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A GEOSPATIAL AND INTEGRATED EVALUATION OF MULTI-HAZARDOUS ENVIRONMENTAL RISKS IN THE SAHELIAN CORRIDOR OF NIGERIA

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ABSTRACT
This study presents a comprehensive, GIS-based multi-hazard risk assessment of the Sahelian corridor of Nigeria, focusing on three dominant and interconnected environmental hazards: flooding, erosion, and desertification. The research was guided by the central aim of assessing the increasing effects of these hazards, with specific objectives including assessing the interconnections of the three hazards. A geo-spatial methodology was employed, utilising a Geographic Information System (GIS) environment and diverse datasets, including DEMs, climate data, and socio-economic indicators, to map susceptibility for each hazard through reclassification and weighted overlay analysis. The analysis revealed a pervasive and interconnected threat landscape: 57.84% of the land falls into the high flood hazard zone, with an additional 12.65% in the very high hazard zone. For erosion, over 95% of the land is at moderate (71.24%) or high (24.35%) risk of soil loss. Desertification is also a significant threat, with 30.39% at moderate risk, 21.34% at high risk, and 7.03% at very high risk. The integrated multi-hazard risk assessment identified that 26.37% of the total study area is at high risk, and 4.07% is at very high risk. High-risk states identified are Jigawa, Sokoto, Yobe, and Zamfara, with the Local Government Areas (LGAs) of Shinkafi and Sokoto South classified as very high-risk hotspots. The study concludes that multi-hazard risk is amplified by human factors such as population density and infrastructure concentration, and recommends structural measures, such as drainage rehabilitation and afforestation, alongside non-structural measures, such as land-use planning and early warning systems, to enhance resilience and integrate risk assessments into local development policies.

Keywords: Exposure; Vulnerability; Multi-hazard risk; Flooding; Erosion; Desertification

INTRODUCTION

Natural hazards, a broad category of phenomena encompassing floods, droughts, heatwaves, and landslides, have become an escalating global concern. Their frequency and intensity have increased markedly in many regions, with West Africa experiencing a significant rise in extreme heatwaves and heavy precipitation events (Daniel et al., 2023). This trend has highlighted the urgent need for adaptive and robust disaster risk management strategies worldwide. The global community has responded through frameworks like the Sendai Framework for Disaster Risk Reduction, which emphasises understanding disaster risk, strengthening governance, investing in resilience, and enhancing preparedness (Tiepolo et al., 2019).

This strategic shift acknowledges that disasters are not isolated events but are often interconnected, with increasing effects that necessitate a comprehensive, systems-based approach to address systemic risk. Disaster risk is recognised as deeply intertwined with the fabric of socio-economic development, often rooted in underlying issues such as poverty and inequality that evolve dynamically (Peters et al., 2022). Consequently, effective management of these risks cannot be separated from the broader governance of socio-economic development. This implies that successful disaster risk reduction (DRR) initiatives must be seamlessly integrated into national development planning, resource allocation, and poverty alleviation strategies, rather than being treated as standalone emergency responses (Shawky & Hassan, 2023).

Nigeria is highly susceptible to a diverse range of natural hazards, with hydro-meteorological events being the most prominent. These include widespread flooding, progressive desertification, and recurrent droughts, alongside geological hazards such as soil and coastal erosion and landslides (Nduji et al., 2023). The country faces a complex interplay of these hazards, each with distinct characteristics yet often interconnected in their causes and impacts (Ibrahim et al., 2022). For example, the southeastern region is particularly prone to erosion due to torrential rainfall and human activities like sand excavation. The vulnerability of Nigerian communities is significantly compounded by factors such as poverty, rapid population growth, and the poor condition of human settlements and infrastructure, which dramatically magnify the human and economic consequences of these events (Ibrahim et al., 2022).

Nigeria has a well-documented history of severe and recurrent disasters. Flooding is recognised as the most common and catastrophic disaster, occurring annually. Between 1984 and 2014, flooding alone impacted an estimated 11 million people, caused over 1100 deaths, and resulted in economic damages exceeding US$17 billion. The catastrophic floods of 2022 further underscored this persistent and escalating nature, displacing 1.5 million people and claiming over 600 lives (Daniel et al., 2023).

Soil erosion, particularly gully erosion, poses a significant threat, with over 1000 active erosion sites. The Sahara Desert is encroaching southward at an alarming rate, affecting up to 63.8% of Nigeria's landmass and directly impacting approximately 30 million people (Peters et al., 2022). This phenomenon leads to extensive land degradation, food insecurity, biodiversity loss, and forced human migrations. Several interconnected anthropogenic factors, including rapid population growth, unsustainable land-use practices, and systemic governance challenges, such as poor urban planning and weak enforcement of existing policies, compound the severity of these hazards. These compounding factors create a complex web of vulnerabilities that necessitate a comprehensive and integrated approach to disaster risk assessment and reduction.

The study aims to assess the multi-dimensional challenges posed by natural hazards in Nigeria by applying Geographic Information Systems (GIS) to the Sahelian corridor. The specific objectives guiding this research are to assess the spread and interconnections of flooding, erosion, and desertification risks in the Sahelian corridor of Nigeria using GIS, to identify and map areas of high multi-hazard risk, and to propose a robust GIS-based framework for multi-hazard risk assessment adaptable to the environment.

MATERIALS AND METHODS

Study Area

The Sahelian corridor of Nigeria encompasses the northern "frontline states" that share direct land borders with the Republic of Niger. These states include Sokoto, Kebbi, Katsina, Jigawa, Yobe, and Borno (Figure 1). This geographical focus is critical because these areas are at the forefront of desert encroachment and experience significant impacts from climate change and unsustainable human activities.

