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GIS Based Multi-Hazard Risk Assessment In Nigeria: Flooding, Erosion, And Desertification In Sudano-Sahelian Region, Northwest Nigeria

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ABSTRACT

This study presents a comprehensive GIS-based multi-hazard risk assessment of the Sudano Sahelian region of North wet of Nigeria, focusing on three dominant environmental hazards: flooding, erosion, and desertification. The research aimed to assess the interconnections of these hazards, and identify areas of high multi-hazard risk by integrating hazard, exposure, and vulnerability indicators. Multiple datasets, including NDVI, settlement density, population, soil characteristics, and topographical variables, were processed in a GIS environment using reclassification and weighted overlay methods to map hazard, exposure, and vulnerability. The results show that flood susceptibility is highest in low-lying floodplains, with Sokoto South and Shinkafi LGAs emerging as very high-risk zones. the analysis reveals that a total of 81,775 km², or 61.79% of the land, falls into the High flood hazard zone. Erosion risk is concentrated in Jigawa, and Kano, States, where sandy soils and steep slopes increase vulnerability. The analysis indicates that a substantial majority of the study area, 62.11%, is at Moderate risk of erosion, while 33.15% is at High risk. Desertification risk is most severe in Zamfara, and parts of Jigawa, driven by vegetation loss. The results show that 31% of the area is at Moderate risk, 20.34% at High risk, and 10.86% at Very High risk. At the state level, Jigawa, Sokoto, and Zamfara were identified as high-risk states. The analysis also identified that 30.7% of the area is at High multi-hazard risk, with an additional 5.76% at Very High risk. The findings highlight that multi-hazard risk is driven not only by hazard intensity but also by population density, settlement clustering, and market concentration, which amplify exposure and vulnerability. The study concludes that the region faces compounded risks from the interaction of these hazards, particularly in areas with high population and economic activity. It recommends a combination of structural (drainage rehabilitation, afforestation) and non-structural (land use planning, early warning systems) measures, as well as the integration of multi-hazard risk assessments into local development policies to enhance resilience.

Keywords: GIS-based multi-hazard risk assessment, resilience,

INTRODUCTION

Environmental hazards such as flooding, erosion, and desertification have become increasingly severe across dryland regions, particularly in sub-Saharan Africa, where climate variability and human pressures interact to intensify landscape degradation. The Northwestern Nigeria is an area widely recognized in research as one of the most environmentally vulnerable regions in West Africa (M. Ibrahim et al., 2025). Recent studies indicate that the combined effects of rapid population growth, land-use transformation, declining vegetation cover, and recurrent extreme weather events have heightened the frequency and spatial extent of these hazards, threatening livelihoods, agricultural productivity, water resources, and infrastructure (Awal & Awal, 2015). Yet, despite extensive research on individual hazards, there remains a critical gap in understanding how these hazards interact spatially, and the degree to which communities and assets across this zone experience multi-dimensional risk.

Research have emphasized that areas experiencing overlapping hazards often suffer disproportionately more severe socio-economic impacts, especially where exposure and vulnerability are high. Nigeria has a well-documented history of severe and recurrent disasters, consistently leading to substantial loss of life, widespread property damage, and significant economic disruption. Flooding is recognized as the most common and catastrophic disaster, occurring annually, particularly during the rainy season. 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. More recently, the catastrophic floods of 2022 displaced 1.5 million people and claimed over 600 lives, further highlighting the persistent and escalating nature of these threats (Daniel et al., 2023).

Soil erosion also poses a significant threat, especially in the southeastern part of the country, where it has been a problem for at least 30 years. Over 1000 active erosion sites exist, with some gullies reaching depths of 120m and widths of 2km in Anambra State. This has led to reduced agricultural productivity, destruction of homes, displacement, and significant loss of property (Ifeanyi et al., 2024). Desertification is also another pronounced ecological disaster affecting arid and semi-arid areas of northern Nigeria, particularly the eleven "frontline states" bordering the Niger Republic. The severity of natural hazards in Nigeria is significantly compounded by several interconnected anthropogenic factors. Rapid population growth and uneven population distribution often lead to increased exposure in hazard-prone areas (Chude et al., 2020). This demographic pressure, coupled with unsustainable land use practices such as rampant felling of trees for fuelwood, overgrazing, unsustainable agriculture, and illegal farming, accelerates land degradation and desertification.

The study area, comprising Sokoto, Zamfara, Katsina, Kano, and Jigawa states is characterized by its location in the Sudano-Sahelian ecological zone (E. S. Ibrahim et al., 2022). This region experiences significant climatic variability, contributing to drought conditions and land degradation. The states rely heavily on agricultural activities, yet regional land suitability analyses indicate that large areas within the North and Northwest have a higher share of moderate to low agricultural suitability compared to southern or north-central regions (Leeonis et al., 2025). This dependence on marginally productive land creates an inherent socio-economic sensitivity to environmental shocks.

Geologically, states such as Jigawa feature a mix of basement complex formations in the northwest and sedimentary basins, which dictate local soil characteristics and hydrological response to rainfall (Zakaria et al., 2022). The consequences of environmental degradation are widespread, cutting across the country but are most prominent in the northern region, where drought, sand dune formation, and desertification are major concerns. Therefore, the objective of the study is to assess the interconnections of flooding, erosion, and desertification risks in the Sudano Sahelian region of Nigeria using GIS as well as identify and map areas of high multi-hazard risk by integrating hazard and exposure

Study Area

The study area is situated predominantly within the Sudano-Sahelian ecological zone, characterized by semi-arid conditions and significant climatic variability. This location makes the region, which accounts for 43% of Nigeria's total land mass, the most vulnerable part of the country to processes like wind erosion, drought, and desertification. Geographically, the region hosts major hydrological features, including the Hadejia River Basin (covering parts of Kano and Jigawa) known for frequent and severe floods (Idris et al., 2025), and the Rima River Basin in Sokoto. States like Jigawa also feature a geology of basement complex formations in the northwest (Shuaibu et al., 2022), which influences local soil composition and hydrological response.

The region is characterized by a semi-arid climate with distinct dry and rainy seasons. Dry weather prevails for approximately eight months of the year, with the rainy season typically producing only about 4-8 inches of water (Federal Ministry of Health - Nigeria Centre for Disease Control., 2020; E. S. Ibrahim et al., 2022). The economy is heavily reliant on agriculture , yet the majority of land within the North and Northwest exhibits a higher share of moderate to low agricultural suitability. This reliance on marginally productive land creates an inherent socio-economic fragility to environmental shocks.

