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Assessment of Major Factors of Climate Change within the Period 1990-2024 in North-Western Region of Nigeria

LAWAL, Muhammad¹

lawalm3@gmail.com

08105010599

UMAR, Muazu Abdulrazak²

aumuazu67@gmail.com

08036970442

¹Department of Economics Education, Federal College of Education (Technical) Gusau, Zamfara State-Nigeria.

²Department of Agriculture Education, Federal College of Education (Technical) Gusau, Zamfara State-Nigeria

Abstract

This study examines the escalating environmental degradation in three states of North-West Nigeria (Katsina, Kebbi, and Zamfara), focusing on desertification and drought as critical manifestations of climate change. The region, characterized by low and erratic rainfall (500-800mm annually) and rising temperatures, is experiencing significant land degradation, including soil erosion, vegetation loss, and declining soil fertility. Drought events are becoming more frequent and severe, jeopardizing agriculture and food security for the largely rain-fed farming population. Using climate data from 1990 to 2024 and survey data from 1050 randomly selected respondents across the three states, the research analyzes temperature and precipitation trends, spatial patterns of desertification, the role of human activities, and identifies vulnerability hotspots. Key findings include a regional temperature increase of 1.8°C, a 10.2% decline in annual precipitation, and a 64.7% rise in areas with moderate to severe desertification across the three states. Katsina exhibits the highest vulnerability with 28.5% of its area under severe desertification. The study highlights the impact of human activities, such as fuelwood collection and overgrazing, on desertification and identifies key vulnerability hotspots in the northern parts of these states and around urban centers. It recommends integrated interventions, including landscape restoration, sustainable land management, and policy reforms, to combat desertification and enhance resilience, aiming to foster sustainable development in the region.

Keywords: Climate Change, Environmental Degradation, Vulnerability Assessment, Sustainable Land Management

Introduction

Katsina, Kebbi, and Zamfara states, situated in North-West Nigeria, have experienced intensifying environmental degradation over recent decades, with desertification and drought emerging as predominant manifestations of climate change in the region. Located in the Sudan-Sahel ecological zone, these states form a critical agricultural belt in Nigeria yet face growing threats from advancing desert frontiers and increasingly erratic rainfall patterns (Olagunju, 2015). The semi-arid nature of these states, characterized by annual rainfall averages ranging from 500mm to 800mm, renders them particularly susceptible to desertification processes and drought events, which have been exacerbated by climate change (Oladipo, 2018). Desertification in these states manifests as the progressive degradation of productive lands through soil erosion, vegetation loss, and declining soil fertility, ultimately reducing the land's capacity to support agriculture and pastoral livelihoods. Concurrently, drought events have become more frequent and severe, disrupting traditional agricultural calendars and threatening food security for millions of residents who depend primarily on rain-fed agriculture (Abdulkadir et al., 2017). The intersection of these twin phenomena—



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desertification and drought—represents a complex challenge that demands robust scientific investigation and targeted policy interventions. The significance of desertification and drought in Katsina, Kebbi, and Zamfara extends beyond environmental concerns to encompass critical socioeconomic dimensions. Approximately 75% of the population in these three states relies directly on agriculture for their livelihoods, making them highly vulnerable to climate-induced land degradation (Nkechi et al., 2016). Furthermore, the region's population growth rate of approximately 3.6% annually intensifies pressure on already fragile land resources, creating a cycle wherein human activities accelerate desertification, which in turn compromises productive capacity (Abdullahi et al., 2020).

Desertification represents a complex land degradation process occurring in arid, semi-arid, and dry sub-humid areas, resulting from various factors including climatic variations and human activities (UNCCD, 2017). The conceptualization of desertification has evolved significantly since the United Nations Conference on Desertification in 1977, moving from simplistic notions of "desert advancement" toward more nuanced understandings that recognize multiple interacting biophysical and socioeconomic drivers (Reynolds et al., 2007). In the specific context of Katsina, Kebbi, and Zamfara states, scholars have proposed several frameworks for understanding desertification. Olagunju (2015) characterizes desertification in the region as a progressive decline in ecosystem services, manifesting through reduced vegetation cover, compromised soil structure, and diminished water retention capacity. Abdulkadir et al. (2017) expand this conceptualization by emphasizing the role of land use intensification, particularly overgrazing and deforestation, in accelerating natural aridity processes. Additionally, Nkechi et al. (2016) highlights the importance of understanding desertification as a socio-ecological phenomenon driven by the interaction between environmental conditions and human adaptation strategies. The Dryland Development Paradigm (DDP) proposed by Reynolds et al. (2007) offers a particularly relevant theoretical framework for analyzing desertification in these three states. This paradigm emphasizes five key principles: (1) the coupled nature of socio-ecological systems; (2) the critical importance of slowly changing variables; (3) the existence of thresholds in system dynamics; (4) the hierarchical structure of cross-scale interactions; and (5) the hybrid knowledge needed to understand these complex systems. This framework helps conceptualize desertification not merely as environmental degradation but as a system-level transformation resulting from multiple interacting processes across temporal and spatial scales.

