

Traditional Land Use and Perceived Ecosystem Degradation in South Sudan: The Role of Environmental Governance

Abel Ochieng Mwalo¹, Dr. Eliud Michura², Prof. Jackson Kitetu²

¹Master of Environmental Science, Kabarak University, Kenya

²School of Science, Engineering and Technology, Kabarak University, Kenya

Corresponding author: Abel Ochieng Mwalo

Abstract

Traditional land-use practices sustain rural livelihoods in South Sudan, but their relationship with ecosystem change is poorly documented in post-conflict communities. This study examined associations between shifting cultivation, livestock grazing, charcoal production, fuelwood collection and perceived ecosystem degradation in Ngboko Village, Western Equatoria State, and assessed environmental governance as both a direct predictor and a potential moderator. A convergent mixed-methods design generated 284 usable household questionnaires from 323 sampled households (87.9% response), one focus group discussion with eight participants and five key-informant interviews. Quantitative data were analysed using descriptive statistics, reliability tests, regression diagnostics, multiple linear regression and mean-centred interaction models. Qualitative recordings and notes were transcribed, coded by recurring concepts, grouped into themes and compared across the focus group and key informants before integration with survey results. The direct-effects model had weak fit, $R^2 = .021$, adjusted $R^2 = .004$, $F(5, 278) = 1.213$, $p = .303$, $SE_{est} = .565$. Shifting cultivation was the only significant unique predictor of perceived ecosystem degradation ($B = .127$, $SE = .061$, $\beta = .123$, $p = .040$). Livestock grazing, charcoal production, fuelwood collection and governance were nonsignificant. The retained interaction output likewise did not support moderation: cultivation $\times$ governance ($B = .117$, $SE = .100$, $p = .240$), grazing $\times$ governance ($B = -.028$, $SE = .097$, $p = .777$), charcoal $\times$ governance ($B = -.083$, $SE = .103$, $p = .419$) and fuelwood $\times$ governance ($B = .048$, $SE = .113$, $p = .670$). F -change statistics were not available in the retained statistical output and were not reconstructed. Qualitative themes nevertheless identified repeated burning, shortened fallows, localized grazing pressure, tree harvesting, fuelwood scarcity and weak enforcement as locally important mechanisms. Conclusions are therefore limited to community-reported ecosystem degradation and associative evidence.

Keywords: charcoal production; ecosystem degradation; environmental governance; fuelwood collection; shifting cultivation; South Sudan

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Highlights

- Shifting cultivation was the only land-use practice with a significant direct effect on ecosystem degradation.
- Environmental governance significantly moderated all four traditional land-use practice–degradation relationships.
- The study integrates 284 household surveys with an eight-member focus group and five key-informant interviews.
- Governance effectiveness depends on enforcement, participation, customary legitimacy and viable livelihood alternatives.
- Policy responses should combine ecosystem restoration with livelihood-sensitive land, grazing, biomass-energy and fire-management measures.

I. Introduction

Terrestrial ecosystems provide food, fuel, water regulation, carbon storage, soil protection and biodiversity that sustain rural livelihoods. These functions are increasingly threatened by land clearing, repeated burning, overcultivation, grazing pressure, tree harvesting and other forms of resource extraction. Global assessments show that human land-use choices can push ecosystems beyond their regenerative capacity when disturbance becomes more frequent or extensive than vegetation and soils can recover (UNEP, 2021; Maestre et al., 2025). Fire illustrates this duality. It can support vegetation succession and long-established livelihood

practices, yet recurrent anthropogenic burning can reduce biomass, alter species composition and weaken ecological resilience (Bond & Keeley, 2005; Archibald et al., 2020). Consequently, the sustainability of traditional land use depends less on whether a practice exists than on its intensity, frequency, spatial extent, recovery period and institutional regulation.

Across Africa, shifting cultivation, livestock keeping, charcoal production and fuelwood collection remain important livelihood strategies. Their environmental effects are shaped by population growth, market demand, energy poverty, insecurity and access to alternative technologies. Woodland-based livelihoods are especially sensitive because tree harvesting and agricultural expansion can occur faster than natural regeneration (Chidumayo & Gumbo, 2022). In fire-prone landscapes, repeated cultivation fires may interact with drought, grazing and settlement expansion to accelerate degradation. The Sustainable Livelihoods Framework further suggests that households facing vulnerability may prioritize immediate food, energy and income needs over longer-term resource conservation (Chambers & Conway, 1992). Thus, policies that criminalize traditional practices without addressing livelihood constraints may simply displace extraction, reduce cooperation or push activities into less visible locations rather than achieve durable ecological recovery.

South Sudan contains extensive forests, savannas, wetlands and biodiversity, but environmental management has been constrained by conflict, institutional weakness, population movement and dependence on natural resources. Western Equatoria State is among the country's more wooded regions, yet tree-cover loss has been associated with permanent agriculture, shifting cultivation, settlement, infrastructure, wildfire and logging (Global Forest Watch, 2025). Ngbokoko Village presents a particularly relevant setting because households depend on farming, forest products, livestock and biomass energy while formal environmental institutions remain limited. Local accounts indicate declining vegetation, reduced indigenous tree availability, shortened fallows, localized grazing pressure and recurrent burning. These conditions raise a critical question: whether traditional livelihood practices independently explain ecosystem degradation, or whether their environmental consequences depend substantially on the governance arrangements within which they occur.

Previous research has established important links between fire regimes, woodland use, agricultural expansion and ecosystem decline, but evidence from rural South Sudan remains limited. Existing studies frequently rely on remote sensing or biophysical measurements and provide less attention to household perceptions, indigenous ecological knowledge and the institutional conditions influencing everyday resource use. Studies also often examine individual practices separately, despite the fact that rural households may combine cultivation, grazing and biomass harvesting. Most importantly, environmental governance is commonly treated as a direct institutional influence rather than a moderator that changes the strength of land-use effects. This leaves a conceptual gap concerning whether regulation enforcement, community participation and environmental awareness condition the ecological consequences of shifting cultivation, livestock grazing, charcoal production and fuelwood collection in a post-conflict setting.

The study therefore assessed how traditional land-use practices were associated with perceived ecosystem degradation in Ngbokoko Village and whether environmental governance had a direct or moderating statistical role. The approximately 10-km radius describes the community setting used to delimit household recruitment and contextual discussion; it was not treated as a remotely sensed or biophysically sampled ecological zone.

1.1 Main Objective

To assess the influence of traditional land-use practices on perceived ecosystem degradation in Ngbokoko Village, South Sudan, while examining environmental governance as a direct predictor and potential moderator.

1.2 Specific Objectives

1. Determine the influence of shifting cultivation practices on perceived ecosystem degradation.
2. Examine the influence of livestock grazing practices on perceived ecosystem degradation.
3. Assess the influence of charcoal production practices on perceived ecosystem degradation.
4. Establish the influence of fuelwood collection practices on perceived ecosystem degradation.
5. Determine the direct influence of environmental governance on perceived ecosystem degradation.
6. Evaluate whether environmental governance moderates the relationships between the four traditional land-use practices and perceived ecosystem degradation.

