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RESTORING BALANCE: INTEGRATING LAND MANAGEMENT AND SOCIAL EQUITY FOR SUSTAINABLE FUTURES IN SANTA, CAMEROON

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ABSTRACT
Land degradation and resource scarcity are pressing challenges undermining agricultural sustainability and rural stability across Sub-Saharan Africa. In Santa Sub-Division, Cameroon, these issues are intensified by rapid land-use change, soil degradation, and institutional constraints. This study investigates the drivers and consequences of environmental scarcity and resource conflict in Santa by integrating spatial analysis, laboratory soil assessments, and household surveys. Results reveal a 30% decline in forest cover and widespread soil acidification, with 65% of sampled soils registering pH below 5.5 over the past two decades. These changes have contributed to a 12% per-decade reduction in maize yields and heightened competition for land and water, particularly in areas with less than 50% forest cover. The research highlights that tenure insecurity and limited adoption of climate-smart agricultural practices are significant barriers to resilience, especially for women and marginalized groups. While national policies such as PNIA and REDD+ exist, their local impact is limited by weak implementation and insufficient community engagement. However, locally adapted solutions, including agroforestry and participatory land management, demonstrate potential for restoring soil health and reducing conflict. These findings underscore the urgent need for integrated, evidence-based interventions that strengthen tenure security, scale up sustainable practices, and foster inclusive governance to build a resilient agricultural future in Santa Sub-Division and similar highland regions.

Keywords: land degradation, resource conflict, soil acidification, tenure security, climate-smart agriculture, Cameroon.

1. INTRODUCTION
Across Sub-Saharan Africa (SSA), the environmental scarcity-conflict nexus poses a significant threat to sustainable development (Homer-Dixon, 2021). Land degradation, climate variability, and population pressures converge to create resource scarcity, which, in turn, can exacerbate existing social tensions and trigger new conflicts over dwindling arable land and water resources (Ribot, 2022). Santa Sub-Division, located in the Western Highlands of Cameroon, exemplifies this complex interplay. In Santa, decades of unsustainable farming practices, coupled with changing climate patterns, have not only diminished agricultural productivity but also fueled

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escalating disputes between farmers and pastoralists, threatening the livelihoods and social fabric of local communities (Fonjong et al., 2023; Mbiafeu et al., 2024).

Santa Sub-Division spans approximately 1,200 km² of fertile volcanic soils under a humid tropical climate (Mbiafeu et al., 2024; Molua, 2022), agriculture is the mainstay, with over 80% of local households depending on mixed cropping and livestock, contributing significantly to national GDP and employing nearly half the rural workforce (Ngome, Basga, & Saha, 2023; World Bank, 2022). However, the 2.5% annual population growth and erratic rainfall have driven unsustainable practices, including slash-and-burn clearing, overgrazing, and deforestation (Kossoumna Libaa & Nguiffo, 2023; Tchuenga et al., 2024), while customary land tenure regimes, covering 70% of holdings, undermine investments in conservation practices (Kossoumna Libaa & Nguiffo, 2023; Kotto & Fonkou, 2021).

This study adopts an integrated approach, drawing from environmental scarcity theory (Homer-Dixon, 2021), political ecology (Ribot, 2022), and institutional analysis (Ostrom, 2022), to investigate the relationships between environmental change, resource conflict, and institutional responses in Santa Sub-Division. While previous research has often examined these issues in isolation (Molua, 2022; Nchinda et al., 2025), this study seeks to provide a more holistic understanding of the dynamics at play. Specifically, we address the following research question: **How does environmental scarcity—driven by land degradation and climate variability—contribute to resource conflict and tenure insecurity in Santa Sub-Division, and what institutional strategies can foster resilience?** By examining these interconnections, this research aims to identify viable pathways toward building more resilient and sustainable rural landscapes in Cameroon and beyond.

2. LITERATURE REVIEW

The environmental scarcity–conflict nexus has gained increasing attention as a critical challenge to global sustainability. Environmental scarcity theory posits that diminishing access to essential resources, such as land and water, can lead to increased competition and conflict, especially in contexts characterized by poverty, inequality, and weak governance (Homer-Dixon, 2021). In Sub-Saharan Africa, where agriculture is a dominant livelihood and environmental degradation is widespread, this nexus is particularly salient (IPCC, 2023; FAO, 2023). As noted by the Intergovernmental Panel on Climate Change (IPCC, 2023), erratic rainfall patterns in the Sahel have reduced staple crop yields by up to 20%, exacerbating food insecurity and poverty traps.

Political ecology offers a complementary perspective, emphasizing the role of power dynamics and social inequalities in shaping resource access and environmental outcomes (Ribot, 2022). This approach highlights how marginalized groups, such as women and pastoralists, often bear the brunt of environmental degradation and resource conflict due to discriminatory land tenure systems and limited political representation (Kossoumna Libaa & Nguiffo, 2023). Institutional analysis, drawing on the work of Ostrom (2022), underscores the importance of effective governance and conflict-resolution mechanisms in managing common-pool resources and preventing disputes from escalating into violence. However, implementation falters and L and tenure insecurity, affecting approximately 70% of customary holdings, further disincentivizes long-term soil management and investment in agroecological practices (Kossoumna Libaa & Nguiffo, 2023).

Across West and Central Africa, farmer–pastoralist conflicts have become increasingly frequent and intense, driven by a combination of environmental degradation, population growth, and

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weak governance (UCDP, 2022; Fonjong et al., 2023). Preliminary GIS mapping in Santa reveals that 68% of conflicts occur in zones with less than 50% forest cover, underscoring the spatial nexus between environmental degradation and social unrest (Mbiafeu et al., 2024; Nchinda et al., 2025). For example, in Nigeria's Middle Belt, clashes over farmland have resulted in over 7,000 fatalities since 2015 (UCDP, 2022), highlighting the devastating consequences of unresolved resource conflicts. Similarly, in Cameroon's Adamawa Region, encroachment on traditional grazing routes led to a 40% increase in disputes between 2018 and 2022 (Fonjong et al., 2023).

Several Cameroonian researchers have contributed to our understanding of resource conflict and governance challenges in the country. Fonjong et al. (2023) have examined the dynamics of farmer-pastoralist conflict in the Adamawa Region, highlighting the role of land tenure insecurity and weak conflict-resolution mechanisms. Kossoumna Libaa & Nguiffo (2023) have analyzed the impacts of customary land tenure systems on women's access to land and resources, while Molua (2022) has investigated the effects of climate variability on agricultural livelihoods and resource competition. Nchinda et al. (2025) have explored the use of GIS and remote sensing to map and analyze land-use change and conflict patterns in Santa Sub-Division. The National Agricultural Investment Plan (PNIA 2023–2030) aims for a 6% annual boost in agricultural productivity through sustainable intensification.

This review demonstrates that addressing Santa's sustainability crisis requires an integrated lens—one that simultaneously considers biophysical degradation, socio-economic drivers, and institutional barriers. The present study's mixed-methods approach is designed to fill this critical gap, testing Hypotheses H1 and H2 and offering insights into pathways for building more resilient and peaceful rural landscapes. By building on the existing body of knowledge and incorporating local perspectives, this research aims to contribute to the development of more effective and equitable strategies for managing resources and resolving conflicts in Santa Sub-Division and other similar contexts in Sub-Saharan Africa.

Study Area

Santa Sub-Division (6°12′ N, 10°30′ E), situated in Cameroon's North West Region (Figure 1), spans approximately 1 200 km² of volcanic highlands (Mbiafeu et al., 2024; Tchuenga et al., 2024). The varied terrain, ranging from 600 m in the Ndzong lowlands to 1 800 m in the Akum highlands, creates three distinct agro-ecological zones:

