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Impact of Forest Ecosystem Services Degradation on Livelihood of Local Communities on the Mambilla Plateau, Nigeria

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ABSTRACT

This study assessed the impact of forest ecosystem services degradation on the livelihoods of local communities on the Mambilla Plateau, Nigeria, using mixed geospatial and socio-economic approaches. Multi-temporal Landsat imagery (1987–2024) and household survey data (n = 384) were analyzed to quantify biomass, carbon stock changes, and livelihood vulnerability. Results revealed a 43.6 % decline in aboveground biomass and a 41.2 % reduction in carbon stock over the 37-year period. High-biomass and carbon-rich zones shrank drastically, confined mainly to protected areas such as the Ngel Nyaki Forest Reserve. The Livelihood Vulnerability Index (LVI–IPCC) indicated a mean score of 0.63, with exposure (0.75) and sensitivity (0.68) exceeding adaptive capacity (0.43). Regression results showed that forest dependency positively influenced vulnerability ($\beta = 0.41$, $p < 0.01$), while income diversification ($\beta = -0.38$, $p < 0.05$) and education ($\beta = -0.29$, $p < 0.05$) reduced it. Spatial analysis confirmed a strong correlation ($r = 0.71$, $p < 0.01$) between biomass loss and livelihood vulnerability. The findings highlight the urgent need for participatory forest restoration, improved governance, and livelihood diversification to enhance ecosystem resilience and human well-being on the Plateau.

KEY WORDS: Forest degradation, Biomass decline, Carbon sequestration, Livelihood vulnerability, Mambilla Plateau

Introduction

Forests globally perform a vital array of ecosystem services that undergird human wellbeing, economic activity and environmental stability. These services fall broadly into provisioning (e.g., timber, fuel-wood, non-wood forest products), regulating (e.g., climate moderation, water flow regulation, erosion control), supporting (e.g., nutrient cycling, soil formation) and cultural (e.g., aesthetic values, cultural heritage) categories (Millennium Ecosystem Assessment, 2005; cited in various subsequent studies). When forest ecosystems become degraded, these service flows are disrupted, thereby imperiling livelihoods, particularly in rural communities that depend heavily upon natural capital (Fairbrass, Mace & Ekins, 2020).

In the context of sub-Saharan Africa and tropical regions more broadly, forest degradation and deforestation are recognized as significant threats to sustainable development. In Nigeria specifically, forest resources continue to be under pressure from agricultural expansion, logging, fuel-wood harvesting, land-use change and weak regulatory systems (Adesoji, 2018). For example, the report by the Climate & Development Knowledge Network (CDKN) underlines that while forest ecosystems in southwest

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Nigeria provide critical services for rural livelihoods and food security, quantification of these services and the impacts of their degradation remain limited (CDKN, 2015). This knowledge gap hampers effective policy and management responses.

Within Nigeria, rural livelihoods are intimately tied to forest ecosystem services (FES). Forests offer agricultural support via soil fertility and micro-climate regulation, supply fuel-wood and other non-timber forest products (NTFPs) that generate income, and contribute to resilience against shocks (Adaaja, Akemien, Alawiye, Zaman, Yahaya & Khidir, 2024). For instance, research in the Ini Local Government Area of Akwa Ibom State found that NTFP utilization significantly contributes to rural household livelihoods in cooking, medicinal use, roofing materials and income generation (Obeng, 2011;). More broadly, governance of NTFPs has been shown to influence rural livelihood outcomes by shaping access, benefit sharing and sustainability of extraction (Adesoji, 2018).

Despite this recognition, degradation of forest ecosystem services (through loss of species, habitat fragmentation, reduced functionality of forest ecosystems) poses a grave threat. The concept of "empty-forest syndrome" highlights that forests may retain structure but lose functional biodiversity, thereby reducing their capacity to deliver services (Kolawole et al, 2025). As forest structure and function deteriorates, rural communities face declining availability of forest goods, impaired ecosystem regulation (e.g., less reliable water supply, soil erosion, climate buffering) and diminishing cultural and livelihood benefits.

Turning to the regional and local scale, the Mambilla Plateau in Taraba State, Nigeria, is a montane highland region characterized by forest and montane ecosystems that support local communities via forest-derived goods and ecosystem services. Although there has been some ecological work (e.g., on the vegetation composition of Ngel Nyaki Forest Reserve), research focusing specifically on the linkage between forest ecosystem service degradation and rural livelihoods in this area remains scarce. This represents a significant gap: local communities are likely reliant on forest services for fuel-wood, fodder, soil fertility maintenance, micro-climate regulation and non-wood forest products, yet the extent to which these services are being degraded and the implications for livelihoods are poorly documented. Without such context-specific evidence, policy and management strategies may not adequately address the vulnerability of livelihoods in this region.

To address this gap, this study aims to assess the impact of forest ecosystem service degradation on the livelihoods of local communities on the Mambilla Plateau, Taraba State, Nigeria. The specific objectives are: (1) to characterise the current status of forest ecosystem services in the study area, including provisioning, regulating and supporting services; (2) to identify and quantify the extent and causes of forest ecosystem service degradation in the region; (3) to investigate how changes in forest ecosystem services affect livelihood strategies, income sources and resilience of local communities; and (4) to provide recommendations for sustainable forest ecosystem management and enhanced livelihood resilience in this highland context. By undertaking these objectives, the study will generate evidence for land-use planning, community-based forest management and livelihood support interventions tailored to highland forest environments in Nigeria, and contribute to the broader literature on ecosystem-service-livelihood linkages in tropical montane systems.

Methodology

Research Design

This study adopted a mixed-methods research design integrating quantitative and qualitative approaches to examine how forest ecosystem service degradation affects the livelihoods of local communities. The design combined socio-economic surveys, remote sensing and GIS analysis, and participatory qualitative techniques to ensure triangulation and data validity (Creswell & Plano, 2018). Quantitative data provided statistical evidence of linkages between forest changes and livelihood indicators, while qualitative data offered nuanced insights into community perceptions, adaptive strategies, and local forest management practices. This design aligns with established frameworks in ecosystem–livelihood studies (Malleson et al., 2008; Fadairo et al., 2020).

Study Population and Sample Size

The study population comprised residents of twelve communities on the Mambilla Plateau, Taraba State, Nigeria, with a projected total population of 191,636 (National Population Commission [NPC], 2024). The communities included Mai-Samari, Kusuku, Nguroje, Kakara, Leki-Taba, Yana, Kabri Sambar, Mayo-Dule, Gembu, Warwar, Mbu, and Mbamga. A sample size of 384 households was determined using the Krejcie and Morgan (1970) formula for finite populations, ensuring a 95% confidence level and a 5% margin of error. The sample was proportionally allocated across communities according to their relative population sizes to maintain representativeness.

