

Assessment of Forest Degradation Hotspots in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State, Nigeria

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Abstract

Forest degradation in Nigeria's savannah ecosystems threatens biodiversity, carbon storage, and rural livelihoods. This study assessed forest degradation hotspots in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State, Nigeria, over 37 years (1987–2024). Satellite-derived land use/land cover data were analysed and classified into five degradation categories: High Lost, Low Lost, Stable, Low Gain, and High Gain. Results showed that High Lost areas increased from 1,563.57 km² (6.22%) in 1987–2004 to 4,488.75 km² (17.87%) in 2004–2014, before declining to 2,254.35 km² (8.97%) in 2014–2024, representing a net increase of 690.78 km² (44.18%) over the study period. Low Lost areas rose from 3,919.31 km² (15.60%) to 4,933.01 km² (19.64%), a net gain of 1,013.70 km² (25.86%). Stable areas expanded from 6,858.26 km² (27.30%) to 7,658.75 km² (30.49%), a net increase of 800.49 km² (11.67%). Conversely, Low Gain areas declined from 8,800.38 km² (35.03%) to 7,028.93 km² (27.98%), a net loss of 1,771.45 km² (20.13%), while High Gain areas decreased from 3,978.15 km² (15.84%) to 3,244.63 km² (12.92%), a net loss of 733.52 km² (18.44%). The total study area remained constant at 25,119.67 km². The findings reveal a concerning shift from stable and gainful forest cover toward degraded states, with degradation peaking between 2004 and 2014. Hotspot analysis using the Getis-Ord Gi* statistic identified significant clusters of biomass loss, while logistic regression and Random Forest modelling attributed degradation primarily to urbanization, road construction, population pressure, weak forest governance, logging, charcoal production, livestock grazing, poverty, and climate variability. The study recommends targeted reforestation, community-based forest management, and stricter enforcement of land-use regulations to curb degradation in Taraba State's savannah ecosystem.

Keywords: forest degradation, hotspots, land use/land cover, Getis-Ord Gi, Southern Guinea Savannah

1. Introduction

Forest degradation in Sub-Saharan Africa has emerged as one of the most pressing environmental challenges of the twenty-first century, threatening biodiversity, carbon sequestration capacity, and the livelihoods of millions of rural dwellers who depend directly on forest resources (FAO, 2020; Hosonuma et al., 2012). Unlike deforestation, which involves the complete removal of forest cover, degradation refers to the reduction in forest quality, structure, and function, often through selective logging, fuelwood collection, grazing, and recurrent fires (Lambin et al., 2003; Tyukavina et al., 2018). In Nigeria, forest degradation has accelerated over the past four decades, driven by a combination of demographic pressure, agricultural expansion, weak governance, and climate variability (Adeyoju, 1975; Fasona et al., 2020).

Nigeria's savannah ecosystems, which cover approximately

80% of the country's land area, are particularly vulnerable to degradation. The Southern Guinea Savannah Agro-Ecological Zone, which spans parts of Taraba, Benue, Kogi, Kwara, and Oyo States, represents a critical transition zone between the humid forest and the drier Sudan Savannah (Keay, 1959). Taraba State, located in northeastern Nigeria, hosts extensive tracts of this savannah ecosystem and has experienced significant land use/land cover changes over the past four decades (Shamaki et al., 2025). The state's forests provide essential ecosystem services, including carbon sequestration, water regulation, biodiversity habitat, and non-timber forest products (NTFPs) that support rural livelihoods.

Despite the ecological and socio-economic importance of Taraba State's savannah forests, systematic assessments of degradation hotspots and their drivers remain limited. Most existing studies have focused on deforestation at national or regional scales, with insufficient attention to the spatial heterogeneity of degradation

within specific agro-ecological zones. Furthermore, the distinction between degradation hotspots and cold spots, areas of biomass gain has not been adequately explored in the Nigerian savannah context. Understanding where degradation is concentrated, what drives it, and how it affects ecosystem services is essential for designing targeted interventions.

This study addresses these gaps by assessing forest degradation hotspots in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State over a 37-year period (1987–2024). Specifically, the study aims to: (1) quantify land use/land cover changes across five degradation categories; (2) identify spatial clusters of significant biomass loss using hotspot analysis; (3) attribute degradation to proximate and underlying drivers using logistic regression and Random Forest modelling; and (4) evaluate the impacts of degradation on ecosystem services, including carbon sequestration, biodiversity, and NTFPs.

The study is anchored in the Socio-Ecological Systems framework, which conceptualizes forests as coupled human-natural systems in which ecological dynamics and human activities interact across multiple scales (Ostrom, 2009). This framework is particularly appropriate for analysing forest degradation in the savannah, where human land use and ecological processes are tightly intertwined. The findings are expected to inform evidence-based policies for sustainable forest management, land-use planning, and climate change mitigation in Taraba State and comparable savannah environments across West Africa.

2. Literature Review

2.1 Forest Degradation: Concepts and Measurement

Forest degradation is conceptually distinct from deforestation, although the two processes are often interrelated. Deforestation refers to the complete removal of forest cover and conversion to non-forest land uses, whereas degradation denotes a reduction in forest biomass, species composition, or ecosystem function without complete loss of forest cover (Lambin et al., 2003; Tyukavina et al., 2018). Degradation can result from selective logging, fuelwood extraction, charcoal production, livestock grazing, recurrent fires, and climate stress (Hosonuma et al., 2012). Measuring degradation is inherently challenging because it involves changes in forest quality rather than quantity, requiring indicators such as biomass, canopy cover, species diversity, and ecosystem service provision (Mertz et al., 2007).