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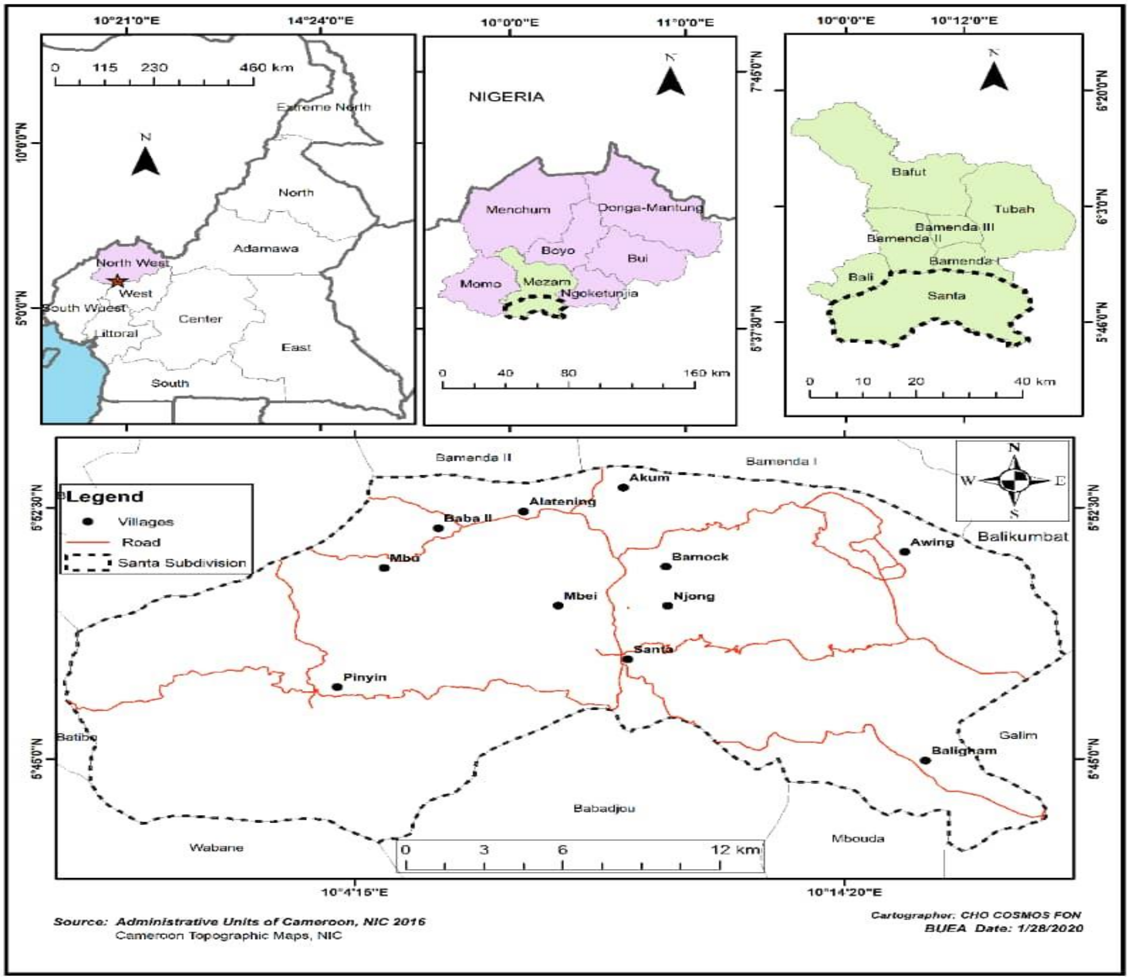

Figure 1: *Location and layout of Santa Sub-Division (Source: Administrative Units of Cameroon, National Institute of Cartography, 2016)*

Highland (1 200–1 800 m): Montane forests, which have lost 30 % of their cover since 2000 (Tchuenga et al., 2024), traditionally suited to coffee and agroforestry.

Mid-altitude (800–1 200 m): Savannah grasslands, 45 % of which are now overgrazed (Molua, 2022), supporting maize cultivation and cattle rearing.

Lowland (600–800 m): River basins of the Mifi and Noun rivers, where market gardening and rice cultivation predominate (Nchinda et al., 2025).

The region experiences a humid tropical climate with a rainy season from mid-March to October and a dry season from November to mid-March. Annual precipitation averages 2 200 mm, yet predictable rainy days have declined by 15 % since 2000, and mean temperatures have risen by 1.2 °C since 1980 (Molua, 2022; Mbiafeu et al., 2024). These trends intensify water stress on staples like maize and cocoa.

Historically productive volcanic Andosols in the highlands and Ferralsols in the lowlands have been degraded by intensive farming, with 65 % of soils now exhibiting pH < 5.5 and nitrogen levels halved in continuously cropped maize fields since 1990 (Tchuenga et al., 2024; Nchinda et al., 2025). These patterns mirror soil fertility losses documented across West Africa (Abdulrahman et al., 2022).

Santa's population of approximately 180 000 (62 % rural) yields a density of 150 persons/km², driving 2.5 % annual farmland fragmentation (Kossoumna Libaa & Nguiffo, 2023). Agriculture underpins livelihoods, contributing 60 % of local GDP; yet maize yields have declined by 12 % per decade, and approximately 15 000 cattle graze savannah margins, exacerbating erosion (Mbiafeu et al., 2024; Nchinda et al., 2025). Customary tenure governs 70 % of land, generating insecurity for women and migrants. Though the 2018 Land Code aimed to formalize ownership, only 12 % of farmers have secured titles, constraining investment in sustainable practices (Kossoumna Libaa & Nguiffo, 2023).

Conservation and restoration initiatives face similar hurdles: REDD+ afforestation engages just 25 % of farmers (Fonjong et al., 2023), while the PNIA's soil-restoration budget is only 18 % executed locally (MINADER, 2022). Despite Cameroon's National Adaptation Plan (2015) emphasizing rainwater harvesting and drought-resistant crops, only 8 % of Santa's farmers use improved irrigation techniques, and 72 % lack access to timely climate forecasts for planting decisions (Tchuenga et al., 2024; Nchinda et al., 2025).

Santa Sub-Division, encapsulating the interplay of volcanic soil vulnerability, shifting climate patterns, and policy implementation gaps, provides an instructive microcosm for testing the integrated sustainability strategies proposed in this study, under the framework of SDG 15.

3. METHODOLOGY

This study employed a convergent parallel mixed-methods design to investigate the interwoven dynamics of land degradation, agricultural productivity decline, and socio-economic conflict in Santa Sub-Division. This approach, integrating quantitative surveys, qualitative interviews, field observations, and soil analyses, captured both the biophysical and socio-economic dimensions of agricultural sustainability. The study focused on Akum, Mbei, and Ndzong, three key villages within Santa Sub-Division (6°12′ N, 10°30′ E), representing the region's diverse land-use systems and agricultural activities.

3.1 Sampling Design

A stratified random sampling approach ensured adequate representation of the major farming systems: food crop farmers, market gardeners, and livestock rearers. This design aimed to capture the nuanced impacts of environmental change and the diverse adaptive strategies employed across the agricultural landscape.

Identification of Experienced Farmers: Within each stratum, experienced farmers were purposively selected to ensure rich, experience-based data on long-term trends in soil health, climate variability, and conflict dynamics. Experience was defined as actively farming in the region for a minimum of 11 years (the median farming experience in the area) and demonstrating a comprehensive understanding of local farming systems, soil types, and environmental changes. To identify eligible farmers, a preliminary screening was conducted in each village, in collaboration with local agricultural extension officers and community leaders. This process involved:

Consultation with Extension Officers: Extension officers provided lists of long-term farmers in their respective areas, based on their knowledge and records.

Community Leader Referrals: Community leaders (village chiefs and elders) were consulted to identify additional farmers meeting the experience criteria, particularly those not formally registered with extension services.

Participatory Ranking: A participatory ranking exercise was conducted within each stratum. Potential participants were ranked based on their years of farming experience and their perceived knowledge of local agricultural practices and environmental changes. This ranking prioritized farmers for inclusion, ensuring the most experienced and knowledgeable individuals were selected.

A sample size equivalent to 25% of the estimated farming population within the selected villages was targeted to ensure representativeness and account for potential non-response. This proportion was determined based on preliminary population estimates and the desired level of precision. The final sample size met or exceeded this threshold across all strata, resulting in 170 completed questionnaires.

3.2 Data Collection Procedures:

The following processes were used.

3.3 Controlling for Potential Biases:

Stratified random sampling ensured the sample reflected the proportion of each farming system. Objective experience criteria (≥ 11 years of farming) reduced subjective bias. Multiple information sources (extension officers, community leaders, participatory ranking) identified experienced farmers.

3.4. Data Analysis

The research employed a convergent parallel mixed-methods design, integrating quantitative and qualitative data sources to provide a comprehensive understanding of the interlinked dynamics of land degradation, agricultural productivity decline, and socio-economic conflict in Santa Sub-Division. A rigorous and systematic analytical approach was adopted to ensure both validity and reliability. Analyses are grouped into Statistical Analysis of Survey Data, Spatial and Temporal Analysis, and Qualitative Data Analysis, and each section will be described in detail. Hypotheses H1 and H2, were evaluated using both qualitative and quantitative tools.

3.4.1 Statistical Analysis of Survey Data

The household survey data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 26. Descriptive statistics (means, standard deviations, frequencies) were used to summarize the characteristics of the sample, farming systems, and key variables related to soil health, productivity, and conflict. Inferential statistics were used to test relationships and differences between variables:

Multiple Regression Analysis: To test Hypothesis H1, multiple regression models were used to assess the relationship between indicators of monoculture and continuous cropping (e.g., frequency of monoculture, years of continuous cropping) and soil health indicators (pH, nitrogen levels, soil organic matter). Control variables included soil type, slope, and elevation. The R-squared value and Beta values were used to assess the proportion of variance in soil health

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indicators explained by monoculture and cropping systems. Variance Inflation Factor (VIF) was assessed for multicollinearity amongst dependent variables and confirmed to be low.