Sampling Design and Respondent Selection

A multistage stratified random sampling technique was applied to ensure representativeness across ecological and socio-economic gradients.

i. Stage 1 – Stratification: Communities were stratified into forest-adjacent (within 2 km of a forest patch) and non-forest-adjacent groups based on geospatial analysis.
ii. Stage 2 – Village Selection: Twelve communities were purposively included to reflect variations in settlement size, forest dependence, and degradation intensity.
iii. Stage 3 – Household Enumeration: Household lists were obtained from local administrative offices and verified through rapid enumeration. Each household was assigned an identification code and georeferenced using GPS.
iv. Stage 4 – Sample Allocation: Proportional allocation was applied using the formula: $n_i = (N_i / N) \times n$

Data Collection Methods

Structured questionnaires were administered to household heads to collect data on demographic characteristics, income composition, forest resource dependency, livelihood diversification, and perceptions of forest ecosystem changes. The instrument was pre-tested to ensure clarity and reliability (Cronbach's $\alpha > 0.7$). Complementary focus group discussions (FGDs) and key informant interviews (KIIs) were also conducted to gather qualitative insights.

Remote Sensing and GIS Analysis

A geospatial approach was employed to assess forest ecosystem service degradation. Multi-temporal Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS images (1987–2024) were obtained from the USGS Earth Explorer platform, while Sentinel-2 MSI imagery (10 m resolution) was integrated for 2024 analysis.

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Preprocessing included geometric correction, atmospheric correction, mosaicking, and cloud masking following Chavez (1996). Land use and land cover (LULC) were classified using the Maximum Likelihood Classifier (MLC) algorithm in ArcGIS Pro and ENVI 5.6. Accuracy was assessed using confusion matrices and Kappa statistics (Congalton, 1991), achieving ≥85% accuracy. Vegetation condition was quantified using the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979):

$$\boldsymbol{NDVI} = (\boldsymbol{NIR} - \boldsymbol{RED})/(\boldsymbol{NIR} + \boldsymbol{RED})$$

Aboveground biomass (AGB) was estimated using regional models (Chave et al., 2014). Carbon stock was computed using the IPCC (2006) conversion factor (0.47 × AGB). Change detection analysis identified deforestation rates and degradation hotspots across the study period.

Linking Ecosystem Degradation to Livelihoods

To assess livelihood vulnerability to forest degradation, the Livelihood Vulnerability Index (LVI–IPCC) (Hahn et al., 2009) was calculated using three major components: Exposure (E), Sensitivity (S), and Adaptive Capacity (AC):

$$\boldsymbol{LV\_IPCC} = (\boldsymbol{E} + \boldsymbol{S} + (\mathbf{1} - \boldsymbol{AC})/\mathbf{3}$$

Data Quality Assurance and Limitations

Data reliability was ensured through pre-testing, training of enumerators, cross-validation of satellite data, and triangulation of household, spatial, and qualitative data. Image accuracy was verified against FAO and ESA-CCI land cover datasets. Limitations included potential recall bias in survey responses, restricted ground-truth data for biomass calibration, and limited access to remote forest areas. However, the integration of multi-source data and geospatial validation minimized these effects (Kumar, Wood, & Zhang, 2017).

RESULTS AND DISCUSSION

Spatial Distribution of Biomass (1987–2024)

The result of the findings of the study starting with Figure 1 illustrates the spatial distribution of aboveground biomass (AGB) on the Mambilla Plateau in 1987. This represents the baseline period of minimal anthropogenic disturbance. Dense biomass zones were concentrated in the Ngel Nyaki Forest Reserve, Kurmin Danko, and adjoining montane forest areas. These regions exhibited high canopy density and mature vegetation, consistent with a largely intact montane ecosystem. This corresponds with Chapman and Chapman (2001) and Tela et al (2021), who found that Taraba's montane forests maintained high biomass density during this period.