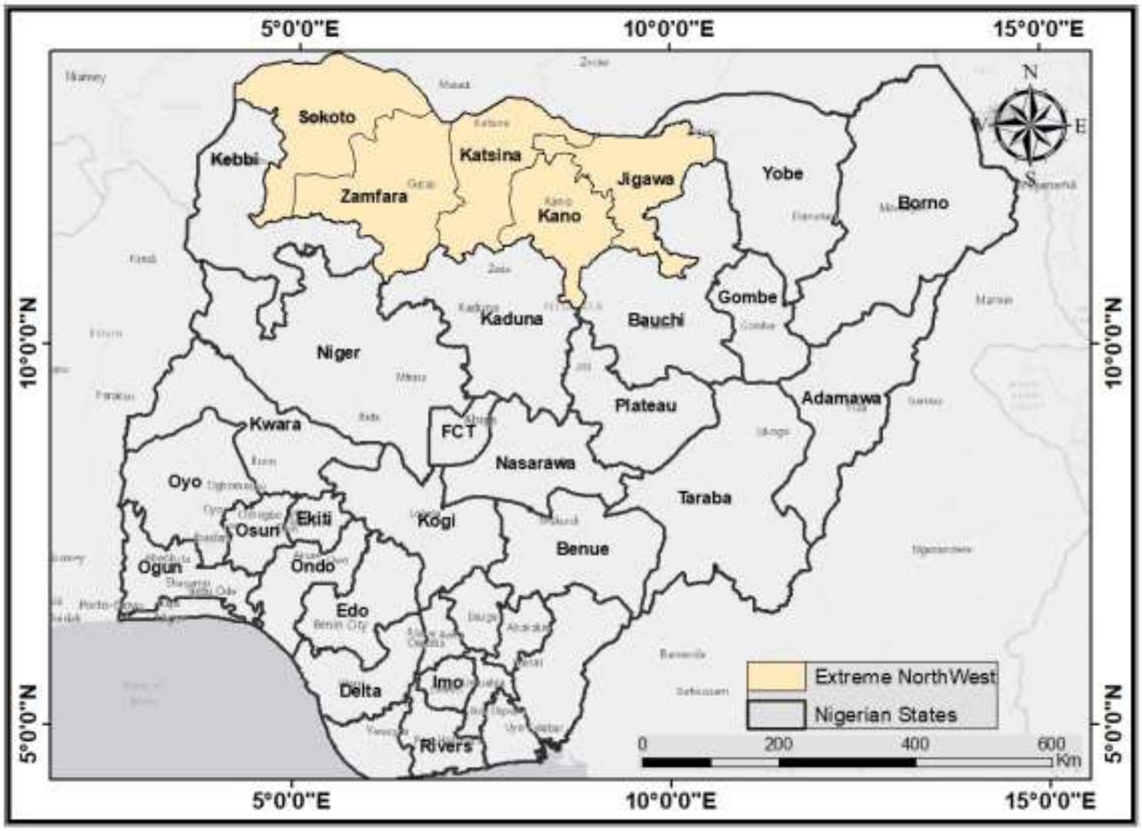

Fig 1: Map showing Sub States within the Sudano-Sahelian Region of North West Nigeria

MATERIALS AND METHODS

The analysis utilized remotely sensed data as well as other ancillary datasets integrated for an understanding of risk as shown in the table below:

Table 1: Data Types and Sources

Data Type	Description	Purpose
Topographical and Hydrological Data	DEMs are fundamental for understanding terrain, identifying low-lying areas, influencing water flow patterns, and assessing flood susceptibility and erosion risk	Derived from the USGS Earth Explorer, utilized for extracting elevation and slope, providing crucial inputs for hydrological modeling (An et al., 2021).
River Networks and Drainage Basins	High-resolution river network data and drainage system maps are essential for flood zone identification, assessing proximity to rivers (a crucial factor for flood risk), and understanding broader hydrological processes	Derived Nigeria - Water Courses dataset from the Humanitarian Data Exchange (HDX) at a scale of 1:1,000,000 and HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales), which provides consistent hydrographic information including stream networks and watershed boundaries

		at 3 arc-second resolution for regional and global applications
Land Use/Land Cover (LULC)	LULC data is critical for understanding and modeling all three hazards, as it directly influences flood risk (e.g., impervious urban surfaces increase runoff), erosion (e.g., loss of vegetation cover accelerates soil degradation), and desertification (e.g., expansion of sand dunes, conversion of vegetated land to farmlands) (Sampson et al., 2021).	Derived from Landsat 8 OLI/TIRS to determine the level of risk with respect to land use and land cover of the study area
Population Density and Distribution	This data is crucial for assessing exposure and social vulnerability, providing insights into population density, distribution, and demographics	High-resolution population density maps and demographic estimates for Nigeria (e.g., for 2020), including data on overall population density, was available from initiatives like GRID3/WorldPop via the Humanitarian Data Exchange (HDX) (Luu et al., 2020).
Assets Exposure (Road, Settlements and Markets)	These datasets were important to derive the level of exposure of economic and social assets to multi-hazards (Tiepolo et al., 2019)	These were derived from GRD3 datasets to map the spatial distribution of assets within the region and their level of susceptibility

GIS-Based Multi-Hazard Assessment Framework

The GIS-based multi-hazard assessment framework systematically integrated hazard, exposure, and vulnerability components to provide a comprehensive understanding of risk in the region. This framework was designed to be flexible and semi-quantitative, suitable for environments with varying data availability. The concetual framework for this study was based on the widely accepted model that defines risk as a function of hazard, exposure, and vulnerability. Hazard assessment involved mapping the susceptibility and intensity of flooding, erosion, and desertification across the study area.

- Flooding Risk Mapping: Flood mapping determine locations most likely to experience flooding by integrating anthropogenic, hydrological, and environmental factors. A Weighted Linear Combination (WLC) approach was utilized, which involves assigning weights to continuous data layers based on their relative importance and combining them through a weighted average.
- Erosion Risk Mapping: Erosion risk mapping was identified areas prone to soil loss and gully formation. The erosion risk integrated elevation, soil texture, soil drainage, land use, slope and road proximity. The computation of slope length and steepness and soil erodibility helped in assessing erosion risk and identify erosion hotspots.
- Desertification Mapping: Desertification progression was mapped primarily through remote sensing and image classification. Satellite imagery was used to detect major conversions from ecologically active land covers to sand dunes and other degraded land types over time.

Exposure and vulnerability assessment involved meticulously mapping the spatial distribution of elements at risk within the identified hazard zones. This includes population assessment, mapping the locations of essential facilities and infrastructure, such as roads, schools, and hospitals, crucial for understanding potential disruptions and damages along with economic assets such as markets and infrastructure.