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A semi-arid climate with distinct dry and rainy seasons characterises the Sahel region. Dry weather prevails for approximately eight months of the year, with the rainy season typically producing only about 4-8 mm of water (Federal Ministry of Health - Nigeria Centre for Disease Control, 2020; E. S. Ibrahim et al., 2022). This inherent climate variability makes the region naturally vulnerable to droughts. Projections for the Sahel indicate a gradual increase in temperature, expected to rise between 2.0 and 4.3 °C by 2080 compared to pre-industrial levels, with higher temperatures and more temperature extremes projected for the northern part of the region (Delves et al., 2025). Precipitation trends are uncertain, but projections indicate an overall increase in annual precipitation of up to 16 mm by 2080, with future dry and wet periods likely to become more extreme.

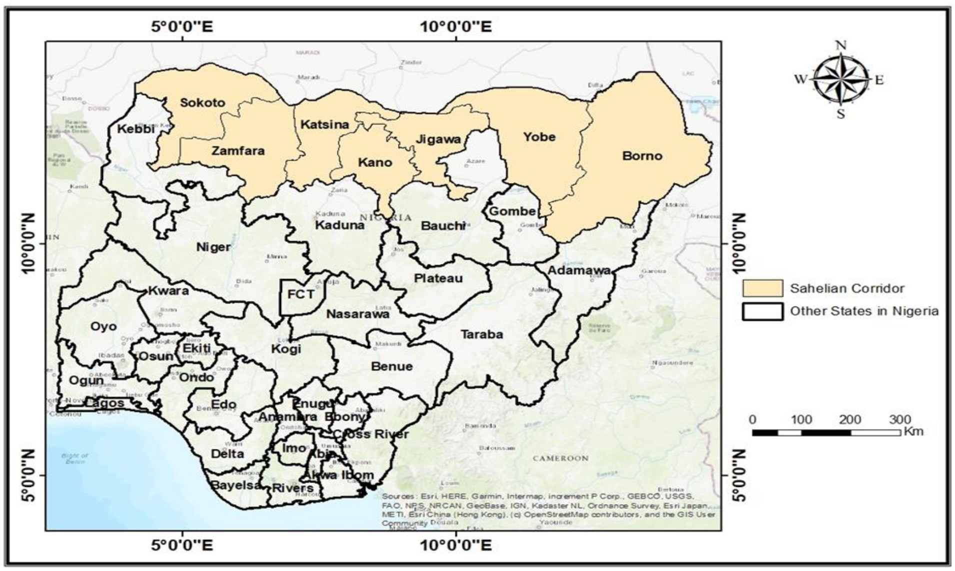


Figure 1: Map of Nigeria showing the Sahelian Corridor (Created by Author, 2025)

Data Types and Sources

This study utilised a wide range of data, including remotely sensed data, GIS raster and vector data, meteorological data, and other ancillary datasets, integrating these sources to achieve a comprehensive understanding of risk. The data used are;

- **Topographical and Hydrological Data:** Digital Elevation Models (DEMs) from SRTM were fundamental for understanding terrain, identifying low-lying areas, and extracting river networks and drainage basins, which are crucial for hydrological modelling and flood zone identification.
- **Land Use/Land Cover (LULC) and Climate Data:** LULC data, acquired through remote sensing, were critical for modelling all three hazards, as it directly influences flood runoff, soil erosion, and desertification. Climate data, including rainfall and temperature patterns, were sourced from the Nigerian Meteorological Agency (NiMet) and WorldClim.
- **Socio-Economic and Population Data:** Data on population density and distribution were utilised to assess exposure and social vulnerability, providing insights into the number and characteristics of people residing in hazard-prone areas. Information on critical infrastructure and economic assets, sourced from initiatives like GRID3, was also mapped to provide a comprehensive picture of potential economic losses.

Method of Data Analysis

The analysis involved a systematic approach to map the susceptibility and intensity of each hazard before integrating them into a final risk assessment.

- **Flood Risk Assessment:** Flood susceptibility was mapped by integrating anthropogenic, hydrological, and environmental factors such as elevation, slope, proximity to rivers, drainage density, and soil texture. These factors were reclassified into five risk levels from 1 to 5 (Very Low – very high), and weights were assigned based on their relative importance (Table 1).

Table 1: Reclassification Scheme for Flood Risk Factors

Factor	Criteria/Classes	Risk Value (1–5)
Elevation	>500 m = Very Low; 400–500 m = Low; 300–400 m = Moderate; 200–300 m = High; <200 m = Very High	1–5
Slope (%)	>15% = Very Low; 10–15% = Low; 5–10% = Moderate; 2–5% = High; 0–2% = Very High	1–5
Proximity to the River	>5 km = Very Low; 3–5 km = Low; 2–3 km = Moderate; 1–2 km = High; <1 km = Very High	1–5
Drainage Density	<0.5 km/km² = Very Low; 0.5–1 = Low; 1–1.5 = Moderate; 1.5–2 = High; >2 = Very High	1–5
Soil Texture	Clay loam = Very Low; Sandy clay = Low; Sandy loam = Moderate; Loamy fine sand = High; Concretionary clay = Very High	1–5

- **Erosion Risk Assessment:** Erosion risk was analysed based on a combination of natural and human factors, including slope, elevation, soil texture, soil drainage, drainage density, settlement density, and market density. Each layer was reclassified into risk values of 1–5, with slope and soil properties prioritised due to their direct influence on erosion susceptibility (Table 2).