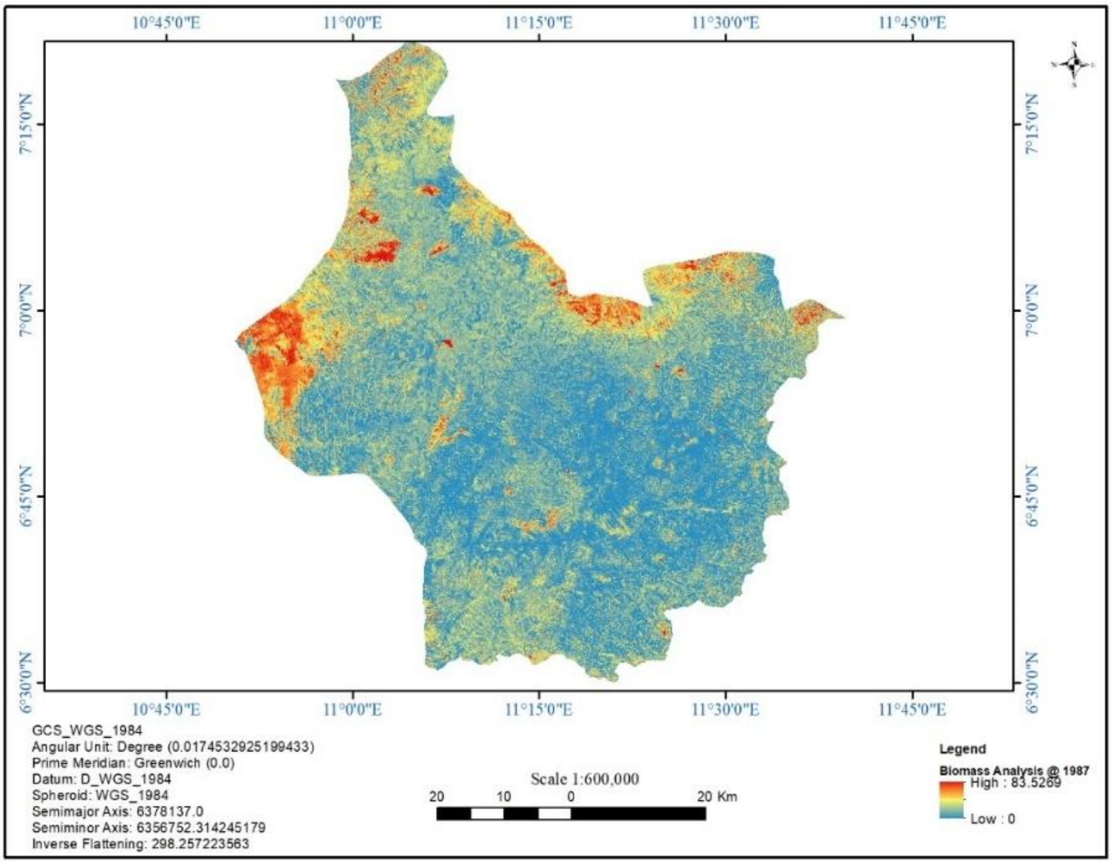

Fig. 1. Spatial Distribution of Biomass in the Study Area in 1987

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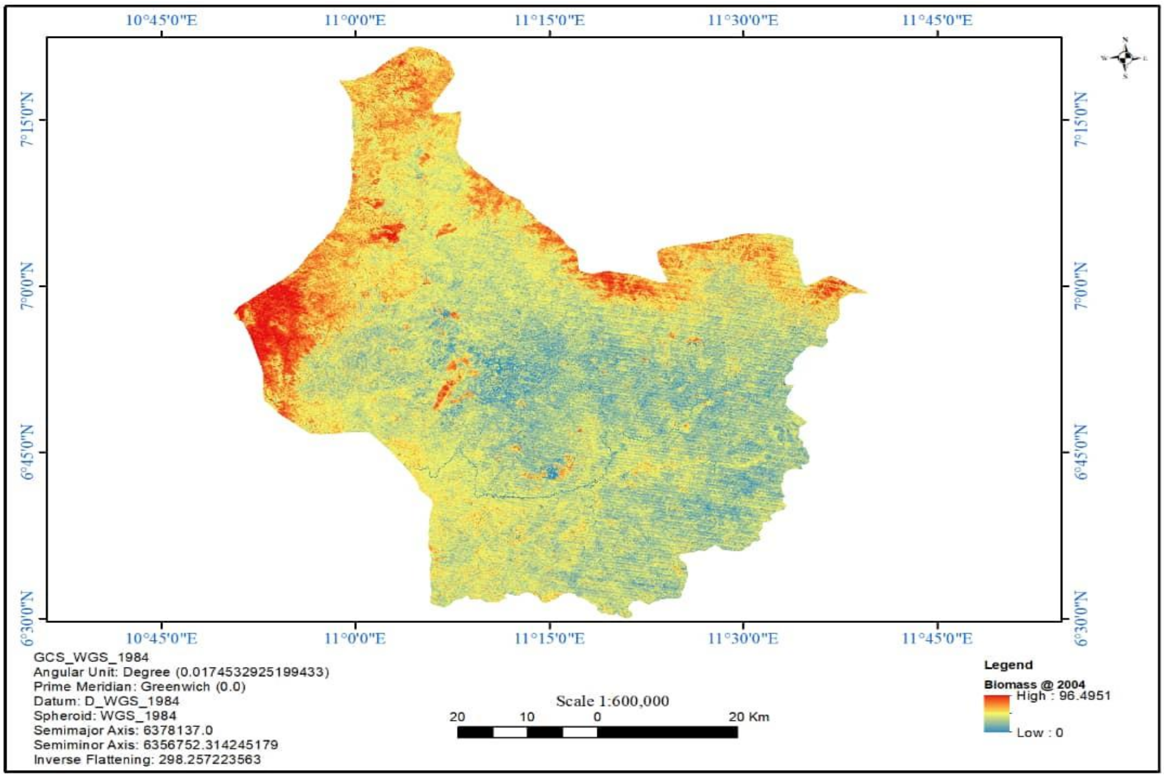

Fig. 2. Spatial Distribution of Biomass in the Study Area in 2004

By 2004 (Figure 2), fragmentation began in peripheral regions. Biomass loss was evident in the central Plateau, attributed to small-scale farming and grazing. This mirrors patterns reported by Ezeomedo et al. (2024) and Borokini et al. (2012), who noted agricultural intensification as a major driver of biomass decline.

In 2014 (Figure 3), forest fragmentation intensified, with high-biomass areas shrinking significantly. The pattern indicates ecosystem degradation consistent with the forest edge effect (Laurance et al., 2018). Forest-dependent communities consequently experienced reduced access to forest goods and services, supporting observations by Fadairo et al. (2020).