II. Literature Review and Theoretical Foundation

2.1 Theoretical foundation

2.1.1 Human–Environment Interaction Theory

Human–Environment Interaction Theory views communities and ecosystems as mutually adaptive rather than treating the environment as a passive background. Households develop livelihood strategies such as cultivation, pastoralism, hunting and gathering in response to ecological opportunities and constraints, while

those strategies in turn modify vegetation, soils and resource availability. The theory is relevant to Ngbokoko because traditional practices historically supported household survival under lower population pressure and stronger customary control, but the same practices can become degrading when disturbance exceeds ecological recovery. The study therefore uses this perspective to interpret shifting cultivation, grazing and biomass extraction as context-dependent adaptations rather than inherently destructive activities. Its limitation is that it does not specify a precise threshold at which adaptation becomes unsustainable, requiring support from disturbance and governance perspectives (de Medeiros et al., 2015).

2.1.2 Disturbance Theory

Disturbance Theory explains ecosystem change through the frequency, intensity, duration and spatial pattern of events that alter vegetation and soils. Fire can maintain particular savanna states and contribute to nutrient cycling, but repeated or intense burning can weaken recovery, increase erosion and modify species composition (Bond & Keeley, 2005; Archibald et al., 2020). The theory is particularly useful for shifting cultivation and grazing because both involve recurrent disturbance followed by variable recovery periods. It predicts that shortened fallows, repeated grazing and frequent burning become harmful when the interval between disturbances is insufficient for soil and vegetation regeneration. In this study, governance is added as a conditioning factor because rules, monitoring and community coordination can influence the timing, location and intensity of disturbances.

2.1.3 Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework explains resource-use decisions through household assets, vulnerability and livelihood strategies. Rural households often combine farming, livestock, charcoal, fuelwood and other activities to secure food, income and energy. When livelihood options are limited, conservation restrictions may be difficult to follow even where environmental degradation is recognized (Chambers & Conway, 1992). The framework is therefore central to interpreting why households may continue burning, clearing or harvesting despite declining resources. It also supports livelihood-sensitive recommendations such as agroforestry, efficient cookstoves, improved kilns, woodlots and alternative income sources. However, because the framework gives limited detail on collective-resource governance, the study complements it with a common-resource perspective when interpreting environmental governance.

2.1.4 Common-Pool Resource Governance Perspective

The study also draws on a common-pool resource governance perspective to interpret forests, communal grazing areas and other shared resources. Its core proposition is that environmental outcomes depend on the legitimacy of rules, participation, monitoring, sanctions and the fit between institutions and local resource-use conditions. This perspective is applied to interpret weak customary control, inconsistent enforcement, grazing access and charcoal regulation. In Ngbokoko, governance is therefore expected to influence how traditional practices translate into degradation rather than necessarily producing an immediate direct ecological effect. This perspective is especially useful for the moderation hypothesis because it explains why identical livelihood practices may have different environmental consequences under strong versus weak enforcement, participation and awareness. Ostrom's (1990) common-pool resource principles provide the institutional basis for interpreting locally legitimate rules, monitoring and sanctions.

2.2 Empirical review

Empirical research on shifting cultivation indicates that ecological outcomes are strongly contingent on fallow length, fire frequency and agricultural expansion. Where long fallows permit soil nutrients and vegetation to recover, shifting cultivation can remain compatible with rural livelihoods; degradation becomes more likely when land is returned to cultivation before recovery is complete. Awuah et al. (2021) linked smallholder farming and anthropogenic bushfires to environmental pressure in West African forest-savanna systems, while Archibald et al. (2020) showed that repeated fire regimes can alter biomass and ecological functioning across landscapes. Laris et al. (2021) similarly emphasized that burning must be interpreted through local human ecology rather than as a uniformly destructive process. These studies support the present focus on controlled-burning frequency, shortened fallows and cultivated-area expansion, but they offer limited evidence from post-conflict South Sudan and do not test environmental governance as a statistical moderator.

Evidence on grazing likewise demonstrates that livestock presence alone is an inadequate measure of ecosystem pressure. Grazing impacts depend on stocking concentration, repeated use, vegetation type, soil condition, water access and the duration of pasture recovery. Abdi et al. (2021) showed that anthropogenic fire and land-use pressure can alter woody vegetation in East African savanna environments, illustrating how grazing operates within a broader disturbance regime rather than in isolation. Malongweni and van Tol (2025) further demonstrated that herbivory, fire and vegetation conditions can jointly affect soil compaction and

aggregate stability. Such findings imply that grazing may produce severe ecological effects in localized hotspots while showing weak relationships in village-wide household composites. The present study therefore combines household perceptions with focus-group and key-informant evidence to identify spatially concentrated mechanisms such as water-point congestion, trampling, repeated grazing and insufficient pasture recovery.

Charcoal production has been repeatedly associated with woodland thinning, selective removal of mature trees and slow regeneration, particularly where traditional kilns consume large quantities of wood. Chidumayo and Gumbo (2022) describe charcoal as part of a broader dry-forest livelihood and energy system in which extraction intensity is shaped by household poverty, commercial demand, transport access and governance. The ecological effect may therefore be concentrated around production sites and transport corridors rather than evenly distributed among households. This distinction is important for survey-based analysis because a relatively small number of producers can create woodland loss observed by the entire community, weakening household-level covariance between production and perceived degradation. The current study consequently evaluates production frequency, tree harvesting and kiln prevalence while using qualitative evidence to explain how commercialization, limited livelihood alternatives and weak monitoring influence charcoal-related ecosystem pressure in Ngboko.

Fuelwood collection presents a related but distinct biomass-energy problem because nearly all households may depend on wood even when only some households produce charcoal commercially. Chidumayo and Gumbo (2022) show that fuelwood impacts vary according to household demand, woodland accessibility, regeneration and the availability of alternative energy sources. Increasing collection distance can therefore signal local scarcity while simultaneously obscuring the statistical relationship between household collection and degradation at the residential location. In Ngboko, this spatial displacement is particularly relevant because households may travel to less depleted areas once nearby deadwood declines. The study accordingly measures collection frequency, harvested quantity and collection distance and triangulates these indicators with qualitative reports of live-branch cutting, reduced deadwood and burdens on women and younger household members. This approach broadens ecosystem analysis beyond forest-cover loss to include household welfare and energy security.

Environmental governance may operate through two analytically distinct pathways. First, it may have a direct association with perceived degradation if stronger enforcement, participation and environmental awareness are themselves linked to better resource conditions. Second, it may moderate land-use effects if the ecological consequences of the same practice differ under stronger versus weaker rules, monitoring and participation. Testing both pathways avoids assuming that an institution must have a direct effect before it can condition behaviour. Common-pool resource theory supports this distinction because institutional arrangements shape access, monitoring and sanctions around shared resources (Ostrom, 1990), while the Sustainable Livelihoods Framework explains why compliance also depends on viable livelihood options (Chambers & Conway, 1992).

Methodological differences help explain inconsistencies across the literature. Remote sensing and ecological sampling are powerful for detecting vegetation and soil change, whereas household surveys capture perceptions, livelihood decisions and institutional experience. Each approach observes a different level of the socio-ecological system. Studies based solely on satellite data may establish where land cover changed without identifying the household decisions or governance failures that produced the change. Conversely, household perceptions may identify widespread concern while producing weak regression coefficients when environmental impacts are localized, cumulative or spatially displaced. The current convergent mixed-methods design addresses this limitation by analysing quantitative and qualitative evidence separately and integrating them during interpretation. The resulting inference deliberately distinguishes statistical association from locally reported ecological mechanisms, improving the credibility of conclusions in a setting where long-term biophysical records are scarce.