Drought represents a recurring feature of climate variability characterized by a deficiency of precipitation over an extended period, resulting in water shortage for some activity, group, or environmental sector (Wilhite and Glantz, 1985). The literature distinguishes four primary categories of drought: meteorological drought (precipitation deficits), agricultural drought (soil moisture deficits), hydrological drought (reduced streamflow and reservoir levels), and socioeconomic drought (demand exceeding supply of economic goods) (Mishra and Singh, 2010). Various indices have been developed to quantify drought severity and extent, each capturing different aspects of the phenomenon. The Standardized Precipitation Index (SPI), developed by McKee et al. (1993), has gained widespread adoption for its flexibility across timescales and its statistical robustness. For Katsina, Kebbi, and Zamfara states, several studies have applied the SPI to characterize historical drought patterns. Oladipo (2018) analyzed SPI values across 30-year periods, finding increasing frequency of moderate to severe drought events since the 1970s. Similarly, Mohammed et al. (2018) utilized the Palmer Drought Severity Index (PDSI) to document a statistically significant trend toward more intense drought conditions in Katsina and Zamfara states. More recently, composite indices



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that incorporate multiple variables have gained traction in drought assessment. The Standardized Precipitation Evapotranspiration Index (SPEI), which accounts for both precipitation and potential evapotranspiration, has proven particularly valuable for regions experiencing warming trends alongside precipitation changes (Vicente-Serrano et al., 2010). Ismail et al. (2019) applied SPEI to Katsina, Kebbi, and Zamfara states, demonstrating that temperature-driven increases in evaporative demand have exacerbated drought conditions even in years with near-normal rainfall. The drivers of desertification and drought in semi-arid regions like Katsina, Kebbi, and Zamfara can be broadly categorized into climatic factors and anthropogenic activities, with complex interactions between these categories. From a climatic perspective, research has identified several key drivers relevant to the region:

Climatic Factors; Global climate change has altered temperature and precipitation patterns in ways that intensify desertification processes. Odjugo (2010) documented a steady increase in mean annual temperature across northern Nigeria, with an average rise of 1.1°C over the past century and an accelerated warming trend of 0.04°C per year since 1971. Concurrently, Nicholson et al. (2018) observed a southward shift in isohyets (lines of equal rainfall) by approximately 200km since the 1960s, indicating a progressive drying of the region. Additionally, rainfall variability has increased significantly, with more frequent extreme events interspersed with prolonged dry spells (Abiodun et al., 2018).

Anthropogenic Factors: Human activities significantly influence desertification processes in the three states. Usman and Nichol (2018) identified agricultural expansion and intensification as primary drivers, with cultivated land area in Katsina state increasing by 36% between 1995 and 2013, largely at the expense of natural vegetation. Similarly, unsustainable livestock management practices, particularly overgrazing in communal rangelands, have contributed to vegetation degradation and soil compaction (Abdullahi et al., 2020). Deforestation represents another critical anthropogenic driver, with fuelwood collection and charcoal production reducing forest cover by approximately 3.5% annually in parts of Kebbi state (Momodu et al., 2011). The interaction between climatic and anthropogenic factors often creates feedback loops that accelerate desertification. For instance, vegetation removal reduces evapotranspiration and increases surface reflectivity (albedo), potentially reducing local rainfall and reinforcing aridity (Charney, 1975). These bio-geophysical feedbacks, coupled with socioeconomic pressures from population growth and changing livelihood strategies, create what Mortimore and Adams (2001) term "poverty-environment traps" wherein resource degradation and economic vulnerability mutually reinforce each other.

This article aims to analyze the extent, patterns, and driving factors of desertification and drought in Katsina, Kebbi, and Zamfara states, utilizing climate data spanning from 1990 to 2024 and survey data from 1050 randomly selected respondents across the three states. Specifically, the study seeks to: (1) quantify changes in temperature and precipitation patterns across the three states; (2) examine the spatial progression of desert encroachment in the region; (3) evaluate the relationship between human activities and desertification processes; and (4) identify vulnerability hotspots requiring prioritized intervention. Through rigorous analysis of climate trends, land degradation patterns, and survey responses, this article will provide an empirical foundation for targeted adaptation and mitigation strategies.

Statement of the Problem



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The states of Katsina, Kebbi, and Zamfara are facing serious climate issues like desertification, unpredictable rainfall, and extreme heat. These problems pose a significant threat to people's livelihoods and food security. However, there is a clear lack of focused research that identifies and ranks the main causes of these changes in this tri-state area. Although human activities like deforestation, unsustainable farming, and biomass burning are recognized, their specific impacts and local factors have not been measured. This gap in knowledge makes it hard to create effective, evidence-based policies. As a result, general and often ineffective strategies are used to address these issues. Environmental damage continues to worsen, increasing vulnerability in one of Nigeria's most climate-sensitive regions.

Objectives of the study

The aim of this study was to investigate the major drivers of climate change in north west Nigeria states of Katsina, Kebbi and Zamfara states respectively. The specific objectives were to:

1. Assess and quantify changes in temperature and precipitation patterns across the affected states in the study.
2. Examine the spatial progression of desert encroachment in the affected state in the region.
3. Evaluate the relationship between human activities and desertification processes.
4. Identify vulnerability hotspots requiring special intervention.

Research Questions

The following research questions were raised to guide the study:

1. What is the magnitude, direction, and statistical significance of trends in annual mean temperature, seasonal rainfall totals, and rainfall variability in the study area?
2. What is the extent and patterns of special average annual rate of desertification in the region?
3. What is the nature and strength of the correlation between proxies for human activity and observed indices of land degradation?
4. Which specific Areas(state) exhibit the highest level of vulnerability and exposure to climatic changes.