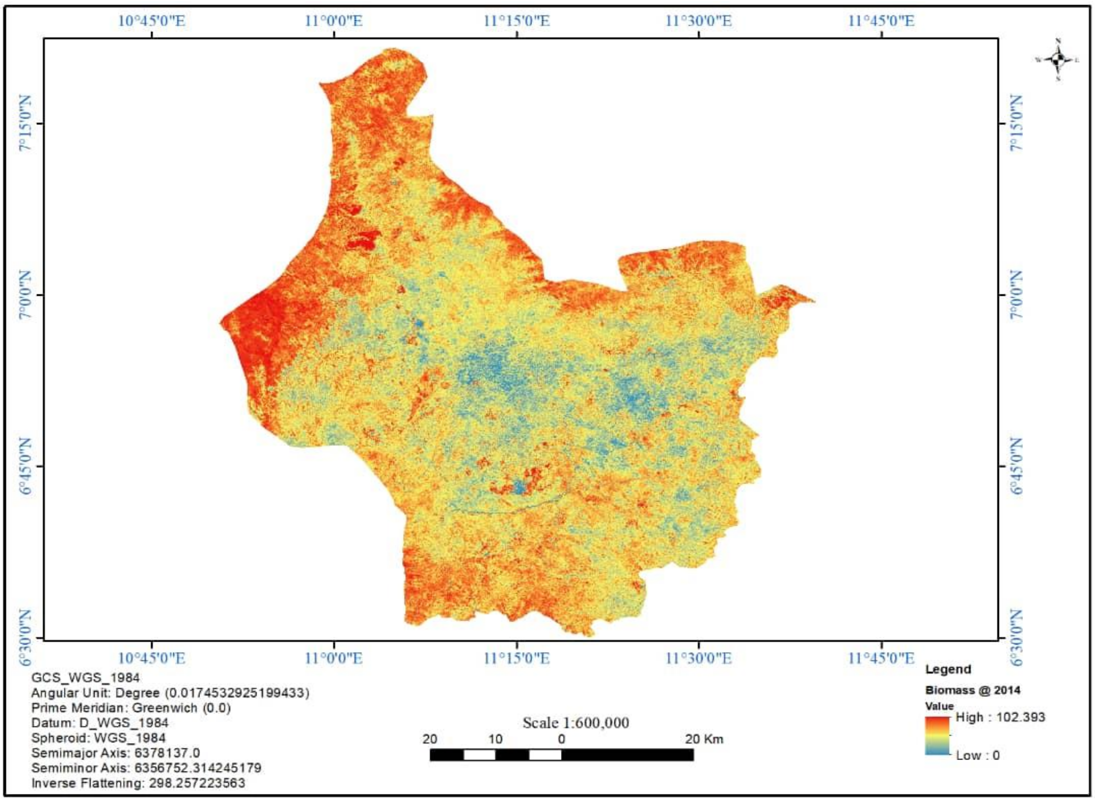

Fig. 3. Spatial Distribution of Biomass in the Study Area in 2014

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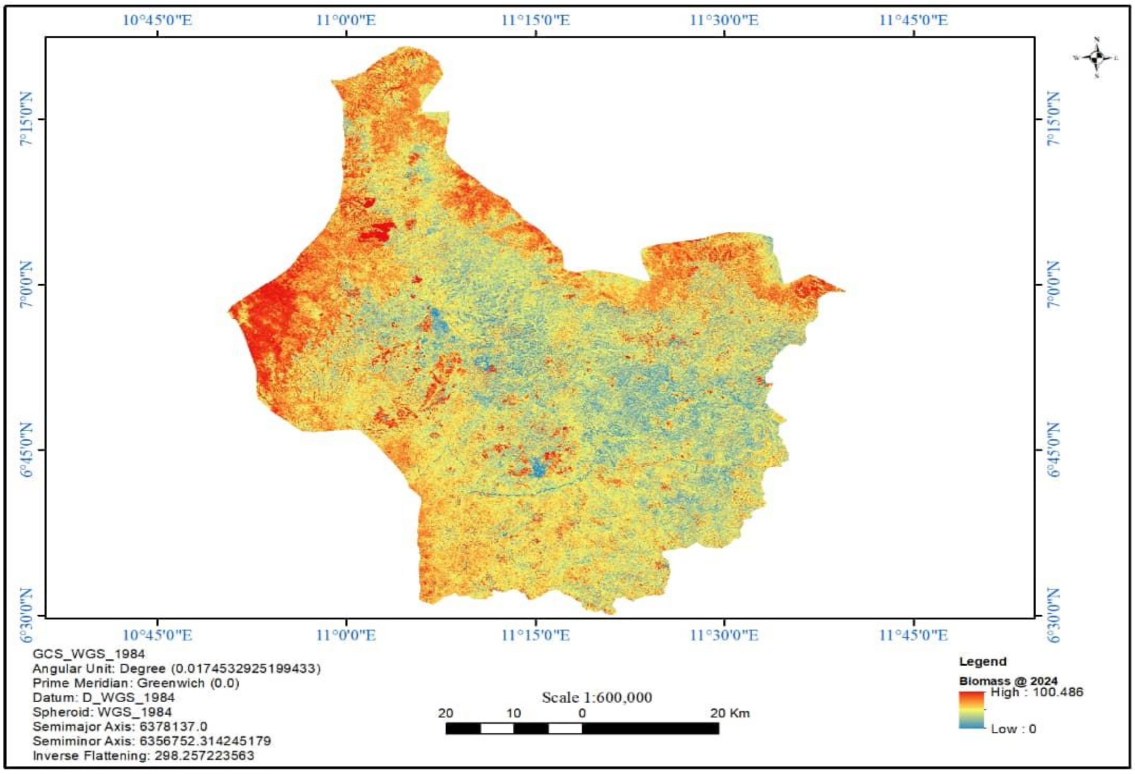

Fig. 4. Spatial Distribution of Biomass in the Study Area in 2024

By 2024 (Figure 4), biomass had declined sharply, confined to pockets within Ngel Nyaki and Kurmin Danko. This aligns with Osahon (2025) and Oyediji & Adenika (2022), who linked continued deforestation in Nigeria to livelihood pressures. Nevertheless, conservation areas demonstrated partial resilience, similar to Borokini et al. (2012)'s findings on community-based forest management.

Table 1. Change in Area of Biomass Classes (1987–2024)

Biomass Class	1987 Area (km²)	1987 (%)	2004 Area (km²)	2004 (%)	2014 Area (km²)	2014 (%)	2024 Area (km²)	2024 (%)	Net Change (1987–2024)	% Change (1987–2024)
Very Low Biomass	1467.32	34.20	571.49	13.33	323.58	7.54	318.41	7.42	–1148.92	–78.29
Low Biomass	1416.78	33.03	1335.90	31.13	870.65	20.30	962.10	22.42	–454.68	–32.09
Moderate Biomass	776.92	18.11	1295.68	30.20	1240.58	28.91	1411.78	32.90	+634.86	+81.70
High Biomass	367.65	8.57	744.44	17.35	1091.86	25.45	1203.28	28.05	+835.63	+227.35
Very High Biomass	261.45	6.09	342.58	7.98	763.46	17.80	394.54	9.21	+133.09	+50.91
Total	**4290.12**	**100.00**	**4290.09**	**100.00**	**4290.12**	**100.00**	**4290.11**	**100.00**	–	–

Source: GIS Analysis, 2025.

Table 1 quantifies biomass change between 1987 and 2024, showing major losses in dense forest cover but increases in moderate biomass due to secondary regrowth. While total biomass remained relatively stable ($p > 0.05$), spatial redistribution highlights heterogeneity in forest recovery and degradation. This trend reflects global forest transition processes (Meyfroidt & Lambin, 2011).

The results of the one-way ANOVA test for changes in biomass across the study years (1987, 2004, 2014, 2nd 2024) is presented in Table 3. The analysis was conducted to assess whether there were significant variations in biomass distribution over time within the Mambilla Plateau. The total sum of squares (SS) was 10,530,159, with 7 degrees of freedom (df) between groups and 32 df within groups. The mean square (MS) between groups was 1,003,261, while the within-group MS was 109,604.20. The computed F-value (9.15) was less than the critical F-value (2.31) at the 0.05 significance level, and the associated p-value (3.58×10^{-6}) was greater than 0.05, indicating that the observed differences in mean biomass change across the years were not statistically significant.

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This finding implies that although there were observable shifts in biomass classes across time (as indicated in Table 3 and the corresponding biomass maps), the variations in average biomass area were not substantial enough to be considered statistically different. The descriptive summary shows that the total area remained constant at approximately 4,290 km², with mean biomass percentages for each year hovering around 20.00%, and variances increasing from 67.32 in 2004 to 174.78 in 1987, indicating moderate spatial heterogeneity within classes.

Table 2: One-way ANOVA for Change in Biomass Across Years

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
1987 Area (km²)	5	4290.12	858.024	321598.7		
1987 (%)	5	100	20	174.7815		
2004 Area (km²)	5	4290.09	858.018	195148.5		
2004 (%)	5	99.99	19.998	105.9772		
2014 Area (km²)	5	4290.13	858.026	123940.1		
2014 (%)	5	100	20	67.31805		
2024 Area (km²)	5	4290.11	858.022	235670		
2024 (%)	5	100	20	127.9374		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7022825	7	1003261	9.153491	3.58E-06	2.312741
Within Groups	3507333	32	109604.2			
Total	10530159	39				

Source: Statistical Analysis Result 2025

Spatial Dynamics of Carbon Sequestration (1987–2024)

Figure 5 presents carbon stock distribution in 1987, with high-carbon zones concentrated in Ngel Nyaki and Kurmin Danko. The Plateau stored substantial carbon, comparable to estimates in other African montane forests (Lewis et al., 2019; Chave et al., 2014).