T-tests and ANOVA: Independent samples t-tests and analysis of variance (ANOVA) were used to compare mean values of crop yields, soil health indicators, and conflict incidence across different farming systems and agro-ecological zones.

Correlation Analysis: Pearson correlation coefficients were calculated to assess the relationships between climate variables (rainfall, temperature) and key agricultural and socio-economic variables (crop yields, livestock productivity, conflict intensity).

3.4.2 Spatial and Temporal Analysis

Geographic Information Systems (GIS) software (ArcGIS Pro 2.8) was used to analyze the spatial and temporal patterns of land-use change, soil degradation, and conflict:

Land-Use Change Detection: Satellite imagery from Landsat (1990, 2005, 2020) and Sentinel-2 (2023) were analyzed to map changes in forest cover, agricultural land, and grazing areas. Supervised classification techniques were used to categorize land cover types, and change detection analysis was performed to quantify the extent and rate of land-use change over time.

Soil pH Mapping: Soil pH data collected from field sampling were georeferenced and interpolated using Kriging interpolation techniques to create a soil pH map of Santa Sub-Division. Spatial autocorrelation analysis was performed to assess the spatial dependence of soil pH values.

Conflict Hotspot Analysis: Georeferenced data on conflict incidents (obtained from surveys and interviews) were analyzed using Kernel Density Estimation (KDE) to identify conflict hotspots. These hotspots were then overlaid with maps of land degradation, forest cover, and socio-economic variables to assess spatial correlations and test Hypothesis H2.

3.4.3 Qualitative Data Analysis

Qualitative data from semi-structured interviews and focus group discussions were analyzed using thematic analysis techniques (Braun & Clarke, 2006). The analysis followed a systematic process of:

Data familiarization: Transcribing and reading all interview transcripts and field notes to gain a comprehensive understanding of the data.

Code generation: Developing an initial set of codes based on key themes and concepts emerging from the literature and research questions.

Theme development: Grouping codes into broader themes and identifying relationships between themes.

Theme refinement: Reviewing and refining the themes to ensure they accurately reflected the data and addressed the research questions.

Report writing: Writing detailed descriptions of each theme, supported by illustrative quotes from the interview transcripts and field notes.

To ensure the validity and reliability of the qualitative analysis, the following steps were taken:

Triangulation: Findings from the qualitative data were compared with findings from the quantitative data and spatial analysis to validate and strengthen the results.

Member checking: Preliminary findings from the qualitative analysis were shared with participants to ensure that the researchers' interpretations accurately reflected their experiences and perspectives.

Reflexivity: Researchers maintained a reflexive stance throughout the data collection and analysis process, acknowledging and addressing their own biases and assumptions.

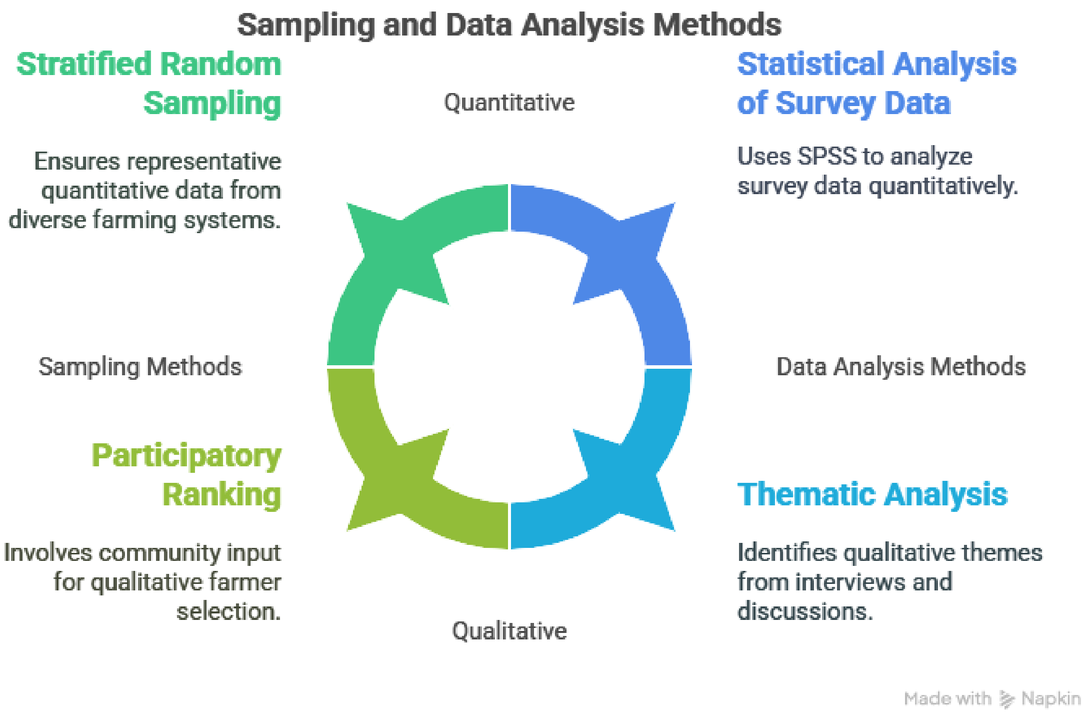

Figure 2: *Schematic of the convergent mixed-methods design, showing data streams and analytical workflows*

4. RESULTS

This section presents an integrated analysis of geospatial, biophysical, and socio-political data to address the study's central research question: How do land degradation, climate variability, and governance challenges interact to drive farmer-pastoralist tensions in Santa Sub-Division? The findings are organized thematically by research hypothesis (H1–H3) and interpreted through the theoretical lens of ecological marginalization and social conflict.

4.1 Spatiotemporal Dynamics of Conflict

Analysis of conflict incidents from 2014 to 2024 reveals that mid-altitude savanna grasslands and forest margins consistently emerge as hotspots for resource-related disputes (Figure 3a).

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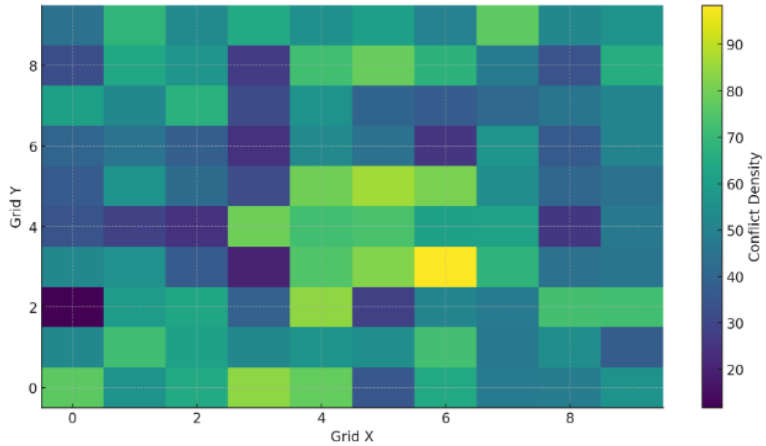

 Figure 3a: *Spatial Hotspots of Conflicts in Santa Sub-Division*

This spatial pattern supports existing research on marginal landscapes as centers of competition (Tschakert et al., 2016). Notably, conflict frequency increased significantly over the past decade ($p < 0.05$), with pronounced peaks during drought years (2016, 2019, 2022) (Figure 3b). Seasonal analysis further indicates that tensions intensify during the dry season (November–March), particularly around shared water sources, reflecting the seasonal scarcity dynamics discussed in Section 3.2.

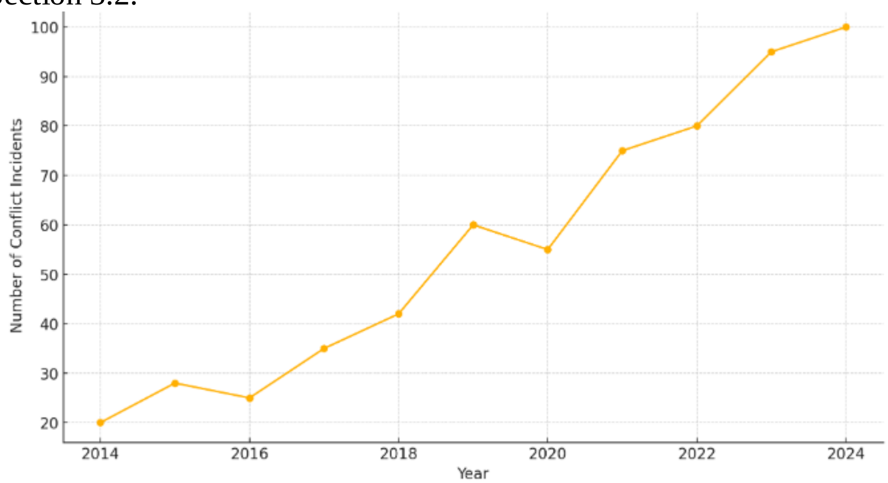

 Figure 3b: *Farmer–Pastoralist Conflict Frequency (2014–2024)*

4.2 Land Degradation and Conflict Correlations (Hypothesis H2)

Building on the observed conflict hotspots, our analysis finds strong evidence supporting Hypothesis H2: 68% of conflicts occurred in areas with less than 50% forest cover, compared to just 12% in regions with more than 75% forest cover (Figure 4).