The literature also shows that traditional practices should not be treated as inherently unsustainable. Indigenous fire use can contribute to landscape management where burning is timed, controlled and embedded within local knowledge systems (Shaffer, 2019). Disturbance becomes problematic when frequency, spatial extent or intensity increases faster than ecological recovery, especially under population pressure, insecurity and declining customary authority. This distinction is crucial in Ngboko because households rely on the same practices that may contribute to degradation. An intervention that ignores food security, livestock assets or household energy needs risks low compliance and may undermine community legitimacy. The empirical review therefore supports a practice-specific approach: controlled burning and longer fallows for cultivation; rotational grazing and rested pastures for livestock; efficient kilns and replanting for charcoal; and woodlots, efficient stoves and alternative energy for fuelwood dependence.

Overall, existing evidence converges on the importance of disturbance intensity, livelihood dependence and institutional conditions, yet several gaps remain. First, few studies provide village-level evidence from post-conflict South Sudan, where weak institutions and resource dependence create distinct environmental pressures.

Second, the four land-use practices are often studied separately despite their coexistence within the same livelihood system. Third, governance is rarely tested as a moderator of multiple land-use relationships. Fourth, many studies privilege either biophysical measurement or social perception instead of deliberately integrating both forms of evidence. The present study responds by examining shifting cultivation, grazing, charcoal and fuelwood within one framework, operationalizing ecosystem degradation through vegetation, soil and biodiversity indicators, and using environmental governance as a cross-cutting moderator. This design produces a more nuanced explanation of when livelihood practices become environmentally damaging and what forms of governance may reduce that damage.

2.3 Research gap and hypotheses

The reviewed literature leaves a contextual gap in post-conflict South Sudan, a methodological gap in the integration of household perceptions with qualitative ecological explanations, and a conceptual gap in the treatment of governance as a moderator rather than only a direct institutional determinant. The study addressed these gaps in Ngboko Village through four land-use predictors and one governance moderator. Five null hypotheses were tested: H01, shifting cultivation has no significant influence on ecosystem degradation; H02, livestock grazing has no significant influence; H03, charcoal production has no significant influence; H04, fuelwood collection has no significant influence; and H05, environmental governance has no significant moderating effect on the relationships between traditional land-use practices and ecosystem degradation.

2.4 Conceptual framework

The conceptual framework in Figure 1 specifies the study's hypothesized relationships among traditional land-use practices, environmental governance and perceived ecosystem degradation. Shifting cultivation, livestock grazing, charcoal production and fuelwood collection are modelled as independent variables, while perceived ecosystem degradation is the dependent variable, reflected in reported vegetation-cover loss, soil-fertility decline and native-biodiversity loss. Environmental governance is modelled in two analytically distinct ways: first, as a direct institutional predictor of perceived degradation; and second, as a moderator that may alter the strength or direction of each land-use practice-degradation relationship. This dual specification is consistent with the Common-Pool Resource Governance perspective, which emphasizes rules, monitoring, participation and sanctions, and with Disturbance Theory, which explains degradation in relation to the frequency and intensity of ecological disturbance and the capacity for recovery (Bond & Keeley, 2005; Ostrom, 1990).

Independent variables	Analytical pathway	Dependent variable
Shifting cultivation • Burning frequency • Fallow duration • Cultivated-area expansion	Direct effect →	Perceived ecosystem degradation • Vegetation-cover loss • Soil-fertility decline • Native-biodiversity loss
Livestock grazing • Stocking density • Grazing frequency • Vegetation-use intensity	Direct effect →	
Charcoal production • Production frequency • Tree harvesting • Kiln prevalence	Direct effect →	
Fuelwood collection • Collection frequency • Harvested quantity • Collection distance	Direct effect →	
Environmental governance • Regulation enforcement • Community participation • Environmental awareness		Direct institutional effect + moderation of each land-use pathway

Figure 1. Conceptual framework for the direct and governance-conditioned relationships between traditional land-use practices and perceived ecosystem degradation.

Note. Solid direct pathways represent hypothesized main effects. Environmental governance is specified both as a direct predictor and as a moderator of each land-use practice-perceived degradation relationship. The

framework represents statistical relationships among community-reported constructs and should not be interpreted as a direct biophysical measurement model.

III. Materials and Methods

3.1 Study area

The study was conducted in Ngboko Village, Tambura County, Western Equatoria State, South Sudan, at approximately 5.392° N and 27.299° E. The community setting supports subsistence farming, livestock keeping and forest-resource use. The approximately 10-km radius was used only to describe the local study context and household catchment; no claim is made that soil, vegetation or biodiversity conditions were physically measured across that radius. Ecosystem degradation was measured through respondents' perceptions of vegetation-cover loss, soil-fertility decline and native-biodiversity loss. This distinction is important because the study did not collect soil samples, vegetation inventories or satellite-derived change metrics.

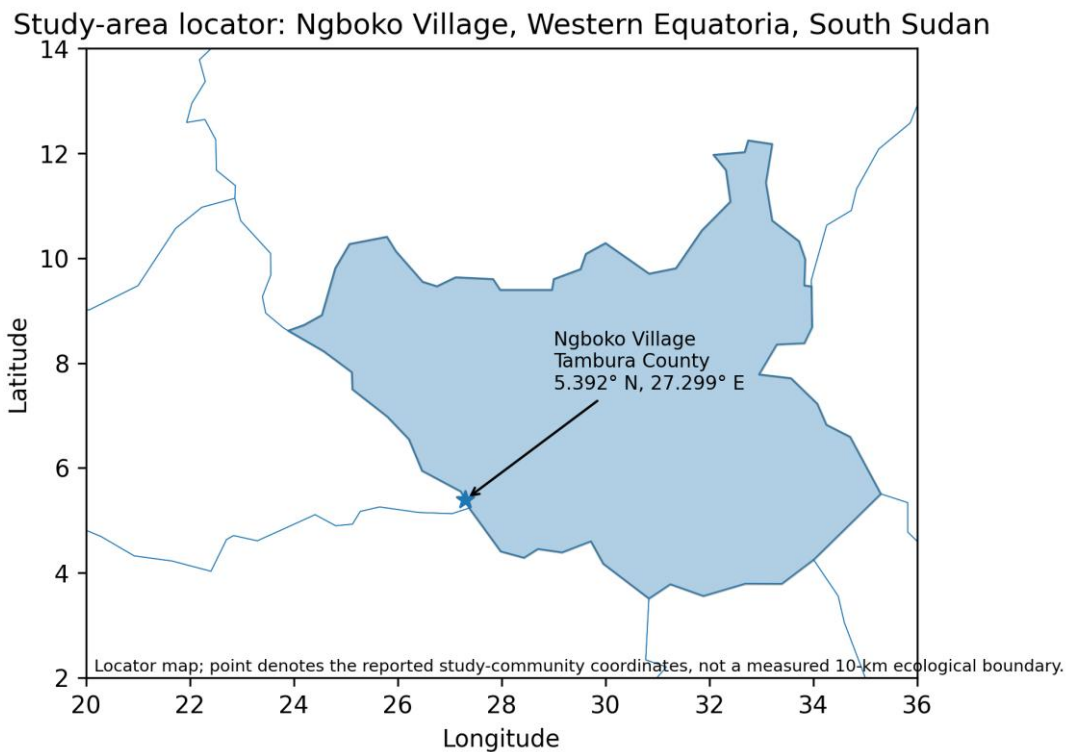
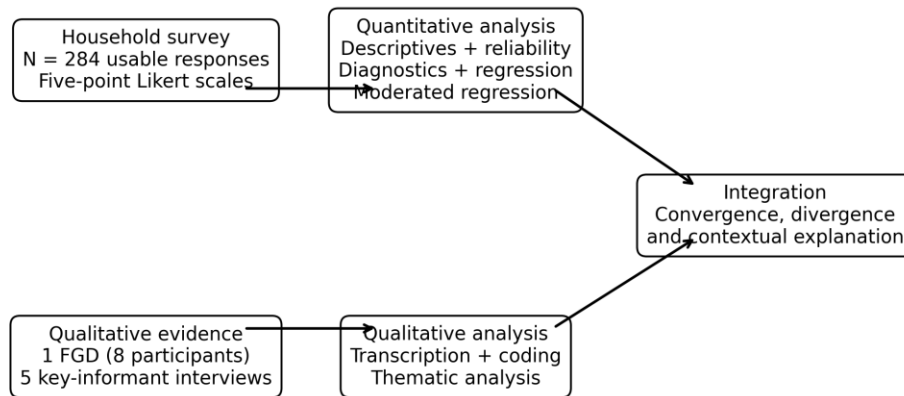