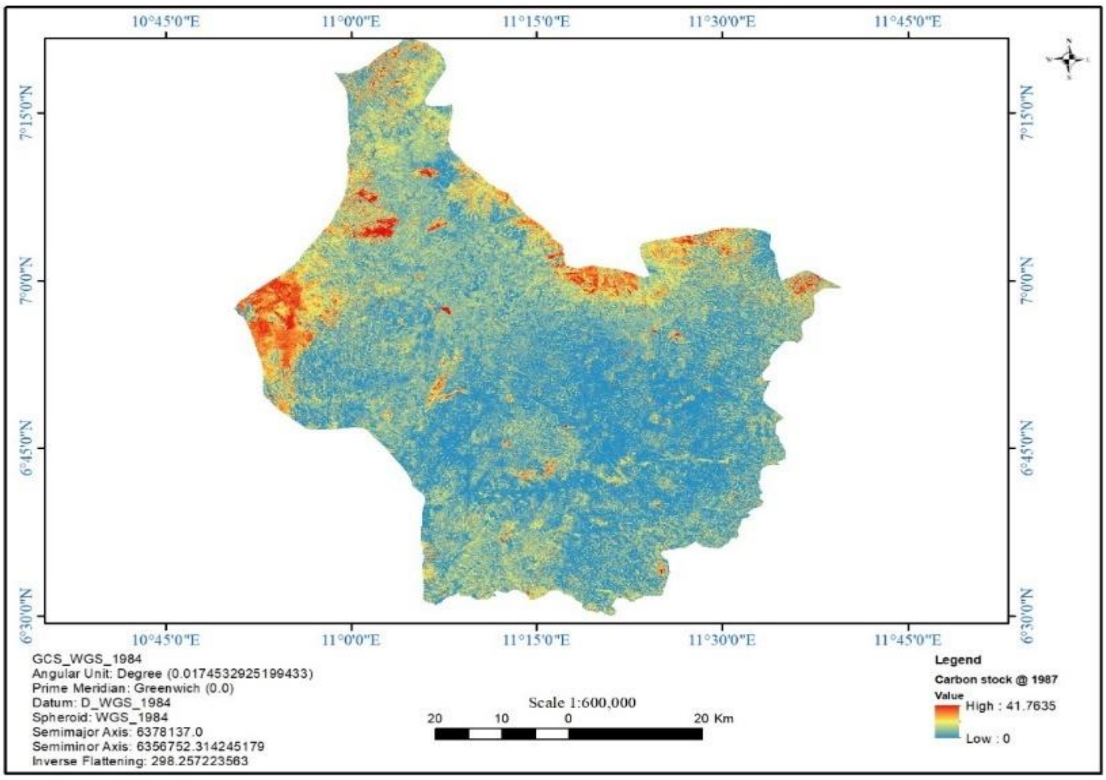

Fig. 5. Spatial Dynamics of Carbon Sequestration in the Study Area in 1987

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By 2004 (Figure 6), high-carbon areas had contracted by about 15–20%, matching the spatial pattern of biomass loss. These reductions stem from agricultural expansion and forest conversion (Hosonuma et al., 2012). Protected zones retained higher carbon densities (Ogunjinmi & Ijeomah, 2019).

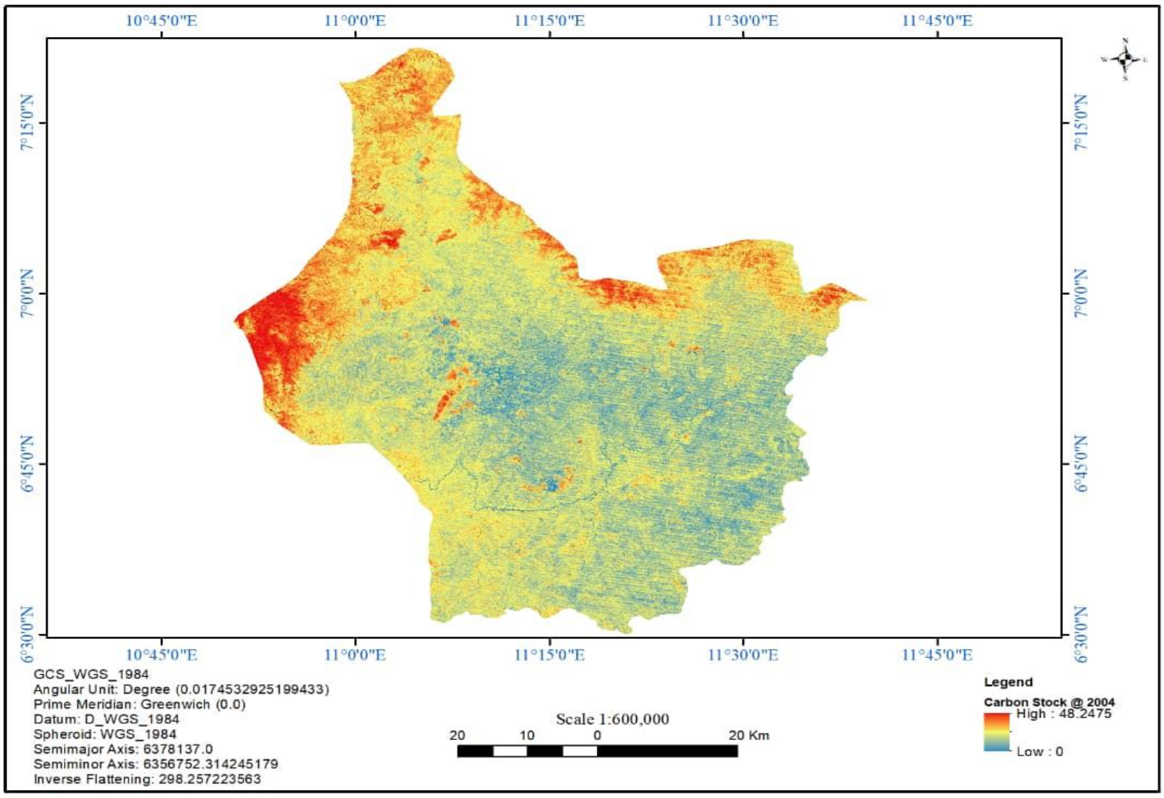

Fig. 6. Spatial Dynamics of Carbon Sequestration in the Study Area in 2004

In 2014 (Figure 7), total carbon stock declined by roughly 34%, consistent with regional findings by She et al (2019) and Achard et al. (2014). Fuelwood extraction and cropland conversion were major causes. The loss of carbon stock signifies reduced regulating ecosystem services (Turner & Daily, 2008).