The final step in the framework involves integrating the individual hazard, exposure, and vulnerability layers within the GIS environment to produce comprehensive multi-hazard risk maps. This was achieved through spatial overlay analysis and the application of a multi-hazard risk index (MHRI) (Luu et al., 2020). The MHRI combined the weighted hazard, exposure, and vulnerability indices to classify areas into different risk categories (e.g., very high, high, medium, low risk) (Fig 2). This integration allows for:

- Identification of High-Risk "Hotspots": Pinpointing specific geographical areas where multiple hazards converge with high levels of exposure and vulnerability, indicating areas that require urgent and integrated interventions.
- Analysis of Increasing Effects: Modeling how one hazard (e.g., desertification) can exacerbate another (e.g., erosion), which in turn amplifies the impacts of a third (e.g., flooding), providing more understanding of compounded risks.

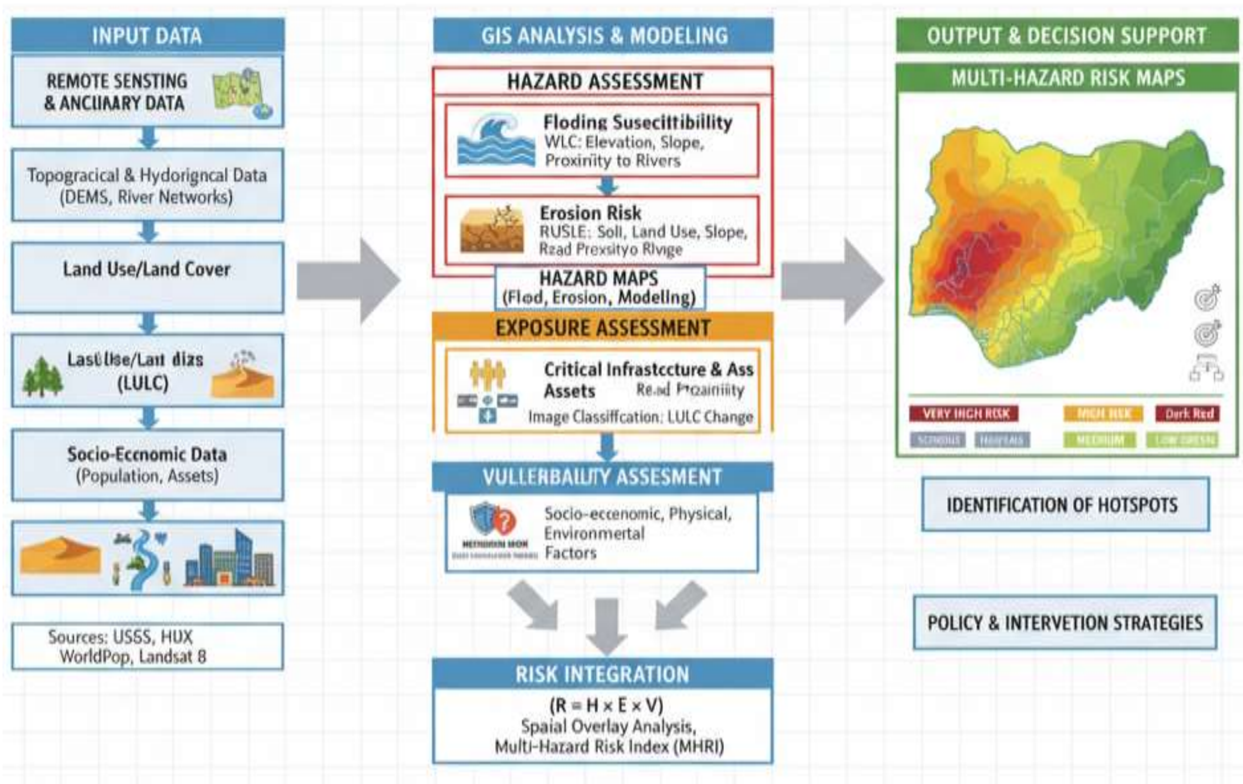

Fig 2: Methodology Framework for Multi-Hazard Assessment

Flood Risk Assessment

The flood risk analysis in this study was conducted using elevation, slope, proximity to river, drainage density, and soil texture (Table 2), as these factors are critical in determining flood susceptibility. Each factor was reclassified into five risk levels: Very Low, Low, Moderate, High, and Very High, on a scale of 1–5. Reclassification ensures that heterogeneous datasets could be compared and integrated into a uniform risk scale.

Table 2: Reclassification Scheme for Flood Risk Factors

Factor	Criteria/Classes	Weight (%)
Elevation	> 500 m = Very Low; 400–500 m = Low; 300–400 m = Moderate; 200–300 m = High; < 200 m = Very High	25
Slope (%)	> 15% = Very Low; 10–15% = Low; 5–10% = Moderate; 2–5% = High; 0–2% = Very High	20
Proximity to River	> 5 km = Very Low; 3–5 km = Low; 2–3 km = Moderate; 1–2 km = High; < 1 km = Very High	20
Drainage Density	< 0.5 km/km² = Very Low; 0.5–1 = Low; 1–1.5 = Moderate; 1.5–2 = High; > 2 = Very High	25
Soil Texture	Clay loam = Very Low; Sandy clay = Low; Sandy loam = Moderate; Loamy fine sand = High; Concretionary clay = Very High	10

After reclassification, weights were assigned based on literature (Delves et al., 2025; Hallett et al., 2017). Elevation, slope, and proximity to river were given higher weights since they directly control water accumulation and runoff. Settlement and market-related factors were weighted lower but included as exposure indicators.

Erosion Risk Assessment

Erosion in the region is influenced by both natural and human factors. For this study, the analysis was based on slope, elevation, soil texture, soil drainage, drainage density, settlement density, and market density. The thematic layers were reclassified into risk values of 1–5 based on their susceptibility to erosion. Weights were assigned with slope and soil properties prioritized, since they are primary determinants of erosion susceptibility.

Table 3: Reclassification Scheme for Erosion Risk Factors

Factor	**Criteria/Classes**	**Weight (%)**
Slope (%)	0–2 = Very Low; 2–5 = Low; 5–10 = Moderate; 10–15 = High; > 15 = Very High	30
Elevation	> 500 m = Very Low; 400–500 = Low; 300–400 = Moderate; 200–300 = High; < 200 = Very High	20
Soil Drainage	Well drained = Very Low; Imperfectly drained = Low; Moderately drained = Moderate; Shallow = High; Poorly drained = Very High	10
Drainage Density	< 0.5 = Very Low; 0.5–1 = Low; 1–1.5 = Moderate; 1.5–2 = High; > 2 = Very High	20
Settlement Density	< 20 = Very Low; 20–40 = Low; 40–60 = Moderate; 60–80 = High; > 80 = Very High	10
Market Density	< 5 = Very Low; 5–10 = Low; 10–15 = Moderate; 15–20 = High; > 20 = Very High	10

Desertification Risk Assessment

The desertification risk assessment integrates multiple biophysical and human-induced factors that influence land degradation processes in dryland environments. In Northwest Nigeria, desertification is driven not only by climatic stress but also by soil characteristics, vegetation loss, topography, and anthropogenic pressure. Therefore, this analysis combines soil texture, soil drainage, land use, vegetation index (NDVI), slope, and elevation into a weighted multi-criteria evaluation framework.