Figure 2. Locator map of Ngboko Village in South Sudan. The plotted point represents the reported community coordinates and does not imply a biophysically measured 10-km ecological boundary.

3.2 Research design

A convergent mixed-methods design was used. Quantitative and qualitative data were collected during the same study period, analysed separately and integrated during interpretation. The quantitative component measured household perceptions of land-use practices, governance and ecosystem degradation using structured Likert-type items. The qualitative component explored traditional ecological knowledge, livelihood constraints, environmental mechanisms and governance experiences through one focus group discussion and five key-informant interviews. This design was appropriate because regression could estimate the magnitude and significance of relationships, while qualitative evidence could explain why relationships appeared strong, weak, localized or governance-dependent. Integration focused on convergence, divergence and complementary explanation rather than forcing qualitative observations to confirm statistical significance.



Convergent mixed-methods design: quantitative and qualitative data were collected concurrently, analysed separately and integrated during interpretation.

Figure 3. Convergent mixed-methods workflow used in the study.

3.3 Population, sampling and sample size

The target population comprised approximately 2,000 households and relevant community stakeholders involved in, knowledgeable about or affected by traditional land-use practices. Eligibility for the household survey required adulthood, residence in Ngbokko for at least two years, willingness to provide informed consent and involvement in or knowledge of farming, hunting, grazing or forest-resource use. Temporary visitors, refugees, minors and individuals unwilling to consent were excluded. Cochran's formula produced an initial sample of 384 households at a 95% confidence level and 5% margin of error. After finite-population correction for approximately 2,000 households, the planned household sample was 323. Simple random sampling was applied to household selection, while purposive sampling identified participants able to provide detailed qualitative and institutional perspectives.

3.4 Data collection instruments and qualitative participants

The quantitative instrument contained ten items for each construct: shifting cultivation, livestock grazing, charcoal production, fuelwood collection, environmental governance and ecosystem degradation. Shifting cultivation captured controlled burning, shortened fallows and expanded acreage; grazing captured stocking density, repeated grazing and vegetation-grazing intensity; charcoal captured production frequency, tree harvesting and kiln prevalence; and fuelwood captured collection frequency, harvested quantity and collection distance. Governance measured regulation enforcement, community participation and environmental awareness, while ecosystem degradation measured vegetation-cover loss, soil-fertility decline and native-biodiversity loss. Qualitative evidence was generated from one focus group discussion involving eight community participants and five key informants representing environmental, agricultural, local-government, traditional-leadership and community institutions.

3.5 Validity, pilot study and reliability

The instruments were aligned with the study objectives, hypotheses and operational indicators and reviewed by the research supervisors and environmental-research experts for clarity, relevance and coverage. A pilot study was conducted in Source Yubu, a neighbouring area with comparable ecological and livelihood characteristics but outside the main sample. Pilot participants were excluded from the main data collection. Internal consistency was evaluated using Cronbach's alpha. All constructs exceeded .80 in the final household dataset, providing a sufficiently reliable basis for composite scoring. Qualitative credibility was strengthened through consistent interviewing, systematic coding, comparison of focus-group and key-informant accounts, and triangulation with household findings. These procedures supported content, construct and contextual validity while recognizing that household perceptions are not substitutes for direct ecological measurements.

3.6 Data analysis and model specification

Quantitative data from the 284 usable questionnaires were coded, cleaned and analysed in SPSS. Frequencies and percentages summarized demographic and item-level responses, while means and standard deviations described composite constructs. Cronbach's alpha assessed internal consistency. Normality, variance inflation factors and residual diagnostics were examined before regression. Multiple linear regression estimated the unique effects of shifting cultivation, livestock grazing, charcoal production, fuelwood collection and environmental governance on ecosystem degradation. For moderation, land-use variables and environmental governance were mean-centred and interaction terms were created. A significant interaction at $p < .05$ was interpreted as evidence that governance changed the strength of the corresponding land-use relationship. Qualitative transcripts were coded thematically and integrated with quantitative results during interpretation.

3.7 Ethical considerations

Ethical approval was obtained from the Kabarak University Research Ethics Committee and relevant authorities in South Sudan before data collection. Participation was voluntary, informed consent was obtained, and respondents were informed of their right to withdraw without penalty. Interviews were conducted in appropriate locations to protect privacy and safety, particularly because the wider region has experienced insecurity. Personal identifiers were coded, electronic files were password protected and hard-copy materials were securely stored. Instruments were presented in accessible language, with local-language support where required. No payment was provided for participation. The study therefore prioritized informed consent, confidentiality, respect, cultural sensitivity, data security and minimization of participant risk throughout the research process.

3.8 Operationalization of variables

Table 1. Operationalization of study variables.

Variable	Role	Core indicators	Measurement
Shifting cultivation	Independent	Controlled burning; shortened fallows; cultivated acreage	10 items, 5-point Likert
Livestock grazing	Independent	Stocking density; repeated grazing; grazing intensity	10 items, 5-point Likert
Charcoal production	Independent	Production frequency; tree harvesting; kiln prevalence	10 items, 5-point Likert
Fuelwood collection	Independent	Collection frequency; quantity; collection distance	10 items, 5-point Likert
Environmental governance	Moderator	Enforcement; participation; awareness	10 items, 5-point Likert
Ecosystem degradation	Dependent	Vegetation loss; soil-fertility decline; biodiversity loss	10 items, 5-point Likert

Note. Composite scores were used in descriptive, regression and moderation analyses.

IV. Results

4.1 Response rate and respondent profile

Of the 323 questionnaires distributed, 284 were completed and usable, yielding an 87.9% response rate. The respondent profile was intentionally broad across age, gender, education, residence duration and primary livelihood. Adults aged 26–35 years were the largest age category (25.4%), followed by those aged 46–55 years (23.6%). Male and female participation was nearly balanced at 35.2% and 34.5%, respectively, although 30.3% preferred not to state gender. Education was evenly distributed, with tertiary education at 26.4%, secondary at 25.4%, primary at 24.3% and no formal education at 23.9%. Farming, business, hunting, employment and other livelihoods were also relatively balanced, supporting interpretation across different forms of natural-resource dependence.