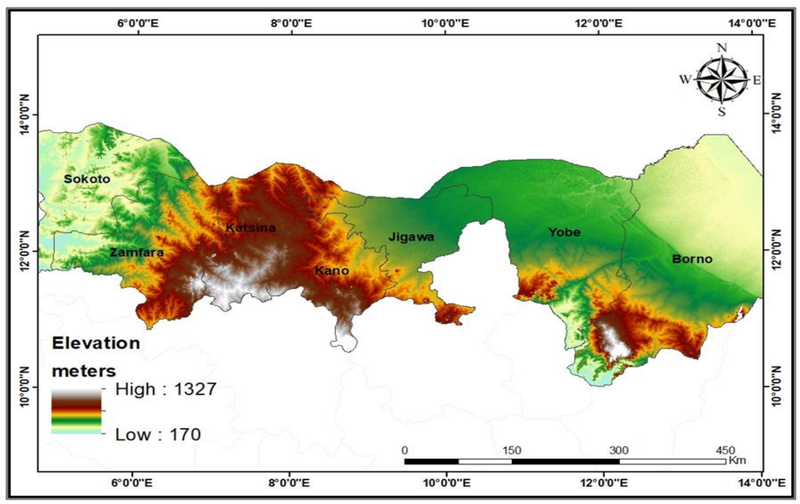
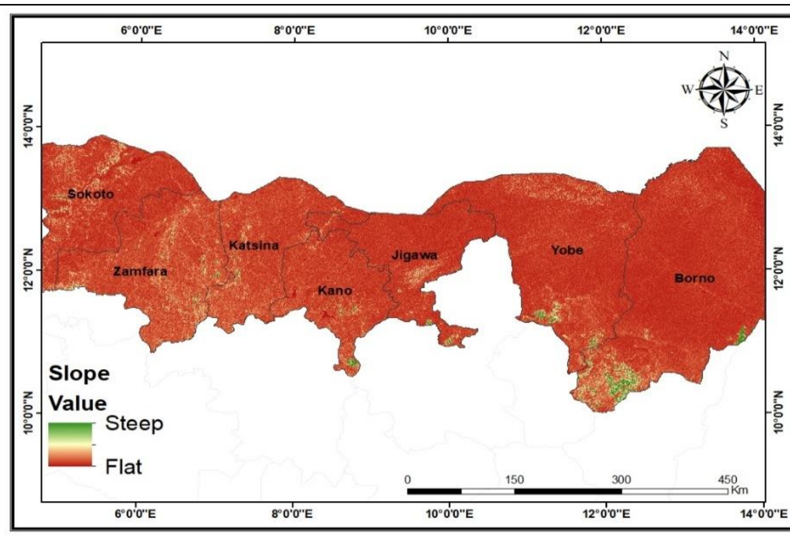
Table 2: Reclassification Scheme for Erosion Risk Factors

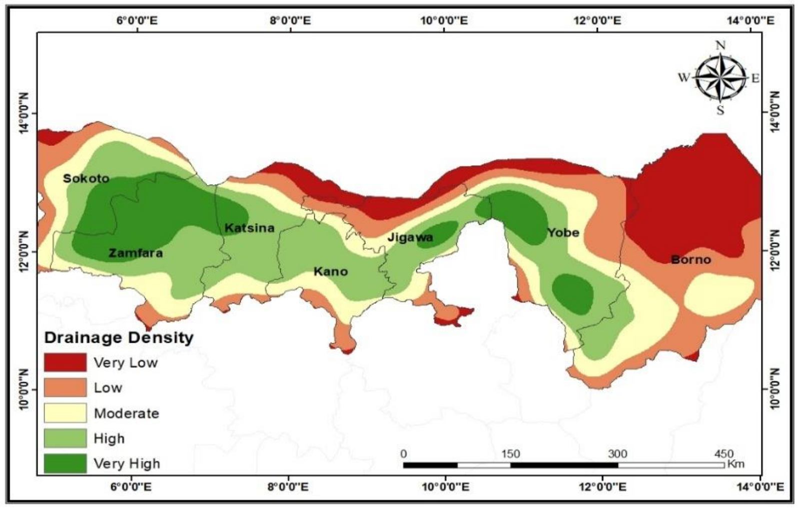
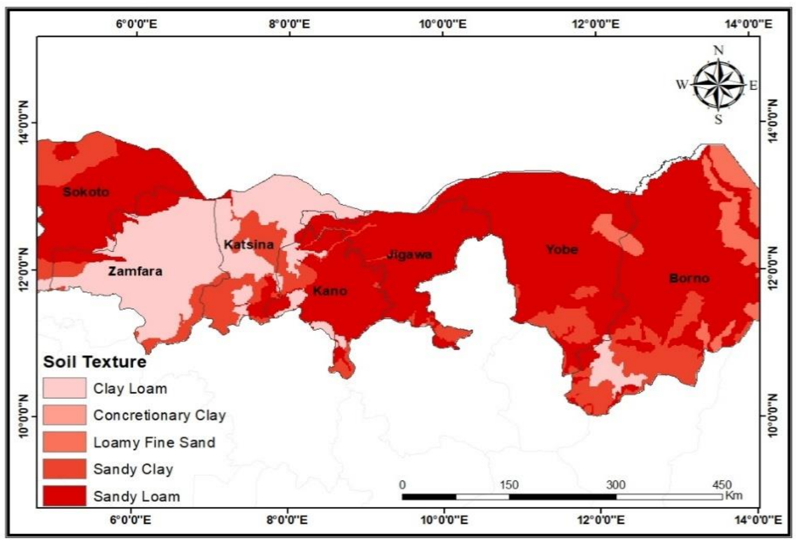
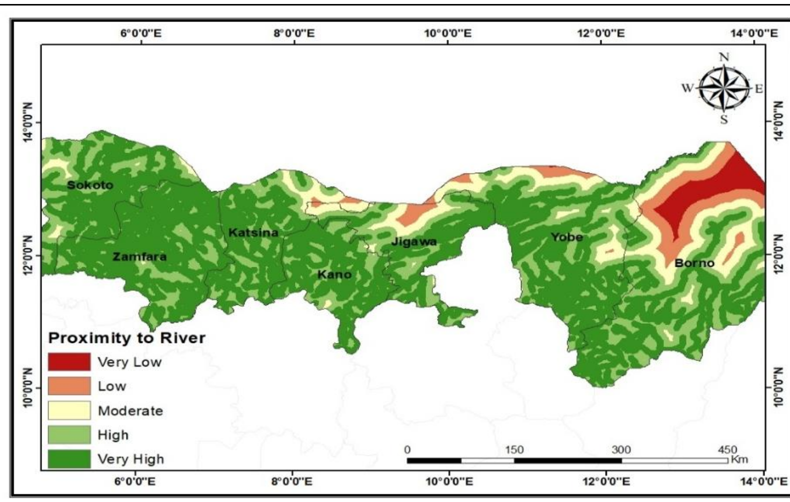
Factor	Criteria/Classes	Risk Value (1–5)
Slope (%)	0–2 = Very Low; 2–5 = Low; 5–10 = Moderate; 10–15 = High; >15 = Very High	1–5
Elevation	>500 m = Very Low; 400–500 = Low; 300–400 = Moderate; 200–300 = High; <200 = Very High	1–5
Soil Drainage	Well drained = Very Low; Imperfectly drained = Low; Moderately drained = Moderate; Shallow = High; Poorly drained = Very High	1–5
Drainage Density	<0.5 = Very Low; 0.5–1 = Low; 1–1.5 = Moderate; 1.5–2 = High; >2 = Very High	1–5
Settlement Density	<20 = Very Low; 20–40 = Low; 40–60 = Moderate; 60–80 = High; >80 = Very High	1–5
Market Density	<5 = Very Low; 5–10 = Low; 10–15 = Moderate; 15–20 = High; >20 = Very High	1–5