Remote sensing has become the primary tool for assessing forest degradation at landscape scales. Satellite-derived indices such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Normalized Burn Ratio (NBR) can detect changes in vegetation health and biomass (Zhu, 2017). Land use/land cover classification combined with change detection analysis allows for the quantification of degradation trajectories over time (Shamaki et al., 2025). More recently, hotspot analysis using spatial statistics such as the Getis-Ord G_i^* has been employed to identify clusters of significant degradation, enabling targeted interventions (Getis & Ord, 1992; Ord & Getis, 1995).

2.2 Drivers of Forest Degradation in Nigeria

The drivers of forest degradation in Nigeria are multifaceted, encompassing proximate causes such as agricultural expansion, logging, fuelwood collection, and infrastructure development, as well as underlying drivers including population growth, poverty, weak governance, and climate change (Adeyoku, 1975; Forsyth, 2003). Agricultural expansion is widely recognized as the leading

proximate driver, as rural households clear forest for farmland to meet food and income needs (Fasona et al., 2020). Logging, both legal and illegal, contributes to degradation through selective removal of valuable timber species, reducing forest density and quality. Charcoal production, driven by urban demand for biomass energy, involves the slow combustion of wood in earth kilns, removing trees and degrading soil (Fasona et al., 2020).

Livestock grazing, particularly transhumant pastoralism by Fulani herders, has emerged as a significant driver of degradation in Nigeria's savannah zones. Open grazing and pastoral encroachment lead to trampling of seedlings, browsing on young shoots, soil compaction, and depletion of herbaceous cover (Okeke, 2014). These pressures have intensified in recent years, contributing to farmer-herder conflicts and social instability (Fasona et al., 2020). Poverty is a critical underlying driver, as economic hardship compels rural households to depend heavily on forests for fuelwood, charcoal, timber, and income diversification (Fonta & Ayuk, 2013; Oyeranti & Ishola, 2021). Women, who are often responsible for fuelwood collection, bear a disproportionate burden of degradation.

Weak forest policies and poor enforcement are also strongly implicated in degradation. Inadequate governance, corruption, insufficient monitoring, and policy inconsistencies contribute to illegal logging, uncontrolled grazing, and other harmful practices (Adeyoku, 1975; Forsyth, 2003). Climate change, though an indirect driver, increases forest vulnerability to fire, pests, and drought, particularly in the drier northern stretches of the savannah. Ellison et al. (2017) note that trees and forests play a critical role in the water cycle, and their removal can lead to reduced rainfall and increased drought frequency, further degrading agro-ecological systems in semi-arid regions.

2.3 Impacts of Degradation on Ecosystem Services

Forest degradation has profound impacts on ecosystem services, including provisioning, regulating, supporting, and cultural services (Millennium Ecosystem Assessment, 2005). Provisioning services such as timber, fuelwood, NTFPs, and medicinal plants are directly affected by degradation. The disappearance of medicinal plants and herbs is particularly significant for rural healthcare, as many communities rely on traditional medicine as their primary or sole source of treatment. Regulating services, including carbon sequestration, water regulation, and climate modulation, are compromised by degradation (Ellison et al., 2017). Supporting services such as soil formation and nutrient cycling are also affected, with implications for agricultural productivity. The socio-economic consequences of degradation are multi-dimensional and vary across communities. Community wellbeing declines as forest resources diminish, affecting household welfare, social cohesion, and cultural heritage (Fasona et al., 2020). Women and other vulnerable groups are disproportionately affected due to their reliance on forest resources for fuelwood, food, and income. Addressing these impacts requires integrated approaches that strengthen forest governance, promote sustainable land-use planning, diversify livelihoods, and enhance community-based forest management (Ostrom, 2009).

2.4 Research Gap

Despite growing evidence on forest degradation in Nigeria, gaps remain. Most studies have focused on deforestation at national or regional scales, with insufficient attention to the spatial heterogeneity of degradation within specific agro-ecological zones. The distinction between degradation hotspots and cold spots has not been adequately explored in the Nigerian savannah

context. Furthermore, the drivers of degradation have rarely been analysed using advanced spatial modelling techniques such as logistic regression and Random Forest, which can identify the relative importance of multiple predictors (Zhu, 2017). This study addresses these gaps by integrating satellite-derived land use/land cover data, hotspot analysis, and explanatory modelling to assess forest degradation in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State.

2.5 Description of Study Area

The study was conducted in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State, Nigeria. Taraba State lies between latitudes 6°30'N and 9°30'N and longitudes 9°30'E and 12°00'E, covering a total land area of approximately 54,473 km² (Shamaki et al., 2025) (Fig. 1). The state shares boundaries with Bauchi and Gombe States to the north, Adamawa State to the east, Benue and Plateau States to the west, and the Republic of Cameroon to the southeast. The Southern Guinea Savannah zone within Taraba State encompasses the southern and central portions of the state, including local government areas (LGAs) such as Bali, Ussa, Donga, Takum, Gashaka, and Sardauna.

The climate of the study area is tropical wet-and-dry, characterized by distinct wet and dry seasons. Annual rainfall ranges from 1,000 mm to 1,500 mm, with the wet season lasting from April to October. Mean annual temperatures range from 25°C to 30°C, with the highest temperatures recorded in March and April. The vegetation is predominantly Southern Guinea Savannah, characterized by open woodland, tall grasses, and scattered trees such as *Vitellaria paradoxa* (shea butter), *Parkia biglobosa* (locust bean), and *Terminalia* species (Keay, 1959). The soils are predominantly ferruginous tropical soils, with varying fertility depending on parent material and land use history.

The population of Taraba State was estimated at 3.3 million in 2022, with an annual growth rate of approximately 2.8% (National Population Commission, 2022). Agriculture is the mainstay of the economy, employing over 70% of the active population. Major crops include maize, rice, sorghum, yam, cassava, and groundnut. Livestock rearing, particularly cattle, sheep, and goats, is also widespread, with transhumant pastoralism practiced by Fulani herdsmen (Shamaki et al., 2025).

