

The gendered effects of agricultural practices on land degradation and restoration in two contrasting agro-ecological zones of Cameroon

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ABSTRACT

Land degradation remains a major challenge to rural livelihoods and ecosystem sustainability across sub-Saharan Africa, with restoration efforts increasingly recognized as both ecological and governance challenges. While growing attention has been paid to gender-responsive restoration, limited research has examined how gendered land governance systems, tenure relations, and socio-ecological contexts shape perceptions of degradation and restoration practices. This study assessed gendered dimensions of land degradation and restoration across two contrasting agroecological zones in Cameroon, Pitoa in the Sudano-Sahelian zone and Balatchi in the humid Western Highlands. Using a mixed-methods approach combining household surveys ($n = 320$), participatory biophysical assessments using the Land Degradation Surveillance Framework (LDSF), and geospatial analysis, the study examined perceptions of degradation, restoration practices, training participation, and factors influencing restoration adoption among male and female land users. The findings reveal both shared and differentiated perceptions of land degradation between men and women. While there was moderate overall agreement on degradation drivers (Kendall's coefficient of concordance (w_t) = 0.64), low within-gender scores ($w_t = 0.30$ for both men and women) highlight substantial intra-group variation. This suggests that gender alone cannot explain the full diversity of perceptions; other intersecting factors, such as age, tenure, education, and livelihood, likely shape individual viewpoints. Women showed stronger engagement in restoration practices linked to soil fertility improvement, including crop rotation, organic manure application, and agroforestry, while men more frequently emphasized market-oriented and input-intensive strategies. However, restoration decisions were strongly shaped not only by gender roles, but also by unequal access to land, labour, financial resources, training opportunities, and decision-making power. The study further demonstrates that access to land does not necessarily translate into secure control over land or restoration benefits, particularly for women operating under customary tenure systems. The results highlight the importance of integrating gender-responsive and rights-based governance approaches into restoration policy and practice. Effective restoration requires not only ecological rehabilitation, but also strengthened tenure security, inclusive participation, and equitable access to restoration resources and benefits. By linking biophysical assessment with gendered land governance analysis, the study contributes to emerging debates on socially inclusive and sustainable land restoration in sub-Saharan Africa.

1. Introduction

In recent decades, the global agricultural landscape has undergone remarkable changes propelled by factors such as population expansion, urban development, climate variability, and unsustainable farming practices (Tarolli and Straffolini, 2020). With the imperative to enhance agricultural production to feed a continuing growing population, there

has been a heightened reliance on land and natural resources, resulting in profound environmental impacts (Steensland and Zeigler, 2021). Among these consequences, land degradation emerges as a critical challenge, posing significant threats to ecosystem health, agricultural sustainability, and food security worldwide. It is estimated that more than a quarter of the Earth's land is degraded, affecting the lives of 3.2 billion people (UNEP, 2025), especially smallholder farmers, people in

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rural communities and the world's poorest populations (Wang and Li, 2019).

Recent global policy frameworks increasingly recognize that land degradation is not only an ecological crisis, but also a governance and social equity challenge. The concept of Land Degradation Neutrality (LDN), promoted under the United Nations Convention to Combat Desertification (UNCCD), emphasizes the need to simultaneously restore degraded ecosystems, strengthen local livelihoods, and improve equitable access to land and natural resources. The Global Land Outlook 2 further highlights that insecure land tenure, unequal access to resources, and weak governance structures are among the major barriers limiting successful land restoration efforts, particularly in smallholder farming systems across sub-Saharan Africa (UNCCD, 2022). These challenges are especially pronounced for women and marginalized groups, whose limited rights to land and decision-making often reduce their incentives and capacities to invest in long-term restoration practices.

Land degradation, characterized by the decline in soil health, loss of biodiversity, and degradation of ecosystem services, represents a multifaceted phenomenon exacerbated by various anthropogenic activities, particularly agricultural practices (Mulinge et al., 2016). The widespread adoption of intensive tillage, monocropping, excessive use of agrochemicals, and deforestation has accelerated soil erosion, nutrient depletion, and desertification, exacerbating the vulnerability of agricultural landscapes to degradation processes (Gomiero, 2016; Gupta, 2019). Soil erosion is the most prevalent form of land degradation, with pronounced hotspots across the drylands (Vågen and Winowiecki, 2019).