Hypothesis

The following Hypotheses were raised to guide the study:

- H₁: There has been a statistically significant increase in mean annual temperature and a significant decrease in total annual rainfall across the three states.
- H₂: There has been significant increase in desertification in the affected states due to their geographical positioning and land use profile
- H₃: Strong positive correlation exists between high-density human activity zones and severe land degradation,
- H₄: Highly vulnerable and critical hotspots exist in the affected states

Methodology

Data Sources

This study employs multiple data sources to comprehensively analyse desertification and drought patterns in Katsina, Kebbi, and Zamfara states:

Climate Data: Historical temperature and precipitation records from 1990 to 2024 were obtained from the Nigerian Meteorological Agency (NiMet) for 6 weather stations distributed across the three states (2 stations per state). These station-based observations were supplemented with gridded climate data from the Climate Research Unit Time Series (CRU TS) dataset version 4.06, which provides monthly climate variables at 0.5° × 0.5° spatial resolution (Harris et al., 2020). Additionally, future climate projections (2023-2025) were derived from the ensemble mean of five Global Climate



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Models (GCMs) under the SSP2-4.5 emissions scenario, downscaled to a resolution appropriate for regional analysis.

Remote Sensing Data: To assess land cover changes and desertification patterns, we utilized multi-temporal satellite imagery from multiple platforms: (i) Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) images at 30m spatial resolution for the years 1990, 2000, 2010, and 2020 (ii) Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices (NDVI and EVI) at 250m resolution for the period 2000-2024 (iii) Advanced Very High-Resolution Radiometer (AVHRR) data for the period 1990-1999

Field Survey and Socioeconomic Data: Primary data were collected through a comprehensive field survey involving 1050 respondents randomly distributed across the three states (350 respondents per state). The survey was conducted among the three states capturing information on observed environmental changes, agricultural practices, water availability, energy sources, and adaptation strategies. Additionally, at 18 sampling sites (6 per state) representing different ecological zones, measurements included ground-based vegetation assessment using the line-intercept method, soil sampling for texture and organic matter analysis, and documentation of land use practices. To assess human factors in desertification processes, we incorporated demographic and agricultural statistics from the National Bureau of Statistics (Nigeria), state-level agricultural departments, and the Food and Agriculture Organization (FAO). These included population density maps, livestock numbers, agricultural land use, and fuelwood consumption statistics.

Analytical Approach for Trend Assessment

The analytical framework employed multiple statistical and geospatial techniques to examine desertification and drought trends:

Climate Trend Analysis: Long-term trends in temperature and precipitation were analyzed using the Mann-Kendall non-parametric test to detect monotonic trends while accounting for seasonal effects. The magnitude of trends was estimated using Sen's slope estimator, which is less sensitive to outliers than linear regression. For drought assessment, we calculated the Standardized Precipitation Evapotranspiration Index (SPEI) at 3-, 6-, and 12-month timescales following the methodology of Vicente-Serrano et al. (2010). Drought events were classified as moderate (SPEI < -1.0), severe (SPEI < -1.5), or extreme (SPEI < -2.0).

Desertification Assessment: Land degradation was quantified using the following approaches: (i) Normalized Difference Vegetation Index (NDVI) trend analysis using seasonal trend decomposition to separate long-term trends from seasonal variations (ii) Land cover classification and change detection using supervised classification with Random Forest algorithm, validated through ground reference data (iii) Calculation of the Land Degradation Neutrality (LDN) indicator following UNCCD methodology, based on changes in land productivity, land cover, and soil organic carbon

Statistical Modeling: To examine relationships between environmental variables and socioeconomic factors, we employed multiple statistical techniques: (i) Principal Component Analysis (PCA) to identify dominant patterns of variability in the climate and land degradation data (ii) Multiple regression analysis to quantify relationships between desertification indicators and potential driving factors (iii) Spatial autocorrelation analysis using Moran's I statistics to identify clustering patterns in desertification processes (iv) Analysis of survey responses from 1050 respondents to assess perceived environmental changes, adaptation strategies, and socioeconomic impacts

All statistical analyses were performed using Stata 17 software, with spatial analyses conducted in ArcGIS Pro 3.0 and QGIS 3.28. The significance level was set at $\alpha = 0.05$ for all statistical tests.



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Spatial and Temporal Framework of the Analysis

The study encompasses Katsina, Kebbi, and Zamfara states of Nigeria, covering approximately 100,754 km² (Katsina: 24,192 km², Kebbi: 36,800 km², Zamfara: 39,762 km²). For analytical purposes, the region was divided into 0.5° × 0.5° grid cells aligned with the climate data resolution, resulting in 40 analysis units across the three states. These units were further stratified based on agroecological zones, distinguishing between the Sudan Savannah and the Northern Guinea Savannah subregions. Temporally, the analysis spans from 1990 to 2024, divided into seven 5-year periods (1990-1994, 1995-1999, 2000-2004, 2005-2009, 2010-2014, 2015-2019, 2020-2024) to facilitate the detection of medium-term trends while smoothing interannual variability. This temporal framework allows for the assessment of: (i) Historical trends in climate variables and land degradation indicators (1990-2024) (ii) Changes in human perceptions and adaptation strategies over time based on survey data (iii) Identification of potential acceleration or deceleration in desertification processes over time.

To ensure robust change detection, baseline conditions were established using the 1990-1994 period, with subsequent periods analyzed relative to this baseline. For the identification of vulnerability hotspots, a multi-criteria evaluation framework was developed that integrates biophysical indicators (aridity index, NDVI trends, soil characteristics) with socioeconomic factors (population density, poverty rates, livelihood diversification) to produce a composite vulnerability index.

Analysis and Results Interpretation

Research Question 1: What is the magnitude, direction, and statistical significance of trends in annual mean temperature, seasonal rainfall totals, and rainfall variability in the study area?

Trends in Temperature and Precipitation (1990-2024)

The analysis of climatological data across Katsina, Kebbi, and Zamfara states revealed significant changes in both temperature and precipitation patterns over the study period. Table 1 presents the results of temperature trend analysis by state, indicating a consistent warming trend across the entire region, though with spatial variations in the magnitude of change.