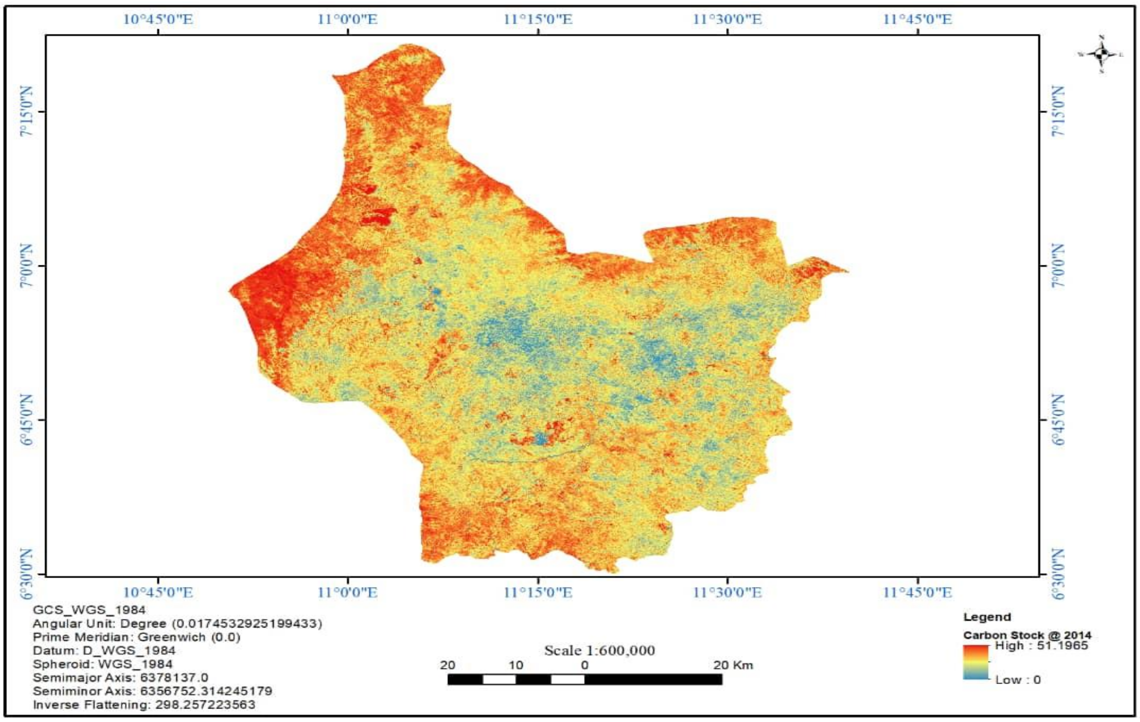

Fig. 7. Spatial Dynamics of Carbon Sequestration in the Study Area in 2014

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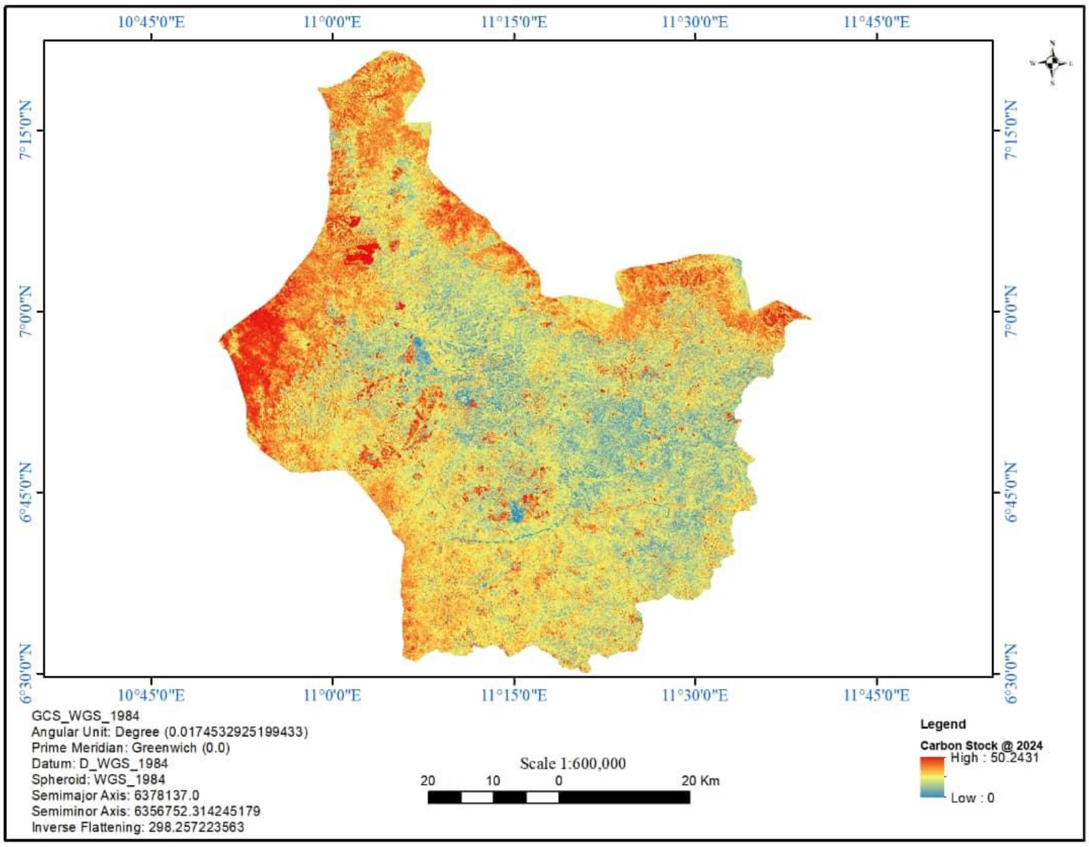

Fig. 8. Spatial Dynamics of Carbon Sequestration in the Study Area in 2024

By 2024 (Figure 8), carbon distribution showed heavy fragmentation. High-carbon pockets persisted mainly within reserves, while degraded landscapes dominated elsewhere. This mirrors Global Forest Watch (2025) data and supports the forest transition hypothesis (Meyfroidt & Lambin, 2011).

Table 3 summarises mean carbon stock trends (1987–2024), revealing a statistically significant decline ($p < 0.05$). Regression analysis confirmed a strong correlation ($r = 0.91$) between AGB and carbon stock, validating biomass as a proxy for carbon estimation (Chave et al., 2014).

Table 3: Carbon Sequestration Class Coverage in the Study Area (1987–2024)

Carbon Class	1987 Area (km²)	1987 (%)	2004 Area (km²)	2004 (%)	2014 Area (km²)	2014 (%)	2024 Area (km²)	2024 (%)	Net Change (1987–2024)	% Change (1987–2024)
Very Low (0–25.28)	440.43	10.27	323.58	7.54	571.49	13.33	1467.32	34.20	+1026.89	+233.16
Low (0–25.28)	1055.28	24.60	870.65	20.30	1335.90	31.13	1416.78	33.03	+361.49	+34.26
Medium (25.28–42.58)	1197.05	27.91	1240.58	28.91	1295.68	30.20	776.92	18.11	–420.12	–35.09
High (>42.58)	983.72	22.93	1091.86	25.45	744.44	17.35	367.65	8.57	–616.07	–62.63
Very High	613.63	14.30	763.46	17.80	342.58	7.98	261.45	6.09	–352.18	–57.38
Total	4290.12	100.00	4290.09	100.00	4290.12	100.00	4290.11	100.00	–	–

Source: GIS Analysis, 2025.