Amidst the pervasive concerns surrounding land degradation, there exists a growing recognition of the potential for agricultural practices to serve as catalysts for land restoration and sustainable land management (Critchley et al., 2023). Through the adoption of agroecological principles, conservation agriculture techniques, and ecosystem-based approaches, innovative agricultural practices hold promise for reversing land degradation trends, enhancing soil fertility, and promoting ecosystem resilience (Gnacadja and Wiese-Rozanov, 2016). However, the adoption of sustainable land management and restoration practices is not determined solely by biophysical conditions or technical knowledge. Farmers' willingness to invest in restoration is strongly influenced by tenure security, perceived land rights, and control over productive resources. Several studies have demonstrated that secure land tenure encourages long-term investments in soil conservation, agroforestry, and ecosystem restoration, while insecure or contested rights often discourage restoration efforts because land users may not fully benefit from future returns on investment (Lawry et al., 2017; Chigbu et al., 2019). Because women in rural contexts often hold only secondary or mediated land rights, their agency in restoration decision-making is severely constrained, ultimately blocking the uptake of long-term sustainable land management practices.

Given the complexity of the landscapes and the challenges in designing restoration projects, their successful implementation requires careful planning to minimize conflicts and ensure a balance among the multiple functions of a landscape and all relevant stakeholders. Despite the burgeoning interest in land restoration and sustainable land management, empirical evidence regarding the efficacy and impact of alternative agricultural practices on land degradation and restoration remains limited and context-dependent (Rajesh Kumar and Rekha, 2024). Consequently, there is a growing recognition that effective restoration requires not only biophysical interventions, but also socially inclusive and rights-based governance approaches capable of addressing inequalities in access to land, resources, knowledge, and decision-making. Recent scholarship increasingly emphasizes that restoration outcomes are shaped by power relations embedded within land governance systems, including customary tenure arrangements, gender norms, and institutional structures that influence who participates in restoration, who benefits from restored landscapes, and whose knowledge is recognized in restoration planning (Mansourian, 2018;

Chigbu, 2023; Elias et al., 2025). The impacts of agricultural practices are not uniform across all stakeholders, and gender dynamics which play a crucial role in both land degradation and restoration processes are often overlooked (Okpara et al., 2019; Crossland et al., 2021a). Gender dynamics, including differential access to resources, land tenure rights, and decision-making power, significantly influence the vulnerability of land-users to land degradation (Doss and Meinzen-Dick, 2020; Crossland et al., 2021b). Importantly, access to land does not necessarily imply secure control over land or authority over land-use decisions. Feminist land governance scholarship has consistently shown that women may cultivate land without possessing formal ownership rights or the ability to make strategic decisions regarding tree planting, soil investments, or long-term restoration measures (Agarwal, 1997; Doss and Meinzen-Dick, 2020). Such tenure insecurity can undermine women's incentives to adopt restoration practices whose benefits materialize over longer time horizons. As a result, gender inequalities in land rights are increasingly recognized as a critical barrier to achieving equitable and sustainable restoration outcomes.

Women, who comprise a significant portion of agricultural labourers and smallholder farmers globally, often face greater challenges in accessing land, financial resources, and agricultural inputs compared to their male counterparts (Yang et al., 2018). As a result, they are disproportionately affected by land degradation, with implications for household food security, livelihoods, and overall well-being. Therefore, rural women and men involved in restoration practices have differing perceptions and knowledge (Yang et al., 2018). Gender equality is essential for achieving sustainable and fair restoration outcomes, yet potential synergies between restoration initiatives and gender equality outcomes are rarely addressed in restoration initiatives and implementation (Abera et al., 2023).

In addition, initiatives tend to focus on biophysical aspects while neglecting sociocultural dimensions that account for gender inclusivity (Crossland et al., 2021b). Fortunately, the linkages between gender equality, women empowerment and land restoration are increasingly recognised and attract a lot of interest among researchers and policy makers (Doss, 2018; Okpara et al., 2019). While strategic gender-responsive and socially inclusive approaches have been recognized as vital for achieving balanced representation in sustainable development initiatives, the incorporation of gender dimensions in assessing the causes of land degradation and restoration options, as well as ensuring equal inclusion and empowerment of women and men, still lacks clarity (Okpara et al., 2019; Huyer et al., 2021).