Table 1: Temperature Trends in Katsina, Kebbi, and Zamfara States (1990-2024)

State	Mean Annual Temp. 1990-1994 (°C)	Mean Annual Temp. 2019-2024 (°C)	Mean Change (°C)	Sen's Slope (°C/year)	p-value	Significance
Katsina	27.1	29.1	+2.0	0.061	<0.001	***
Kebbi	27.8	29.5	+1.7	0.052	0.002	**
Zamfara	26.9	28.7	+1.8	0.055	0.001	***
Regional Average	27.3	29.1	+1.8	0.056	<0.001	***

Note: ** significant at $p < 0.01$; *** significant at $p < 0.001$

As evident from Table 1, all three states experienced statistically significant warming over the 34-year period (1990-2024). The most pronounced warming occurred in Katsina state, with a mean annual temperature increase of 2.0°C and a trend of 0.061°C per year. Zamfara and Kebbi followed with increases of 1.8°C and 1.7°C, respectively. The regional average warming of 1.8°C (0.056°C/year) substantially exceeds the global average warming of approximately 0.18°C per decade reported by the IPCC for the same period (IPCC, 2021), highlighting the enhanced vulnerability of this semi-arid region to climate change. Survey responses from the 1050 respondents across the



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three states corroborated these instrumental records. When asked about perceived temperature changes over the past 20-30 years, 88.7% of respondents reported that temperatures had increased, with 67.3% characterizing the increase as "substantial." This perception was most pronounced among respondents in Katsina state, where 93.2% reported increased temperatures.

Seasonal analysis revealed that warming trends were not uniform throughout the year. The largest temperature increases occurred during the dry season months (October-April), with February and March showing the highest rates of warming (0.075°C/year on average). This amplified dry season warming potentially extends the period of high evapotranspiration and water stress, exacerbating drought conditions even without changes in precipitation. Precipitation trends across the three states show a more complex pattern than temperature, with substantial spatial and temporal variability. Table 2 presents the precipitation trend analysis by state, revealing divergent patterns across the region.

Table 2: Precipitation Trends in Katsina, Kebbi, and Zamfara States (1990-2024)

State	Mean Annual Precip. 1990-1994 (mm)	Mean Annual Precip. 2019-2024 (mm)	Mean Change (mm)	Sen's Slope (mm/year)	p-value	Significance
Katsina	684	591	-93	-2.82	0.021	*
Kebbi	768	721	-47	-1.43	0.132	ns
Zamfara	726	653	-73	-2.21	0.038	*
Regional Average	726	655	-71	-2.15	0.029	*

Note: ns = not significant; * significant at $p < 0.05$

While all three states showed declining precipitation trends, the magnitude and statistical significance varied considerably. Katsina and Zamfara states exhibited statistically significant decreases in annual precipitation, with Katsina showing the most substantial decline of 93mm over the study period (2.82mm/year). Although Kebbi showed a negative trend, it was not statistically significant at the $\alpha = 0.05$ level. The regional average indicates a significant decline of 71mm in annual precipitation (2.15mm/year), representing approximately a 9.8% reduction in rainfall since 1990. Survey data strongly aligned with these instrumental observations. Among the 1050 respondents, 82.3% reported perceived decreases in rainfall amounts, with 79.1% noting changes in rainfall timing or distribution. The highest percentage of respondents reporting rainfall decreases was in Katsina (89.7%), followed by Zamfara (84.1%) and Kebbi (73.2%).

Beyond these annual averages, important changes were observed in precipitation characteristics:

- i. **Rainfall Onset and Cessation:** Analysis of pentad (5-day) rainfall accumulation revealed a statistically significant delay in the onset of the rainy season by approximately 9-13 days ($p < 0.05$) across the three states since 1990, with the most pronounced delays in northern Katsina. Concurrently, an earlier cessation of rains by 5-8 days was observed, effectively shortening the growing season by approximately two weeks.



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- ii. **Rainfall Intensity and Distribution:** Despite the overall decline in annual precipitation, the number of heavy rainfall events (>30mm/day) increased by 19% across the three states, while the number of rain days decreased by 16%. This indicates a shift toward more intense but less frequent rainfall events, with longer dry spells between rains—a pattern particularly problematic for rain-fed agriculture.
- iii. **Spatial Regression of Isohyets:** Spatial analysis of 30-year average rainfall isohyets showed a southward shift of approximately 35-45km for the critical 600mm isohyet that roughly marks the limit of reliable rain-fed agriculture. This shift has effectively expanded the zone of high agricultural vulnerability. The findings agrees with Hypothesis 1

Research Question 2: what is the extent and patterns of average annual rate of desertification in the region?

Desert Encroachment Patterns across the Three States

The analysis of satellite imagery and derived vegetation indices revealed significant land degradation across Katsina, Kebbi, and Zamfara states, though with considerable spatial heterogeneity in the patterns and rates of desertification. Table 3 quantifies the extent of different desertification categories by state.

Table 3: Extent of Desertification Categories by State (1990-2024)

State	Total Area (km ²)	Severe Desertification (%)	Moderate Desertification (%)	Stable/Slight Degradation (%)	Improvement (%)
Katsina	24,192	28.5	45.2	22.8	3.5
Kebbi	36,800	15.8	37.9	39.7	6.6
Zamfara	39,762	19.3	41.2	34.5	5.0
Regional Total	100,754	20.5	41.2	33.0	5.3

Note: Classification based on combined assessment of NDVI trends, land cover changes, and field verification. Severe desertification indicates >40% reduction in vegetation productivity; moderate desertification indicates 15-40% reduction; stable/slight degradation indicates 0-15% reduction; improvement indicates increase in vegetation productivity.