Each factor was reclassified into five risk categories (Very Low, Low, Moderate, High, and Very High) based on their relative contribution to land degradation. Slope and elevation influence runoff, soil stability, and moisture retention; soils with poor drainage or coarse texture degrade faster under dryland conditions; vegetation cover (NDVI) indicates the degree of land productivity or degradation; and land-use intensity reflects human pressure on fragile ecosystems. The weighted factors were then integrated into a composite Desertification Risk Index (DRI). Through the Overlay Analysis, multiple thematic layers (e.g., hazard maps, population density, infrastructure locations, and vulnerability indices) were combined to produce integrated multi-hazard risk maps. This allows for the identification of areas where different risk factors overlap and compound.

RESULTS AND DISCUSSION

The application of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) enabled the creation of detailed maps for each of the three major hazards (flooding, erosion, and desertification) in the study area. These maps classify the region into different hazard and risk zones, providing a foundational understanding of the spatial distribution of each threat. The flood hazard assessment, which integrated factors such as elevation, slope, drainage density, soil texture, and river proximity, 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 faces moderate to high flood susceptibility (Figure 3).

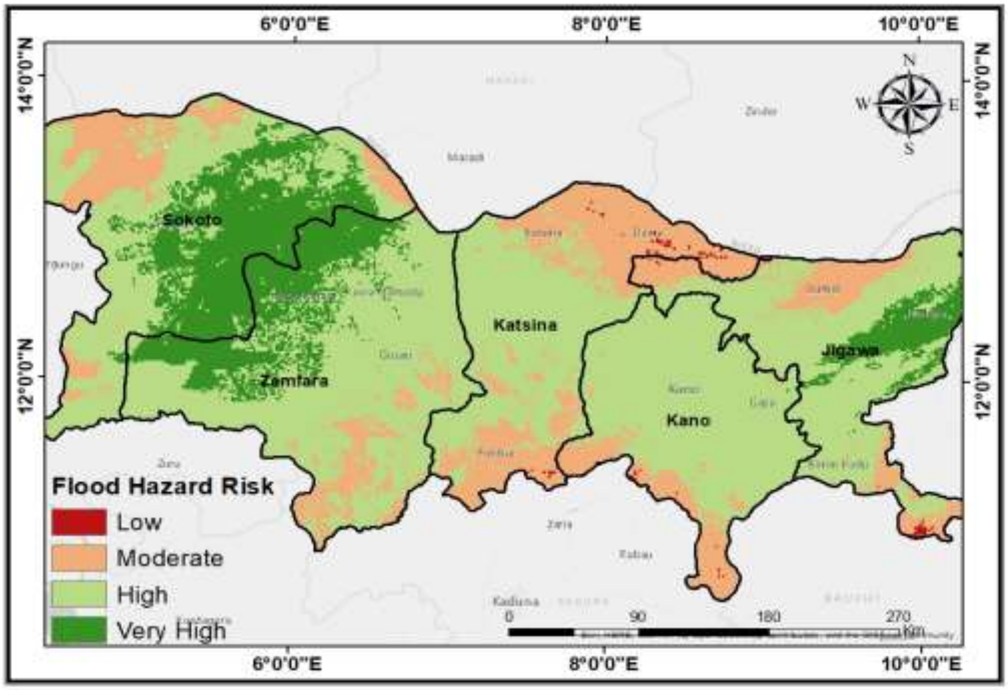

Figure 3: Flood Hazard Risk

Table 5: Flood Risk Zone in the Study Area

Value	Area (km²)	Percent (%)
Low	320.79	0.2424
Moderate	26,715.20	20.1874
High	81,775.40	61.7938
Very High	23,524.60	17.7764

As shown in the table above, the analysis reveals that a total of 81,775 km², or 61.79% of the land, falls into the High flood hazard zone, while 23,524km², or 17.77%, is categorized as having Very High flood hazard. This implies that a substantial majority of the study area, over 70%, is highly susceptible to flooding. This finding is consistent with literature highlighting Nigeria's extensive flood-prone areas, particularly in low-lying regions and river basins (Shuaibu et al., 2022; Zakaria et al., 2022).

The erosion risk assessment, which was based on factors such as land cover, soil drainage, rainfall, and topography, revealed a similar pattern of widespread risk (Figure 4). The analysis indicates that a substantial majority of the study area, 62.11%, is at Moderate risk of erosion, while 33.15% is at High risk (Table 6).

Table 6: Erosion Risk Class

Value	**Area (km²)**	**Percent (%)**
Low	5,806.01	4.3871
Moderate	82,208.90	62.1187
High	43,881.80	33.1579
Very High	445.06	0.3363