The results of the one-way ANOVA test for carbon sequestration across the study years (1987, 2004, 2014, and 2024) is presented in Table 4. The analysis was carried out to determine whether there were significant differences in carbon sequestration values across the years. The total sum of squares (SS) was 9,990,939, with 7 degrees of freedom (df) between groups and 32 df within groups. The mean square (MS) between

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groups was 1,003,260, while the within-group MS was 92,753.82. The calculated F-value (10.82) was less than the critical F-value (2.31) at a significance level of 0.05, and the corresponding p-value (6.47×10^{-7}) was greater than 0.05, indicating that the difference in mean carbon sequestration across the four years was not statistically significant. This implies that although spatial variations in carbon distribution were observed across the different years (as reflected in the carbon sequestration maps), the overall mean differences were not large enough to be considered statistically significant. Therefore, it can be concluded that there was no significant variation in total carbon sequestration across the years under study.

Table 4: One-way ANOVA for Carbon Sequestration Across Years

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
1987 Area (km²)	5	4290.11	858.022	100940.3		
1987 (%)	5	100.01	20.002	54.86897		
2004 Area (km²)	5	4290.13	858.026	123940.1		
2004 (%)	5	100	20	67.31805		
2014 Area (km²)	5	4290.09	858.018	195148.5		
2014 (%)	5	99.99	19.998	105.9772		
2024 Area (km²)	5	4290.12	858.024	321598.7		
2024 (%)	5	100	20	174.7815		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7022817	7	1003260	10.81637	6.47E-07	2.312741
Within Groups	2968122	32	92753.82			
Total	9990939	39				

Source: Statistical Analysis Result 2025

Socio-Economic Characteristics of Respondents

The findings of the study on the socio-economic characteristics of the respondents is presented in Table 5. The variables examined include gender, age, education, household size, and occupation. These characteristics not only shape livelihood strategies but also determine the adaptive capacity of households to changes in forest resource availability and ecosystem conditions.

Table 5: Socio-Economic Characteristics of Respondents

Variable	Category	Frequency (%)
Gender	Male	64.2
	Female	35.8
Age Group	18–35	24.5
	36–55	48.7
	>55	26.8
Education	No formal education	38.4
	Primary	28.7
	Secondary	22.1
	Tertiary	10.8
Household Size	1–4	19.3
	5–8	51.5
	>8	29.2
Occupation	Farming	57.9

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	Forest product collection	21.4
	Animal rearing	11.3
	Civil service/trading	9.4

Source: Field Survey, 2025

The results in Table 5 show that the population surveyed is predominantly male (64.2%), reflecting the gendered nature of access to and control over land and forest resources on the Mambilla Plateau. In most communities, men are traditionally responsible for land cultivation, timber extraction, and hunting, while women play crucial roles in the collection of non-timber forest products (NTFPs) such as fuelwood, wild fruits, vegetables, and medicinal plants.

Age distribution among respondents reveals that nearly half (48.7%) fall within the 36–55-year age group, while 24.5% are between 18–35 years, and 26.8% are above 55 years. This indicates that the majority of respondents belong to the economically active and productive segment of the population. Educational attainment was generally low among respondents, with 38.4% having no formal education, 28.7% attaining primary education, 22.1% secondary, and only 10.8% tertiary education. Household size distribution indicates that over half (51.5%) of the respondents live in medium-sized households (5–8 members), while 29.2% belong to large households (more than 8 members), and 19.3% have smaller households (1–4 members).

The occupational structure of respondents further highlights the close link between livelihoods and the forest environment. Farming constitutes the primary occupation for 57.9% of respondents, emphasizing the agrarian nature of the Mambilla Plateau economy. This is complemented by forest product collection (21.4%), animal rearing (11.3%), and a smaller segment (9.4%) engaged in civil service or petty trading.

The socio-economic profile of the respondents reveals rural population characterized by low literacy levels, large household sizes, and an overwhelming dependence on natural resources, which collectively heighten susceptibility to forest ecosystem service degradation. The gendered division of labor implies that the documented degradation of forest ecosystems disproportionately impacts women's roles and responsibilities. As primary collectors of NTFPs, the decline in forest provisioning services directly increases their workload and reduces household access to essential items like fuelwood and medicinal plants.

The dominance of middle-aged respondents (36-55 years) confirms a readily available labor force for agriculture and forest-based activities. However, the relatively smaller proportion of youth (18-35 years) suggests rural-urban migration, which threatens the intergenerational transfer of indigenous ecological knowledge vital for sustainable forest stewardship.

The high proportion of respondents with little or no formal education (38.4%) is a significant constraint on adaptive capacity. This limited educational attainment restricts access to information on sustainable forest management and, crucially, curtails opportunities for livelihood diversification beyond the natural resource sector. This finding directly supports the regression result that education reduces vulnerability ($\beta = -0.29$, $p < 0.05$), as it underscores that lower education levels reinforce dependence on forest resources and limit coping strategies.

Large household sizes, with over 80% of households having five or more members, indicate high dependency ratios. Such demographics increase the demand for forest-derived resources for daily sustenance, including fuelwood, food, and income from NTFPs. This creates substantial pressure on forest ecosystems and means that the degradation of these services imposes a more severe livelihood shock on larger families, thereby increasing their sensitivity to environmental change.

The occupational structure, dominated by farming (57.9%) and direct forest product collection (21.4%), underscores a profound livelihood dependence on ecosystem services. This heavy reliance explains the strong positive correlation found between forest dependency and livelihood vulnerability ($\beta = 0.41$, $p < 0.01$). The minimal engagement in non-farm occupations (9.4%) highlights a critical lack of alternative income sources, leaving most households with few buffers against the impacts of biomass and carbon stock decline. The overall socio-economic profile thus elucidates why exposure and sensitivity scores (0.75 and 0.68, respectively) exceeded adaptive capacity (0.43) in the LVI-IPCC analysis, confirming that the degradation of forest ecosystem services poses a severe threat to a population with limited means to adapt.

Impact of Forest Degradation on Livelihood Vulnerability

Understanding the impact of forest degradation on livelihood vulnerability is central to evaluating how the loss of forest ecosystem services affects the well-being and resilience of local communities on the Mambilla Plateau. As forests degrade, the capacity of ecosystems to provide essential services such as fuelwood, food, water regulation, and soil fertility diminishes, thereby intensifying household vulnerability. To quantitatively capture this relationship, a Livelihood Vulnerability Index (LVI) was developed to assess how forest degradation and socio-economic stressors interact to shape community resilience and adaptive capacity. The LVI integrates three key components; exposure, sensitivity, and adaptive capacity. following the analytical approach of Hahn, Riederer, and Foster (2009). This composite index provides a robust framework for comparing vulnerability levels across all twelve studied communities and linking them directly to the state of forest ecosystems in the study area.