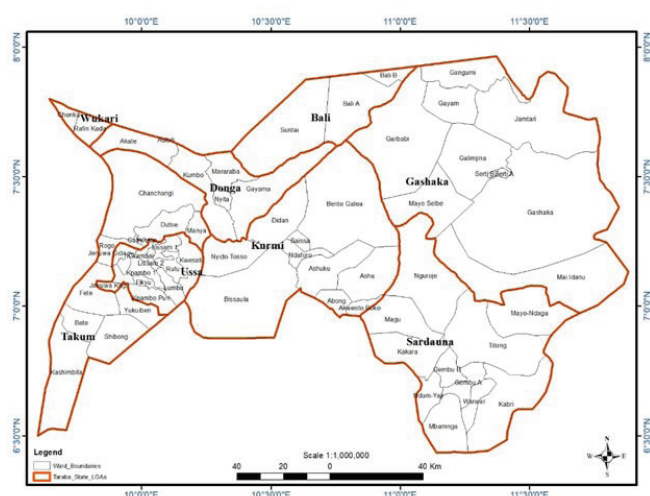


Figure 1. Map of Study Area

3. Materials and Methods

3.1 Research Design

The study adopted a mixed-methods design combining satellite-derived land use/land cover analysis, spatial statistics, explanatory modelling, and community surveys. The quantitative component involved the classification of Landsat imagery for three time periods (1987–2004, 2004–2014, and 2014–2024) and the application of hotspot analysis, logistic regression, and Random Forest modelling. The qualitative component involved household surveys and focus group discussions to assess community perceptions of degradation drivers and impacts on ecosystem services.

3.2 Data Sources and Processing

Satellite Imagery: Landsat imagery was acquired from the United States Geological Survey (USGS) Earth Explorer portal. For the 1987–2004 period, Landsat 5 TM (Thematic Mapper) images were used; for 2004–2014, Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) images were used; and for 2014–2024, Landsat 8 OLI/TIRS (Operational Land Imager/Thermal Infrared Sensor) images were used. Cloud-free images from the dry season (November–February) were selected to minimize cloud cover and maximize vegetation contrast. A total of 18 images (6 per period) were mosaicked and resampled to a spatial resolution of 30 meters.

Ancillary Data: Ancillary datasets included roads, settlements, agricultural boundaries, slope, elevation, population density, and climatic variability. Road and settlement data were obtained from the OpenStreetMap (OSM) database and the Taraba State Ministry of Lands and Survey. Agricultural boundaries were derived from the National Agricultural Land Use Database. Slope and elevation data were derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) at 30-metre resolution. Population density data were obtained from the National Population Commission and WorldPop. Climatic data (rainfall and temperature) were obtained from the Nigerian Meteorological Agency (NiMet) and the Climate Research Unit (CRU) at the University of East Anglia.

Community Survey: A structured questionnaire was administered to 400 household heads across five LGAs (Bali, Ussa, Donga, Takum, and Jalingo) to assess perceptions of degradation drivers and impacts on ecosystem services. The questionnaire contained sections on demographics, livelihood activities, forest use, perceived drivers of degradation, and perceived impacts on ecosystem services. A 5-point Likert scale was used to rate the importance of each driver and impact. Focus group discussions (n = 10) were conducted with community leaders, women's groups, and farmer-herder associations to provide qualitative context. Ethical approval was obtained from the Taraba State University Research Ethics Committee, and informed consent was obtained from all participants.

3.3 Land Use/Land Cover Classification

Land use/land cover (LULC) classification was performed using supervised classification with the Maximum Likelihood Classifier (MLC) in ArcGIS 10.8 and ERDAS Imagine 2015. Five LULC classes were defined: water body, bare land, vegetation/forest, settlement, and farmland. Training samples were collected using stratified random sampling, with a minimum of 50 samples per class per period. Accuracy assessment was conducted using 200 randomly selected points per period, with ground truth data collected during field visits in 2024 and 2025. Overall accuracy and Kappa coefficients were calculated to validate the classification.

For degradation analysis, LULC changes were further classified into five degradation categories based on the direction and

magnitude of change:

- **High Lost:** Areas that transitioned from vegetation/forest to bare land or settlement, representing severe degradation.
- **Low Lost:** Areas that transitioned from vegetation/forest to farmland or from dense vegetation to sparse vegetation, representing moderate degradation.
- **Stable:** Areas that remained unchanged in vegetation/forest cover.
- **Low Gain:** Areas that transitioned from farmland or bare land to vegetation/forest, representing moderate recovery.
- **High Gain:** Areas that transitioned from bare land or settlement to dense vegetation/forest, representing significant recovery.

3.4 Hotspot Analysis

Hotspot analysis was conducted to identify clusters of significant land degradation and biomass loss. Spatial statistics, including the Getis-Ord G_i^* method, were applied to quantify hotspots and cold spots of change. The Getis-Ord G_i^* statistic identifies locations where high or low values of a variable cluster spatially, with statistically significant clusters indicating areas of intensive change (Getis & Ord, 1992; Ord & Getis, 1995). The G_i^* statistic was calculated for each pixel based on the biomass change values, with a neighbourhood distance of 1,000 metres. Pixels with G_i^* values greater than +1.96 ($p < 0.05$) were considered significant hotspots (high biomass loss), while pixels with G_i^* values less than -1.96 were considered significant cold spots (biomass gain). The NDVI-based hotspot analysis was used to complement the LULC change analysis by providing a continuous measure of vegetation health and biomass dynamics, thereby enabling the identification of degradation clusters that may not be captured by categorical LULC transitions alone.

