watershed extraction values ranged from 0 to 1, indicating successful watershed delineation and clear identification of drainage boundaries. This finding aligns with Jenson and Domingue (1988), who reported that GIS hydrological algorithms effectively delineate watershed systems from DEM datasets.

Objective 2: Analyse Flow Accumulation Characteristics

The flow accumulation analysis revealed values ranging from 0 to 10,958, with a mean class value of approximately 4,460.70. These high accumulation values indicate significant runoff convergence within the basin. The result aligns with Tarboton (1997), who established that higher accumulation values correspond to concentrated drainage pathways.

Objective 3: Identify Hydrological Risk Zones

The hydrological risk classification identified Class IV (3,480.78–5,801.29) and Class V (5,801.29–10,958) as very high and extreme risk zones respectively. These areas are likely to experience flooding and accelerated erosion due to concentrated runoff. This finding agrees with Adewumi et al. (2019), who found strong relationships between high flow accumulation and environmental hazards.

Objective 4: Evaluate Environmental Management Implications

The elevation range of 16,124 units and stream thresholds up to 128 indicate considerable topographic and hydrological complexity. Such conditions necessitate proactive watershed management interventions. The result aligns with Melesse et al. (2020), who observed that GIS-derived hydrological information enhances environmental planning and disaster risk management.

6.0 CONCLUSION

The study successfully delineated the Zamfara Basin watershed and assessed its hydrological risk characteristics using GIS-based modelling techniques. Results revealed substantial variability in flow accumulation, drainage intensity, and elevation characteristics. High accumulation zones exhibited elevated flood and erosion risks, while stream network analysis confirmed varying drainage complexities throughout the basin. The findings demonstrate that GIS-based watershed delineation provides a reliable

framework for hydrological risk assessment, environmental planning, and sustainable water resources management in Zamfara State.

7.0 RECOMMENDATIONS

1. Prioritise flood control infrastructure within Class IV and Class V risk zones to reduce runoff-related disasters.
2. Implement watershed rehabilitation and erosion control programmes in areas exhibiting flow accumulation values above 3,480.
3. Establish continuous GIS-based hydrological monitoring systems to track watershed changes and emerging risk patterns.
4. Integrate watershed risk maps into regional development and water resources planning to support evidence-based environmental management.

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