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Research Article

Spatio-Temporal Patterns of Land Degradation Vulnerability in the Semi-Arid Parts of Katsina State, Nigeria

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ABSTRACT
Land degradation poses a critical threat to sustainable livelihoods in semi-arid regions, particularly in northern Nigeria. This study analyzed the spatio-temporal patterns of land degradation vulnerability in Katsina State, Nigeria, over a thirty-year period (1990 to 2020). Using Geographic Information System (GIS) and remote sensing techniques, combined with the Modified Mediterranean Desertification Index (MMDI), the research mapped vulnerability levels (very low to very high) for 1990, 2000, 2010, and 2020. Results revealed a decline in very low vulnerability areas from 28.1% in 1990 to 8.6% in 2020, with moderate and high vulnerability zones expanding significantly. The findings highlighted increasing exposure of land resources to degradation, driven by climatic variability, agricultural expansion, and demographic pressures. This study provided an evidence-based foundation for achieving Land Degradation Neutrality (LDN) targets in Katsina State. Based on the results, it is recommended that sustainable land management practices, community-based adaptation strategies, and policy interventions be prioritized to mitigate further degradation and promote resilience in the semi-arid environment.
Keywords: Katsina State; Land degradation; LDN; Remote sensing; Vulnerability mapping; Spatio-temporal analysis

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INTRODUCTION

In arid and semi-arid areas, land degradation is a recurring environmental problem that threatens ecosystem services, human well-being, and agricultural productivity (UNCCD, 2017). Climate variability, unsustainable land use practices, and rapid population growth make the semi-arid north of Nigeria especially vulnerable to degradation (Ndabula *et al*., 2013; Ati *et al*., 2010). The Sudano-Sahelian ecological zone is particularly at risk due to its fragile soils, erratic rainfall, and increasing human pressures. Land degradation vulnerability refers to the degree to which land resources are exposed and susceptible to processes of degradation, given the interplay of environmental conditions and human activities. In simpler terms, it describes how fragile or resilient land is in the face of pressures such as over-cultivation, deforestation, and climate variability. Understanding this concept is vital because it helps identify areas that are more likely to degrade and, therefore, require urgent attention.

To guide sustainable land management practices and support the achievement of the Land Degradation Neutrality (LDN) target under the United Nations Sustainable Development Goals (SDG 15.3), it is essential to evaluate the spatial and temporal patterns of land degradation vulnerability. This study therefore focuses on mapping and assessing changes in vulnerability classes between 1990 and 2020 to better understand the dynamics of land degradation risks.

The idea of Land Degradation Neutrality (LDN), which seeks to balance land degradation, restoration, and sustainable management, has become a crucial framework for shaping policy and practice (Orr *et al*., 2017). Tracking progress toward LDN and effectively prioritizing interventions requires consistent monitoring of temporal and spatial patterns of land degradation vulnerability. Although several studies in northern Nigeria have examined land use dynamics (Ndabula *et al*., 2015) and vegetation change (Ibrahim *et al*., 2018), few have employed multi-decadal vulnerability mapping to capture both the progression and possible recovery of degraded areas.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out in the semi-arid zone of Katsina State, Nigeria, specifically covering Daura, Zango, Mai'adua, and Baure Local Government Areas (LGAs) (Figure 1). Geographically, the study area lies between latitudes 12°30′0″ and 13°30′0″ North and longitudes 9°00′0″ and 9°15′0″ East. These LGAs form the northernmost belt of the state, directly bordering the Niger Republic, and represent the portion of Katsina's most affected by semi-arid conditions.