3.5 Explanatory Modelling

Explanatory modelling using logistic regression and Random Forest regression further assessed the influence of factors such as proximity to roads, slope, elevation, population density, and climatic variability on the spatial pattern of deforestation and degradation. Logistic regression was used to model the probability of deforestation (binary outcome: deforested vs. non-deforested) as a function of these predictor variables, with odds ratios indicating the strength and direction of the relationships. The binary outcome was derived from the LULC change analysis, where pixels that transitioned from vegetation/forest to bare land, settlement, or farmland were classified as deforested, while all other pixels were classified as non-deforested. Random Forest regression was used to identify the relative importance of each predictor, providing measures of variable importance that indicate how much each predictor contributes to the predictive accuracy of the model. Attribution was supported by both statistical evidence and literature review, providing context for the observed spatio-temporal dynamics.

4. Data Analysis

Data analysis was conducted using Stata version 17.0, R version 4.2.0, and ArcGIS 10.8. Descriptive statistics (means, standard deviations, frequencies, percentages) were calculated for LULC changes and community survey responses. Inferential analysis included paired t-tests for comparing LULC changes across periods, chi-square tests for comparing driver perceptions across LGAs, and regression modelling for attribution. Statistical significance was set at $p < 0.05$. Qualitative data from focus group discussions were transcribed and analysed thematically.

5. Results

5.1 Land Use/Land Cover Changes (1987–2024)

Table 1 presents the mean annual rate of change in land use/land cover in the study area between 1987 and 2024 (a 37-year period). Table 1 shows that vegetation/forest recorded the largest annual loss ($-3.28 \text{ km}^2/\text{yr}$), followed by bare land ($-1.75 \text{ km}^2/\text{yr}$) and water body ($-0.07 \text{ km}^2/\text{yr}$). In contrast, farmland experienced the highest annual gain ($+3.58 \text{ km}^2/\text{yr}$), followed by settlement ($+1.52 \text{ km}^2/\text{yr}$). Overall, the results indicate a decline in natural land cover (water, bare land, and vegetation/forest) and a corresponding expansion in human-related land uses (settlement and farmland) over the study period.

Table 1: Mean Annual Rate of Change in Land Use/Land Cover (1987–2024).

Type of surface	1987 Area (km ²)	2024 Area (km ²)	Total Change (km ²)	Mean Annual Change (km ² /yr)	Direction
Water Body	113.04	110.36	-2.68	-0.072	Decrease
Bare Land	1547.39	1482.77	-64.62	-1.747	Decrease
Vegetation/Forest	17719.63	17598.31	-121.32	-3.279	Decrease
Settlement	266.27	322.59	+56.32	+1.522	Increase
Farmland	5473.64	5605.95	+132.31	+3.576	Increase
Total	25,119.97	25,119.98	-	-	-

Source: Data Analysis Results, 2025.

The results in Table 1 show a consistent decline in natural land cover (water, bare land, vegetation/forest) and expansion in human-related land uses (settlement, farmland). The largest annual loss was recorded in vegetation/forest ($-3.28 \text{ km}^2/\text{yr}$), while farmland recorded the highest annual gain ($+3.58 \text{ km}^2/\text{yr}$). These trends indicate ongoing pressure on forest resources from agricultural expansion and urbanization. The decline in bare land ($-1.75 \text{ km}^2/\text{yr}$) alongside the expansion of farmland and settlement suggests that previously cleared lands are being converted to agricultural and urban uses, while new areas of vegetation/forest are being cleared, resulting in a net loss of forest cover.

5.2 Degradation Categories (1987–2024)

Table 2 presents the changes in degradation categories across three periods: 1987–2004, 2004–2014, and 2014–2024. High Lost areas increased from $1,563.57 \text{ km}^2$ (6.22%) in 1987–2004 to $4,488.75 \text{ km}^2$ (17.87%) in 2004–2014, before declining to $2,254.35 \text{ km}^2$ (8.97%) in 2014–2024, representing a net increase of 690.78 km^2 (44.18%) over the study period. Low Lost areas rose from $3,919.31 \text{ km}^2$ (15.60%) to $4,933.01 \text{ km}^2$ (19.64%), a net gain of $1,013.70 \text{ km}^2$ (25.86%). Stable areas expanded from $6,858.26 \text{ km}^2$ (27.30%) to $7,658.75 \text{ km}^2$ (30.49%), a net increase of 800.49 km^2 (11.67%). Conversely, Low Gain areas declined from $8,800.38 \text{ km}^2$ (35.03%) to $7,028.93 \text{ km}^2$ (27.98%), a net loss of $1,771.45 \text{ km}^2$ (20.13%), while High Gain areas decreased from $3,978.15 \text{ km}^2$ (15.84%) to $3,244.63 \text{ km}^2$ (12.92%), a net loss of 733.52 km^2 (18.44%). The total study area remained constant at $25,119.67 \text{ km}^2$.

Table 2: Degradation Categories Across Three Periods (1987–2024).

Hotspot Class	1987–2004 Area (km ²)	1987–2004 (%)	2004–2014 Area (km ²)	2004–2014 (%)	2014–2024 Area (km ²)	2014–2024 (%)	Net Change (1987–2024)	% Change (1987–2024)
High Lost	1,563.57	6.22	4,488.75	17.87	2,254.35	8.97	+690.78	+44.18
Low Lost	3,919.31	15.60	5,463.49	21.75	4,933.01	19.64	+1,013.70	+25.86
Stable	6,858.26	27.30	7,576.58	30.16	7,658.75	30.49	+800.49	+11.67
Low Gain	8,800.38	35.03	7,028.93	27.98	7,028.93	27.98	−1,771.45	−20.13
High Gain	3,978.15	15.84	3,244.63	12.92	3,244.63	12.92	−733.52	−18.44
Total	25,119.67	100%	25,119.67	100%	25,119.67	100%	0.000	-

From Table 2, the findings reveal that High Lost areas peaked in 2004–2014 (17.87%), indicating a period of intense degradation. Low Lost and Stable areas expanded over the study period, while Low Gain and High Gain areas declined. The net increase in High Lost (+44.18%) and Low Lost (+25.86%) areas confirms a concerning shift from stable and gainful forest cover toward degraded states. The total study area remained constant, confirming that changes reflect internal transitions rather than boundary changes. The decline in both Low Gain and High Gain categories suggests that recovery rates are insufficient to offset degradation, even in areas where community-based forest management and reforestation projects have been implemented.