These results reveal that approximately 61.7% of the three states' land area has experienced moderate to severe desertification over the 34-year study period, with only 5.3% showing signs of improvement. The spatial pattern of desertification follows a general north-south gradient, with the northern parts of Katsina experiencing the most severe degradation. However, this gradient is modified by local factors, creating a more complex mosaic of degradation patterns. Survey responses from the 1050 randomly selected participants provide valuable insights into public perceptions of land degradation. When asked about observed changes in vegetation cover over their lifetime, 86.5% of respondents reported decreases, with 59.7% characterizing these decreases as "severe." The highest perception of vegetation loss was reported in Katsina (92.1% of respondents), followed by Zamfara (87.4%) and Kebbi (80.0%).

Land cover change analysis provides additional insight into the desertification process. Between 1990 and 2024, the three states experienced a net loss of 34.2% of natural vegetation cover (including woodlands, shrublands, and perennial grasslands). Conversely, bare ground and sparsely vegetated areas increased by 31.3%, while cultivated land initially expanded by 17.5% between 1990 and 2005 but subsequently contracted by 5.3% between 2005 and 2024 as land degradation rendered some



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areas unsuitable for cultivation. The most rapid rates of desertification were observed in the 2000-2010 decade, coinciding with a period of accelerated population growth, expanded agricultural activities, and increased rainfall variability. The rate of desertification has moderated slightly since 2010, potentially reflecting increased awareness and implementation of soil and water conservation measures in some areas, although the overall trend remains negative.

- iv. Analysis of the fractional vegetation cover (FVC) derived from high-resolution satellite imagery provides further evidence of the desertification process. The average FVC across the three states decreased from 41.2% in 1990 to 27.8% in 2024, representing a 32.5% reduction in vegetation density. This trend was most pronounced in Katsina state, where average FVC declined by 36.9%, followed by Zamfara (32.7%) and Kebbi (28.4%). The findings equally agrees with Hypothesis 2 There has been significant increase in desertification in the affected states.

Research Question 3: What is the nature and strength of the correlation between proxies for human activity and observed indices of land degradation.

Relationship between Human Activities and Desertification

Statistical analysis of the relationship between human activities and desertification indicators revealed significant associations, as summarized in Table 4.

Table 4: Multiple Regression Analysis of Desertification Drivers in the Three States

Independent Variable	Coefficient	Std. Error	t-value	p-value	Significance
Population Density (people/km ²)	-0.0172	0.0033	-5.21	<0.001	***
Cropland Expansion (% change)	-0.0226	0.0051	-4.43	<0.001	***
Livestock Density (TLU/km ²)	-0.0207	0.0039	-5.31	<0.001	***
Fuelwood Collection (tons/km ²)	-0.0365	0.0065	-5.62	<0.001	***
Distance to Water Sources (km)	-0.0293	0.0058	-5.05	<0.001	***
SPI (12-month average)	0.0412	0.0084	4.90	<0.001	***
Temperature Anomaly (°C)	-0.0332	0.0073	-4.55	<0.001	***
Slope Gradient (%)	-0.0171	0.0055	-3.11	0.002	**
Soil Organic Matter (%)	0.0503	0.0094	5.35	<0.001	***
Protected Area Status (dummy)	0.0245	0.0069	3.55	<0.001	***

Note: Dependent variable is annual NDVI change (continuous variable ranging from negative to positive values, with negative values indicating degradation); $R^2 = 0.69$; Adjusted $R^2 = 0.66$; $n = 40$ grid cells; TLU = Tropical Livestock Unit; SPI = Standardized Precipitation Index; ** significant at $p < 0.01$; *** significant at $p < 0.001$

The regression model explained approximately 69% of the spatial variation in vegetation degradation (as measured by NDVI change), indicating that the combination of anthropogenic and climatic factors accounts for most of the observed desertification patterns. All variables included in the model showed statistically significant relationships with land degradation, with fuelwood collection exhibiting the strongest negative association among human factors. This finding aligns with field observations and



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survey responses indicating that wood harvesting for fuel and commercial charcoal production has resulted in widespread deforestation, particularly around urban centers and along major transportation corridors. Survey data from the 1050 respondents reinforced these statistical findings. When asked about primary energy sources, 78.2% of respondents reported relying on fuelwood as their main cooking energy source, with particularly high dependence in rural areas of all three states. Furthermore, 63.7% of respondents reported increasing difficulty in accessing fuelwood over the past decade, necessitating longer collection times or greater expenditure for purchased wood.

Population density showed a significant negative relationship with vegetation conditions, supporting the hypothesis that demographic pressure contributes to land degradation through increased resource demands. However, the relationship is not strictly linear, as evidenced by spatial analysis showing that some areas with moderate population density but poor land management practices experienced more severe degradation than certain high-density areas where sustainable practices have been adopted. The significant negative relationship between livestock density and vegetation conditions highlights the impact of grazing pressure on land resources. Field surveys revealed that areas with high livestock concentrations, particularly in northern Katsina state, exhibited soil compaction, reduced plant diversity, and diminished vegetation cover. Transhumance routes, traditionally used by pastoralists moving seasonally between ecological zones, showed particularly severe degradation, reflecting both intensive use and the breakdown of traditional management systems. Among the survey respondents involved in livestock keeping (64.3% of the total sample), 71.8% reported increasing difficulties in finding adequate grazing land over the past decade. This perception was most pronounced in Katsina (82.3%) and Zamfara (76.5%), and somewhat lower in Kebbi (57.4%). Among climatic factors, both precipitation (measured by SPI) and temperature anomalies significantly influenced vegetation condition, with drought periods strongly associated with accelerated land degradation. Importantly, the interaction between climatic and anthropogenic factors appears to create synergistic effects that amplify degradation beyond what either factor would produce individually.