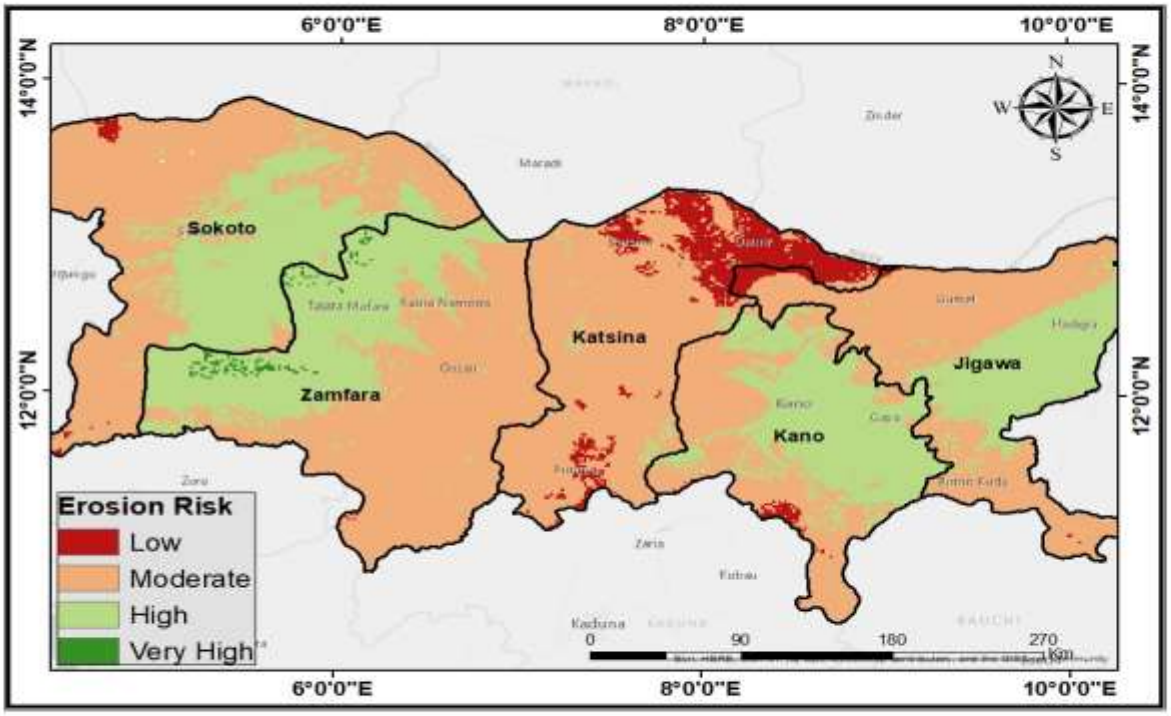

Figure 4: Erosion Risk Class

While the area classified as Very High risk is comparatively small at 445 km², the findings emphasize that erosion is a widespread problem across the region, particularly in areas with torrential rainfall and unconsolidated soils (Chude et al., 2020; Eborka, 2024). The high percentage of land in the Moderate to High categories suggests a broad susceptibility to soil loss, which is a major environmental issue in Nigeria and can lead to severe gully formation, especially in the southeastern part of the country (Ikhile, 2016).

The desertification risk assessment provided insights into the spatial extent of land degradation in the Sahelian corridor (Fig 5). The results show that 31% of the area is at Moderate risk, 20.34% at High risk, and 10.86% at Very High risk (Table 7). This confirms that a significant portion of the region is under threat from desertification, which aligns with previous studies that have estimated that up to 63.8% of Nigeria's total landmass is affected by desert features (E. S. Ibrahim et al., 2022).

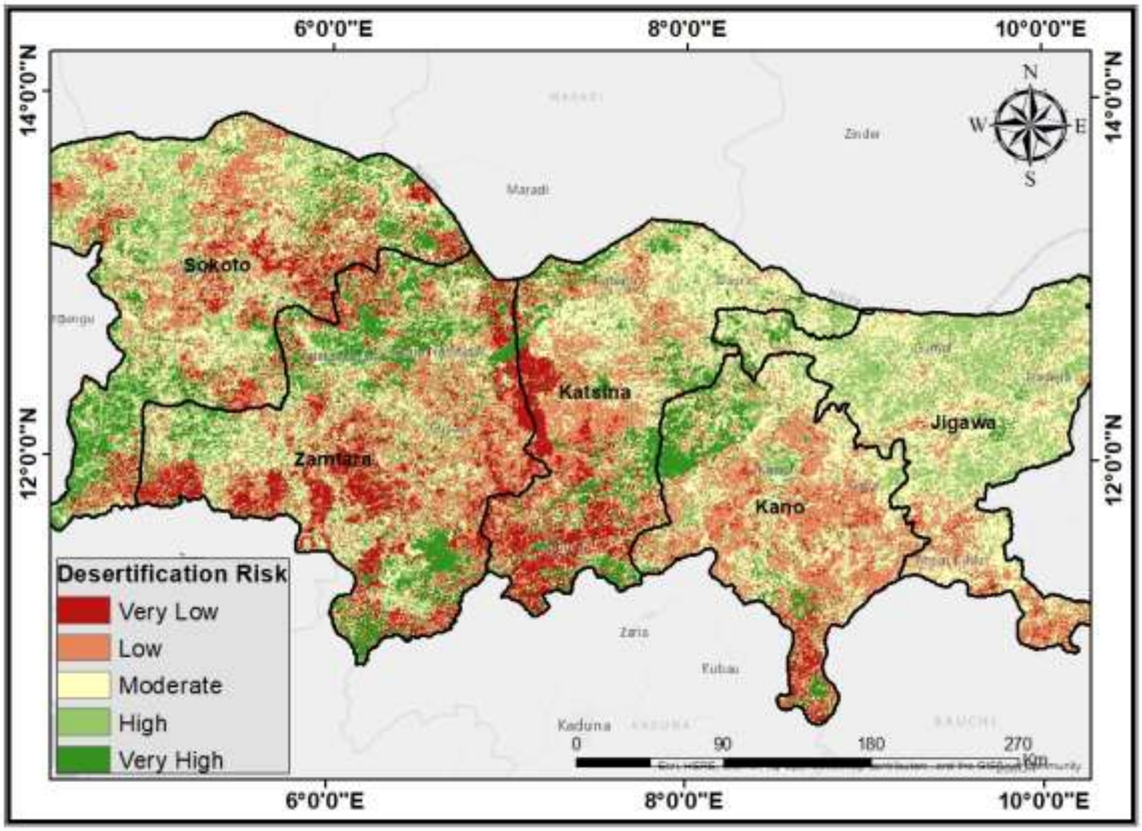

Figure 5: Desertification Risk Map

Table 7: Desertification Risk Class

Value	Area	Percent
Very Low	14075.8	10.5792
Low	36084.3	27.1204
Moderate	41377.6	31.0988
High	27064.7	20.3415
Very High	14449.7	10.8602

The study integrated exposure and vulnerability data to provide a holistic view of risk, which is defined as the combination of hazard, exposure, and vulnerability. The analysis of population data revealed that a significant portion of the population resides in areas classified as having a high risk of flooding, erosion, and desertification. Through spatially overlaying population density maps with the hazard maps, it was possible to identify the number of people exposed to each hazard. The results confirmed that areas with high population densities and rapid urbanization, particularly along river basins and in the Sahelian states, correspond with areas of high hazard susceptibility, thus increasing the overall exposure (Fig 7). This is a critical finding, as it provides decision-makers with the precise locations where human lives are most at risk, a key factor for prioritizing interventions (Komolafe et al., 2020).