A common approach to gaining insights into land management practices at the farm or plot level is to gather perspectives from those directly impacted or involved in the process (Braitto et al., 2020; Klebl et al., 2024). The majority of assessments concerning land degradation and restoration, as well as the design of measures to address these issues, primarily rely on scientific and empirical approaches, often overlooking the invaluable indigenous knowledge and contributions of farmers (Crossland et al., 2018; Pandit et al., 2020). Recognizing the human dimension of land degradation and restoration underscores the pivotal role of farmers as central actors operating within distinct socio-economic, cultural, and ecological contexts. These socio-economic and cultural contexts are themselves shaped by local land governance systems, including customary tenure arrangements, inheritance norms, and socially differentiated access to productive resources. In many African smallholder systems, restoration decisions are embedded within broader negotiations over land access, authority, and resource control. Understanding how these governance structures intersect with gender relations is therefore essential for designing restoration interventions that are socially legitimate, locally adopted, and sustainable over time.

Despite growing recognition of the importance of gender-responsive restoration, significant knowledge gaps remain regarding how gendered land governance systems influence perceptions of degradation, restoration priorities, and adoption of sustainable land management practices. Existing studies often focus either on the biophysical dimensions of

degradation or on socio-economic aspects in isolation, with limited integration of gendered tenure relations, decision-making power, and ecological outcomes. Furthermore, many restoration initiatives continue to adopt gender-neutral approaches that inadequately capture how differences in land rights, labour responsibilities, access to training, and control over productive resources shape restoration behaviour among women and men (Crossland et al., 2021b; Elias et al., 2021).

Recent global assessments, including the UNCCD Global Land Outlook 2, emphasize that restoration success depends not only on technical interventions, but also on strengthening tenure security, inclusive governance, and equitable participation in land management processes (UNCCD, 2022). However, empirical evidence examining these interactions remains limited in Central African contexts, particularly in Cameroon, where restoration policies are expanding under AFR100 and other landscape restoration initiatives. Moreover, few studies have simultaneously integrated biophysical assessments, geospatial analysis, and gender-disaggregated socio-economic data to examine how men and women perceive degradation, prioritize restoration strategies, and manage restored landscapes under contrasting agroecological conditions.

Addressing these gaps, the present study adopts an interdisciplinary and gender-responsive approach combining biophysical assessments, household surveys, participatory methods, and geospatial analysis to examine land degradation and restoration dynamics across two contrasting agroecological zones in Cameroon. By explicitly integrating gendered perceptions of the individual primarily responsible for managing each sampled plot (hereafter referred to as the "plot manager"), land management practices, and restoration governance dimensions, the study contributes to emerging scholarship on equitable and socially inclusive land restoration. A plot manager was defined as the person who makes key decisions regarding land use, cultivation practices, and restoration strategies on a given plot; this was determined during interviews with household members and field observations.

The specific objectives of this study were as follows: (i) Assess the current status of land degradation across the study sites, taking into account gender-based differences in plot management; (ii) Examine how men and women perceive and value the primary causes of land degradation, the trends observed, and the effectiveness of restoration

practices, thereby addressing gender data gaps; (iii) Identify practical entry points and policy recommendations for promoting gender-responsive and socially inclusive land restoration, with particular attention to women's participation, tenure security, decision-making power, and equitable access to restoration resources and benefits.

2. Methodology

2.1. Study areas and site selection

The research was conducted across two distinct landscapes in Cameroon, chosen purposively to represent varying agroecological characteristics (Fig. 1). These landscapes exhibit contrasting features in terms of climate, soil types, and vegetation profiles: the humid highlands and the Sudano-Sahelian region. Both landscapes are recognized as hotspots for land degradation within Cameroon, as highlighted in the country's strategic framework for landscape restoration (AFR100, 2024). The humid highland region, situated in the western highland agroecological zone, is characterized by higher rainfall and lush vegetation compared to the Sudano Sahelian agroecological zone, which is located in the drier parts of the country. We selected Pitoa and Balatchi as representative study sites for the Sudano Sahelian and humid highland regions, respectively. These sites were chosen to capture the typical environmental conditions and land use practices prevalent in each landscape, allowing for a comprehensive assessment of land degradation and restoration strategies tailored to the specific challenges and opportunities present in these areas.