Principal Component Analysis (PCA) identified three primary components explaining 74% of the variance in desertification patterns across the three states: (i) A "climate-driven degradation" component (32.6% of variance), strongly associated with drought indices and temperature anomalies (ii) A "resource extraction" component (25.9% of variance), associated with fuelwood collection, cultivation intensity, and distance to settlements (iii) A "grazing pressure" component (15.5% of variance), associated with livestock density and mobility patterns

This multifactorial nature of desertification underscores the need for integrated approaches to address both the climatic and anthropogenic dimensions of the problem. The findings is in agreement with Hypothesis (H₃): Strong positive correlation exists between high-density human activity zones and severe land degradation.

Research Question 4: Which specific Areas(state)exhibit the highest level of vulnerability and exposure to climatic changes

Identification of Critical Zones and Vulnerability Hotspots

The integration of desertification indicators, climate vulnerability metrics, and socioeconomic data allowed for the identification of critical zones and vulnerability hotspots across Katsina, Kebbi, and Zamfara states. Table 5 presents the vulnerability classification of areas within each state.



Table 5: Vulnerability Classification of Areas in the Three States

State	Extreme Vulnerability (% of area)	High Vulnerability (% of area)	Moderate Vulnerability (% of area)	Low Vulnerability (% of area)
Katsina	32.6	42.8	18.7	5.9
Kebbi	18.5	39.2	32.1	10.2
Zamfara	23.8	39.7	29.4	7.1
Regional Average	24.5	40.4	27.2	7.9

Note: Vulnerability classification based on composite index incorporating biophysical indicators (NDVI trends, aridity index, soil degradation) and socioeconomic factors (population density, poverty rates, infrastructure access)

The analysis identified 24.5% of the three states' area as facing extreme vulnerability to desertification and drought, with an additional 40.4% classified as highly vulnerable. Spatially, these vulnerability hotspots are concentrated in: (i) The northern portions of Katsina and parts of northern Zamfara, where advancing desert conditions, high aridity indices, and limited alternative livelihoods create severe challenges (ii) Areas surrounding major urban centers, including the peripheries of Katsina, Gusau (Zamfara), and Birnin Kebbi cities, where high population pressure and intensive resource extraction have led to circular patterns of degradation (iii) Transboundary zones along the Nigeria-Niger border in Katsina state, characterized by high mobility of people and livestock, contested resource access, and limited governance capacity.

Survey responses provided insights into community perceptions of vulnerability. When asked to rate the severity of environmental changes in their localities, respondents in northern Katsina reported the highest perceived impact (average severity rating of 4.6 on a 5-point scale), followed by northern Zamfara (4.3) and northern Kebbi (3.9). Temporal analysis indicates that both the extent and intensity of vulnerability have increased over the study period, with areas classified as highly or extremely vulnerable expanding from 48.2% of the region in 1990 to 64.9% in 2024. This expansion has predominantly occurred through the conversion of moderately vulnerable areas to highly vulnerable status, reflecting the progressive nature of desertification processes. Socioeconomic vulnerability amplifies the impact of biophysical degradation. Areas with limited livelihood diversification, poor market access, and inadequate infrastructure demonstrated reduced adaptive capacity to climate stressors. Notably, communities with high dependence on natural resource-based livelihoods (exceeding 75% of household income) exhibited the greatest susceptibility to desertification impacts, with livelihood diversification serving as a key resilience factor. The survey revealed that adaptation strategies varied by vulnerability level. In areas of extreme vulnerability, migration (seasonal or permanent) was reported by 42.3% of respondents as a key coping strategy. In contrast, areas of moderate vulnerability showed higher rates of agricultural adaptation through changed planting dates (68.7%) and crop diversification (57.4%).



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Geospatial analysis of vulnerability trends revealed directional patterns of desertification, with a general southward progression of high-vulnerability zones at an average rate of 0.7-1.3 km per year. However, this progression is not uniform, with "leapfrog" patterns emerging where isolated degradation hotspots develop ahead of the main degradation front, often associated with localized resource extraction or land use intensification. These spatial dynamics present challenges for containment strategies and highlight the need for anticipatory rather than reactive interventions. The findings equally support Hypothesis 4 (H₄): Highly vulnerable and critical hotspots exist in the areas affected by desertification.

Key Findings on Desertification and Drought Trends

The major findings can be summarized as follows:

- i. Temperature across the three states has increased by an average of 1.8°C between 1990 and 2024, with warming most pronounced during the dry season. This rate of warming (0.056°C/year) substantially exceeds global averages for the same period. Annual precipitation has declined by an average of 9.8% across the three states, with statistically significant decreases in Katsina and Zamfara states. More importantly, rainfall patterns have become increasingly erratic, with delayed onset, earlier cessation, fewer rainy days, and more intense rainfall events.
- ii. Approximately 61.7% of the three states' land area has experienced moderate to severe desertification over the 34-year study period, with natural vegetation cover declining by 34.2% and bare ground increasing by 31.3%.
- iii. Human activities—particularly fuelwood collection, livestock grazing, and agricultural expansion—have significantly contributed to desertification processes, with statistical models indicating that anthropogenic factors explain a substantial portion of observed land degradation patterns.
- iv. Climate and human factors interact synergistically, creating amplifying feedback that accelerates desertification beyond what either factor would produce individually.
- v. Vulnerability to desertification and drought is unevenly distributed, with 64.9% of the region classified as highly or extremely vulnerable, concentrated in northern Katsina, northern Zamfara, and areas surrounding major urban centers.
- vi. Survey data from 1020 respondents across the three states confirmed widespread public perception of environmental change, with 88.7% reporting increased temperatures, 82.3% perceiving decreased rainfall, and 86.5% noting vegetation loss.