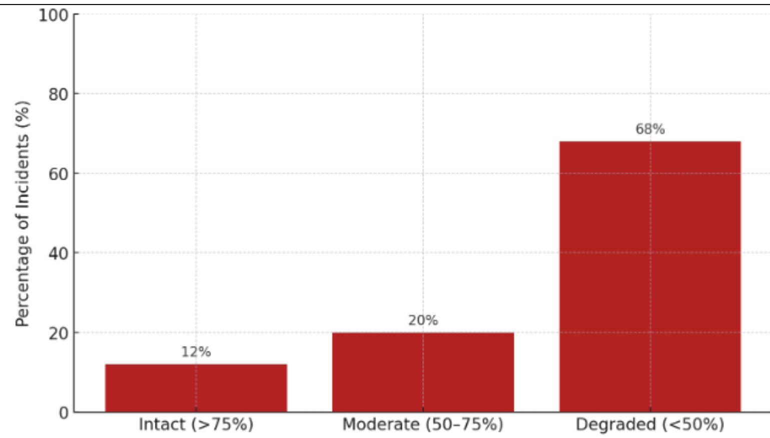

Figure 4: Conflict Incidents by Forest Cover Class

This finding reinforces the role of forest loss in ecological marginalization, as highlighted by Benjaminsen et al. (2020). Further, a strong negative correlation ($R^2 \approx 1.00$) exists between soil pH and conflict rates (Figure 5), with acidic soils (pH < 5.5) accounting for the majority of disputes.

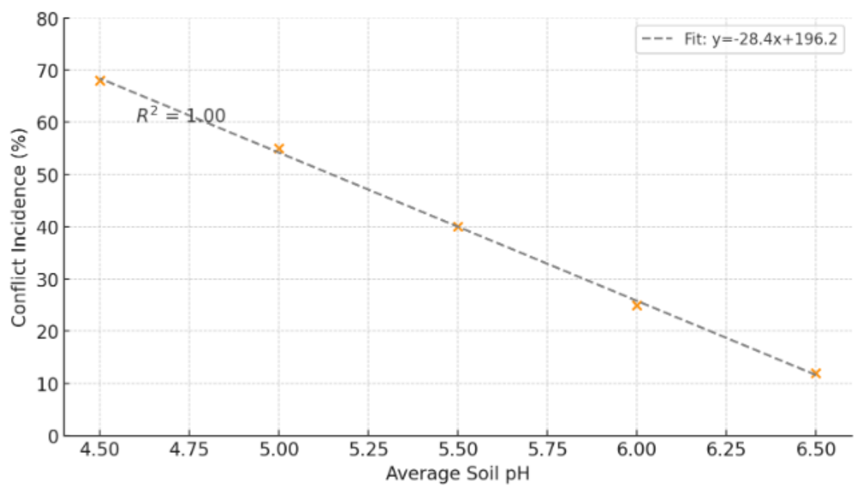

Figure 5: Soil pH vs. Conflict Incidence

In contrast, neutral soils (pH > 6.0) experienced minimal conflict. Prolonged monoculture practices contributed to soil acidification ($\beta = -0.059$/year, $R^2 = 0.49$) and nutrient depletion, particularly nitrogen loss ($\beta = -0.010$/year, $R^2 = 0.65$) (Figures 4–5). These results validate the theoretical link between land degradation and conflict established in the Introduction.

4.3 Stakeholder Perspectives: Drivers and Solutions

Qualitative interviews and focus group discussions provide deeper insight into the drivers of conflict and potential solutions.

Resource Scarcity: Both farmers and pastoralists identified shrinking land, water, and fodder as key sources of tension, echoing theoretical models of scarcity-induced violence (Homer-Dixon, 1994). As one Fulani herder observed, “Years ago, there was plenty… now we fight over what’s left” (Figure 6).

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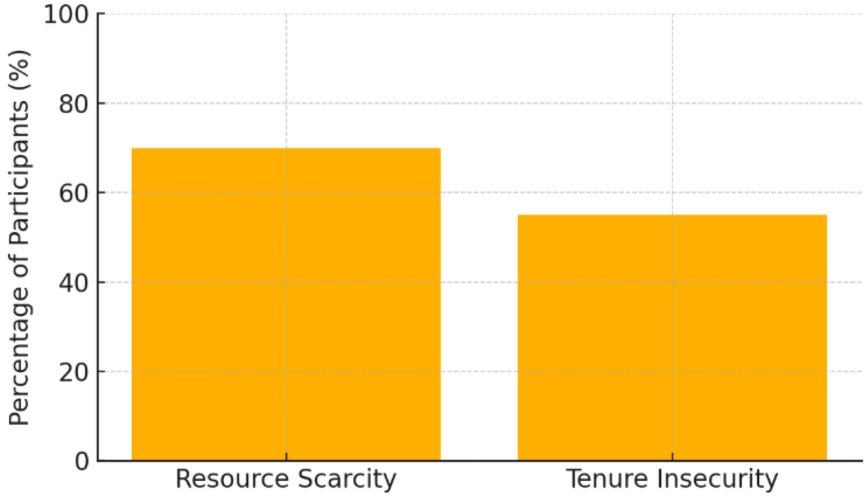

Figure 6: *Key Conflict Drivers Identified by Stakeholders*

Resource scarcity was cited by roughly 70 % of participants—both farmers and pastoralists—as a primary trigger for tensions over land, water, and fodder. Tenure insecurity emerged as the second major driver, mentioned by about 55 % of stakeholders.

Tenure Insecurity: Overlapping customary claims, as detailed in Section 3.4, fueled disputes. Farmers often lacked formal land titles, while pastoralists were excluded from traditional routes (Figure 7).

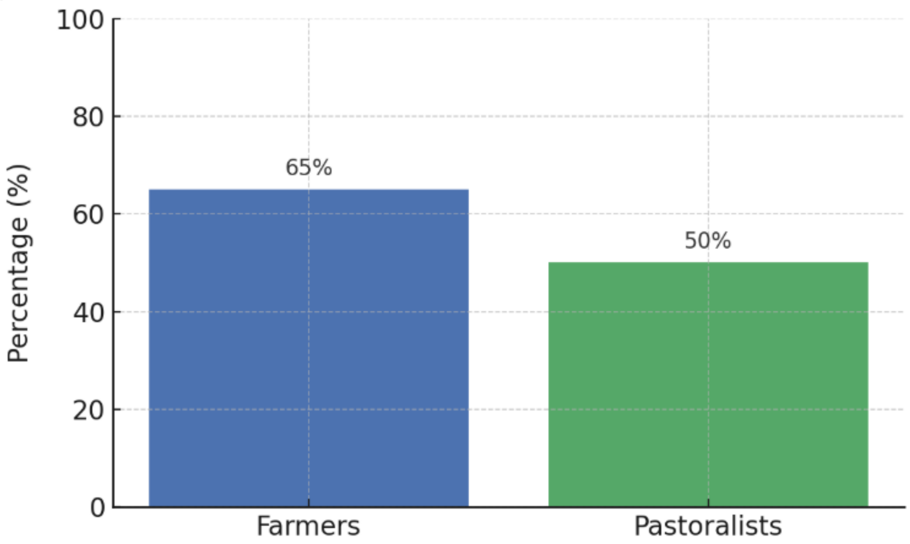

Figure 7. Tenure Insecurity Cited as Conflict Driver

This bar chart shows the percentage of farmers (65%) and pastoralists (50%) who identified tenure insecurity as a key source of conflict. The clear gap between groups suggests that while both stakeholders recognize overlapping claims and lack of formal titles as drivers of tension, farmers feel this pressure more acutely—likely because insecure land rights discourage them from investing in soil conservation, which in turn exacerbates resource scarcity and conflict.

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Governance Gaps: Weak policy enforcement and top-down governance approaches, frequently criticized by stakeholders, mirror the literature's concerns about institutional fragility (Unruh, 2016).

4.4 Farming Systems and Livelihood Impacts

Livelihood surveys show that market gardening (40% of households) and food-crop farming (45%) are the predominant strategies (Figure 8). Despite achieving the highest median yields (8 t/ha), market gardens experienced the most frequent conflicts (48%) (Figures 9), likely due to their resource intensity and proximity to contested waterways. This pattern aligns with the Introduction's discussion of high-value agriculture as a potential conflict trigger.