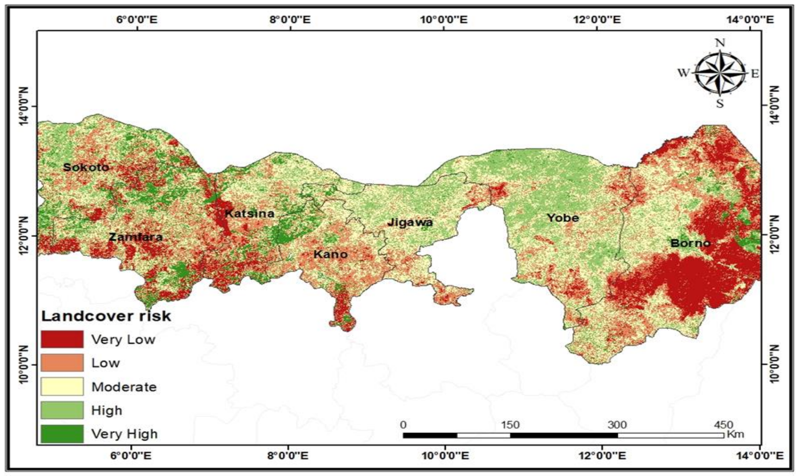
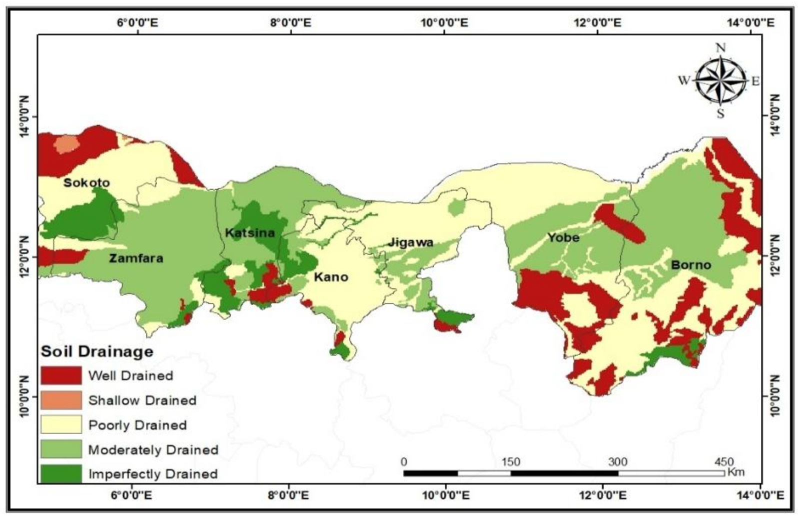
Desertification Progression Mapping: Remote sensing and change detection analysis were used to map desertification by detecting conversions from ecologically active land covers to degraded land types over time (Ibrahim et al., 2022).

The final step involved integrating the individual hazard layers using spatial overlay analysis to produce a multi-hazard risk index (MHRI). This process enabled the identification of high-risk "hotspots" where multiple hazards converge, resulting in high levels of exposure and vulnerability. Vector data containing local government areas was also overlaid on the final map to detect how many LGAs are within the category. Using Zonal Statistics Analysis, the number of local governments within each category (very low to very high) was determined.