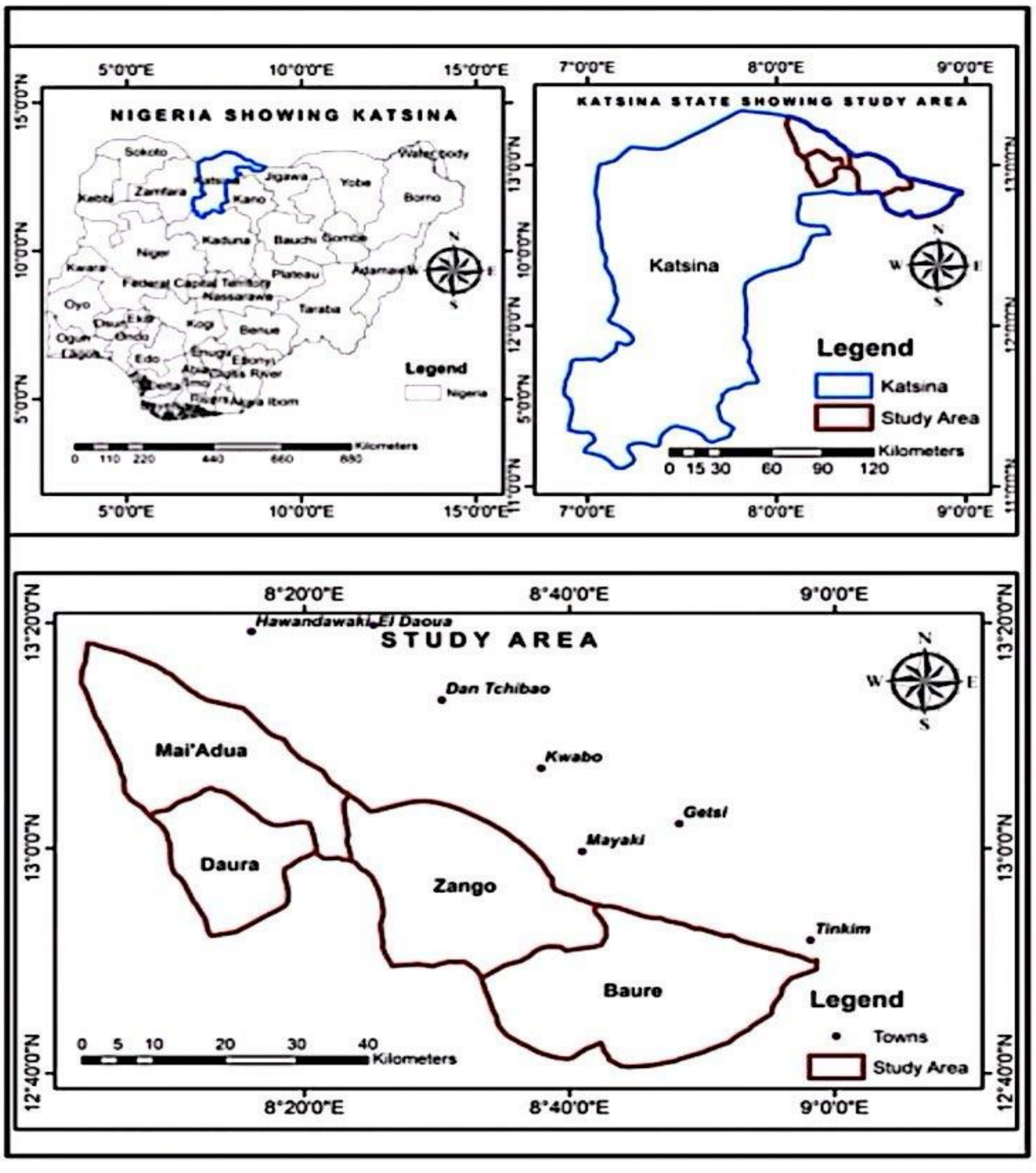

Figure 1: Study Area showing Katsina State and Nigeria (Source: GIS LAB FUDMA, 2024)

The climate of the study area reflects the broader characteristics of northern Katsina State, classified as "AW" under Köppen's climatic system a tropical wet and dry climate with distinct rainy and dry seasons. Rainfall begins as the Inter-Tropical Convergence Zone (ITCZ) shifts northward around May, peaks in August, and declines by October (El-Tantawi and Saleh, 2013). Average annual rainfall ranges between 500mm and 800mm, with significant variability across years. The coolest months are December to February, when temperatures may drop to about 18°C, while peak temperatures exceeding 40°C are common between March and May.

Topographically, the terrain consists of gently undulating plains, rising from about 360m in the northeast near Daura to approximately 600m in the southwest. The vegetation belongs to the Sudan
The study evaluated Katsina State's vulnerability to land degradation using a multi-temporal remote sensing and GIS approach. Landsat imagery for 1990, 2000, 2010, and 2020 (TM, ETM+, and OLI) was obtained from the USGS Earth Explorer platform. Image pre-processing, including layer stacking, atmospheric correction, and subset extraction for the study area, was conducted using ENVI 5.3.