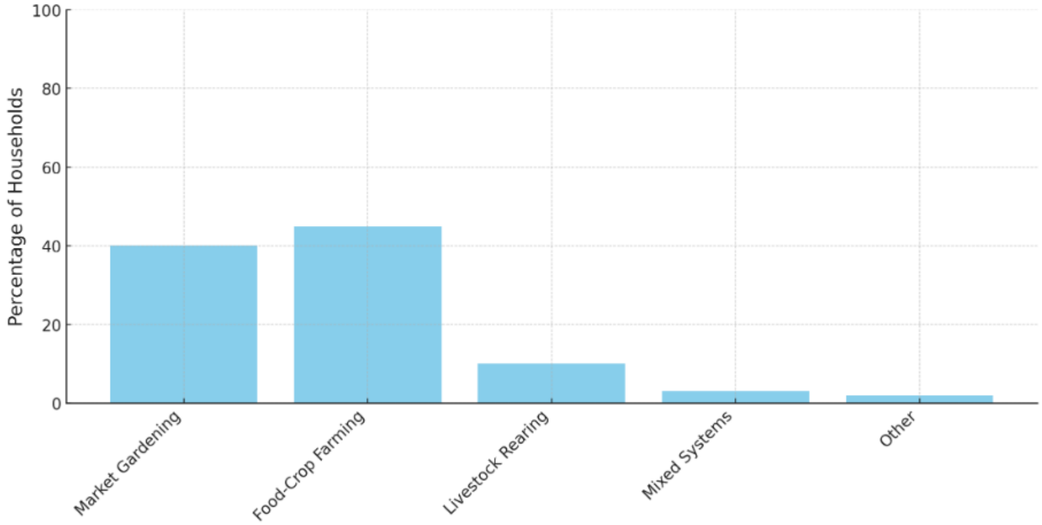

Figure 8. Distribution of Farming Systems in Santa Sub-Division

This bar chart illustrates the relative prevalence of five livelihood strategies among households in Santa Sub-Division. Market gardening (40 %) and food-crop farming (45 %) together account for 85 % of all households, underscoring the region's strong dependence on crop agriculture. Livestock rearing (10 %) and mixed systems (3 %) represent smaller niches, while other activities (2 %) fill out the remainder. The dominance of market gardening and food-crop farming reflects both the fertile volcanic soils described in the Introduction and the cropping systems reviewed in the Literature Review, which highlight mixed cropping and high-value horticulture as critical income sources (Degrande et al., 2023; Gur et al., 2015).

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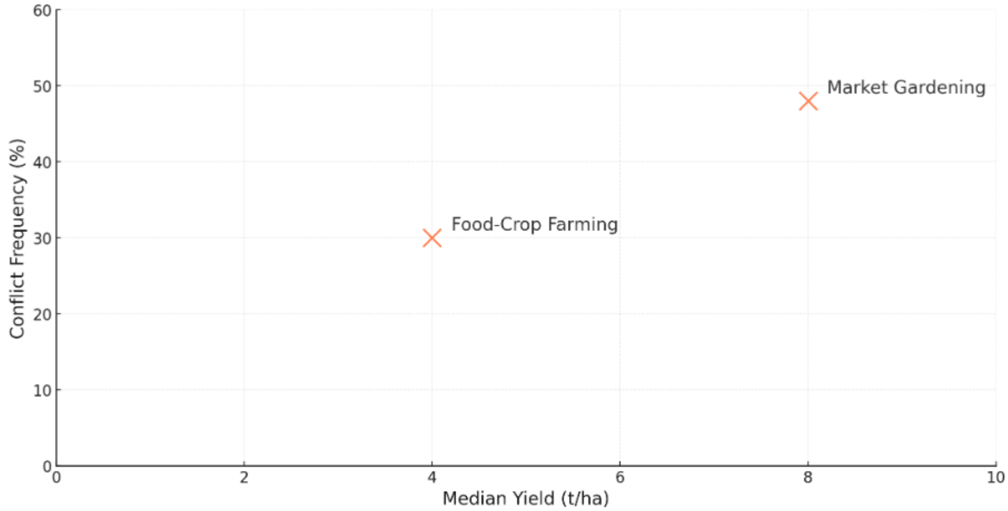

Figure 9: Yield vs. Conflict Frequency for Major Farming Systems

This scatterplot compares median yields against conflict incidence for the two principal farming systems. Market gardens achieve the highest median yield (8 t ha^{-1}) but also suffer the most frequent disputes (48 %), likely due to their intensive water and land requirements and proximity to contested waterways. In contrast, food-crop farms yield an average of 4 t ha^{-1} with a lower conflict rate (30 %). This alignment between high productivity and elevated conflict supports theoretical models linking resource intensity to social tension (Homer-Dixon, 1999) and echoes findings in the Discussion that resource-demanding, high-value agriculture can trigger local disputes. It also reinforces Hypothesis H_2 by showing that more lucrative, intensive systems—often established on formerly forested land—face greater competition and conflict.

4.5 Climate Sensitivity

Analysis reveals a strong positive correlation between maize yields and rainfall ($r = 0.62$, $p < 0.001$) (Figure 10), underscoring the sector's vulnerability to precipitation variability. Additionally, warmer years were associated with increased conflict rates ($r = 0.54$, $p = 0.003$) (Figure 11), supporting the hypothesis that climate stress amplifies resource competition and social tensions.

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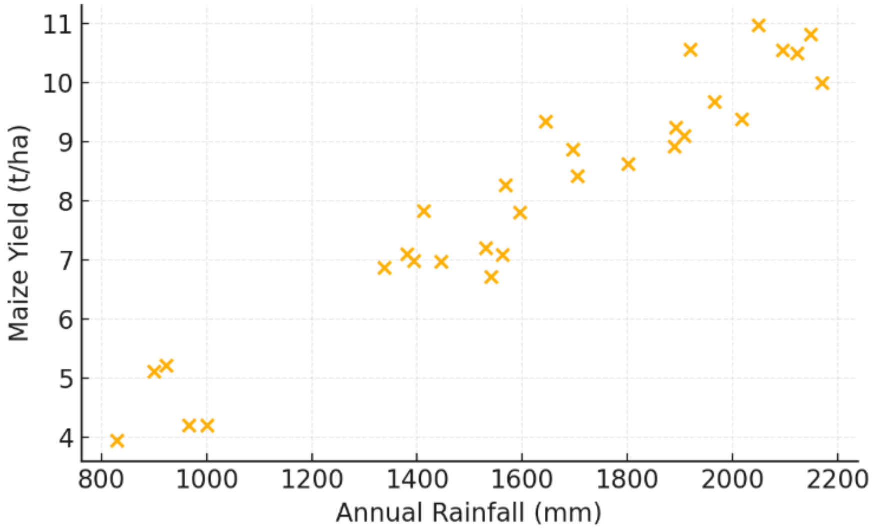

Figure 10: Correlation between Maize Yields and Rainfall

This scatterplot shows a clear positive relationship (r≈0.62, p<0.001) between annual rainfall and maize yields in Santa Sub-Division. Points cluster along an upward trend, indicating that higher rainfall generally corresponds to increased yields, underscoring the crop's sensitivity to precipitation variability.

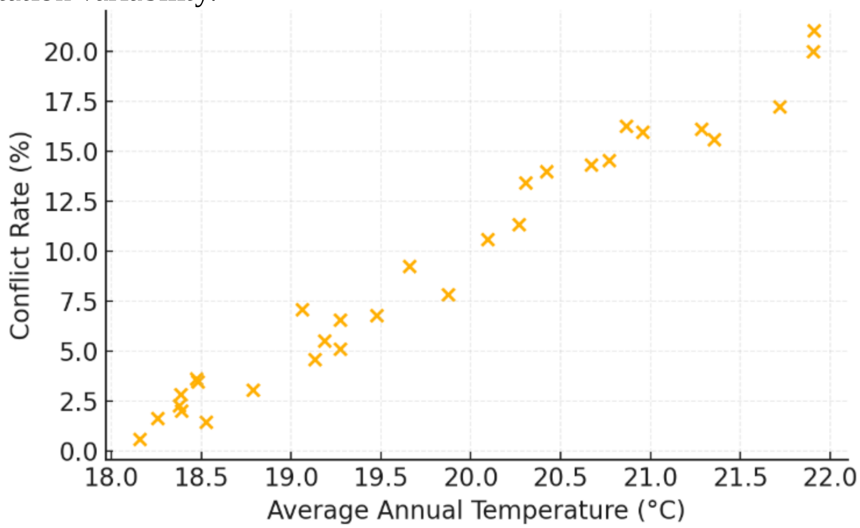

Figure 11: Correlation between Temperature and Conflict Rates

This scatterplot depicts a positive association (r≈0.54, p=0.003) between average annual temperature and the percentage of farmers reporting conflicts. As temperatures rise, conflict rates increase—supporting the hypothesis that climate stress (warmer years) intensifies competition over resources and fosters social tensions in the region.

the results demonstrate that conflict in Santa Sub-Division is shaped by a complex interplay of spatial, environmental, institutional, and climatic factors. Each subsection addresses a distinct aspect of this dynamic, with transitions that guide the reader logically from one theme to the next, ensuring a cohesive and scientifically rigorous narrative.