Table 3: Maps showing the Factors for Hazard Risks in the Sahelian Corridor

Hazard Assessment Factors	Maps
Elevation	
Slope	

Drainage Density	
Soil Texture	
Proximity to the River	

Land Cover Risk	
Soil Drainage	

RESULTS AND DISCUSSION

Flood Susceptibility and Hazard Zones

The flood hazard assessment, which integrated factors such as elevation, slope, and drainage density, classified the study area into four distinct hazard zones: Low, Moderate, High, and Very High. The results indicate that a significant portion of the area is moderately to highly susceptible to flooding. As shown in Table 4, a total of 143,093 km², or 57.84% of the land, falls within the High flood hazard zone (including central Katsina, Kano, Yobe, and parts of Borno). In comparison, 31,284.3 km², or 12.65%, is categorised as having a Very High flood hazard (areas between Sokoto and Zamfara, as well as Jigawa and Yobe) (Fig 2). This finding indicates that a substantial majority of the study area, over 70%, is highly susceptible to flooding, a conclusion consistent with literature highlighting Nigeria's extensive flood-prone areas, particularly in low-lying regions and river basins (Ifiok Enobong Mfon et al., 2022).

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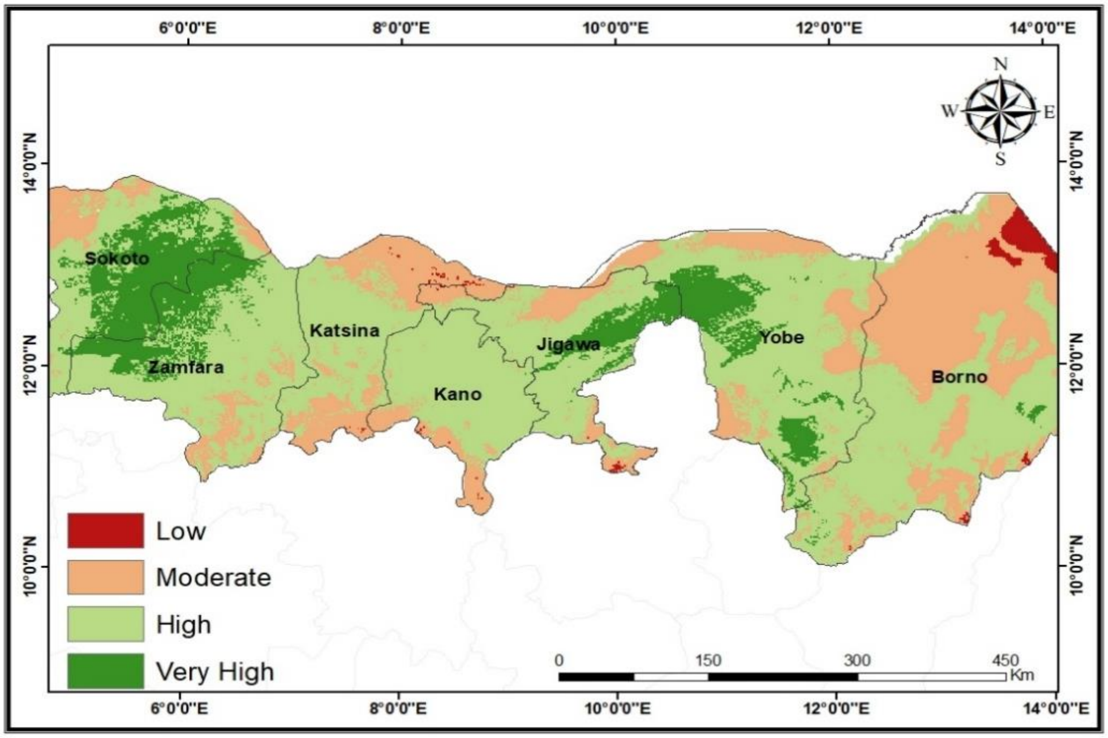

Figure 2: Flood Hazard Map

Table 4: Risk Zones in Sahelian Corridor (Flooding)

Value	**Area (km²)**	**Per cent (%)**	**Representative Areas/States**
Low	2572.1	1.04	Generally, sparsely populated hinterlands, and potentially some areas in Borno
Moderate	70423.5	28.47	Transitional zones, potentially including the moderate-risk state of Kano, Borno and Katsina
High	143093	57.84	High-risk states like Jigawa, Yobe, Zamfara, and urban centres like Maiduguri and Damaturu
Very High	31284.3	12.65	Known flood and population hotspots, including the very high-risk LGAs of Shinkafi and Sokoto South

Erosion Risk and Gully Hotspots

The erosion risk assessment, based on factors such as land cover, soil drainage, and topography, revealed a similar pattern of widespread risk. The analysis indicates that a substantial majority of the study area, 71.24%, is at Moderate risk of erosion, while 24.35% is at High risk (Table 5). Although the area classified as Very High risk is comparatively small, the findings emphasise that erosion is a widespread problem across the region, particularly in areas with torrential rainfall and unconsolidated soils. The high percentage of land in the Moderate to High categories suggests broad susceptibility to soil loss, a major environmental issue that can lead to severe gully formation (Ifeanyi et al., 2024).