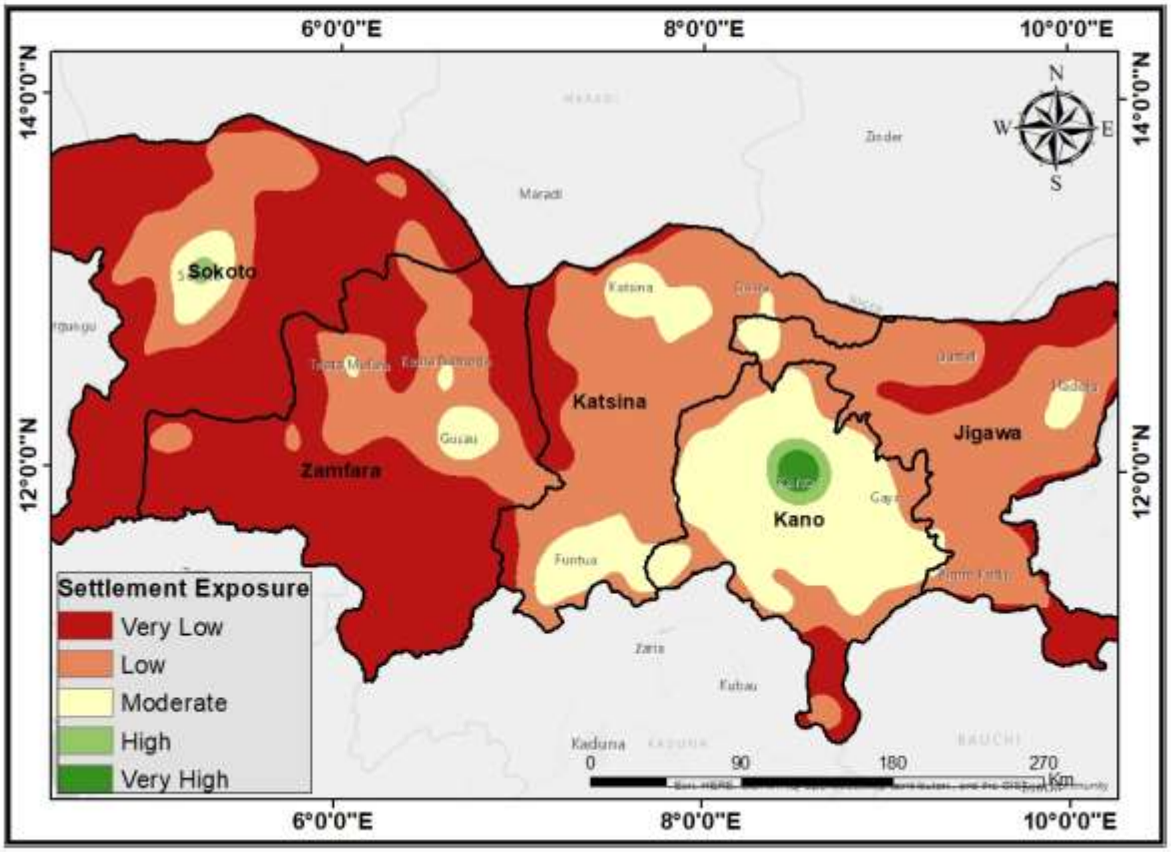

Figure 7: Population/Settlement Exposure

Also, the exposure assessment also focused on mapping critical infrastructure and economic assets, which are particularly vulnerable to losses from natural hazards. The analysis showed that areas of high economic activity especially in Kano State and Sokoto, which provide livelihoods for a majority of the region's population, are heavily exposed to all three hazards (Fig 8).

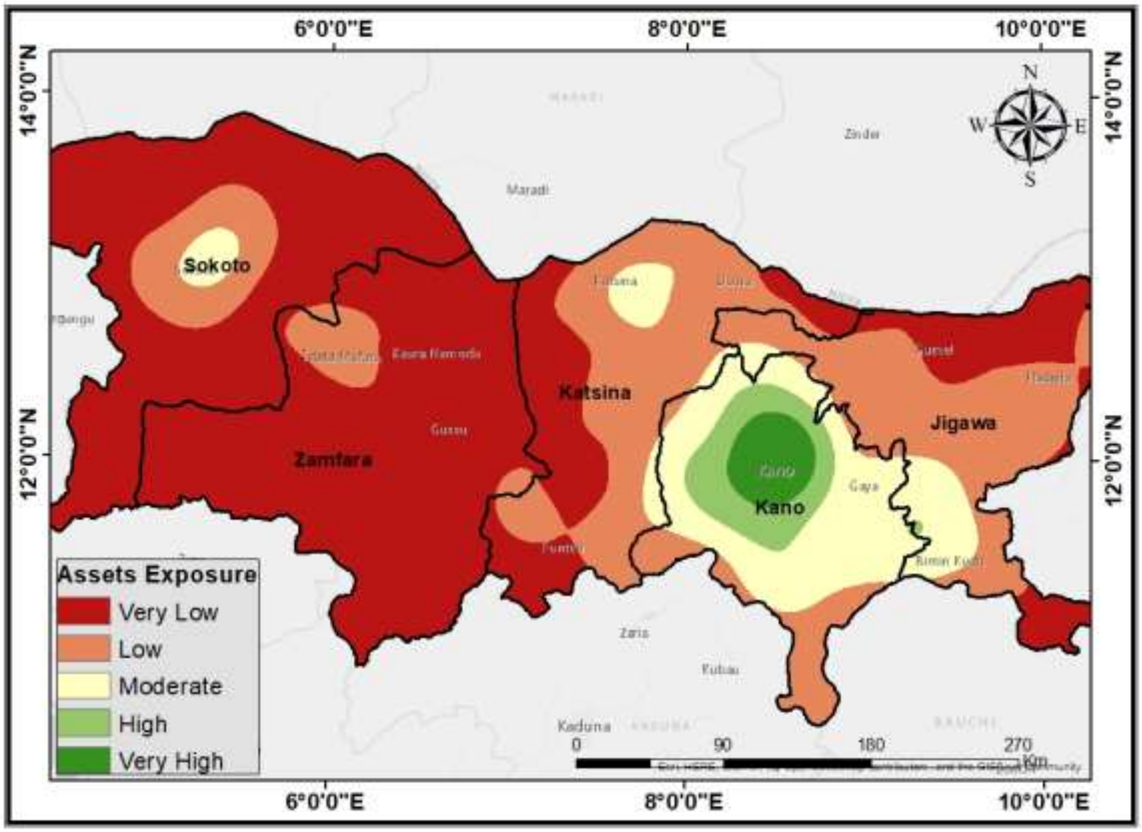

Figure 8: Assets Exposure to multi hazard risk

The final multi-hazard risk assessment provided a holistic view of risk, identifying "hotspots" where multiple hazards and high vulnerabilities converge (Figure 9). The results of the multi-hazard risk zonation reveal a clear spatial pattern of risk across the study area (Table 8).