The Modified Mediterranean Desertification Index (MMDI) framework adopted from (Basso *et al*., 2000). Four (4) key environmental factors; soil texture, slope (derived from a Digital Elevation Model), Land Surface. Temperature (LST), and the Normalized Difference Vegetation Index (NDVI) were integrated using overlay analytical tool in ArcGIS 10.8. The analysis generated vulnerability maps for the respective years (1990, 2000, 2010 and 2020). The Analytical Hierarchy Process (AHP) was implemented in IDRISI TerrSet 2020, to classify the continuous values of based on assigned weights into five classes; Very low (VL), Low (L), Moderate (M), High (H), and very high (VH).

Savannah ecological zone, dominated by short grasses interspersed with shrubs and scattered trees, which are increasingly threatened by human activities and climate variability.

Culturally and historically, the area is significant as it forms part of the ancient Hausa kingdoms, particularly Daura, which is considered a cradle of Hausa civilization. Today, the population is predominantly Hausa and Fulani, with Islam as the major religion, although minority groups such as Maguzawa (animist Hausa) and Christians are also present.

By focusing on Daura, Zango, Mai'adua, and Baure LGAs, this study narrows its scope to the most vulnerable semi-arid portion of Katsina State, thereby ensuring a clear and consistent basis for assessing land degradation vulnerability.

RESULTS AND DISCUSSIONS

Spatio-Temporal Trends in Land Degradation Vulnerability (1990)

The spatial analysis revealed notable shifts in land degradation vulnerability between 1990 and 2020. Areas categorized as having very low vulnerability declined sharply from 28.1% in 1990 to only 8.6% in 2020, indicating a substantial reduction in land resilience. At the same time, moderate vulnerability zones expanded from 21.3% to 35.9%, while low vulnerability areas showed a slight decline from 32.4% to 28.7%. The share of high vulnerability areas rose from 12.5% to 20.4%, and very high vulnerability zones increased modestly from 5.7% to 6.4%.

These findings suggest a gradual but steady shift from low and very low vulnerability categories toward moderate and high vulnerability levels. Particularly in the central and northern parts of the study area, locations that were once relatively resilient to degradation have transitioned into intermediate and high-risk zones. This progression highlights the growing exposure of land resources to degradation pressures over the three decades under review (Figure 2).