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Table 5: Erosion Risk Class

Value	Area (km²)	Per cent (%)	Representative Areas/States
Low	10898.2	4.41	Areas with low settlement and market density, potentially in Borno and Katsina
Moderate	176238	71.24	Areas with broad susceptibility to soil loss and mixed exposure, such as Kano (Moderate multi-hazard risk)
High	60242.1	24.35	States identified for gully rehabilitation projects: Jigawa and Yobe (High multi-hazard risk)
Very High	5.78	0.002336	Localised gully hotspots within the high-risk states

The current assessment, which utilises factors such as land cover, soil drainage, and topography, primarily captures the susceptibility to water-driven erosion and subsequent gully formation. Given that the Sahelian corridor is characterised by a semi-arid climate and advancing desertification, it is crucial to consider wind erosion as well. This phenomenon, driven by the strong dry-season winds and extensive loss of vegetative cover, plays a critical role in land degradation by removing fine, fertile topsoil and contributing to the formation of dunes. Future iterations of this GIS-based erosion risk model, particularly for this arid region, would need to integrate proxy variables for wind erosion potential, such as wind speed data and the erodibility of exposed, degraded land covers, to provide a more comprehensive risk profile.

Desertification Progression and Land Degradation Areas

The desertification risk assessment provided insights into the spatial extent of land degradation in the Sahelian corridor. The results show that 30.39% of the area is at Moderate risk, 21.34% at High risk, and 7.03% at Very High risk (Table 6). This confirms that a significant portion of the region is under threat from desertification, aligning with previous studies estimating that up to 63.8% of Nigeria's total landmass is affected by desert features (Ibrahim et al., 2022). The analysis of Land Use/Land Cover (LULC) changes supports these findings, indicating that areas covered by dunes have been progressing at a mean annual rate of 15.2 km² between 1990 and 2015, primarily driven by human activities like deforestation and unsustainable agriculture (Ibrahim et al., 2025; Leeonis et al., 2025).

Table 6: Desertification Risk Areas

Value	Area (km²)	Per cent (%)	Locations
Very Low	40876.7	16.33	Borno, Katsina and Zamfara
Low	62320.9	24.90	Locations within Kano
Moderate	76045.1	30.39	Minor areas within Yobe and Jigawa
High	53411.2	21.34	Ocurring within all states in the region
Very High	17590.6	7.03	Locations with Katsina, Zamfara and Sokoto

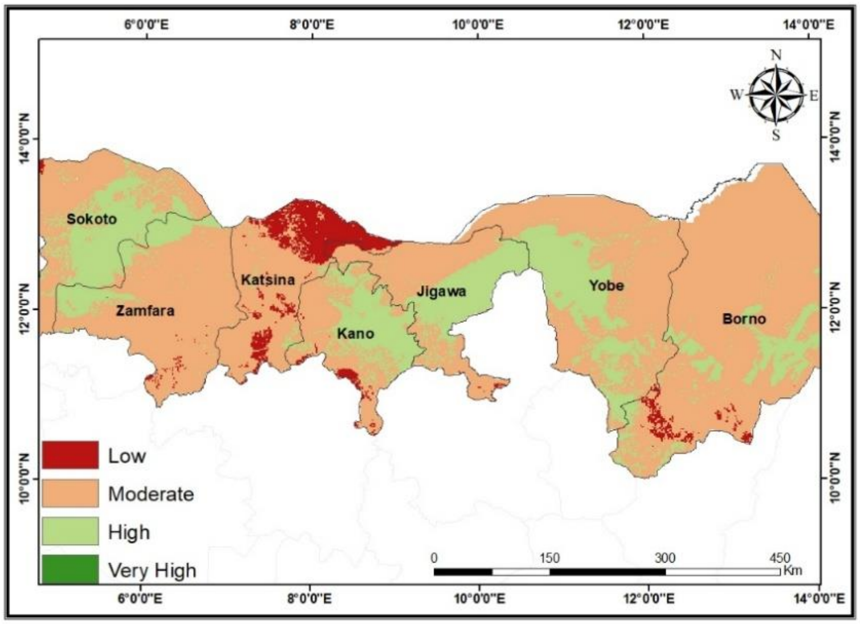

Figure 3: Erosion Risk in the states of the Sahelian Corridor

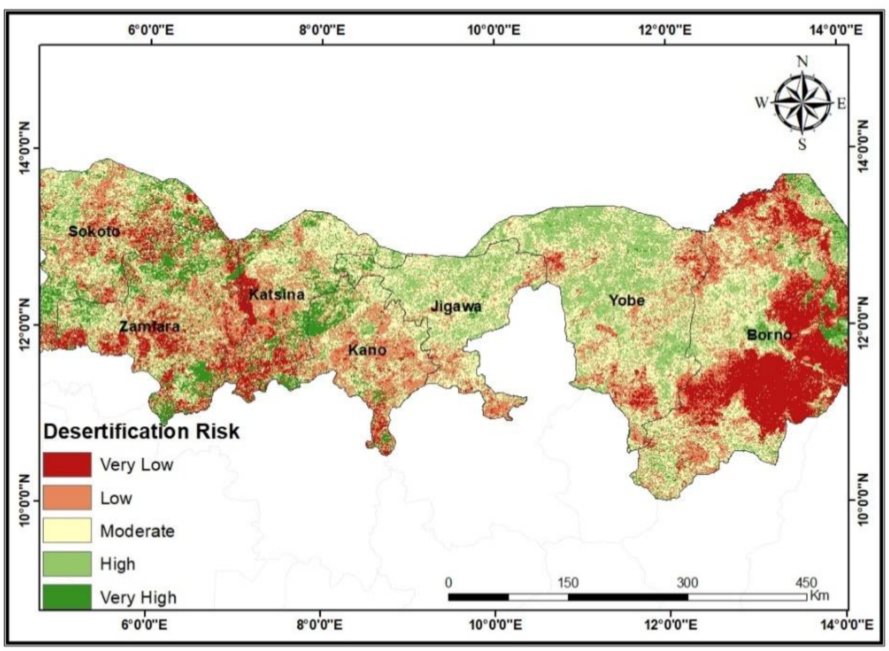

Figure 4: Desertification Risk in Sahelian Corridor

Integrated Multi-Hazard Risk Analysis

The integration of the hazard, exposure, and vulnerability layers culminated in a comprehensive multi-hazard risk map and index. The final multi-hazard risk assessment provided a holistic view of