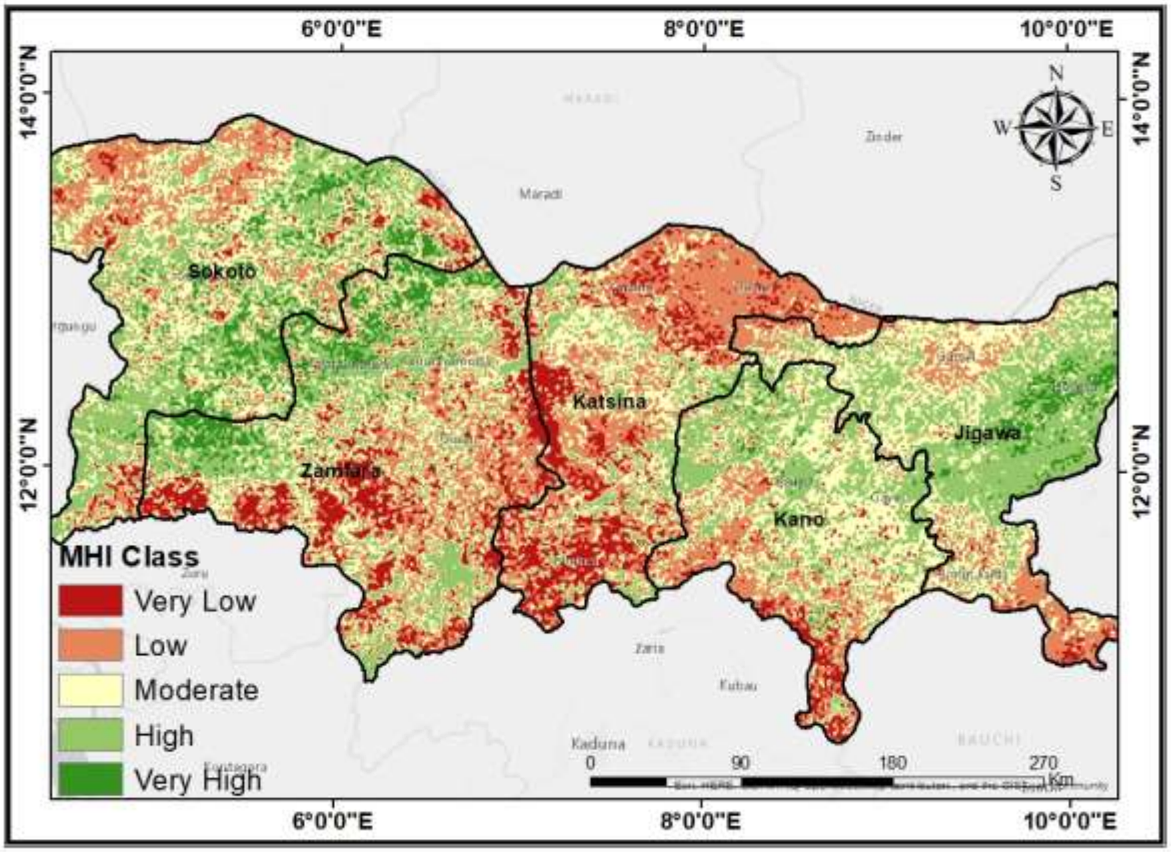

Figure 9: Multi-Hazard Classification

Table 7: Multi Hazard Classification by Composition

Value	Area	Percent
Very Low	14178.3	10.72
Low	34801.4	26.3127
Moderate	34989.2	26.4547
High	40665.2	30.7462
Very High	7626.71	5.76642

The analysis identified that 30.7% of the area is at High multi-hazard risk, with an additional 5.76% at Very High risk. These findings are comparable to other multi-hazard studies in different regions, which have also identified high-risk zones where concurrent vulnerabilities and multiple hazards converge. For example, a study in North Macedonia found that 11.0% of the municipality's territory faced concurrent vulnerabilities from multiple hazards (Aleksova et al., 2024). Similarly, a multi-hazard assessment in the Pak Phanang Basin found that 25% of the total land area exhibited a high multi-hazard risk (Wipulanusat et al., 2009).

Through using administrative boundaries as the unit of analysis, the multi-hazard risk map was used to classify different communities and local government areas (LGAs) according to their overall risk level. This classification enables a more targeted approach to disaster risk reduction, similar to studies in the Dosso region of Niger and Hodh Chargui, Mauritania, which classified communities based on their multi-hazard risk levels and proposed tailored risk treatment actions (Tiepolo et al., 2018). This approach provides a practical tool for regional and local governments to prioritize communities for intervention, focusing resources on those at the highest risk.

As shown in Table 7, the spatial distribution of risk can be classified as:

- High/Very High-Risk States (Jigawa, Sokoto, Zamfara): These states represent the core hazard hotspots in the region. They combine frequent flooding and erosion (e.g., Jigawa's Hadejia-Nguru wetlands and Sokoto floodplains) and advancing desertification in Yobe and parts of Zamfara, driven by vegetation loss and sand encroachment (E. S. Ibrahim et al., 2022). This can be attributed to high population and settlement pressure in riverine and semi-arid zones. Jigawa and Sokoto's high risk classification is strongly tied to river proximity and drainage density, making them flood and erosion prone.
- Moderate/High Risk State (Kano): Kano is a transitional zone with both high exposure (very dense population and markets) and moderate hazards. While erosion and flooding occur, large-scale desertification is relatively less severe compared to Jigawa. Kano has one of the highest settlements and market densities in the corridor, raising exposure even where hazard intensity is moderate.
- Low/Moderate Risk States (Katsina): Surprisingly, Katsina fall under low multi-hazard risk. This is explained by the fact that in Katsina, despite pockets of desertification and flooding, much of the state has low settlement/market density, reducing overall multi-hazard risk (Afriyie et al., 2020).

A key component of this research was the analysis of how hazards are interconnected and how their effects compound one another. This integrated approach is essential for developing thorough strategies towards disaster resilience. 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.

CONCLUSION

This research set out to assess the complex and compounding risks posed by flooding, erosion, and desertification in the Sudano-Sahelian region of North west Nigeria using an integrated GIS-based framework. The findings reveal a landscape of pervasive and interconnected threats, which are exacerbated by underlying socio-economic vulnerabilities and systemic governance deficits. The study successfully mapped the spatial distribution of each hazard, revealing that a significant portion of the study area is at moderate to high risk. For instance, the flood hazard assessment classified over 70% of the land as having high to very high susceptibility to inundation, while over 95% of the area was found to be at moderate to high risk of erosion. The desertification assessment confirmed that land degradation is a widespread threat, with more than half of the region categorized as being at moderate to very high risk.

Critically, the integrated multi-hazard risk assessment identified high-risk "hotspots" where these individual hazards converge with high levels of population and infrastructure exposure. The results indicate that a substantial 30.44% of the area faces high to very high multi-hazard risk, underscoring the compounding nature of these threats. The study's analysis of adjoining effects confirmed that desertification acts as a key driver of risk amplification; by removing vegetative cover, it increases soil susceptibility to erosion, which, in turn, can amplify the destructive power of floods through increased sediment loading, a phenomenon consistent with observations from recent disasters in other arid regions.

REFERENCES

Afriyie, K., Abass, K., & Adjei, P. O. W. (2020). Urban sprawl and agricultural livelihood response in peri-urban Ghana. *International Journal of Urban Sustainable Development*, *12*(2), 202–218. https://doi.org/10.1080/19463138.2019.1691560

Aleksova, B., Milevski, I., & Dragi, S. (2024). *GIS-Based Integrated Multi-Hazard Vulnerability Assessment in Makedonska Kamenica Municipality, North Macedonia*.