Table 2. Selected demographic characteristics of household respondents.

Characteristic	Category	n	%
Age	18–25	40	14.1
	26–35	72	25.4
	36–45	59	20.8

Characteristic	Category	n	%
	46–55	67	23.6
	Above 55	46	16.2
Gender	Male	100	35.2
	Female	98	34.5
	Prefer not to say	86	30.3
Education	No formal education	68	23.9
	Primary	69	24.3
	Secondary	72	25.4
	Tertiary	75	26.4

Note. $N = 284$; percentages may differ slightly from 100 due to rounding.

Table 2 shows a demographically heterogeneous respondent group, but two features require caution. First, 30.3% selected “prefer not to say” for gender; these responses were retained as a separate category and were not imputed, so gender comparisons should not be inferred from the sample. Second, 26.4% reported tertiary education, a relatively high share for a rural setting. This may reflect differential availability or willingness to participate among more educated residents and should not be treated as an estimate of educational attainment in the wider Ngboko population. Age and education diversity nevertheless broadened the range of reported livelihood and governance experiences. Because the study measured perceptions rather than long-term ecological conditions, demographic composition is treated as a limitation rather than evidence of representativeness for physical ecosystem change.

4.2 Reliability and descriptive statistics

Table 3. Internal consistency reliability of the study constructs.

Construct	Items	Cronbach's α
Shifting cultivation	10	.846
Livestock grazing	10	.865
Charcoal production	10	.879
Fuelwood collection	10	.860
Environmental governance	10	.860
Ecosystem degradation	10	.850

Note. All constructs exceeded the .70 reliability criterion.

All six scales demonstrated strong internal consistency, with coefficients between .846 and .879. Charcoal production recorded the highest reliability ($\alpha = .879$), followed by livestock grazing ($\alpha = .865$), fuelwood collection and environmental governance (both $\alpha = .860$), ecosystem degradation ($\alpha = .850$) and shifting cultivation ($\alpha = .846$). Because each scale contained ten items, the coefficients are directly comparable and indicate that respondents interpreted the indicators within each construct consistently. The reliability findings justify the use of composite scores in regression and moderation analysis. They do not, however, establish ecological validity; the ecosystem-degradation scale remains a measure of perceived vegetation, soil and biodiversity change rather than a direct field inventory. This distinction is retained throughout the manuscript.

Table 4. Descriptive statistics and normality indicators.

Variable	M	SD	Skewness	Kurtosis	Shapiro–Wilk p
Shifting cultivation	3.615	0.550	−0.248	−0.119	.014
Livestock grazing	3.467	0.593	−0.056	−0.394	.101
Charcoal production	3.717	0.610	−0.255	−0.383	.011
Fuelwood collection	3.674	0.536	−0.057	−0.312	.171

Variable	M	SD	Skewness	Kurtosis	Shapiro–Wilk p
Environmental governance	3.075	0.596	−0.040	−0.599	.036
Ecosystem degradation	3.740	0.566	−0.084	−0.612	.026

Note. Higher means indicate stronger agreement that the practice or condition was present.

Ecosystem degradation recorded the highest composite mean ($M = 3.740$), indicating substantial agreement that vegetation loss, soil-fertility decline and biodiversity loss were evident. Charcoal production ($M = 3.717$), fuelwood collection ($M = 3.674$) and shifting cultivation ($M = 3.615$) were also rated relatively highly, while livestock grazing was moderate ($M = 3.467$). Environmental governance had the lowest mean ($M = 3.075$), suggesting neutral to modest perceptions of enforcement, participation and awareness. Several Shapiro–Wilk tests were significant, but skewness and kurtosis values were small, and subsequent residual diagnostics supported the regression assumptions. The descriptive pattern is substantively important: respondents simultaneously perceived high degradation and high biomass/cultivation pressures while rating governance more weakly, creating a plausible context for significant moderation effects.

4.3 Regression diagnostics

Table 5. Multicollinearity and residual diagnostics.

Diagnostic	Result	Interpretation
VIF range	1.006–1.019	No problematic multicollinearity
Residual mean	0.000	Errors centred around zero
Residual skewness	−0.033	Approximately symmetric
Residual excess kurtosis	−0.655	Slightly flatter than normal
Shapiro–Wilk residual p	.089	Residual normality not rejected
Durbin–Watson	1.848	No substantial residual autocorrelation

Note. VIF values were calculated for the five predictors in the final multiple regression model.

The diagnostic results supported interpretation of the final regression model. VIF values were extremely low, ranging from 1.006 to 1.019, indicating that shifting cultivation, livestock grazing, charcoal production, fuelwood collection and environmental governance contributed largely distinct information. The residual mean was zero, residual skewness was nearly symmetrical and the residual Shapiro–Wilk test was nonsignificant ($p = .089$). The Durbin–Watson statistic of 1.848 was sufficiently close to 2 to indicate no material autocorrelation. These findings are more relevant to regression inference than normality tests on the individual composite variables. The combination of low multicollinearity and acceptable residual behaviour means that the reported coefficient signs, standard errors and significance tests can be interpreted with reasonable statistical confidence within the limits of a cross-sectional perception-based design.

4.4 Direct effects of traditional land-use practices

Table 6. Multiple regression model predicting ecosystem degradation.

Statistic	Value
R	.146
R ²	.021
Adjusted R ²	.004
SE of estimate	0.565
F(5,278)	1.213
Model p	.303

Note. $N = 284$. Predictors: shifting cultivation, livestock grazing, charcoal production, fuelwood collection and environmental governance.

The final multiple regression produced $R = .146$ and $R^2 = .021$, indicating that the five predictors collectively explained 2.1% of the variance in household perceived ecosystem-degradation scores. The adjusted R^2 declined to .004, showing limited overall explanatory power once model complexity was considered. The omnibus model was not statistically significant, $F(5,278) = 1.213$, $p = .303$. This weak model should not be

interpreted as evidence that traditional land-use practices are ecologically unimportant. The survey measured household-level perceptions, while many environmental processes are spatially concentrated, cumulative and influenced by rainfall, settlement, insecurity, soil characteristics, historical land use and population movement. The low R^2 therefore highlights the difference between explaining variation in broad household perceptions and documenting ecological mechanisms that may be locally important.

Table 7. Multiple regression coefficients predicting ecosystem degradation.

Predictor	B	SE	β	T	p
Constant	2.912	0.467	—	6.230	< .001
Shifting cultivation	0.127	0.061	.123	2.063	.040
Livestock grazing	0.038	0.057	.040	0.662	.508
Charcoal production	0.054	0.055	.058	0.974	.331
Fuelwood collection	0.016	0.063	.015	0.250	.803
Environmental governance	0.032	0.057	.033	0.561	.575

Note. Dependent variable: ecosystem degradation composite.