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risk, identifying hotspots where multiple hazards and high vulnerabilities converge. The results of the multi-hazard risk zonation reveal a clear spatial pattern of risk across the study area (Table 7).

Table 7: Multi-Hazard Zonation Area and Percentage

Value	Area (km²)	Per cent (%)
Very Low	40379.1	16.33
Low	70253	28.41
Moderate	61369.1	24.82
High	65198.4	26.37
Very High	10063	4.07

The analysis identified that 26.37% of the area is at High multi-hazard risk, with an additional 4.07% at Very High risk. These findings are comparable to other multi-hazard studies in different regions, such as the community-level assessment conducted in Hodh Chargui, Mauritania, which also identified high-risk zones where concurrent vulnerabilities and multiple hazards converge (Tiepolo et al., 2019). Mauritania is part of the broader Sahelian region, making the comparison particularly relevant due to shared climatic and socio-economic vulnerabilities. The results confirm that disaster risk is not merely a function of natural events but is deeply rooted in socio-economic factors such as poverty, rapid population growth, and poor governance666. (Nduji et al., 2023).

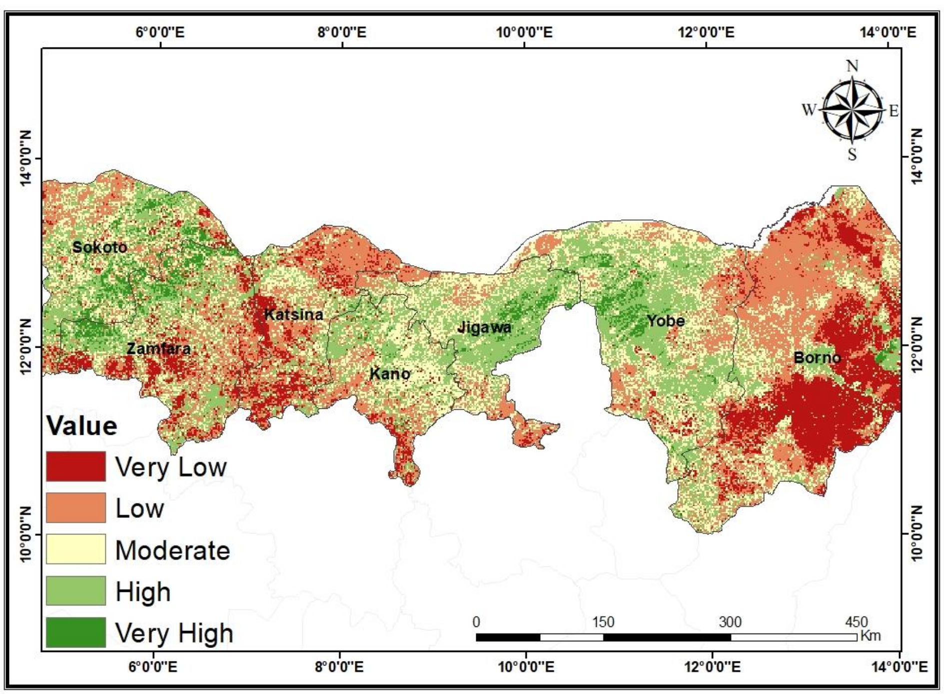

Figure 5: Multi-Hazard Risk Map

The integrated multi-hazard assessment provided a holistic view of risk, revealing how individual hazards are interconnected and how their effects compound. The analysis of cascading effects revealed that desertification is not just a standalone hazard but a key driver that amplifies the risk of erosion and flooding. The loss of vegetative cover due to desertification and unsustainable land use practices weakens the soil, making it highly susceptible to erosion from rainfall and runoff. This creates a direct causal chain: desertification contributes to erosion, which in turn can amplify the destructive power of floods through increased sediment loading. This phenomenon was starkly observed during the 2023 floods in Derna, Libya, where sediment loading from surface erosion exacerbated the catastrophic impact (Oduoye et al., 2024). The GIS framework enabled modelling of this progression, in which areas of high desertification and erosion risk were assigned greater weight in the flood risk assessment, yielding a more realistic risk profile. This demonstrates that tackling one hazard, such as desertification through afforestation, has a positive ripple effect on the others, reducing both erosion and flood risk.

Geographic Analysis of Multi-Hazard Risk by Administrative Unit

State-Level Risk: The state-level aggregation of the multi-hazard risk index reveals notable disparities across the Sahelian corridor. The corridor is divided into High, Moderate, and Low risk categories, highlighting areas where hazards and exposure interact most strongly (Table 8).