Both Pitoa and Balatchi sites exhibit a significant degree of biophysical and socioeconomic variability representative of their respective agroecological zones, encompassing diverse land uses, farming systems, and other socio-economic activities. Over time, both sites have witnessed extensive land degradation characterized by soil nutrient depletion - primarily stemming from unsustainable farming practices and the overexploitation of natural resources, as is common in many smallholder farming systems across sub-Saharan Africa (Suh and Tshenko, 2024). These detrimental activities have contributed to the degradation of soil health and fertility, posing significant challenges to agricultural production and environmental sustainability in both regions. Over the

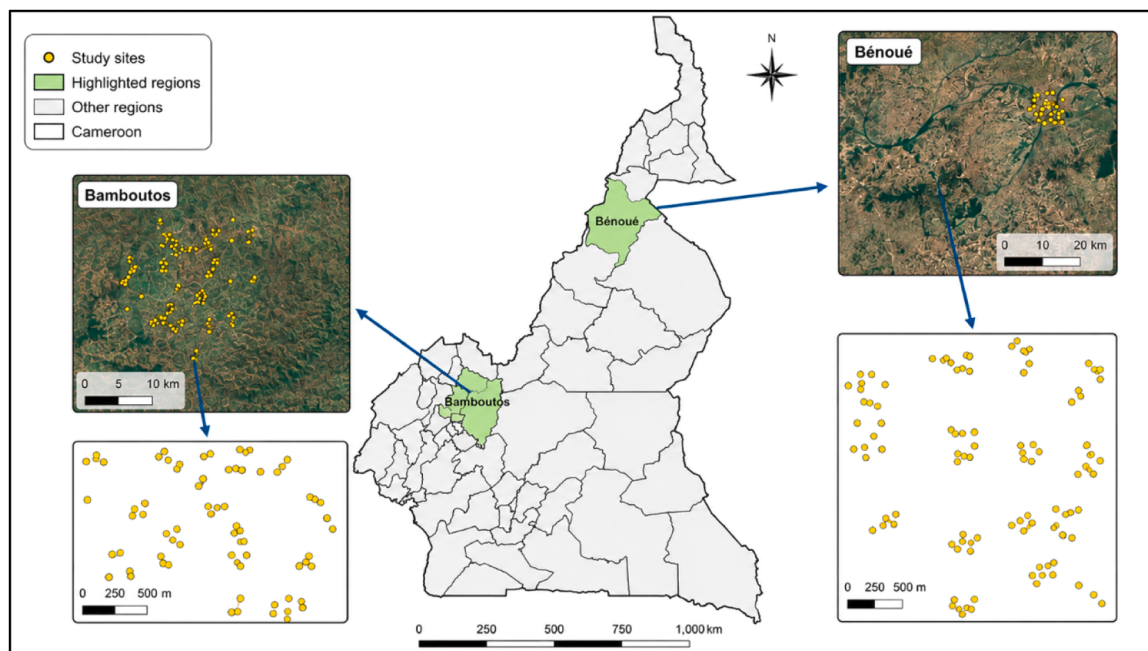


Fig. 1. Map of Cameroon showing the study sites. Soil sampling was done in two 10 km × 10 km sites. Left and right-lower panels zoom in the two sites to show the 160 sampling plots.

past years, the local population in these areas has made substantial investments in restoration efforts aimed at mitigating land degradation. These initiatives encompass a variety of strategies, including the promotion of agroforestry and agroecological practices, soil and water conservation practices, and climate-smart agricultural techniques. Additionally, enclosures have been established as a means of preserving and restoring natural ecosystems. These restoration efforts demonstrate a concerted commitment by local communities to combat land degradation and promote sustainable land management practices, thereby safeguarding the environment and ensuring the resilience of agricultural systems in the face of ongoing environmental challenges.

Farming practices in these areas are primarily characterized by mixed crop and livestock systems, which serve both as a means of subsistence and income generation for households. Small farm sizes are typical, and a significant portion of the population, particularly younger individuals, lack secure access to land for agricultural purposes. Open grazing of livestock is a prevalent practice throughout the year, with animals roaming freely on most lands. This extensive grazing system reflects the traditional livestock management approach in these regions and underscores the integral role of livestock in the livelihoods of local communities. The summary of the physical characteristics of the two sites are presented in [Table 1](#).