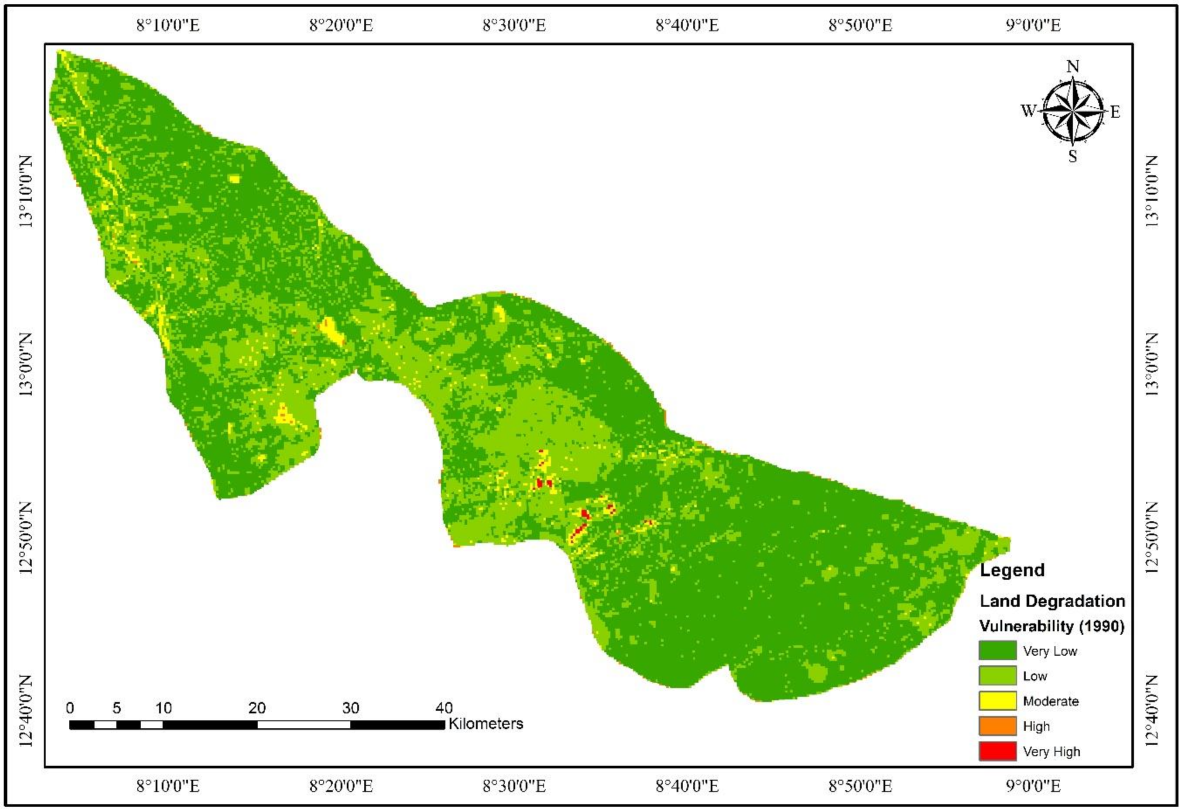

Figure 2: Spatial Patterns of Land Degradation Vulnerability in 1990 (Source: Fieldwork, 2024)

Table 1: Extents of Land Degradation Vulnerability in 1990

S/N	Level	Area (Km^2)	Percentage (%)
1	Very Low	1515	66.9
2	Low	652.78	28.8
3	Moderate	90.31	4.0
4	High	2.36	0.1
5	Very High	2.49	0.1
		2262.94	100.0

Source: Fieldwork, 2024

Land Degradation Vulnerability in 2000

In the year 2000, much of the study area (66.9%) was categorized as having a very low degree of land degradation vulnerability (Figure 3; Table 2). A substantial portion (28.8%) fell into the low vulnerability category, while 4.0% of the area was classified as having moderate vulnerability. Very limited parts of the study area were mapped as high (0.1%) and very high (0.1%) vulnerability zones. The distribution of vulnerability classes in 2000 suggests that the majority of the study area remained relatively resilient, with land resources largely in the low to very low vulnerability categories. This provides an important comparative basis for understanding the progressive changes that occurred in subsequent years.