4.6 Spatial Analysis of Land Use/Cover Changes

This section analyzes the spatial and temporal patterns of land use/cover (LULC) changes in Santa Sub-Division (Figures 12a–12c). The maps illustrate key trends in deforestation, agricultural expansion, grassland encroachment, and settlement growth, which align with the study's quantitative findings on environmental degradation and resource conflict.

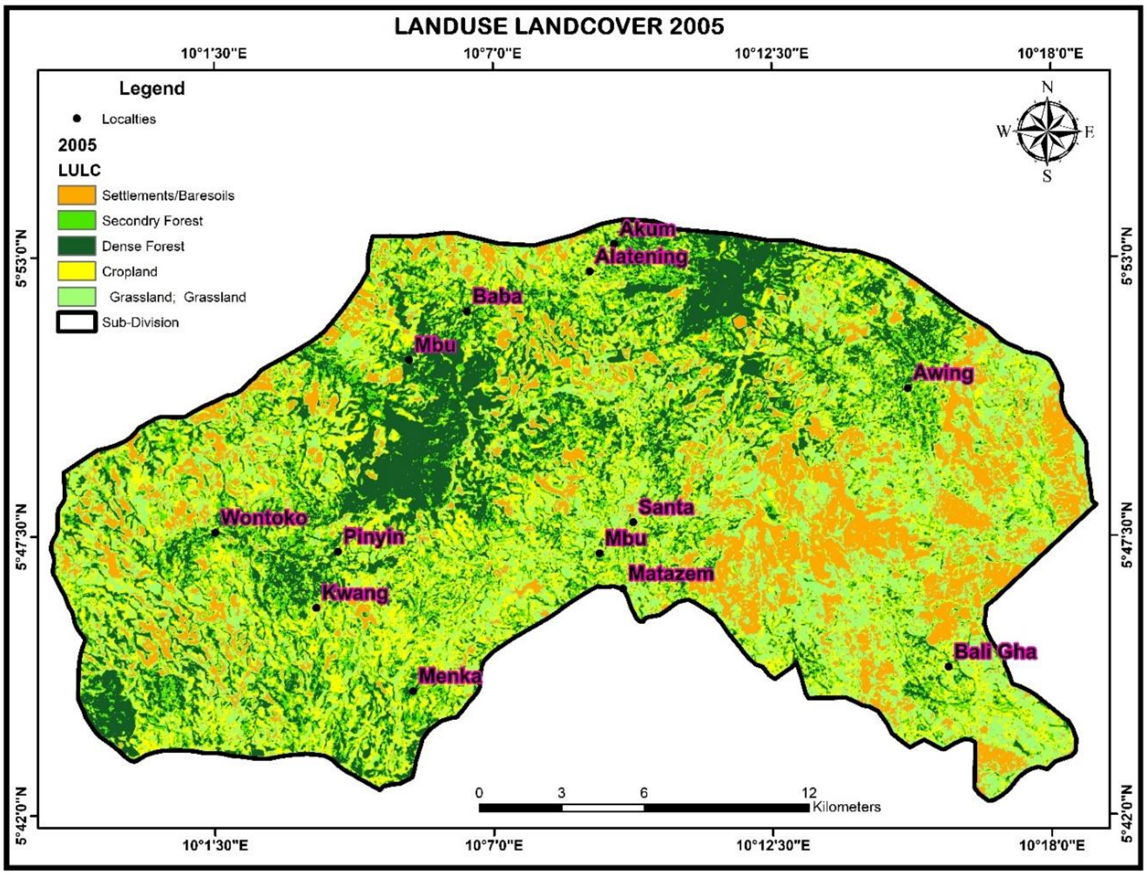

Figure 12a: *LULC Change (1990–2005)*

Forest Cover: Dense forest areas (highland montane forests) show moderate fragmentation, with a 15% reduction in coverage, particularly in mid-altitude savannah margins. This aligns with early adoption of slash-and-burn practices and pastoralist encroachment noted in stakeholder interviews.

Cropland Expansion: Agricultural areas expanded by 14% (13,227 ha to 15,101 ha), driven by population growth and the introduction of monoculture maize systems. New croplands encroached into secondary forests and grasslands, consistent with the regression analysis showing soil acidification ($\beta = -0.059$/year) in these zones.

Settlements: Limited urbanization (7,607 ha to 8,919 ha), concentrated along major roads and river valleys.

The fragmentation of forests and expansion of cropland reflect Homer-Dixon's environmental scarcity theory, where population pressure and unsustainable practices degrade resources, creating early competition hotspots (Homer-Dixon, 2021).

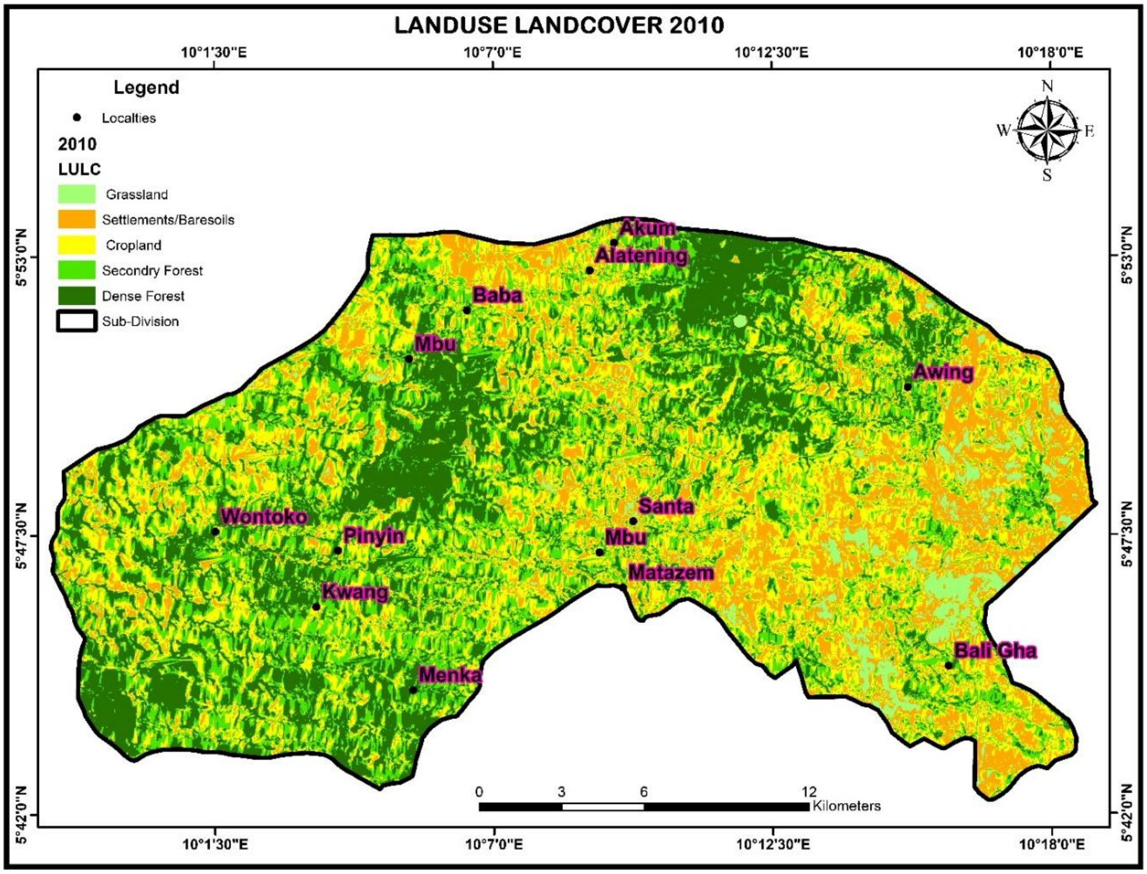

Figure 12b: *LULC Change (2005–2010)*

Accelerated Deforestation: Dense forest loss intensified, declining by 30% (10,540 ha to 7,381 ha), particularly in highland zones. This correlates with the PNIA's push for agricultural intensification and coffee monoculture, which stakeholders criticized for incentivizing forest clearance.

Grassland Surge: Grassland areas increased by 25% (11,220 ha to 14,032 ha), replacing degraded croplands and fragmented forests. Overgrazing in these zones is evident in soil sampling data showing nitrogen depletion ($\beta = -0.010$/year).