2.2. Experimental design

This study adopted a mixed-methods approach that combined biophysical assessments with qualitative and quantitative socio-economic data collection to investigate land degradation dynamics and gendered land management practices. The Land Degradation Surveillance Framework (LDSF) was employed to generate standardized, landscape-level biophysical data, while a range of complementary social science methods was used to capture local knowledge, perceptions, and decision-making processes (Vågen and Winowiecki, 2023).

Multiple data collection techniques were applied, including field surveys and observations, in-depth semi-structured interviews with household members, focus group discussions, non-participant observation, literature reviews, and participatory methods such as transect walks. This triangulation of methods enabled a comprehensive understanding of both environmental conditions and the socio-cultural dimensions of land management. A multi-stage sampling approach was employed for the biophysical assessments. In each study area, a 10 × 10 km site was delineated in accordance with the Land Degradation Surveillance Framework (LDSF) protocol developed by Vågen and Winowiecki (2023). Each site was divided into 16–1 km² clusters, within which 10 plots of 1000 m² were randomly allocated, resulting in 160 plots per site and a total of 320 plots across both sites. Each 1000 m² plot contained four 100 m² subplots for detailed biophysical measurements, allowing for statistical modelling across scales.

Following the field assessments, the 320 LDSF plot owners or managers, defined as the individuals responsible for day-to-day decision-making and land use practices on the plot, were identified and selected for household-level interviews. These interviews, along with focus groups and participatory exercises, provided rich insights into land degradation and restoration practices, as well as the gendered roles and constraints associated with land management in the study sites.

Table 1
Characteristics of study sites.

Sites	Location	Climate	Vegetation	Land use
Pitoea	Sudano Sahelian	Dry, arid conditions, Annual rainfall (800–1200 mm).	Sparse shrubs, grasslands	Extensive grazing, farming
Balatchi	Humid Highlands	Humid and subhumid conditions, Annual rainfall (1500–2500 mm)	Lush vegetation, Forest galleries	Mixed crop-livestock farming

2.3. Data collection

Data collection followed the standardized protocols of the Land Degradation Surveillance Framework (LDSF) for biophysical measurements and household surveys. Fieldwork was conducted across both study sites during May and June 2023; a timeframe chosen to ensure consistency and limit the influence of seasonal variability on the data.

Prior to full-scale data collection, a pilot phase was carried out. This involved pre-testing the LDSF field forms and household survey questionnaires with enumerators to assess their clarity, relevance, and usability. Based on feedback from the pilot, minor revisions were made before the instruments were digitized and deployed using the Open Data Kit (ODK) platform (Hartung et al., 2010). The use of ODK enabled efficient, standardized, and high-quality data collection across all sites. This rigorous and systematic approach helped to ensure the reliability and validity of both biophysical and socio-economic data, thereby enhancing the credibility and robustness of the study's overall findings.

2.3.1. Field surveys

Field surveys were conducted across all 320 plots, with data collected at both plot and subplot levels. At each plot (n = 160 per site), various observations were recorded, including slope (measured in degrees), vegetation structure categorized using the FAO Land Cover Classification System (Gregorio and Jansen, 1998), topographic position (classified as upland, ridge/crest, midslope, footslope, or valley), and land management and land-use history. At the sub-plot level, visible observations of soil erosion types (e.g., gully, rill, sheet, or none) were documented within circular subplots (n = 4 per plot, totalling 640 per site). These observations were used to compute a plot-level severe erosion binary index. For instance, if more than two subplots per plot exhibited visible signs of erosion, the severe erosion index for the plot was recorded as '1'; otherwise, it was designated as '0'. Vegetation measurements were also conducted, with woody and herbaceous cover ratings assessed using the Braun-Blanquet scale ranging from 0 (bare) to 5 (greater than 65% cover) (Braun-Blanquet, 1932). Woody vegetation, comprising trees (woody vegetation above 3 m) and shrubs (woody vegetation between 1.5 and 3 m tall), within each subplot were identified at the species level, counted, and used for density calculations, such as trees or shrubs per hectare.

2.3.2. Household surveys

In addition to the field survey, a semi-structured questionnaire was developed to gather comprehensive information on 320 household gender perceptions related to land degradation and restoration, as well as socio-economic attributes. The respondents consisted of landowners or managers of the LDSF plots who possessed substantial knowledge of the practices implemented on the farms over the past five years. Prior to the interview, each respondent provided consent by accompanying the enumerators to their LDSF plots.