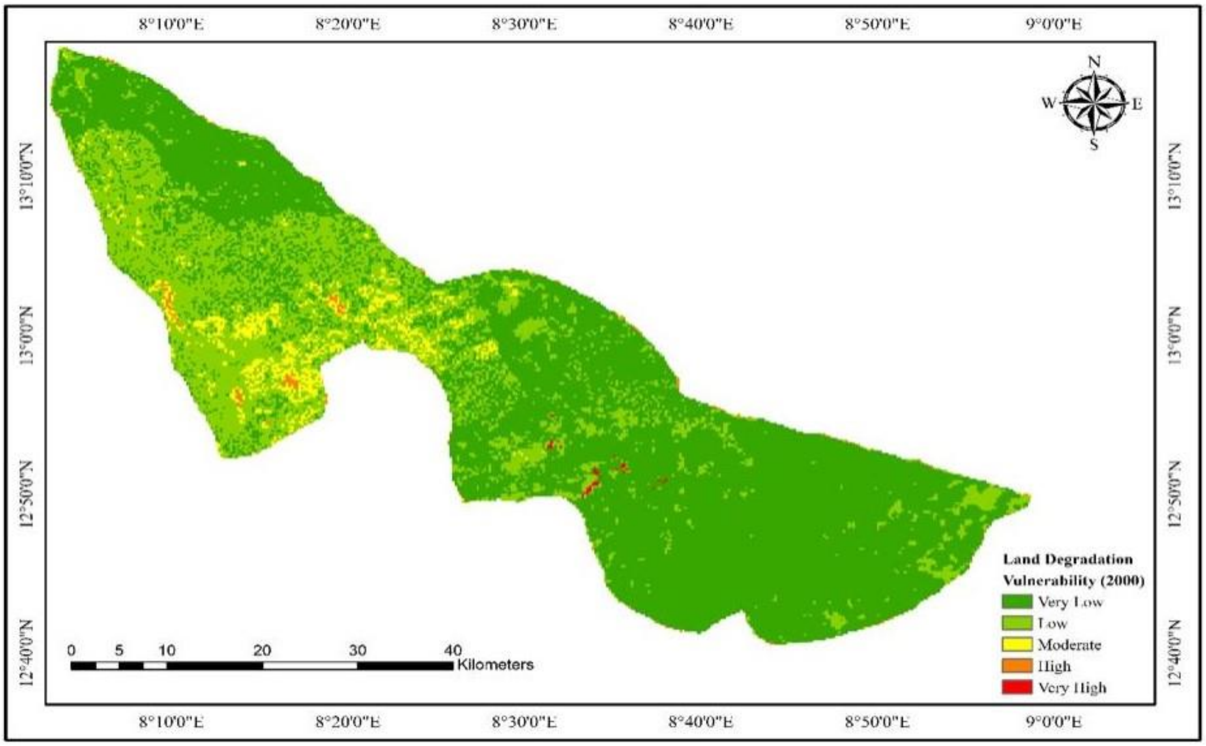

Figure 3: Spatial Patterns of Land Degradation Vulnerability in 2000 (Source: Fieldwork, 2024)

Table 2: Extents of Land Degradation Vulnerability in 2000

S/N	Level	Area (Km^2)	Percentage
1	Very Low	1474.5625	65.2
2	Low	728.3125	32.2
3	Moderate	55.5625	2.5
4	High	1.99	0.1
5	Very High	2.5125	0.1
		2262.94	100.0

Source: Fieldwork, 2024

Land Degradation Vulnerability in 2010

In 2010, the majority of the study area (65.2%) was still classified as having a very low level of land degradation vulnerability (Table 3; Figure 4). The share of land categorized as low vulnerability increased slightly from 28.8% in 2000 to 32.2% in 2010. In contrast, the proportion of moderate vulnerability areas declined from 4.0% in 2000 to 2.5% in 2010. The extent of high (0.1%) and very high (0.1%) vulnerability zones remained relatively small and unchanged.

The distribution of classes indicates a slight improvement in land resilience between 2000 and 2010, with more of the study area concentrated in the low and very low vulnerability categories. This improvement may suggest that some previously degraded or at-risk lands experienced recovery or benefited from improved management practices, as reflected in the reduction of moderate vulnerability zones.

However, the continued presence of high and very high vulnerability areas, although limited in size, highlights the persistence of localized land degradation problems that require targeted interventions. Thus, while land degradation vulnerability in 2010 showed marginal improvements compared to 2000, underlying risks remained in specific parts of the study area.