These findings confirm that desertification and drought represent major manifestations of climate change in Katsina, Kebbi, and Zamfara states, with significant implications for ecosystem sustainability, agricultural productivity, and human welfare. The observed trends suggest that without substantial intervention, the region faces increasing environmental degradation and livelihood challenges in the coming decades.

Implications for Ecosystem Sustainability

The documented patterns of desertification and drought carry profound implications for ecosystem sustainability across the three states. The progressive degradation of vegetation cover compromises critical ecosystem services, including:

- i. **Biodiversity Support:** Natural vegetation communities have experienced fragmentation and compositional shifts, with drought-tolerant and grazing-resistant species becoming increasingly dominant. Field surveys documented an average 40% reduction in plant species richness in severely degraded areas compared to reference sites, with native perennial grasses particularly affected.



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- ii. **Hydrological Regulation:** Reduced vegetation cover and soil degradation have altered hydrological processes, increasing surface runoff and decreasing infiltration. This hydrological disruption manifests in more erosive flood events during intense rains and reduced moisture availability during dry periods, effectively amplifying both flood and drought impacts.
- iii. **Carbon Storage:** Soil organic carbon has declined by an estimated 45% in severely degraded areas, representing both a loss of soil fertility and a contribution to atmospheric carbon dioxide levels. This carbon loss creates positive feedback to climate change while reducing the productive capacity of the land.
- iv. **Microclimate Regulation:** Vegetation loss alters surface energy balances, potentially reinforcing aridity through reduced evapotranspiration and increased surface albedo. Local temperature measures showed that severely degraded areas exhibited daytime surface temperatures 3-7°C higher than adjacent vegetated areas.

These ecosystem impacts are not merely environmental concerns but directly affect human welfare through compromised agricultural productivity and increased vulnerability to climate extremes. The degradation trajectory observed in some areas suggests the potential for threshold-crossing events, where degradation becomes effectively irreversible under current climatic conditions, highlighting the urgency of intervention. Survey responses indicated growing awareness of these ecological connections. Among the 1020 respondents, 73.8% identified direct links between vegetation loss and other environmental changes such as reduced water availability (mentioned by 68.5%), increased erosion (62.9%), and greater temperature extremes (57.2%).

Conclusion

This study has documented significant climate change impacts across Katsina, Kebbi, and Zamfara states, characterized by increasing temperatures, declining and increasingly erratic precipitation, and widespread land degradation.

Recommendations

Practical Interventions for Combating Desertification

Based on the findings of this study, several practical interventions can be recommended to combat desertification and mitigate drought impacts in Katsina, Kebbi, and Zamfara states:

Landscape Restoration Approaches: Implementing integrated landscape management through:

- i. Assisted natural regeneration (ANR) of degraded woodlands, particularly focusing on native Acacia species and other drought-tolerant natives
- ii. Establishment of greenbelts and shelter belts in strategic locations to reduce wind erosion and create microclimate benefits
- iii. Implementation of soil and water conservation structures (half-moons, stone bunds, etc.) to maximize water infiltration and reduce erosion

Sustainable Land Management Practices:

Promoting agricultural techniques that enhance resilience:

- i. Farmer-managed natural regeneration (FMNR) to integrate trees into farming systems
- ii. Conservation agriculture practices (minimum tillage, cover cropping, crop rotation) to improve soil health Agroforestry systems that combine production with environmental benefits
- iii. Improved rangeland management through rotational grazing and strategic placement of water points

Alternative Energy Solutions: Addressing fuelwood demand through:



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- i. Promotion of improved cookstoves that reduce firewood consumption by 40-60%
- ii. Development of community woodlots for sustainable fuelwood production
- iii. Exploration of alternative energy sources, including solar cookers and biogas systems

Water Management Innovations: Enhancing water security through:

- i. Small-scale irrigation technologies such as California drip systems and treadle pumps
- ii. Rainwater harvesting techniques at household and community scales
- iii. Floodwater harvesting systems to capture and utilize seasonal flows
- iv. Rehabilitation of traditional water harvesting structures

Livelihood Diversification: Reducing pressure on land resources through:

- i. Promotion of non-timber forest products (NTFPs) such as honey, gum Arabic, and medicinal plants
- ii. Development of climate-smart value chains and market linkages
- iii. Support for off-farm income generation, particularly targeting women and youth
- iv. Skills development programs aligned with emerging economic opportunities

Survey respondents showed strong interest in several of these interventions. When asked about willingness to adopt different adaptation strategies, the highest interest was expressed for improved water harvesting (86.2%), drought-resistant crop varieties (84.9%), and small-scale irrigation (79.3%). Interest in alternative energy solutions was moderate (58.1% for improved cookstoves, 51.7% for solar alternatives), suggesting the need for demonstration and awareness-raising in this area.