The semi-structured questionnaire comprised three parts and was administered during face-to-face interviews with the respondents on the plot. The first part focused on general information of the surveyed farmers, including age, gender, marital status, educational level, and types of training received. The second part delved into the farmers' perceptions and degree of cognition regarding land degradation, including their assessment of changes in farm productivity over the last five years, the indicators used for such assessment, and the main causes of farm degradation. Respondents were also asked to rate the degradation of their farms on a 5-point Likert Scale, ranging from "very severe" to "no degradation". The third part addressed the respondents' strategies to reverse land degradation and the effectiveness of these practices. This section explored various aspects such as sources of knowledge and information on land restoration practices, types of training received, restoration practices implemented on their farms, and factors influencing their decision-making process when choosing a restoration strategy. These three parts were interrelated, reflecting the farmers'

perceptions regarding the effects of their agricultural practices on land degradation and restoration strategies in the surveyed areas.

2.4. Data analysis

The study employed a combination of descriptive and inferential statistics to analyse the data collected from the field and household surveys. Descriptive statistics were used to summarize and describe the characteristics of the household data, offering insights into key trends, patterns, and distributions. To examine the relationships and agreements between variables, Spearman's rank correlation coefficient was used to measure the ordinal association between pairs of rating sets for the variables. This rank correlation provided insights into the (dis) agreement between men and women within the study sites, enabling a comparison of their perceptions.

Moreover, Kendall's coefficient of concordance (w_t) was employed to assess the degree of agreement or disagreement among multiple sets of ratings provided by men and women for a common set of items or outcomes. The w_t index quantified the ratio of observed variance of the sum of the ratings to the maximum possible variance of a sum of ratings, ranging from zero to one. A lower w_t score indicated a higher degree of disagreement among the ratings provided by men and women, highlighting potential gender dynamics in land degradation assessment. Conversely, a higher w_t score suggested greater similarity in the ratings, indicating a more harmonized understanding of land degradation issues and restoration efforts between genders.

Similar to correlation coefficients, w_t provided valuable insights into the agreement or disagreement among different groups, specifically men and women, regarding their opinions and value judgments related to land degradation assessment and restoration practices. By quantifying the level of concordance or discordance between the ratings provided by men and women, w_t helped elucidate gender dynamics and disparities in the evaluation of restoration outcomes, facilitating more inclusive and equitable decision-making processes in environmental management.

According to Edwards (1954) and Martey et al. (2014), w_t is determined using the following formula:

$$W_t = \frac{12 \sum S_i^2 - 3N(n+1)^2}{N(N^2 - 1)} \quad (1)$$

Where w_t is Kendall's coefficient of concordance, S represents the sum of ranks for the i^{th} item across all raters, N is the total number of raters (males and/or females), n is the number of ratings per rater (number of outcomes). By using both descriptive and inferential statistics, the study comprehensively analysed the collected data, providing a deeper understanding of the factors influencing land degradation and restoration strategies in the study areas. The entirety of the analyses was conducted using the statistical software R version 4.3.2 (R Core Team, 2021), which served as the primary tool for data processing, visualization, and statistical inference throughout the study.

3. Results

3.1. Characteristics of the household respondents in the study sites

Table 2 summarizes the socio-demographic characteristics of respondents in Pitoa and Balatchi. The gender distribution was relatively balanced in both sites, reflecting the study's stratified sampling approach to ensure equitable representation of men and women respondents. In both locations, most respondents were married, though Balatchi had a slightly higher proportion. Marital status can influence access to land and decision-making power, potentially affecting individuals' ability or motivation to engage in restoration efforts. Respondents' ages ranged widely, with the average in both sites in the mid-40s, and a substantial proportion falling within the 30–50-year range—an age group typically active in agricultural production.

Table 2

Socio-demographic characteristics of respondents in Pitoa and Balatchi.