An, T. T., Raghavan, V., Long, N. V., Izuru, S., & Tsutsumida, N. (2021). A GIS-based Approach for

Flood Vulnerability Assessment in Hoa Vang District, Danang City, Vietnam. *IOP Conference Series: Earth and Environmental Science*, *652*(1). https://doi.org/10.1088/1755-1315/652/1/012003

Awal, M. A., & Awal, M. A. (2015). International Journal of Environmental Monitoring and Protection Vulnerability to Disaster: Pressure and Release Model for Climate Change Hazards in Bangladesh Vulnerability to Disaster: Pressure and Release Model for Climate Change Hazards in Bangladesh. *International Journal of Environmental Monitoring and Protection*, *2*(2), 15–21. http://www.openscienceonline.com/journal/ijemp

Chude, V. ., Ezendu C.O, Ugadu, M. ., & Adiaha, M. . (2020). A Review of the menace of soil erosion in Nigeria with specific reference to Southeastern States. *Colloquia Series*, *44*(June), 405–414. https://doi.org/10.36265/colsssn.2020.4455

Daniel, F., Gbuchie, M., Emeruwa, V., Ike, W., Udam, N., & Torubiri, A. (2023). Nigeria's Flood Disaster Unpreparedness: Impacts On Health And Society. *Cross River Journal of Medicine*, *2*(2), 12. https://doi.org/10.5455/crjmed.162000

Delves, J., Renner, K., Campalani, P., Piñón, J., Schneiderbauer, S., Steger, S., Moreno, M., Oterino, M. B. B., Perez, E., & Pittore, M. (2025). *Comprehensive multi-hazard risk assessment in data-scarce regions. A study focused on Burundi*. *January*, 1–30. https://egusphere.copernicus.org/preprints/2025/egusphere-2024-3445/

Eborka, F. N. (2024). Desertification in northern nigeria: a study on the effect of desertification on yobe state. *Wukari International Studies*, *8*(6), 254–259.

Federal Ministry of Health - Nigeria Centre for Disease Control. (2020). *National Public Health Multi-Hazard EmergencyPreparedness and Response Plan*.

Hallett, S. H., Sakrabani, R., Keay, C. A., & Hannam, J. A. (2017). Developments in land information systems: examples demonstrating land resource management capabilities and options. *Soil Use and Management*, *33*(4), 514–529. https://doi.org/10.1111/sum.12380

Ibrahim, E. S., Ahmed, B., Arodudu, O. T., Abubakar, J. B., Dang, B. A., Mahmoud, M. I., Shaba, H. A., & Shamaki, S. B. (2022). Desertification in the Sahel Region: A Product of Climate Change or Human Activities? A Case of Desert Encroachment Monitoring in North-Eastern Nigeria Using Remote Sensing Techniques. *Geographies*, *2*(2), 204–226. https://doi.org/10.3390/geographies2020015

Ibrahim, M., Huo, A., Ullah, W., Ullah, S., & Xuantao, Z. (2025). An integrated approach to flood risk assessment using multi-criteria decision analysis and geographic information system. A case study from a flood-prone region of Pakistan. *Frontiers in Environmental Science*, *12*(January), 1–16. https://doi.org/10.3389/fenvs.2024.1476761

Idris, M., Mustapha, A., & Komolafe, A. A. (2025). Application of GIS and MCDA in flood susceptibility modeling in Jigawa. *Water and Soil Management and Modeling*, *5*(4), 1–14. https://doi.org/10.22098/mmws.2025.18160.1653

Ifeanyi, B., Nkiru, C., & Awka, U. (2024). Comprehensive GIS-Based Flood Risk Assessment of Vulnerable Areas in Anambra State, Nigeria. *World Journal of Innovation and Modern Technology E*, *8*(4), 1–23. https://doi.org/10.56201/wjimt.v8.no4.2024.pg1.23

Komolafe, A. A., Awe, B. S., Olorunfemi, I. E., & Oguntunde, P. G. (2020). Modelling flood-prone area and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River Basin, Nigeria. *Hydrological Sciences Journal*, *65*(10), 1766–1783. https://doi.org/10.1080/02626667.2020.1764960

Leeonis, A. N., Ahmed, M. F., Mokhtar, M. Bin, Halder, B., Lim, C. K., Majid, N. A., & Scholz, M. (2025). Importance of Geographic Information System (GIS) Application to Reduce the Impact of Flood Disasters in Malaysia: A Meta-Analysis. *Water (Switzerland)*, *17*(2), 1–28. https://doi.org/10.3390/w17020181

Luu, C., Tran, H. X., Pham, B. T., Al-Ansari, N., Tran, T. Q., Duong, N. Q., Dao, N. H., Nguyen, L. P., Nguyen, H. D., Ta, H. T., Le, H. Van, & von Meding, J. (2020). Framework of spatial flood risk assessment for a case study in quang binh province, Vietnam. *Sustainability (Switzerland)*, *12*(7), 1–17. https://doi.org/10.3390/su12073058

Sampson, A. P., Weli, V. E., Nwagbara, M. O., & Eludoyin, O. S. (2021). Urban growth dynamics and land use change in port harcourt metropolis, nigeria between 1986 and 2020. *International Journal of Progressive Research in Science and Engineering*, *2*(11), 47–56.

Shuaibu, A., Hounkpè, J., Bossa, Y. A., & Kalin, R. M. (2022). Flood Risk Assessment and Mapping in the Hadejia River Basin, Nigeria, Using Hydro-Geomorphic Approach and Multi-Criterion Decision-Making Method. *Water (Switzerland)*, *14*(22). https://doi.org/10.3390/w14223709

Tiepolo, M., Bacci, M., & Braccio, S. (2018). Multihazard risk assessment for planning with climate in the Dosso region, Niger. *Climate*, *6*(3), 1–29. https://doi.org/10.3390/cli6030067

Tiepolo, M., Bacci, M., Braccio, S., & Bechis, S. (2019). Multi-hazard risk assessment at community level integrating local and scientific knowledge in the Hodh Chargui, Mauritania. *Sustainability (Switzerland)*, *11*(18). https://doi.org/10.3390/su11185063

Wipulanusat, W., Nakrod, S., & Prabnarong, P. (2009). Multi-hazard Risk Assessment Using GIS and RS Applications : A Case Study of Pak Phanang Basin. *Walailak Journal of Science and Technology*, *6*(1), 109–125.

Zakaria, A., Umar, N. K., Mohammad, L. A., & Yusuf, R. O. (2022). Flood risks factors and their prevalence in some selected local government areas of Jigawa State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, *7*(4b), 68–77. https://doi.org/10.4314/dujopas.v7i4b.8