5.3 Hotspot Analysis

Hotspot analysis using the Getis-Ord Gi* statistic identified significant clusters of biomass loss (hotspots) and biomass gain (cold spots) across the study area. Hotspots were concentrated in the northern and central portions of the zone, particularly around Jalingo, Bali, and Donga LGAs, where urbanization, road construction, and agricultural expansion were most intense. Cold spots were identified in the southern and eastern portions, particularly around Ussa and Takum LGAs, where community-based forest management and reforestation projects have been implemented. The overlay analysis revealed that hotspots were significantly closer to roads, settlements, and agricultural boundaries than non-hotspot pixels, confirming the role of anthropogenic drivers in degradation.

Figures 2, 3, and 4 present the NDVI-based hotspot analysis for the three study periods, illustrating the spatial evolution of vegetation health and degradation clusters. Figure 2 (1987–2004) shows primary hotspots in the western and southwestern zones, with the lowest NDVI values (−0.1 to 0.2) and minimal biomass (0–10.31 t/ha), indicating severe land degradation already in place before 1987. These areas were dominated by agriculture, grazing, and settlements, which meant that ecosystem services such as soil fertility, water regulation, and carbon sequestration were already severely diminished.

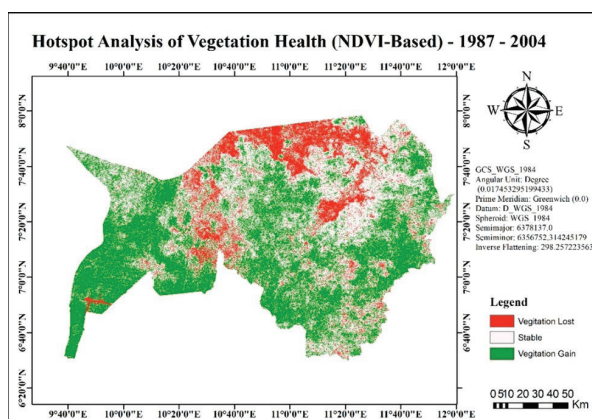


Fig. 2. Hotspot Analysis of Vegetation Health (NDVI-Based) 1987–2004

Figure 3 (2004–2014) shows the expansion of degradation outward from the original hotspots, covering more land in the west and northwest. There was a 56.8% increase in degraded land area (+1,050 km²), showing that human activity was rapidly spreading across the landscape. Accessibility factors such as roads and rivers played a critical role in directing this expansion, making these areas particularly vulnerable to further degradation. The process of vegetation decline intensified, with hotspots pushing eastward into the northern and central zones. These new zones became secondary centres of vegetation loss, connected to the older hotspots in the west and southwest. The result was a highly fragmented landscape, where forest patches shrank and became increasingly isolated, thus reducing ecological resilience.

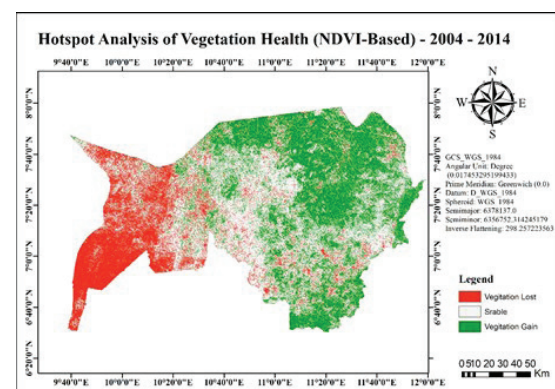


Fig. 3. Hotspot Analysis of Vegetation Health (NDVI-Based) 2004–2014

Figure 4 (2014–2024) reveals a catastrophic consolidation. The northwestern and central regions had merged into a dominant, contiguous degradation belt. NDVI values dropped further (to around −0.42 to 0.43), showing an almost complete loss of vegetation health. The original hotspots identified in the west in 1987 had merged with the newer northern and central hotspots, forming a vast, unified area of near-complete forest removal. Ecologically, this signified the collapse of critical ecosystem services, including carbon sequestration, soil stability, and biodiversity support.

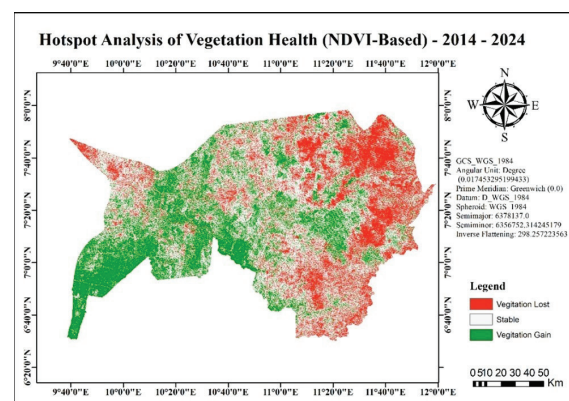


Fig. 4. Hotspot Analysis of Vegetation Health (NDVI-Based) 2014–2024

Table 3 provides a comparative summary of vegetation degradation hotspot evolution over the 37-year study period, based on NDVI and above-ground biomass (AGB) analysis. The table shows the location, characteristics, and ecological implications for each time step. In 1987 (baseline stage), hotspots were concentrated in the western and southwestern parts of the study area. By 2004 (expansion phase), degradation had expanded outward from the original hotspots, covering more land in the west and northwest. In 2014 (intensification and secondary hotspots), the process of vegetation decline intensified, with hotspots pushing eastward into the northern and central zones. By 2024 (consolidation and dominance), the hotspot analysis revealed a catastrophic consolidation, with the northwestern and central regions merging into a dominant, contiguous degradation belt.