Variable	Category	Pitoa (%)	Balatchi (%)
Gender	Male	57.5	49.4
	Female	42.5	50.6
Marital status	Married	60	55
	Single	25	22
	Widowed/Divorced	15	17
Age	Average (years)	45.7 ± 13	44.5 ± 16
	Aged 30–50	53	41
Education level	No formal education	85	26
	Primary education	9	56
	Secondary education	0	16
	Tertiary or higher	6	3
Land ownership	Own land	68	74
	Tenant or inherited land	20	22

Notably, there were stark differences in educational attainment between the two sites. While the majority of respondents in Pitoa had no formal education, those in Balatchi displayed a more diverse educational profile, suggesting potentially higher literacy rates and greater capacity for accessing information and extension services. Land ownership was relatively high in both areas, although a fifth of the respondents accessed land through rental or inheritance, reflecting varied tenure systems that may shape farmers' incentives and ability to invest in long-term land restoration.

3.2. Ecological characteristics of the LDSF plots

3.2.1. Access to land by respondents

Field surveys conducted between March and June 2023 resulted in the sampling of 160 plots in each of the two sites, Pitoa and Balatchi. Fig. 2 illustrates the spatial distribution of plots managed by male and female respondents at both locations. In Pitoa (Fig. 2a), 93% of plots were classified as cultivated, while in Balatchi (Fig. 2b), the proportion was 85%, indicating that annual cropping systems are the predominant land use in both sites.

The spatial distribution of plots reveals that both men and women are actively managing land across each landscape. As shown in the figure, red and blue dots, representing plots managed by female and male respondents, respectively, are dispersed throughout the sites without clear evidence of gender-specific clustering or segregation. This relatively even geographic spread suggests that access to land is not confined to particular zones by gender. In both sites, men's and women's plots are interspersed rather than isolated, which may reflect relatively equitable access to agricultural land within the surveyed communities.

3.2.2. Tree diversity and farming practices

A total of 22 tree species were identified across the two study sites, with 11 species recorded in Balatchi and 10 in Pitoa (Fig. 3). Tree diversity was generally modest, with few indigenous species recorded. In Pitoa, dominant species included *Azadirachta indica*, *Faidherbia albida*, and *Acacia nilotica*, while in Balatchi, fruit trees such as *Persea americana*, *Mangifera indica*, *Cola acuminata*, and *Dacryodes edulis* were more prevalent. These differences reflect contrasting agroecological conditions, with Pitoa located in the Sudano-Sahelian zone and Balatchi in the humid highlands.

Alongside tree diversity, farming practices also varied between the two sites and between genders. In Pitoa, farming systems were largely characterized by cereal-based monocultures such as millet and sorghum, interspersed with legumes and scattered trees. In contrast, Balatchi farmers practiced more diversified agroforestry systems combining staple crops like maize, cassava, and beans with a higher density of fruit trees and shrubs. Notably, female-managed plots in both locations tended to include more intercropping with short-cycle crops, vegetables, and multipurpose trees, suggesting an emphasis on food and income security at the household level.

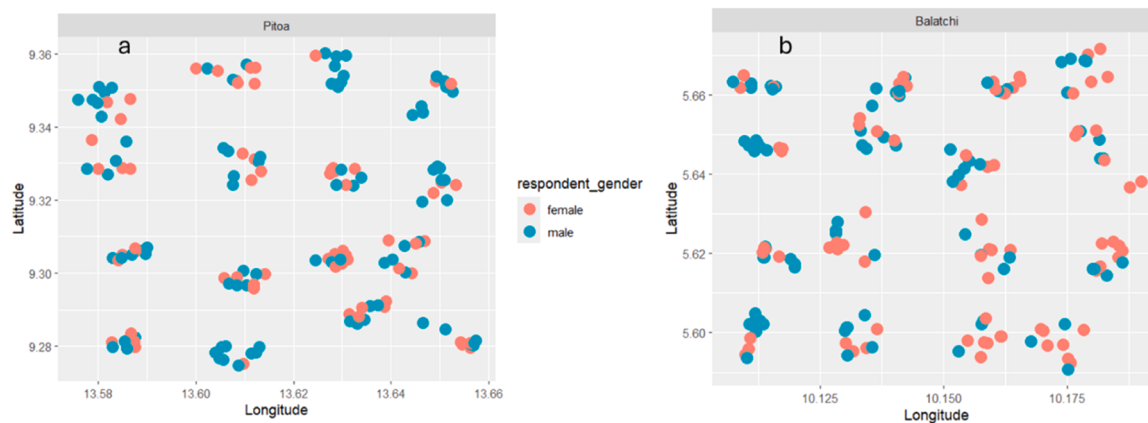


Fig. 2. Spatial distribution of sampling plots in the two study sites: (a) Pitoa and (b) Balatchi. Red dots represent plots managed by female respondents, and blue dots represent plots managed by male respondents.