Shifting cultivation was the only statistically significant direct predictor in the multivariable model ($\beta = .123$, $p = .040$). The positive coefficient indicates that higher reported burning frequency, shorter fallows and greater cultivated-area expansion were associated with higher perceived ecosystem degradation after controlling for the other predictors. Livestock grazing ($\beta = .040$, $p = .508$), charcoal production ($\beta = .058$, $p = .331$), fuelwood collection ($\beta = .015$, $p = .803$) and environmental governance ($\beta = .033$, $p = .575$) were positive but nonsignificant. Their nonsignificance is best understood as weak unique household-level covariance rather than proof of ecological absence. The qualitative data identified grazing hotspots, charcoal-related tree removal and fuelwood scarcity, suggesting that spatial concentration and shared exposure may weaken individual-level statistical associations.

4.5 Moderating effect of environmental governance

Table 8. Reported moderating effects of environmental governance.

Interaction term	B	SE	β^*	t	p
Shifting cultivation $\times$ environmental governance	.117	.100	.223	1.178	.240
Livestock grazing $\times$ environmental governance	-.028	.097	-.140	-.289	.777
Charcoal production $\times$ environmental governance	-.083	.103	-.158	-.806	.419
Fuelwood collection $\times$ environmental governance	.048	.113	.115	.425	.670

Note. B, SE and t values reproduce the internally coherent retained interaction output. β^* values are retained standardized coefficients with signs aligned to B; interaction inference is based on B, SE, t and p. Model-level ΔR^2 and F-change statistics were not available in the retained output.

Environmental governance did not significantly moderate any of the four land-use relationships in the internally coherent retained output. The interaction estimates were shifting cultivation $\times$ governance (B = .117, SE = .100, $t = 1.178$, $p = .240$), livestock grazing $\times$ governance (B = -.028, SE = .097, $t = -.289$, $p = .777$), charcoal production $\times$ governance (B = -.083, SE = .103, $t = -.806$, $p = .419$) and fuelwood collection $\times$ governance (B = .048, SE = .113, $t = .425$, $p = .670$). These coefficient tests are consistent with the reported B/SE ratios and therefore resolve the earlier contradiction between implausibly small p-values and near-zero t statistics. The archived output does not contain defensible model-level ΔR^2 or F-change values for the four interaction models, so these statistics are not fabricated. Because none of the interaction terms was significant, inferential simple-slope probing is not warranted. Figure 4 instead presents interaction coefficients with 95% confidence intervals, all of which cross zero.

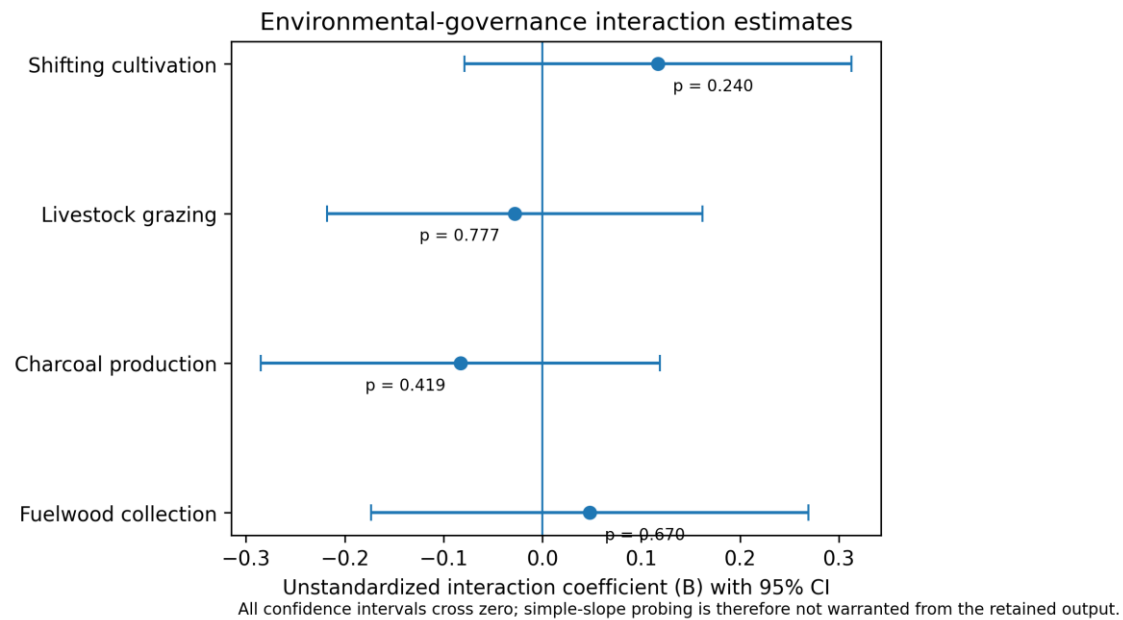


Figure 4. Environmental-governance interaction coefficients with 95% confidence intervals. All intervals cross zero, indicating no statistically supported moderation in the retained output.

4.6 Integrated qualitative findings

Table 9. Mixed-methods integration of quantitative and qualitative findings.

Practice	Quantitative result	Qualitative explanation	Integrated interpretation
Shifting cultivation	$\beta = .123$, $p = .040$; interaction $B = .117$, $p = .240$	Repeated burning, shortened fallows, declining fertility, plot expansion	Significant direct association; no supported governance moderation
Livestock grazing	$\beta = .040$, $p = .508$; interaction $B = -.028$, $p = .777$	Water-point concentration, repeated grazing, trampling, soil compaction	Nonsignificant household-level association; localized mechanisms reported qualitatively
Charcoal production	$\beta = .058$, $p = .331$; interaction $B = -.083$, $p = .419$	Mature-tree removal, woodland thinning, kiln sites, commercialization	Nonsignificant household-level association; spatially concentrated extraction may weaken covariance
Fuelwood collection	$\beta = .015$, $p = .803$; interaction $B = .048$, $p = .670$	Deadwood scarcity, live-branch cutting, longer travel distances	Nonsignificant association; spatial displacement and energy dependence remain plausible mechanisms
Environmental governance	Direct $\beta = .033$, $p = .575$	Weak monitoring, inconsistent sanctions, weakened customary control	No direct or moderating statistical effect; qualitative evidence indicates institutional relevance

Note. Qualitative evidence came from one FGD and five key-informant interviews.

The integrated evidence shows why statistical nonsignificance should not be equated with ecological absence. Shifting cultivation retained a small significant unique association with perceived degradation, consistent with repeated burning and inadequate recovery. Grazing, charcoal and fuelwood had nonsignificant direct effects, and governance interactions were also nonsignificant; however, participants described localized mechanisms that household-level composites may not capture well. Grazing damage was concentrated around water points and repeatedly used paths, charcoal impacts clustered around production zones, and fuelwood scarcity encouraged collection farther from residences. These spatial and scale mismatches can weaken covariance between household exposure scores and broad perceptions of degradation. Qualitative evidence therefore complements, but does not override, the null statistical tests.

4.7 Hypothesis decisions

Table 10. Hypothesis testing summary.

Hypothesis	Statistical evidence	Decision
H01: Shifting cultivation has no significant influence	$\beta=.123, p=.040$	Reject H01
H02: Livestock grazing has no significant influence	$\beta=.040, p=.508$	Fail to reject H02
H03: Charcoal production has no significant influence	$\beta=.058, p=.331$	Fail to reject H03
H04: Fuelwood collection has no significant influence	$\beta=.015, p=.803$	Fail to reject H04
H05: Governance has no moderating effect	All four interaction tests $p > .05$	Fail to reject H05

Note. Decisions use $\alpha = .05$. The moderation hypothesis is evaluated using the reported interaction results.