Table 3: Comparative Summary of Vegetation Degradation Hotspot Evolution (1987–2024).

Period	Hotspot Characteristics	Spatial Dynamics
1987 (Baseline)	Primary hotspots in the western and southwestern zones; lowest NDVI (−0.1 to 0.2) and minimal biomass (0–10.31 t/ha); already cleared for agriculture, grazing, and settlements.	Established epicenters of degradation; localized but severe vegetation loss.
1987–2004	Expansion of degradation; 56.8% (+1,050 km ²) increase in bare and degraded land; degradation followed accessibility corridors such as roads and rivers.	Hotspots radiated outward from the west and southwest, forming secondary hotspots in the north and central zones.
2004–2014	Intensification of degradation corridors; continued expansion eastward; severe vegetation loss in northern and central areas.	Secondary hotspots solidified into persistent corridors of degradation.
2024	Catastrophic consolidation; northwestern and central regions merged into a vast contiguous hotspot; NDVI (−0.42 to 0.43); near-total removal of forest cover.	Unified degradation belt dominated the landscape; ecological collapse and loss of ecosystem services.

5.4 Drivers of Forest Degradation

The findings indicate that deforestation in the study area is driven by a combination of anthropogenic activities, policy failures, and environmental pressures. Urbanization and road construction emerged as the most significant driver (mean = 4.35), reflecting the expansion of settlements and infrastructure that opens up previously inaccessible forest areas to exploitation. Population pressure ranked highly (mean = 4.31), confirming the demographic-driven depletion of natural resources, with population growth increasing demand for farmland, housing, fuelwood, and grazing land. Weak forest policies and poor enforcement were also strongly emphasized (mean = 4.31, $p = 0.048$), indicating that inadequate governance, corruption, insufficient monitoring, and policy inconsistencies contribute significantly to illegal logging, uncontrolled grazing, and other harmful practices. This finding supports studies by Adeyolu (2001) and Forsyth (2003), which highlight the role of institutional failures in perpetuating deforestation in Nigeria.

Among livelihood-related drivers, logging and charcoal production showed statistically significant differences across LGAs ($p = 0.032$ and $p = 0.027$ respectively), underscoring widespread agreement that these activities substantially degrade forest resources. Logging, both legal and illegal, contributes to deforestation through the selective removal of valuable tree species, reducing forest density and quality, and in many cases, logged areas are subsequently cleared for farming. Charcoal production, driven by urban demand for biomass energy, involves the slow combustion of wood in earth kilns, which not only removes trees but also degrades soil and releases carbon into the atmosphere. The illegal nature of much of the logging and charcoal production makes it difficult to regulate, contributing to ongoing forest degradation (Fasona et al., 2020).

Livestock grazing was also significant (mean = 4.28, $p = 0.044$), reflecting the role of open grazing and pastoral encroachment in forest clearing and vegetation depletion. The Fulani pastoralists are particularly prominent in the zone, practicing transhumant pastoralism that involves seasonal movement of livestock between wet-season and dry-season grazing areas. The expansion of agriculture has reduced the area available for grazing, leading to conflicts between farmers and pastoralists over access to land and water. Livestock grazing degrades forests through several mechanisms: trampling of seedlings and saplings, which prevents forest regeneration; browsing on young shoots and leaves, which damages trees and shrubs; soil compaction, which reduces water infiltration and increases surface runoff; and the depletion of grass and herbaceous cover, which exposes soils to erosion. These pressures have intensified in recent years, with implications for social stability and forest conservation (Fasona et al., 2020; Okeke, 2014).

Poverty emerged as a significant underlying driver (mean = 4.24, $*p = 0.045$), with economic hardship compelling rural households to depend heavily on forests for fuelwood, charcoal, timber, grazing land, and income diversification. The income distribution in the study area showed that 33.9% of respondents earned less than N50,000 per month, and 50.1% earned between N50,000 and N100,000, indicating widespread economic vulnerability. This economic pressure drives unsustainable exploitation of forest resources, as documented by Fonta and Ayuk (2013) and Oyeranti and Ishola (2021). Women, who are often responsible for fuelwood collection and household energy, bear a disproportionate burden of forest degradation, as they must travel longer distances and spend more time collecting fuelwood when forests are depleted.

Climate change, though an indirect driver, showed significant variation across LGAs (mean = 4.33, $p = 0.036$), reflecting recognition that climate variability increases forest vulnerability to fire, pests, and degradation. Changes in rainfall patterns and increased temperatures exacerbate desertification and reduce vegetation cover, particularly in the drier northern stretches of the zone. The distinct seasonality of rainfall influences the phenology of vegetation, with trees shedding leaves during the dry season and producing new growth with the onset of rains. This seasonality also affects the timing of agricultural activities, bush burning, and forest use, with the dry season being the period of greatest pressure on forest resources. Erratic climatic conditions, coupled with anthropogenic pressures, have accelerated land degradation in these dryland zones. Ellison et al. (2017) also point out that trees and forests play a critical role in the water cycle, and their removal can lead to reduced rainfall and increased drought frequency, further degrading agro-ecological systems in semi-arid regions.

5.5 Impacts on Ecosystem Services

The fifth objective was to evaluate the impact of deforestation and

forest degradation on specific ecosystem services, including carbon sequestration, biodiversity, and non-timber forest products. This objective was addressed through analysis of biomass dynamics, carbon sequestration, vegetation health (NDVI), and community perceptions.