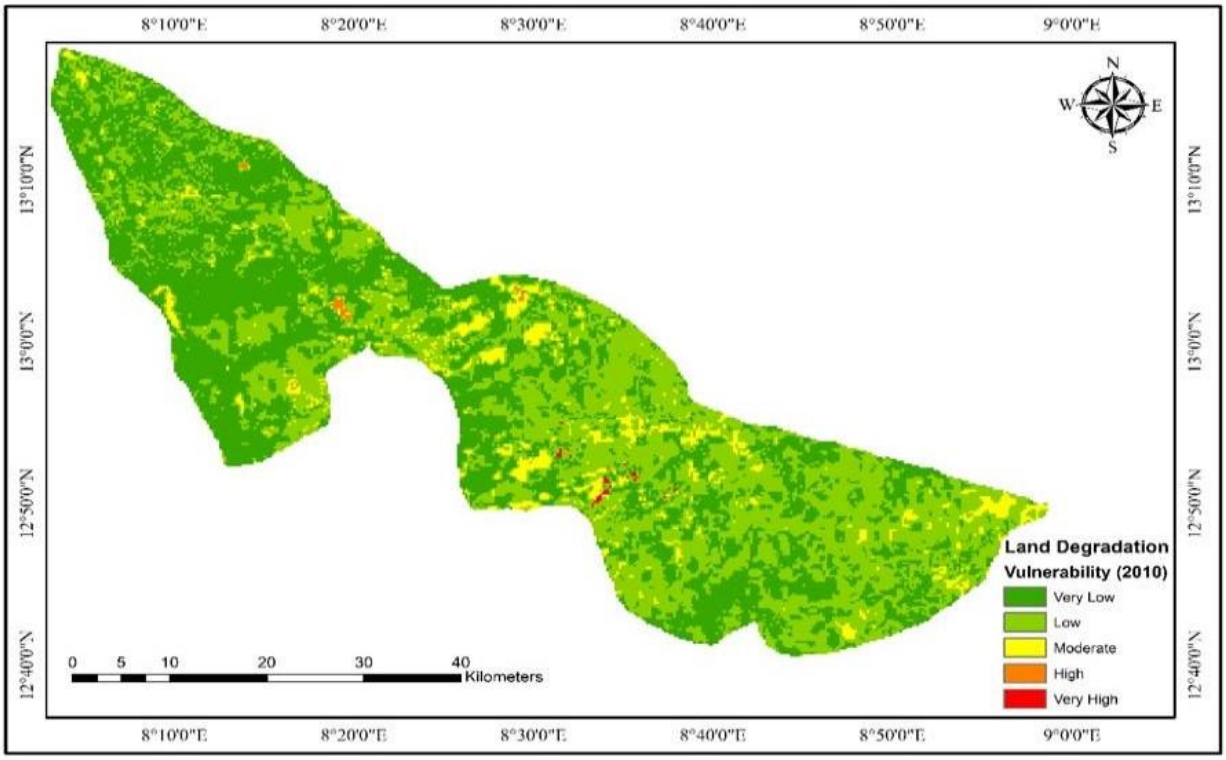

Figure 4: Spatial Patterns Land Degradation Vulnerability in 2010 (Source: Fieldwork, 2024)

Table 3: Extents of Land Degradation Vulnerability in 2010

S/N	Level	Area (Km^2)	Percentage
1	Very Low	1042.6875	46.1
2	Low	1085.9375	48.0
3	Moderate	126.8975	5.6
4	High	4.48	0.2
5	Very High	2.935	0.1
		2262.94	100.0

Source: Fieldwork, 2024

Land Degradation Vulnerability in 2020

By 2020, the study area showed a marked shift in land degradation vulnerability patterns (Table 4; Figure 5). The majority of the area was categorized as low (48.0%) or very low (46.1%) vulnerability. However, unlike earlier decades, the proportion of land in the moderate vulnerability category rose significantly from 2.5% in 2000 to 5.6% in 2020. Although still relatively small, the share of land classified as high (0.2%) and very high (0.1%) vulnerability also increased when compared with 2000.

The data revealed a progressive decline in the share of very low vulnerability areas over the three decades from 66.9% in 1990 to 65.2% in 2000, and further down to 46.1% in 2020. Meanwhile, areas classified as low vulnerability expanded consistently, rising from 28.8% in 1990 to 32.2% in 2000 and then to 48.0% in 2020. The increase in both low and moderate vulnerability areas, along with the emergence of more high and very high zones, indicates that the overall vulnerability to land degradation worsened between 2000 and 2020.

This trend suggests that while a considerable proportion of the study area still retains resilience against degradation, a growing share of land has become increasingly vulnerable. The rise in moderate to severe vulnerability categories points to intensifying pressures on land resources, reflecting the spread of unsustainable land use practices and environmental stressors. Without targeted management strategies, these patterns could escalate, placing more communities and livelihoods at risk.