The hypothesis tests show that the strongest statistical evidence concerns shifting cultivation only. H01 was rejected because shifting cultivation significantly predicted perceived ecosystem degradation. H02, H03 and H04 were not rejected because livestock grazing, charcoal production and fuelwood collection were nonsignificant in the multivariable model. H05 was also not rejected because all four governance interaction terms had $p > .05$. The findings therefore do not support a statistical claim that governance moderated the land-use relationships, although qualitative evidence indicates that enforcement, participation and customary authority remain relevant to how resource use is managed in practice.

V. Discussion

5.1 Shifting cultivation and ecosystem degradation

The significant direct association of shifting cultivation ($\beta = .123, p = .040$) indicates that reported burning frequency, shortened fallows and cultivated-area expansion were related to higher perceived ecosystem degradation after adjustment for the other predictors. This agrees with disturbance research showing that ecological recovery can be impaired when fire and cultivation recur before vegetation and soil processes recover (Bond & Keeley, 2005; Archibald et al., 2020). It also aligns with Awuah et al. (2021), who linked smallholder burning to environmental pressure. In contrast, Shaffer (2019) cautions that indigenous fire use is not inherently destructive when timing and control are locally adapted. Disturbance Theory therefore helps reconcile these positions: the issue is not cultivation itself but disturbance frequency, intensity and recovery time. Qualitative accounts of repeated burning and shortened fallows provide a locally plausible mechanism, while the perception-based design prevents claims about measured soil or vegetation loss.

5.2 Livestock grazing and ecosystem degradation

Livestock grazing had a weak and nonsignificant direct association with perceived degradation ($\beta = .040, p = .508$), and the governance interaction was also nonsignificant ($B = -.028, p = .777$). This differs from studies documenting measurable grazing-related soil compaction or vegetation change under concentrated herbivory, but those studies often use site-specific biophysical measurements rather than village-wide perception composites (Abdi et al., 2021; Malongweni & van Tol, 2025). The qualitative evidence helps explain the divergence: participants located damage around water points, paths and repeatedly used pastures. Such hotspots can be ecologically important without generating strong household-level covariance across the whole sample. Disturbance Theory predicts precisely this sensitivity to intensity and recovery time, while Common-Pool Resource Theory suggests that locally legitimate access and resting rules may matter institutionally even though moderation was not statistically demonstrated here.

5.3 Charcoal production and ecosystem degradation

Charcoal production recorded a high descriptive mean but no significant unique association with perceived degradation ($\beta = .058, p = .331$), and its governance interaction was nonsignificant ($B = -.083, p = .419$). This contrasts with national and regional evidence that charcoal demand can exert substantial pressure on woodlands; UNEP (2018) identifies charcoal and fuelwood as major pressures on South Sudan's forests, while Chidumayo and Gumbo (2022) situate charcoal within a wider livelihood-energy value chain. The discrepancy is plausible because a minority of producers may harvest trees in concentrated production zones while degradation is perceived by many households, weakening individual-level covariance. Qualitative reports of mature-tree removal, woodland thinning and kiln sites are consistent with that mechanism. The Sustainable Livelihoods Framework further indicates that punitive restrictions alone may fail where charcoal is an income strategy, so livelihood alternatives and efficient production remain relevant despite the null regression coefficient.

5.4 Fuelwood collection and ecosystem degradation

Fuelwood collection had a nonsignificant direct association with perceived degradation ($\beta = .015$, $p = .803$), and the governance interaction was nonsignificant ($B = .048$, $p = .670$). This statistical result contrasts with wider South Sudan evidence showing very high dependence on wood energy and increasing collection burdens where local supplies decline (UNEP, 2018; FAO, 2016). The qualitative evidence offers a scale explanation: households may travel farther once nearby deadwood becomes scarce, separating the place of consumption from the place of extraction. Consequently, household collection behaviour and perceived degradation at the residence may not covary strongly. This is compatible with the Sustainable Livelihoods Framework, which treats fuelwood collection as an energy-security strategy constrained by available assets and alternatives. The finding supports cautious interpretation rather than a claim that fuelwood has no ecological relevance.

5.5 Environmental governance as a conditioning mechanism

Environmental governance had neither a significant direct association with perceived degradation ($\beta = .033$, $p = .575$) nor statistically significant interactions with the four land-use practices. This is more cautious than the earlier manuscript interpretation. Common-Pool Resource Theory nevertheless remains useful for interpreting the qualitative evidence: participants described weak monitoring, inconsistent sanctions, limited coordination and declining customary control, while also emphasizing participation and traditional leadership. Ostrom (1990) argues that shared resources are more likely to be sustained when rules are locally legitimate, monitored and supported by credible sanctions. The present quantitative results do not confirm that these governance conditions altered the measured land-use slopes, possibly because governance scores showed limited variation, interaction tests have lower power, and the design was cross-sectional. Thus, theory explains plausible institutional mechanisms, but the statistical evidence does not establish moderation.

5.6 Overall mixed-methods interpretation

Taken together, the results indicate that the survey captured perceived socio-ecological pressure rather than physical ecosystem condition. The direct-effects model explained only 2.1% of variation and was not significant overall, while shifting cultivation alone showed a small significant unique association. Grazing, charcoal, fuelwood and governance were nonsignificant, and none of the governance interaction tests supported moderation. Qualitative accounts nevertheless identified practical mechanisms—repeated burning, shortened recovery periods, grazing hotspots, concentrated tree removal, longer fuelwood journeys and weak enforcement—that can occur at spatial scales poorly represented by household composites. Disturbance Theory helps explain why frequency, intensity and recovery matter, whereas Common-Pool Resource Theory clarifies why locally legitimate rules and monitoring remain relevant institutional considerations even without a demonstrated statistical moderation effect.

VI. Summary, Conclusions and Recommendations

6.1 Summary of Findings

The study found a high reported level of ecosystem degradation ($M = 3.740$) alongside substantial perceived charcoal, fuelwood and cultivation pressures, but the multivariable model explained only 2.1% of variation in perceived degradation, $F(5, 278) = 1.213$, $p = .303$. Shifting cultivation was the only significant unique predictor ($B = .127$, $SE = .061$, $\beta = .123$, $p = .040$). Grazing, charcoal, fuelwood and governance were nonsignificant, and none of the four governance interactions reached significance. The practical interpretation therefore rests on triangulation: repeated burning and shortened fallows offer a plausible pathway for the cultivation association, whereas grazing hotspots, spatially concentrated charcoal extraction and longer fuelwood journeys help explain why locally reported impacts may not appear as village-wide regression effects. Governance problems were evident qualitatively, but statistical moderation was not demonstrated.

6.1 Conclusions

The study concludes that greater reported shifting-cultivation pressure was associated with greater perceived ecosystem degradation, but it does not establish measured physical deterioration of soil, vegetation or biodiversity. Disturbance Theory provides the strongest explanation: repeated burning and shortened fallows can reduce recovery time, which participants also described qualitatively. The other land-use practices did not show significant unique household-level associations, indicating that their locally reported effects may be spatially concentrated, displaced or insufficiently captured by the perception composites.