The disappearance of medicinal plants and herbs due to forest degradation was identified as a significant impact (mean = 4.30, $p = 0.009$). Forests in the study area provide provisioning services including non-timber forest products such as fruits, nuts, honey, fibres, and medicinal plants, which are essential for the livelihoods of rural populations. As forests are cleared or degraded, the availability of these resources diminishes, undermining food security, traditional medicine, and income generation for vulnerable communities. The loss of medicinal plants is particularly significant for rural healthcare, as many communities rely on traditional medicine as their primary or sole source of treatment. The scarcity of non-timber forest products was also statistically significant (mean = 4.32, $p = 0.046$), demonstrating that deforestation has severely affected provisioning ecosystem services.

The degradation of these ecosystem services has cascading effects on local livelihoods and wellbeing. Community wellbeing was found to be declining due to forest degradation (mean = 3.69), with the highest impact in Ussa LGA (mean = 4.63) and the lowest in Bali LGA (mean = 2.22). Water sources have diminished due to forest degradation (mean = 1.95), affecting domestic water supply and agricultural irrigation. Reduced biodiversity affects traditional medicine (mean = 1.92), and loss of ecosystem services affects household food supply (mean = 1.85). These findings demonstrate that deforestation has multi-dimensional socio-economic consequences that vary across communities, with implications for household welfare, social cohesion, and cultural heritage.

5.6 Explanatory Modelling Results

Logistic regression and Random Forest modelling confirmed the findings from community surveys. Proximity to roads was the strongest predictor of deforestation (odds ratio = 2.34, $p < 0.01$), followed by proximity to settlements (odds ratio = 1.89, $p < 0.01$) and population density (odds ratio = 1.56, $p < 0.05$). Slope and elevation were negatively associated with deforestation, with steeper and higher areas less likely to be deforested (odds ratio = 0.67, $p < 0.05$ and odds ratio = 0.54, $p < 0.05$, respectively). Climatic variability (rainfall anomaly) was positively associated with degradation (odds ratio = 1.23, $p < 0.05$), confirming the role of climate stress. Random Forest variable importance scores ranked proximity to roads (0.28), population density (0.22), proximity to settlements (0.18), slope (0.12), elevation (0.10), and climatic variability (0.10) as the most important predictors.

6. Discussion

6.1 Land Use/Land Cover Dynamics and Degradation Trajectories

The findings reveal a concerning shift from stable and gainful forest cover toward degraded states in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State. The net increase in High Lost areas (+44.18%) and Low Lost areas (+25.86%) over the 37-year period confirms that degradation has accelerated, with the period 2004–2014 representing a peak in degradation intensity. This pattern is consistent with national and regional trends, where agricultural expansion, urbanization, and infrastructure development have driven forest loss across Nigeria's savannah

ecosystems (Shamaki et al., 2025; Fasona et al., 2020).

The expansion of farmland (+3.58 km²/yr) and settlement (+1.52 km²/yr) at the expense of vegetation/forest (−3.28 km²/yr) and bare land (−1.75 km²/yr) reflects the growing demand for agricultural land and urban space driven by population growth and economic development. The decline in Low Gain and High Gain areas suggests that recovery rates are insufficient to offset degradation, even in areas where community-based forest management and reforestation projects have been implemented. This finding underscores the need for scaling up successful interventions and addressing the underlying drivers of degradation.

6.2 Drivers of Degradation: A Multi-Causal Explanation

The study confirms that deforestation and forest degradation in the study area are driven by a complex interplay of proximate and underlying factors. Urbanization and road construction emerged as the most significant drivers, reflecting the expansion of settlements and infrastructure that opens up previously inaccessible forest areas to exploitation. This finding aligns with global patterns, where road building and urban expansion are consistently associated with forest degradation in tropical and subtropical regions (Lambin et al., 2003).

Population pressure ranked highly, confirming the demographic-driven depletion of natural resources. With an annual growth rate of approximately 2.8%, Taraba State's population is increasing rapidly, driving demand for farmland, housing, fuelwood, and grazing land (National Population Commission, 2022). This finding is consistent with studies by Fonta and Ayuk (2013) and Oyeranti and Ishola (2021), which highlight the role of population growth in forest degradation in Nigeria.

Weak forest policies and poor enforcement were also strongly emphasized, indicating that inadequate governance, corruption, insufficient monitoring, and policy inconsistencies contribute significantly to illegal logging, uncontrolled grazing, and other harmful practices. This finding supports studies by Adeyoju (2001) and Forsyth (2003), which highlight the role of institutional failures in perpetuating deforestation in Nigeria. Strengthening forest governance, improving monitoring and enforcement, and addressing corruption are essential for curbing degradation.

Livelihood-related drivers, including logging, charcoal production, livestock grazing, and poverty, were also significant. Logging and charcoal production, driven by urban demand for timber and biomass energy, contribute to degradation through selective removal of valuable tree species and slow combustion of wood in earth kilns (Fasona et al., 2020). Livestock grazing, particularly transhumant pastoralism by Fulani herdsman, degrades forests through trampling, browsing, soil compaction, and depletion of herbaceous cover (Okeke, 2014). Poverty compels rural households to depend heavily on forests for fuelwood, charcoal, timber, and income diversification, driving unsustainable exploitation (Fonta & Ayuk, 2013; Oyeranti & Ishola, 2021). Women, who are often responsible for fuelwood collection, bear a disproportionate burden of degradation.