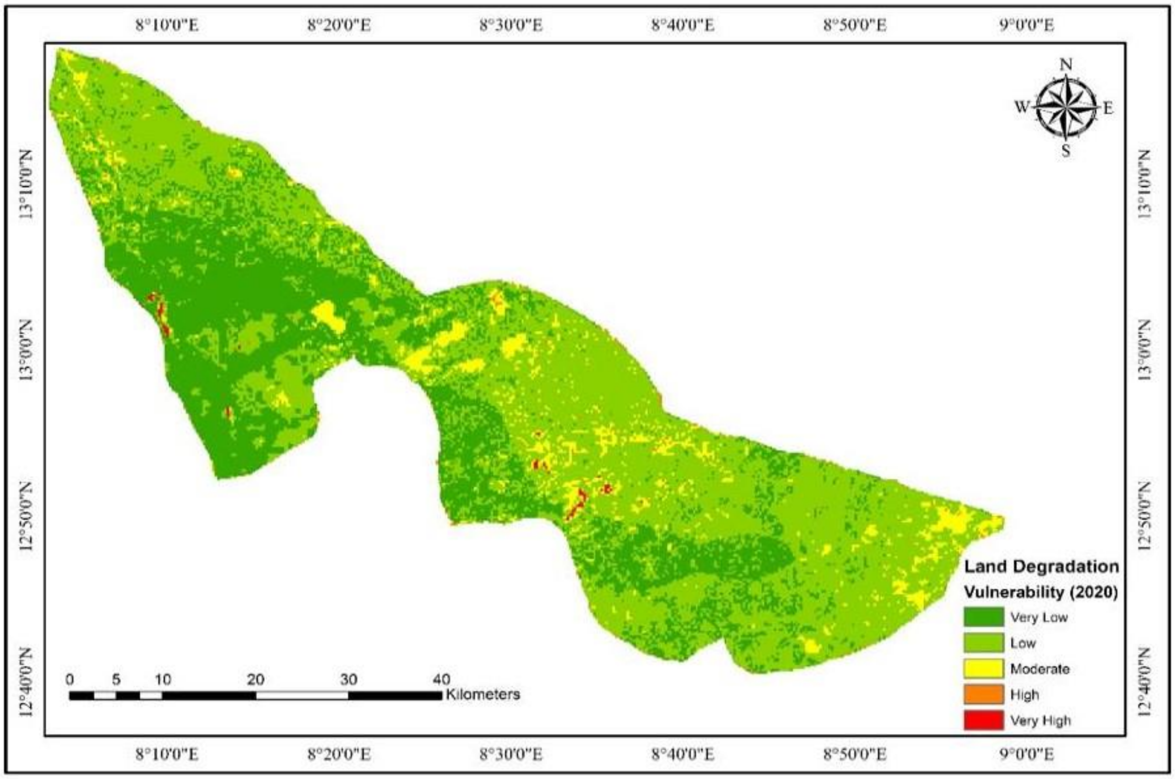

Figure 5: Spatial Patterns Land Degradation Vulnerability in 2020 (Source: Fieldwork, 2024)

Table 4: Extents of Land Degradation Vulnerability in 2020

S/N	Level	Area (Km^2)	Percentage
1	Very Low	771.875	34.1
2	Low	1322.375	58.4
3	Moderate	152.625	6.7
4	High	11.1925	0.5
5	Very High	4.875	0.2
		2262.94	100.0

Source: Fieldwork, 2024

Summary of Decadal Extents of Land degradation Vulnerability Classes (1990 – 2020)

The results across the study period (1990–2020) reveal important shifts in land degradation vulnerability. In 2020, much of the study area was classified as either low (58.4%) or very low (34.1%) vulnerability (Table 5). Between 2010 and 2020, areas in the moderate vulnerability class increased from 5.6% to 6.7%. Although still relatively minor, the extent of land in the high (0.5%) and very high (0.2%) categories declined compared to 2010. This improvement suggests that parts of the landscape previously at greater risk may have benefited from restoration or better land management practices. Nonetheless, the persistence of moderate vulnerability indicates that some areas continued to face degradation pressures.

Table 5: Summary of Land Degradation Vulnerability

S/N	Level	1990	2000	2010	2020
1	Very Low	66.95	65.16	46.08	34.11
2	Low	28.85	32.18	47.99	58.44
3	Moderate	3.99	2.46	5.61	6.74
4	High	0.10	0.09	0.20	0.49
5	Very High	0.11	0.11	0.13	0.22

Source: Fieldwork, 2024

A broader comparison across the three decades highlights the long-term dynamics. The proportion of very low vulnerability areas declined steadily from 66.9% in 1990 to 65.2% in 2000, 46.1% in 2010, and 34.1% in 2020. In contrast, low vulnerability zones expanded consistently from 28.8% in 1990 to 32.2% in 2000, 48.0% in 2010, and 58.4% in 2020. Moderate vulnerability areas also grew over time, rising from 2.5% in 2000 to 5.6% in 2010 and 6.7% in 2020. Although the shares of high and very high vulnerability zones remained relatively small, they showed fluctuations—peaking in 2010 (0.3%) before declining slightly in 2020 (0.7%).