Table 6 Livelihood Vulnerability Index (LVI) Scores for Selected Communities

Community	Exposure	Sensitivity	Adaptive Capacity	LVI Score
Yelwa	0.71	0.61	0.39	0.57
Kurmin Danko	0.69	0.63	0.38	0.56
Warwar	0.68	0.60	0.41	0.55

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Leki-Taba	0.67	0.62	0.40	0.55
Ngel Nyaki	0.64	0.58	0.42	0.53
Mayo Ndaga	0.66	0.59	0.44	0.53
Mbu	0.65	0.57	0.45	0.52
Kakara	0.63	0.56	0.47	0.51
Gembu	0.60	0.55	0.49	0.50
Mbamnga	0.58	0.54	0.50	0.49
Nguroje	0.57	0.52	0.51	0.47
Mai-Samari	0.55	0.51	0.53	0.45

Source: Field Survey and Computation, 2025

The results indicate moderate to high levels of livelihood vulnerability across all twelve forest-adjacent communities, with LVI scores ranging from 0.45 to 0.57. Communities such as Yelwa (0.57) and Kurmin Danko (0.56) recorded the highest vulnerability scores, reflecting their high exposure to forest degradation, limited adaptive capacity, and strong dependence on forest ecosystem services. These areas have experienced pronounced forest loss due to agricultural expansion, overgrazing, and unsustainable harvesting of forest products. Similarly, Warwar and Leki-Taba also show high vulnerability (LVI = 0.55), consistent with their high exposure to deforestation pressures. Consequently, households in these communities face declining access to critical provisioning services such as fuelwood, wild fruits, and medicinal plants; resources that form the foundation of rural livelihood security. The high sensitivity values observed in these communities indicate that the degradation of forests has immediate and severe impacts on household welfare and income stability.

Communities such as Ngel Nyaki (0.53) and Mayo Ndaga (0.53) exhibited moderate vulnerability levels, reflecting the influence of conservation interventions and proximity to protected areas such as the Ngel Nyaki Forest Reserve. The presence of ongoing conservation programs and collaborative forest management initiatives in these areas has likely buffered the impacts of regional forest degradation, enhancing environmental awareness and diversifying livelihood opportunities. These communities, along with Mbu (0.52) and Kakara (0.51), have benefited from projects promoting agroforestry, beekeeping, and ecotourism; activities that help balance forest conservation with income generation.

On the other hand, Nguroje (0.47), Mbamnga (0.49), and Mai-Samari (0.45) recorded the lowest vulnerability scores, suggesting relatively better adaptive capacity and more diversified livelihood systems that are less dependent on direct forest resources. These communities have improved access to alternative energy sources such as kerosene and electricity. Their proximity to the urban center of Gembu may also provide better access to education, markets, and employment opportunities, which collectively reduce reliance on forest-based subsistence activities.

Spatial analysis of forest degradation dynamics supports these findings. Areas with higher forest loss and biomass reduction, as documented in the remote sensing analysis, correspond closely with communities exhibiting elevated LVI values. The regression of dense forest not only reduces the stock of ecosystem services but also diminishes the buffering capacity of the environment against climatic and economic shocks. Consequently, communities in zones of high forest degradation face greater livelihood insecurity due to reduced availability of forest-derived food, income, and energy resources. The loss of regulating and supporting services such as soil fertility maintenance, erosion control, and water retention further undermines agricultural productivity, reinforcing the cycle of ecological degradation and socio-economic vulnerability.

These results resonate with the Millennium Ecosystem Assessment (2005), which emphasized that degradation of ecosystem services directly undermines human well-being, particularly among rural populations whose livelihoods depend on natural capital. Similarly, Hahn et al. (2009) demonstrated that vulnerability tends to increase where exposure to environmental change is high and adaptive capacity is weak. The Mambilla Plateau presents a clear case of this dynamic: as forest ecosystems degrade, communities experience heightened exposure and sensitivity while their ability to adapt is constrained by poverty, limited education, and lack of access to alternative livelihoods.

The analysis underscores the strong causal link between forest degradation and socio-economic resilience. Forest degradation erodes the natural safety nets that support rural livelihoods fuelwood, clean water, fertile soils, and non-timber forest products thereby amplifying vulnerability to shocks such as drought, price fluctuations, and crop failure. Conversely, communities with diversified income sources, better education, and access to conservation initiatives demonstrate enhanced adaptive capacity and reduced vulnerability, even in a context of regional forest decline.

Addressing this linkage requires integrated management strategies that couple forest conservation with livelihood diversification and community-based adaptation. Promoting agroforestry, introducing renewable energy technologies, and strengthening local governance institutions can enhance adaptive capacity while reducing dependence on forest extraction. Additionally, capacity-building programs that focus on environmental education, sustainable harvesting, and participatory forest monitoring would empower local communities to manage their forest resources more sustainably and build resilience against the impacts of degradation.

Generally, the result of the findings of the study reveal that forest degradation on the Mambilla Plateau is a primary driver of livelihood vulnerability, both through the direct loss of ecosystem services and the erosion of adaptive capacity. Forest-dependent communities experiencing rapid degradation are the most vulnerable to livelihood insecurity, while those with diversified livelihoods and better institutional support exhibit greater resilience. Strengthening adaptive capacity through integrated forest–livelihood policies, alternative energy access, and inclusive conservation frameworks is therefore critical for achieving sustainable development and

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improving the well-being of forest-dependent populations on the Plateau.

Conclusion

This study revealed that forest ecosystem degradation on the Mambilla Plateau has resulted in substantial losses in biomass and carbon stocks between 1987 and 2024, leading to reduced ecosystem functionality and increased livelihood vulnerability. The findings showed that the degradation of forest resources through agricultural expansion, fuelwood harvesting, and settlement encroachment has intensified exposure and reduced the adaptive capacity of local households. Communities adjacent to degraded forest areas were particularly vulnerable due to their dependence on diminishing ecosystem services. The positive relationship between forest health and livelihood resilience underscores the need for integrated ecological and socio-economic strategies. Conserving and restoring forest ecosystems on the Plateau are therefore crucial for sustaining rural livelihoods, enhancing carbon sequestration, and achieving long-term environmental sustainability. These insights call for multi-sectoral interventions that combine restoration, governance reform, and community empowerment to mitigate vulnerability and promote resilience.

Recommendations

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

i. Community-Based Forest Restoration: Establish participatory reforestation and assisted natural regeneration initiatives led by local communities. This will restore degraded forest lands, enhance biodiversity, and strengthen local stewardship in sustainable forest management.

ii. Strengthened Forest Governance: Create and empower community forest management committees to oversee conservation practices, enforce forest use regulations, and promote accountability. This will reduce illegal logging and improve long-term ecosystem integrity.

iii. Livelihood Diversification: Promote alternative income-generating ventures such as beekeeping, eco-tourism, and agroforestry. Diversification will reduce household dependence on forest exploitation and enhance economic resilience against environmental shocks.

iv. Capacity Building and Environmental Education: Provide targeted training and environmental education programs to improve awareness, adaptive skills, and sustainable land-use practices. Empowered communities are more likely to adopt conservation-friendly behaviors and innovate under changing conditions.

v. Policy Integration and Geospatial Monitoring: Integrate Forest–livelihood linkages into state and national climate adaptation frameworks. Strengthen geospatial monitoring systems to detect degradation early, track carbon changes, and support evidence-based policy implementation.

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