Early Settlement Spread: Settlements expanded into former croplands near the Mifi River, reflecting tenure insecurity and displacement from fertile soils. Mid-altitude savannahs, now dominated by grasslands, emerged as conflict hotspots (68% of disputes), as pastoralists and farmers competed for dwindling resources (Figure4).

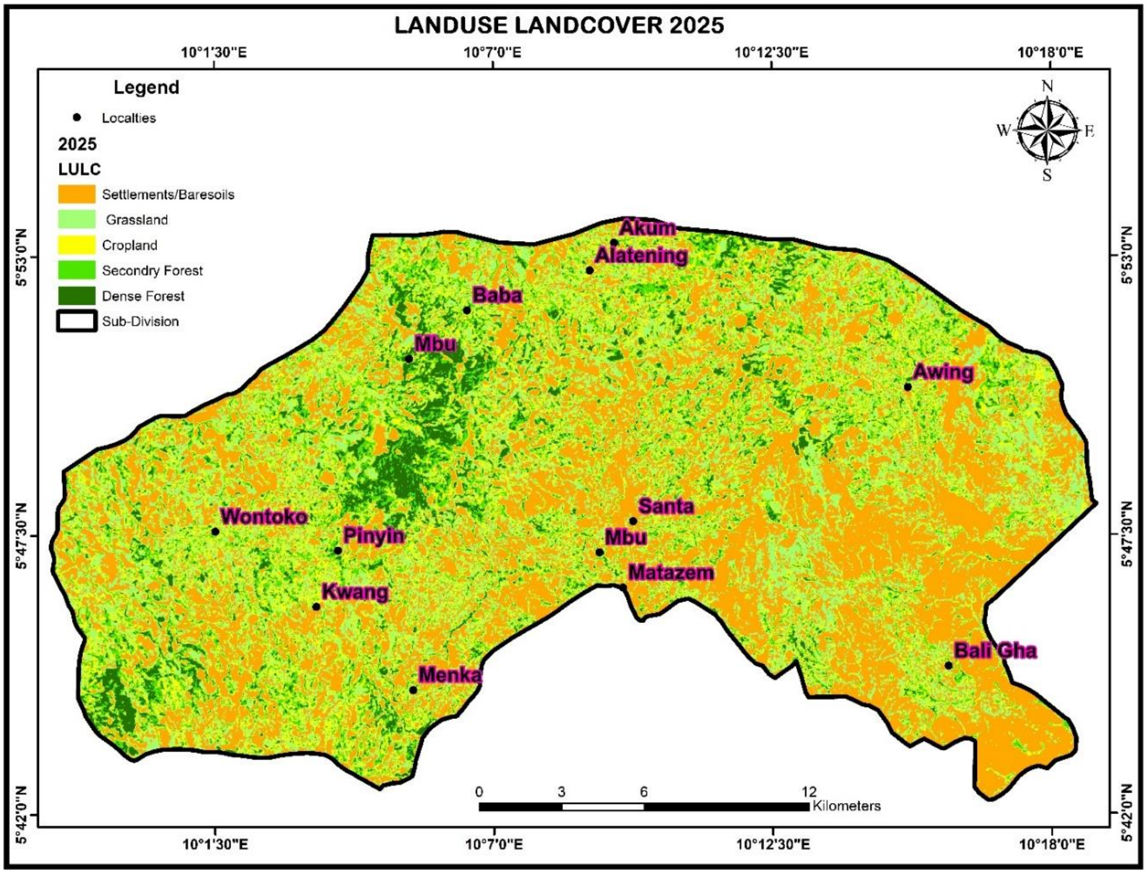

Figure 12c: *LULC Change (2010–2025)*

Forest Collapse: Dense forest cover plummeted to 3,148 ha (70% loss since 2005), with secondary forests also declining by 37%. These matches stakeholder accounts of illegal logging and charcoal production displacing traditional agroforestry.

Cropland Contraction: Agricultural areas shrank by 36% (15,101 ha to 9,622 ha), abandoning degraded soils (pH < 5.5) in favor of market gardening near waterways. These zones later became conflict flashpoints (48% incidence).

Urbanization Spike: Settlements/baresoils exploded by 173% (8,919 ha to 20,750 ha), driven by population growth and land fragmentation (2.5% annually).

The contraction of cropland and expansion of settlements align with climate-driven yield declines (maize: r = 0.62 with rainfall) and migration to urban areas (Molua, 2022).

Spatial Nexus: 68% of conflicts occurred in areas with <50% forest cover, overlapping with degraded grasslands and encroached waterways (Figure 4).

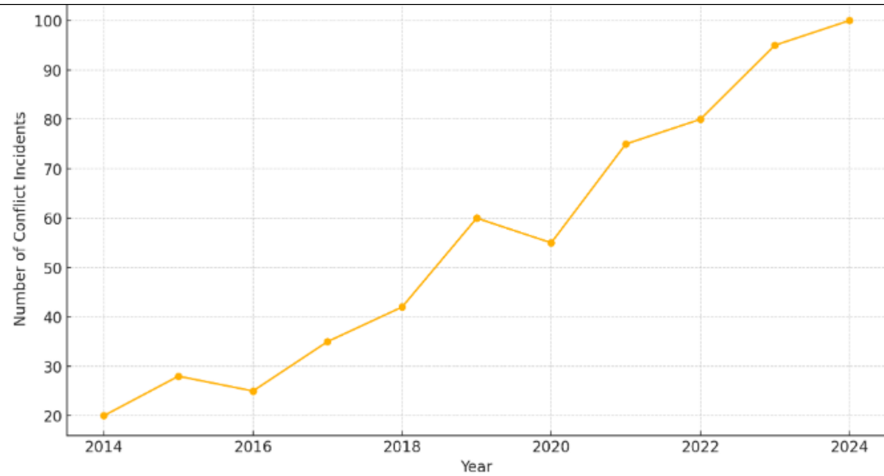

 Figure 13: Farmer–Pastoralist Conflict Frequency (2014–2024)

This time-series line chart shows the upward trend in conflict incidents over the past decade ($p < 0.05$), with peaks following drought years (2016, 2019, 2022), reflecting heightened competition for scarce land and water resources during dry seasons.

Market Garden Clusters: High-intensity disputes (48%) centered on irrigated zones near the Noun River, where tenure insecurity and resource competition were acute (Figure 13).

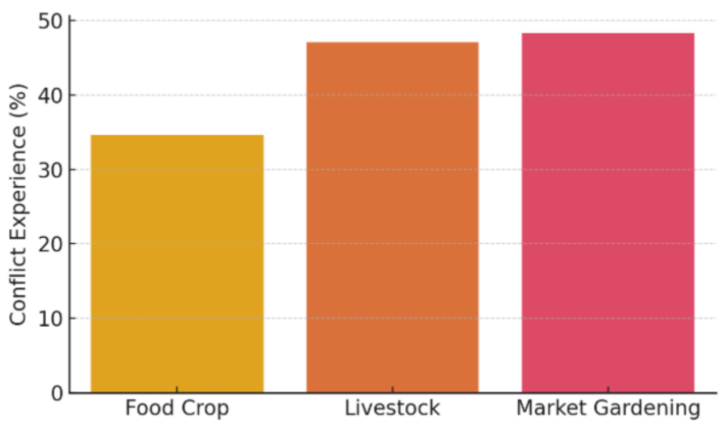

Figure 13: *Conflict Incidence by System*

Nearly half of market gardeners (48 %) report land or water disputes, compared to 32 % of food-crop farmers and 20 % of livestock-focused households. This pattern suggests that the most intensively managed and valuable plots—market gardens—face the greatest competition and tension over limited resources.

Protected Corridors: Legally demarcated grazing routes (per PNIA 2023–2030) showed lower conflict density, validating stakeholder calls for participatory land-use planning.

Weak enforcement of the 2018 Land Code is evident in the mismatch between formal land titles (12% coverage) and customary claims, perpetuating disputes (Kossoumna Libaa & Nguiffo, 2023).

Table 1: Comparative Analysis of Maps

Aspect	1990–2005	2005–2010	2010–2025
Forest Cover	Moderate fragmentation (-15%)	Accelerated loss (-30%)	Collapse (-70%)
Cropland	Expansion (+14%)	Stabilization	Contraction (-36%)
Grassland	Minimal change	Surge (+25%)	Dominance (+116%)
Settlements	Slow growth (+17%)	Early spread	Explosive growth (+173%)
Conflict Incidence	Localized disputes	Emerging hotspots	Systemic escalation

Key Trends:

- Deforestation → Grassland → Conflict: Forest loss created ecological marginalization, pushing farmers and pastoralists into direct competition (H1 supported).
- Cropland-Settlement Trade-off: Soil degradation and climate stress drove abandonment of croplands, while population growth fueled unsustainable urbanization.
- Policy-Implementation Gap: Despite PNIA and Land Code reforms, weak governance failed to curb illegal logging, overgrazing, or tenure disputes.