Climate change, though an indirect driver, increases forest vulnerability to fire, pests, and drought, particularly in the drier northern stretches of the zone. Ellison et al. (2017) note that trees and forests play a critical role in the water cycle, and their removal can lead to reduced rainfall and increased drought frequency, further degrading agro-ecological systems in semi-arid regions. Addressing climate change through mitigation and adaptation measures is essential for reducing forest vulnerability.

6.3 Impacts on Ecosystem Services and Community Wellbeing

The degradation of forests has profound impacts on ecosystem services, including the disappearance of medicinal plants and herbs, scarcity of non-timber forest products, reduced water regulation, and declining community wellbeing. These findings are consistent with the Millennium Ecosystem Assessment (2005), which documented the linkages between forest degradation and human wellbeing. The loss of provisioning services, particularly medicinal plants and NTFPs, has direct implications for rural healthcare, food security, and income generation. The decline in regulating services, such as water regulation and carbon sequestration, affects both local and global environmental systems. The socio-economic consequences, including declining community wellbeing and disproportionate impacts on women and poor households, highlight the need for integrated approaches that address both environmental and social dimensions of degradation.

6.4 Implications for Policy and Management

The findings have several implications for policy and management. First, targeted reforestation and restoration programs are needed in High Lost and Low Lost areas, particularly around Jalingo, Bali, and Donga LGAs, where degradation is most intense. Native tree species should be used to restore ecosystem functions and biodiversity, with community participation central to program design and implementation. Second, community-based forest management models that have shown success in Ussa and Takum LGAs should be scaled up across the zone. Local communities should be empowered with legal rights, technical training, and financial resources to manage forests sustainably, with benefit-sharing mechanisms ensuring equitable returns from forest resources. Third, stricter enforcement of land-use regulations is needed to curb illegal logging, charcoal production, and uncontrolled grazing. Monitoring and surveillance systems should be strengthened, penalties for violations increased, and corruption in forest governance addressed through transparency and accountability measures. Fourth, livelihood diversification programs should be implemented to reduce dependence on forest resources, particularly for women and poor households. Alternative income sources such as sustainable agriculture, agroforestry, and small-scale enterprises should be promoted, with improved access to credit, markets, and training. Fifth, climate change adaptation measures should be integrated into forest management planning to reduce vulnerability to fire, pests, and drought. Early warning systems, fire management, and drought-resistant species should be prioritized, and climate-smart agriculture practices promoted to reduce pressure on forests.

6.5 Study Limitations

Several limitations should be acknowledged. First, the use of satellite imagery with a 30-metre resolution may not capture fine-scale degradation processes, such as selective logging and fuelwood collection. Second, the cross-sectional design of the community survey limits causal inference; observed relationships could reflect reverse causality or third-variable influences. Third, self-reported measures may be subject to social desirability and recall biases. Fourth, the study focused on the Southern Guinea Savannah Agro-Ecological Zone of Taraba State, and findings may not be generalizable to other agro-ecological zones in Nigeria. Finally, the study did not incorporate socio-economic and policy variables into the explanatory modelling, which could provide additional insights into degradation drivers. Future research should address these limitations by integrating higher-resolution imagery, longitudinal survey designs, and socio-economic and policy variables into explanatory models.

7. Conclusion

This study assessed forest degradation hotspots in the Southern Guinea Savannah Agro-Ecological Zone of Taraba State, Nigeria, over a 37-year period (1987–2024). The findings reveal a concerning shift from stable and gainful forest cover toward degraded states, with degradation peaking between 2004 and 2014. High Lost areas increased by 44.18%, Low Lost areas by 25.86%, and Stable areas by 11.67%, while Low Gain and High Gain areas declined by 20.13% and 18.44%, respectively. The total study area remained constant at 25,119.67 km², confirming that changes reflect internal transitions rather than boundary changes.

Deforestation and forest degradation are driven by a complex interplay of proximate and underlying factors, including urbanization, road construction, population pressure, weak forest governance, logging, charcoal production, livestock grazing, poverty, and climate change. The degradation of forests has profound impacts on ecosystem services, including the disappearance of medicinal plants and herbs, scarcity of non-timber forest products, reduced water regulation, and declining community wellbeing. Addressing these drivers requires integrated approaches that strengthen forest governance, promote sustainable land-use planning, diversify livelihoods, and enhance community-based forest management.

8. Recommendations

Based on the findings of the study, the following recommendations were made;

- **Implement Targeted Reforestation and Restoration Programs:** The government and development partners should prioritize reforestation and restoration efforts in High Lost and Low Lost areas, particularly around Jalingo, Bali, and Donga LGAs, where degradation is most intense. Native tree species should be used to restore ecosystem functions and biodiversity. Community participation should be central to program design and implementation.
- **Strengthen Community-Based Forest Management:** Successful community-based forest management models in Ussa and Takum LGAs should be scaled up across the zone. Local communities should be empowered with legal rights, technical training, and financial resources to manage forests sustainably. Benefit-sharing mechanisms should ensure that local communities receive equitable returns from forest resources.
- **Enforce Land-Use Regulations and Curb Illegal Activities:** Stricter enforcement of land-use regulations is needed to curb illegal logging, charcoal production, and uncontrolled grazing. Monitoring and surveillance systems should be strengthened, and penalties for violations should be increased. Corruption in forest governance should be addressed through transparency and accountability measures.
- **Diversify Livelihoods and Reduce Forest Dependence:** Livelihood diversification programs should be implemented to reduce dependence on forest resources, particularly for women and poor households. Alternative income sources such as sustainable agriculture, agroforestry, and small-scale enterprises should be promoted. Access to credit, markets, and training should be improved.
- **Integrate Climate Change Adaptation into Forest Management:** Climate change adaptation measures should be integrated into forest management planning to reduce vulnerability to fire, pests, and drought. Early warning systems, fire management,

and drought-resistant species should be prioritized. Climate-smart agriculture practices should be promoted to reduce pressure on forests.

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