Table 8: Multi-Hazard Risk by States in Sahelian Corridor

States	Multi-Hazard Risk
Borno	Low
Jigawa	High
Kano	Moderate
Katsina	Low
Sokoto	High
Yobe	High
Zamfara	High

High-risk states (Jigawa, Sokoto, Yobe, Zamfara) represent the core hazard hotspots, combining frequent flooding and erosion with advancing desertification. Their classification is attributed to a combination of high population pressure, fragile ecosystems, and strong trends of desert encroachment (Table 9). These states are part of Nigeria's "frontline" desertification zone, with 50–75% of their land area affected. Severe vulnerability is particularly pronounced in Jigawa, Sokoto, Yobe, and Zamfara, where dunes, vegetation loss, and land degradation are advancing rapidly (Azare et al., 2020; Yahaya et al., 2024).

Frequent riverine flooding and wind erosion are exacerbated by deforestation, poor land management, and population-driven land use changes (Table 9). Local governments in Jigawa, for example, such as Auyo, Hadejia, Kirika-samma, Kafin-Hausa, Ringim, Miga, Jahun, and Dutse, are mapped as very high flood risk zones (Aliyu et al., 2024). Kano is classified as a moderate-risk state, but it demonstrates that high exposure (a very dense population and markets) can elevate overall risk, even when hazard intensity is not at its peak. Kano exhibits a spectrum from areas with no desertification (e.g., Falgore Game Reserve) to very severe vulnerability at the city's outskirts, highlighting the role of urbanisation and market-driven land use (Yelwa et al., 2019).

Table 9: Hazard Profile and Drivers of Risk

State	Hazard Profile	Drivers of Risk
Jigawa	Severe desertification, frequent flooding, and erosion	High population, fragile land, desert encroachment
Sokoto	Severe desertification, wind erosion, and flooding	Population pressure, land degradation
Yobe	Severe desertification, dune movement, and flooding	Ecosystem fragility, population growth
Zamfara	Severe desertification, wind erosion, and flooding	Land use change, population, and climate variability
Kano	Moderate to severe desertification, moderate flooding	High exposure, urbanisation, market activity

Interestingly, Borno and Katsina fall under low multi-hazard risk. This is explained by the fact that Borno's overall risk score is lowered by the comparatively minimal adequate exposure found in several of its LGAs, which have lower settlement density and reduced infrastructure concentration. This finding illustrates a crucial concept: disaster risk is not static; it is a dynamic function of human presence. The overall multi-hazard risk is determined by the intersection of natural hazards with the mapped social and economic exposure and vulnerability in the study (Shawky & Hassan, 2023).

LGA-Level Risk

The multi-hazard risk assessment across LGAs reveals significant spatial variation in exposure to hazards, as shown by zonal analysis (Table 10).

Table 10: Summary of Multi-Hazard Risk by LGA Category

Risk Category	Number of LGAs	Representative LGAs	Spatial Characteristics
Very High	2	Shinkafi, Sokoto South	Highly urbanised or ecologically fragile zones with dense population and infrastructure (Azare et al., 2020)
High	~65	Maiduguri, Damaturu, Kano Municipal, Gwarzo, Hadejia, Nguru	Urban centres, floodplains, high settlement/market density, intense desertification pressures (Yelwa et al., 2019)
Moderate	~45	Batagarawa, Dawakin Kudu, Gujba, Gulani, Wudil	Transitional zones with mixed rural-urban exposure, moderate hazard intensity
Low	~55	Katsina, Gusau, Fika, Potiskum, Geidam, Jibia	Predominantly rural LGAs with lower settlement and market density; hazards present but less intense
Very Low	~15	Bama, Gwoza, Marte, Funtua, Dandume	Sparsely populated hinterlands, areas with minimal infrastructure exposure despite hazard potential (Azare et al., 2020)

The highest-risk LGAs (e.g., Sokoto South, Shinkafi, Maiduguri) are predominantly urban or semi-urban centres where flooding, erosion, and desertification hazards intersect with high population density and concentrated markets. This trend demonstrates that while hazards are natural, the scale of a disaster is overwhelmingly human-made, driven by rapid and often unplanned urbanisation. The concentration of people and economic assets in hazard-prone zones dramatically increases exposure and vulnerability, underscoring that poor urban planning and a lack of governance are critical risk multipliers.

CONCLUSION AND RECOMMENDATIONS

This research successfully assessed the complex, compounding risks of flooding, erosion, and desertification in Nigeria's Sahelian corridor, confirming a landscape of pervasive and interconnected threats amplified by socio-economic vulnerabilities and governance deficits. The integrated multi-hazard risk assessment identified that over 30% of the area faces high-to-very-high risk, with high-risk "hotspots" resulting from the convergence of these hazards and high levels of population and infrastructure exposure. A key finding is the analysis of cascading effects, which demonstrates that desertification is a key driver of risk amplification, increasing soil susceptibility to erosion and thereby intensifying the impact of floods. The GIS-based framework provides a practical model for future risk assessments, yielding actionable intelligence through multi-hazard risk maps and administrative unit classifications that can directly inform policy and planning.

To enhance resilience, comprehensive strategies integrating flooding, erosion, and desertification into a single framework are essential. Targeted structural and non-structural interventions are required, including the expansion and rehabilitation of drainage infrastructure in dense, flood-prone towns such as Damaturu and Sokoto South. For soil stability, the study recommends gully monitoring and rehabilitation in hotspots across states like Jigawa, Kano, and Yobe, alongside scaling up afforestation projects in high-encroachment states such as Yobe, Jigawa, and Zamfara, notably through the Great Green Wall initiative. Furthermore, State- and LGA-level risk maps must be institutionalised as planning tools, and early warning systems must be established. Finally, strong governance, policy harmonisation, and mainstreaming disaster risk reduction into climate change adaptation policies are necessary for sustainable risk reduction.

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