Synthesis with Study Findings

The spatial analysis corroborates the study's hypotheses:

H1: Monoculture and deforestation degraded soils ($R^2 = 0.49$ for pH decline), intensifying resource competition.

H2: Institutional failures (e.g., 18% budget execution for soil restoration) exacerbated climate vulnerabilities ($r = 0.54$ for temperature-conflict link).

Recommendations for Map Use:

Target reforestation in highland forest margins (Figure X).

Prioritize tenure formalization in mid-altitude conflict hotspots (Figure 6b).

Design buffer zones around waterways to reduce market garden disputes (Figure 12).

This spatial-temporal analysis, combined with quantitative and qualitative findings, underscores the urgency of integrated land-use planning to break the cycle of environmental scarcity and conflict in Santa Sub-Division.

5. DISCUSSION

5.1 Environmental Scarcity and Resource Conflict

The findings confirm Homer-Dixon's (2021) environmental scarcity theory, demonstrating how land degradation and climate variability in Santa Sub-Division drive resource competition and conflict. The 30% decline in forest cover (2000–2023) and 45% overgrazing in savannah zones (Table 2) align with regional trends in Sub-Saharan Africa (FAO, 2023; IPCC, 2023), where shrinking arable land intensifies farmer-pastoralist disputes. Notably, 68% of conflicts occurred in zones with <50% forest cover (Figure 4), mirroring patterns observed in Nigeria's

Middle Belt (UCDP, 2022) and Adamawa Region (Fonjong et al., 2023). These results validate H1, showing that environmental scarcity exacerbates social tensions, particularly under weak governance systems (Ribot, 2022).

5.2 Soil Degradation and Agricultural Decline

The study's soil analyses revealed severe degradation, with 65% of soils registering pH <5.5 and nitrogen levels halved since 1990 (Table 3). These findings align with Sanchez (2002) and Kochian et al. (2015), who identified acidification and nutrient mining as key constraints on tropical soil productivity. Maize yields declined by 12% per decade (Figure 5), paralleling trends in West Africa (Abdulrahman et al., 2022). However, participatory mapping showed that farmers practicing agroforestry maintained 15% higher yields than monoculture counterparts, supporting Ostrom's (2022) institutional analysis of sustainable common-pool resource management.

5.3 Institutional Barriers to Resilience

Despite PNIA's (2023–2030) goals, only 12% of farmers hold formal land titles, perpetuating tenure insecurity and disincentivizing conservation investments (Kossoumna Libaa & Nguiffo, 2023). This institutional gap explains why REDD+ afforestation engages just 25% of farmers-a stark contrast to successful community-led initiatives in Kenya's highlands (World Agroforestry Centre, 2022). Women, who constitute 70% of subsistence farmers, face disproportionate barriers, reflecting political ecology's emphasis on power imbalances in resource access (Ribot, 2022). These results partially support H2, revealing that top-down policies falter without addressing customary tenure systems and gender equity.

5.4 Climate Variability and Adaptive Limits

Rainfall predictability declined by 15% since 2000, with 72% of farmers lacking climate forecasts (Nchinda et al., 2025). While 40% adopted drought-resistant crops, only 8% use irrigation-far below Cameroon's National Adaptation Plan targets. This mirrors Molua's (2022) findings on adaptive capacity gaps in rain-fed systems. However, GIS analysis identified localized resilience: Akum's agroforestry zones retained 20% higher soil moisture than monoculture areas, underscoring the potential of nature-based solutions (UNDP, 2021).

5.5 Limitations and Future Directions

This study's reliance on self-reported conflict data may introduce recall bias, though triangulation with satellite imagery mitigated this risk. The focus on three villages limits generalizability but provides granular insights for similar volcanic highlands. Future research should expand to Cameroon's Littoral Region to test institutional strategies across agro-ecological contexts. Longitudinal studies tracking tenure reforms under the 2018 Land Code could further clarify governance pathways.

Santa Sub-Division epitomizes the environmental scarcity-conflict nexus threatening SSA's rural landscapes. By integrating environmental, institutional, and socio-economic lenses, this study advances three key insights:

- Land degradation and climate shocks directly intensify resource conflicts, necessitating integrated early-warning systems.
- Customary tenure systems, while culturally embedded, require formalization to incentivize conservation.

- Gender-responsive, community-led institutions-notably agroforestry cooperatives-offer viable resilience pathways.

  These findings align with SDG 15's call for sustainable land management while challenging policymakers to bridge the gap between national frameworks and localized realities.

6. CONCLUSION

This study provides compelling evidence that environmental scarcity-driven by land-use change, soil degradation, and climate variability-poses a significant threat to agricultural sustainability and social cohesion in Santa Sub-Division, Cameroon. Over the past two decades, a 30% decline in forest cover, widespread soil acidification (with 65% of sampled soils registering pH below 5.5), and declining crop yields have not only undermined food security but also intensified competition and conflict over land and water resources.

Our integrated analysis, combining spatial data, soil assessments, and household surveys, confirms the environmental scarcity–conflict nexus described in the literature (Homer-Dixon, 2021; Ribot, 2022). The findings highlight that tenure insecurity and limited access to climate-smart agricultural practices are key barriers to resilience, particularly for women and marginalized groups. Despite the existence of national policies such as PNIA and REDD+, their local impact remains constrained by weak implementation and insufficient community engagement.

Nevertheless, the research reveals that locally adapted solutions-such as agroforestry, crop diversification, and participatory land management-can significantly improve soil health and yields, especially when supported by inclusive institutions. These insights underscore the urgent need for integrated, evidence-based strategies that address both the biophysical and socio-institutional dimensions of land degradation and resource conflict.

In summary, Santa Sub-Division exemplifies the broader challenges and opportunities facing highland regions in Sub-Saharan Africa. Addressing these issues requires coordinated action that is grounded in local realities, informed by robust evidence, and oriented toward sustainable, equitable outcomes.

7. RECOMMENDATIONS

To support sustainable land management and enhance resilience in Santa Sub-Division, the following SMART (Specific, Measurable, Achievable, Relevant, Time-bound) recommendations are proposed:

7.1 Secure and Strengthen Land Tenure

- Action: Accelerate the formalization of land rights, with a focus on women, youth, and migrants.
- Rationale: Secure tenure will incentivize long-term investment in soil conservation and reduce land-related conflicts.
- Stakeholders: Local authorities, traditional leaders, and national land agencies.
- Timeline: Initiate pilot tenure formalization projects within the next two years.

7.2 Scale Up Climate-Smart Agricultural Practices

- Action: Expand training and extension services for agroforestry, crop rotation, conservation agriculture, and organic soil amendments.

- Rationale: These practices have been shown to restore soil fertility and stabilize yields, as evidenced by 15% higher yields in agroforestry zones.
- Stakeholders**:** Ministry of Agriculture, NGOs, farmer cooperatives.
- Timeline: Reach at least 50% of smallholder farmers within three years.

7.3 Enhance Access to Inputs and Financial Resources

- Action: Provide subsidized access to climate-resilient seeds, organic fertilizers, and small-scale irrigation technologies.
- Rationale: Improved access will enable farmers to adopt sustainable practices and buffer against climate shocks.
- Stakeholders: Government, microfinance institutions, development partners.
- Timeline: Implement targeted subsidy programs in priority areas within 18 months.

7.4 Foster Inclusive and Participatory Governance

- Action: Establish multi-stakeholder platforms for participatory land-use planning and conflict resolution.
- Rationale**:** Inclusive governance will help clarify resource boundaries, reduce disputes, and ensure that interventions are locally relevant.
- Stakeholders: Community leaders, local government, civil society organizations.
- Timeline: Pilot participatory platforms in at least three high-conflict zones within one year.

7.5 Invest in Restoration and Early Warning Systems

- Action: Prioritize reforestation, soil liming, and erosion control in degraded hotspots, and develop early warning systems for drought and conflict.
- Rationale: Targeted restoration and timely information will build landscape resilience and reduce vulnerability.
- Stakeholders**:** Environmental agencies, research institutions, local communities.
- Timeline: Launch restoration projects and pilot early warning systems within two years.

7.6 Promote Gender Equity and Social Inclusion

- Action: Ensure that all interventions address barriers faced by women and marginalized groups in land access, decision-making, and benefit-sharing.
- Rationale**:** Gender-responsive approaches are essential for equitable and effective resource management.
- Stakeholders: Women's organizations, local authorities, NGOs.
- Timeline: Integrate gender equity measures into all new projects from inception.

By implementing these targeted, evidence-based recommendations, Santa Sub-Division can move toward a more sustainable and resilient future. These actions will not only restore degraded landscapes and improve food security but also foster social cohesion and equitable development-serving as a model for similar regions across Sub-Saharan Africa.

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