Policy Recommendations and Institutional Frameworks

Addressing desertification and drought effectively requires supportive policy environments and institutional arrangements. Based on the findings of this study, the following policy recommendations are proposed for Katsina, Kebbi, and Zamfara states:

Integrated Land Use Planning:

- i. Develop and implement participatory land use plans at local government levels that recognize ecological conditions and traditional land management systems
- ii. Establish clear demarcation of grazing reserves, forest reserves, and agricultural zones to reduce resource conflicts
- iii. Integrate climate change projections into spatial planning to anticipate vulnerability transitions

Cross-Sectoral Coordination:

- i. Establish state-level desertification coordinating bodies with representation from agriculture, environment, water, energy, and planning departments
- ii. Develop joint programs between forestry departments and energy agencies to address fuelwood challenges comprehensively
- iii. Align drought management strategies with broader development planning

Economic Incentives and Financial Mechanisms:

- i. Implement payment for ecosystem services (PES) schemes to reward sustainable land management
- ii. Develop weather-indexed insurance products for smallholder farmers
- iii. Establish revolving funds for adoption of climate-smart technologies
- iv. Redirect agricultural subsidies toward sustainable practices

Monitoring and Knowledge Management:

- i. Strengthen early warning systems for drought and desertification
- ii. Establish participatory monitoring networks involving local communities



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- iii. Document and disseminate traditional ecological knowledge relevant to drought and land management
- iv. Create knowledge-sharing platforms across the three states

Capacity Development:

- i. Strengthen extension services with a focus on climate-resilient practices
- ii. Develop training programs for local government officials on integrated natural resource management
- iii. Support farmer-to-farmer learning networks and demonstration sites
- iv. Incorporate climate change and sustainable land management into educational curricula

Ultimately, addressing desertification and drought in Katsina, Kebbi, and Zamfara states requires a multi-faceted approach that combines ecological restoration, sustainable land management, alternative livelihoods, and enabling policies. By integrating scientific understanding with local knowledge and addressing both immediate symptoms and underlying drivers, there is potential to reverse degradation trends and build resilience to climate change in this vulnerable region. The findings from the 1020 survey respondents across the three states provide a solid foundation for developing locally appropriate and socially acceptable interventions that can effectively combat these interlinked challenges.

Acknowledgement

The researchers would like to extend their heartfelt thanks to the Tertiary Education Trust Fund (TET Fund) for its generous funding of this research work (through IBR). This crucial financial assistance played a key role in enabling the data gathering, analysis, and overall completion of this research. TET Fund's dedication to promoting knowledge and innovation in higher education is highly praiseworthy. We sincerely appreciate this vital contribution to academic excellence.

References

- Abdulkadir, A., Lawal, M. A., & Muhammad, T. I. (2017). Climate change and desertification vulnerability in Northern Nigeria. *Journal of Environmental Management*, 155, 34-43.
- Abdullahi, H., Saidu, Y., & Mohammed, I. U. (2020). Land degradation and livelihood vulnerability in Northern Nigeria. *Environmental Science & Policy*, 115, 57-66.
- Abiodun, B. J., Salami, A. T., & Tadross, M. (2018). Climate change scenarios for Nigeria: understanding biophysical impacts. Climate Systems Analysis Group, Cape Town, South Africa.
- Charney, J. G. (1975). Dynamics of deserts and drought in the Sahel. *Quarterly Journal of the Royal Meteorological Society*, 101(428), 193-202.
- Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data*, 7(1), 1-18.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Ismail, S. A., Ibrahim, A. A., & Nuru, M. (2019). Application of Standardized Precipitation Evapotranspiration Index in drought assessment in Northwest Nigeria. *Journal of Arid Land Studies*, 28(4), 151-163.
- McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).
- Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 391(1-2), 202-216.
- Mohammed, Y., Yamba, F., & Sawa, B. A. (2018). Trend analysis of drought severity in Katsina, Sokoto and Zamfara states. *Journal of Applied Sciences and Environmental Management*, 22(5), 675-680.



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- Momodou, A. S., Addo, A., & Akinbami, J. F. K. (2011). Forestry management and deforestation in northwestern Nigeria: A case study of Kebbi state. *Energy & Environment*, 22(5), 525-536.
- Mortimore, M. J., & Adams, W. M. (2001). Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change*, 11(1), 49-57.
- Nicholson, S. E., Fink, A. H., & Funk, C. (2018). Assessing recovery and change in West Africa's rainfall regime from a 161-year record. *International Journal of Climatology*, 38(10), 3770-3786.
- Nkechi, G. O., Kabir, M. A., & Abdullahi, M. B. (2016). Vulnerability assessment of households in northwestern Nigeria. *Climate and Development*, 8(3), 266-278.
- Odjugo, P. A. O. (2010). General overview of climate change impacts in Nigeria. *Journal of Human Ecology*, 29(1), 47-55.
- Olagunju, T. E. (2015). Drought, desertification and the Nigerian environment: A review. *Journal of Ecology and the Natural Environment*, 7(7), 196-209.
- Oladipo, E. O. (2018). Drought in West Africa: Progress and challenges in detection, monitoring and management. *WMO Bulletin*, 67(1), 26-31.
- Reynolds, J. F., Smith, D. M. S., Lambin, E. F., Turner, B. L., Mortimore, M., Batterbury, S. P., & Walker, B. (2007). Global desertification: building a science for dryland development. *Science*, 316(5826), 847-851.
- UNCCD. (2017). *The Global Land Outlook*, first edition. Bonn, Germany.
- Usman, B. A., & Nichol, J. E. (2018). Assessing land cover change and degradation in the Central highland woodlands of Katsina state, Nigeria, using remote sensing and GIS. *Land Degradation & Development*, 29(7), 2034-2046.
- Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscale drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of Climate*, 23(7), 1696-1718.
- Wilhite, D. A., & Glantz, M. H. (1985). Understanding: the drought phenomenon: the role of definitions. *Water International*, 10(3), 111-120.