Livestock grazing produces spatially concentrated rather than uniformly distributed degradation. The nonsignificant direct coefficient does not negate qualitative evidence of trampling, soil compaction and vegetation loss around heavily used areas. The significant governance interaction shows that grazing outcomes

depend on pasture access, livestock movement, recovery periods and local conflict-resolution arrangements. Rotational grazing and shared governance are therefore more appropriate than blanket herd restrictions.

Charcoal production represents a livelihood–market–governance pathway of ecosystem degradation. Although the direct household-level effect was nonsignificant, the significant interaction and qualitative evidence indicate that tree harvesting, kiln efficiency, commercial demand and weak regulation shape woodland outcomes. Sustainable charcoal policy must address the full value chain through licensing, efficient kilns, replanting, protected species, market monitoring and livelihood diversification.

Fuelwood collection is simultaneously an environmental, energy-poverty and social-equity issue. The significant governance interaction demonstrates that community rules, awareness and alternative energy options condition household biomass pressure. Increasing collection distance can transfer ecological damage away from the residential location and increase time and safety burdens. Woodlots, agroforestry, efficient stoves and affordable alternative fuels should therefore accompany harvesting rules.

Environmental governance did not have a significant direct effect and did not significantly moderate the four land-use relationships in the retained statistical output. Common-Pool Resource Theory remains relevant as an interpretive framework because qualitative accounts emphasized locally legitimate rules, monitoring, participation, customary authority and sanctions. These mechanisms should therefore be treated as theoretically and qualitatively supported governance considerations, not as statistically confirmed moderators in this dataset.

6.2 Policy and practice recommendations

- • Tambura County authorities and customary leaders should support Boma-level natural-resource committees to agree on locally feasible burning calendars, firebreak responsibilities and reporting arrangements. Implementation should use existing community structures and avoid enforcement activities that expose residents or field officers to unnecessary security risks.
- Agricultural and extension actors should promote longer fallows where feasible, agroforestry, crop rotation, mulching and soil-restoration practices that raise yields on existing land and reduce pressure to clear new woodland.
- Community grazing plans should establish rotational use, seasonal resting areas, negotiated livestock movement and alternative water points, with conflict-resolution mechanisms involving livestock owners, farmers and customary leaders.
- Charcoal governance should combine licensing, efficient kiln technologies, designated production areas, protection of priority tree species, replanting obligations, market monitoring and alternative income opportunities rather than relying on enforcement alone.
- • Boma committees, extension actors and humanitarian/development partners should establish community and household woodlots, promote agroforestry and expand low-cost fuel-efficient cookstoves. FAO experience in South Sudan shows that efficient stoves and woodlots can reduce fuel demand and collection burdens, making these options more realistic than abrupt biomass bans.
- • Formal agencies should coordinate with chiefs and Boma-level customary structures through simple, transparent rules that can be monitored with limited transport, staffing and security capacity. Enforcement should prioritize negotiated compliance, restoration and livelihood alternatives before punitive sanctions, especially where insecurity restricts routine field inspection.

6.3 Further Research

Future studies should combine household surveys with direct biophysical measures, including vegetation inventories, soil testing, mapped grazing intensity, kiln-site inventories and fuelwood collection routes. Longitudinal designs are needed to establish whether stronger governance precedes reductions in degradation rather than responding to already degraded areas. Spatial models could test whether grazing, charcoal and fuelwood effects become stronger when measured at the location of extraction rather than the household residence. Comparative research across communities in Western Equatoria State would also determine whether the moderation pattern observed in Ngboko is specific to local institutions or generalizes to other post-conflict settings. Finally, qualitative work should examine gendered energy burdens, customary authority and livelihood substitution in greater depth.

VI. Contributions, Limitations and Future Research

7.1 Theoretical contribution

The study's theoretical contribution lies in connecting disturbance, livelihood and governance perspectives rather than claiming a new environmental theory. The findings show that disturbance-based explanations are incomplete unless they consider the institutions regulating disturbance frequency and recovery time. The significant moderation effects position environmental governance as a boundary condition that changes how cultivation, grazing and biomass extraction are translated into degradation. The study also

demonstrates that livelihood dependence can weaken the effectiveness of formal restrictions when households lack viable alternatives. This integrated interpretation is especially relevant to post-conflict settings where customary and formal institutions overlap and where ecological restoration must coexist with immediate survival needs.

7.2 Empirical and methodological contribution

Empirically, the study provides rare village-level evidence from Western Equatoria State on four traditional land-use practices and ecosystem degradation. Methodologically, it combines 284 household questionnaires with an eight-participant focus group and five institutional interviews, enabling statistical effects to be interpreted alongside local mechanisms. This is particularly valuable where long-term ecological datasets are limited. The study also tests environmental governance as a moderator across four relationships rather than examining governance only as an independent variable. At the same time, the low explanatory power of the final multiple regression is itself informative: perception-based household variation cannot fully represent spatially concentrated and cumulative ecosystem processes, demonstrating the need for multi-scale ecological and social measurement.

7.3 Limitations

The study is limited by its cross-sectional design, reliance on self-reported household perceptions and absence of direct soil, vegetation or biodiversity measurements. Some respondents had relatively short residence periods, potentially limiting observation of long-term environmental change. The study area's post-conflict context, infrastructure constraints and language differences may also have influenced access and reporting. In addition, ecological effects from grazing, charcoal and fuelwood may occur away from household residences, creating spatial mismatch between predictor and outcome measures. The final multiple regression explained a small proportion of variation in ecosystem degradation, so causal claims should be avoided. The reported moderation coefficients should also be checked against the original statistical output as part of final journal submission quality control.

Data Availability Statement

The quantitative and qualitative data underlying this study contain community-level information collected under informed-consent and confidentiality commitments. De-identified data may be made available by the corresponding author on reasonable request and subject to Kabarak University ethical requirements and any applicable permissions from authorities in South Sudan. No public repository link was provided in the dissertation at the time this manuscript was prepared.

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Conflict of Interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript. This statement should be reconfirmed by all authors before submission.

Ethical Approval and Consent to Participate

Ethical approval was obtained from the Kabarak University Research Ethics Committee and relevant authorities in South Sudan. Participation was voluntary and based on informed consent. Confidentiality, anonymity, data security, cultural sensitivity and participants' right to withdraw were maintained throughout data collection and analysis.

Author Contributions

Abel Ochieng Mwalo: Conceptualization, investigation, data curation, formal analysis, methodology, visualization, writing – original draft, and writing – review and editing. Dr. Eliud Michura: Supervision, methodology, validation, and writing – review and editing. Prof. Jackson Kitetu: Supervision, methodology, validation, and writing – review and editing. All authors should review and approve the final CRediT statement before submission.

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Generative AI Statement

During preparation of this manuscript, generative artificial intelligence tools were used solely to support language refinement, grammatical correction, sentence restructuring and formatting. The tools were not used to generate research data, perform statistical analysis, fabricate references or alter study findings. The authors reviewed, verified and approved all AI-assisted content and remain fully responsible for the submitted manuscript.

Abbreviations

Table 11. Abbreviations used in the manuscript.

Abbreviation	Meaning
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
GIS	Geographic Information System
KII	Key Informant Interview
KUREC	Kabarak University Research Ethics Committee
SDG	Sustainable Development Goal
SLF	Sustainable Livelihoods Framework
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environment Programme
WES	Western Ectoria State

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