The data points to a worsening trend in land degradation vulnerability from 1990 to 2010, followed by signs of partial recovery between 2010 and 2020. The shift from very low to low vulnerability classes suggests that while degradation pressures intensified during the earlier decades, the latter decade experienced modest improvements, possibly due to land management interventions, improved awareness, and adaptive practices. This trend underscores the importance of sustained and targeted management efforts to consolidate gains and address persistent moderate vulnerability hotspots.

A thorough summary of the shifts in the study area's susceptibility to land degradation between 1990 and 2020 is given in Table 4.9, which can help guide the creation of suitable land management plans and interventions to deal with the issues that have been identified. Between 1990 and 2020, the percentage of land designated as "Very Low" vulnerable fell from 66.95% to 34.11%. Between 1990 and 2020, the "Low" vulnerability area grew from 28.85% to 58.44%. Between 1990 and 2020, the "Moderate" exposure area grew from 3.99% to 6.74%. Despite being relatively small, the "High" and "Very High" vulnerability areas grew with time, rising from 0.21% in 1990 to 0.71% in 2020. The pattern points to a rise in low and moderate sensitivity areas and a decline in very low vulnerability areas throughout the course of the 30-year period. With more land being categorized as having moderate to high vulnerability, this suggests that the land degradation condition in the study area has generally gotten worse. The rise in the "Low" vulnerability region, however, also raises the possibility that some land management strategies or organic recovery processes may have been successful in lessening the degree of degradation in specific study area areas. The necessity for focused and ongoing efforts to address the most severely degraded lands is highlighted by the continued existence of "High" and "Very High" susceptibility zones.

The observed rise in areas of moderate and high vulnerability is consistent with regional patterns seen in other Sudano-Sahelian contexts (Oladipo, 1993; Ibrahim *et al*., 2015). Decreased rainfall and rising temperatures, in particular, have made plant loss and soil exposure worse. Overgrazing, fuelwood exploitation, and the spread of farming onto marginal lands are examples of anthropogenic factors that have increased the danger of deterioration. Intensive agricultural usage and dense populations are correlated with the spatial clustering of high susceptibility in the northern and central LGAs. This research emphasizes the necessity of focused interventions to prevent more deterioration, such as agroforestry, soil conservation techniques, and sustainable water management.

CONCLUSION

The study revealed that Katsina State experienced significant shifts in land degradation vulnerability between 1990 and 2020. Over the three decades, resilient areas (classified as very low vulnerability) declined, while zones of low to moderate vulnerability expanded across the state. Although there was some improvement between 2010 and 2020 marked by a reduction in high and very high vulnerability areas the overall trend underscores the growing fragility of land resources in Katsina State. If such patterns persist, the state faces heightened risks of further productive land loss, which could undermine food security, rural livelihoods, and the attainment of sustainable development goals.

Addressing these challenges requires site-specific, evidence-based interventions aligned with the realities of Katsina State. Integrated land management practices such as regulated grazing, reforestation, and sustainable agriculture can help restore vegetation cover and reduce soil erosion. Given the semi-arid setting of the state, climate-smart farming techniques including water-harvesting technologies, drought-tolerant crop varieties, and soil conservation measures are essential for building resilience against climatic variability.

Equally important is fostering community participation. Environmental education, awareness campaigns, and participatory restoration projects should be employed to increase local ownership of interventions, ensuring that strategies are adapted to the socio-ecological realities of farming and pastoralist communities in the state. Policy frameworks should be anchored on the Land Degradation Neutrality (LDN) targets of the United Nations Convention to Combat Desertification (UNCCD), supported by strong monitoring and evaluation mechanisms to track progress.

Furthermore, expanded research and monitoring, particularly through remote sensing and GIS-based systems, would provide timely assessments and early warning signals on land degradation dynamics within Katsina State. Promoting alternative livelihood options beyond land-intensive activities such as small-scale agro-processing, skills development, and non-farm enterprises would also help reduce pressure on already degraded landscapes and strengthen the state's adaptive capacity.

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