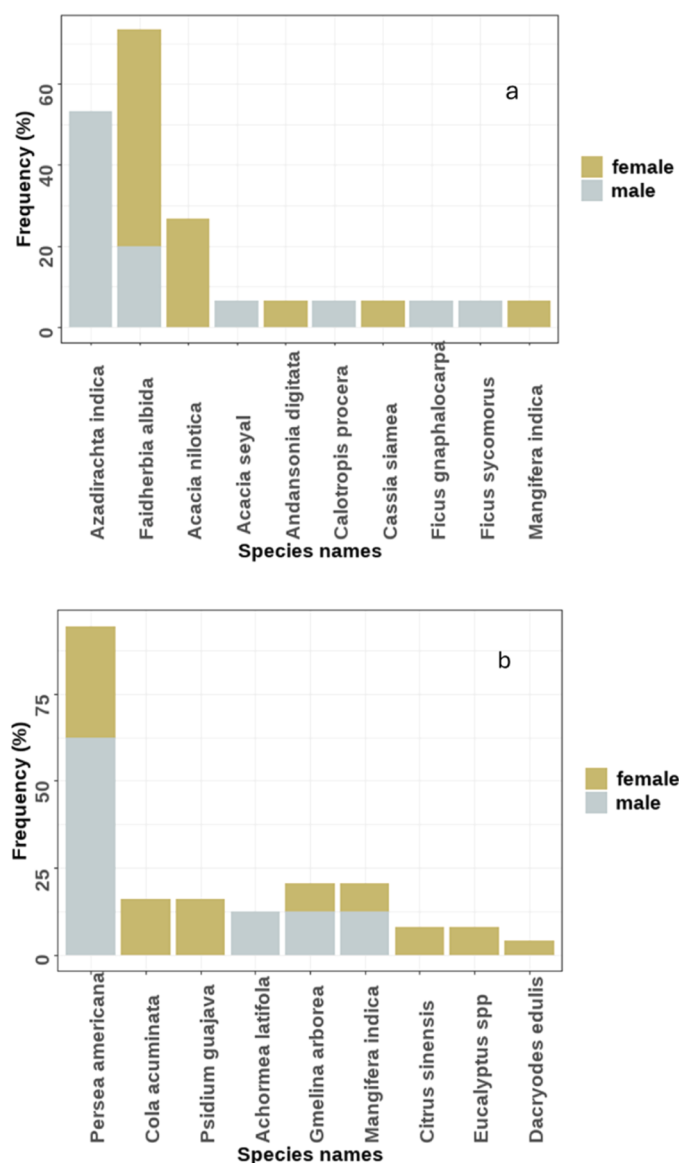


Fig. 3. Frequency of tree species (% of gender-specific plots where each species is present) in plots managed by male and female respondents: a) Pitoa and b) Balatchi.

The analysis of tree species composition in plots managed by male and female respondents revealed notable gender-based differences in tree selection (Fig. 3). Men generally favored species such as *Azadirachta indica* and *Persea americana* for commercial or income-generation purposes. Women, on the other hand, showed preferences for species like *Acacia nilotica* and *Adansonia digitata*, valued for subsistence uses such as fuelwood, soil fertility, fodder, and food products. *Faidherbia albida*, known for its agroecological benefits, was commonly found in plots managed by both men and women. These findings suggest that tree species composition is influenced not only by ecological conditions but also by the types of farming systems and gendered priorities in land use. The observed differences point to distinct strategies in crop-tree integration, which have implications for land restoration and sustainable management practices.

3.3. Gendered perceptions of land degradation

3.3.1. Causes of land degradation

An analysis of the perceived causes of land degradation reveals distinct gendered perspectives across the two study sites, with significant variation in the degree of consensus and in the prioritization of key drivers (Table 3; Fig. 4). In Pitoa, a moderate level of agreement is observed among all respondents, with a Kendall's coefficient of concordance (w_t) of 0.64. Disaggregated by gender, concordance drops to 0.30 for both men and women, indicating limited intra-group

Table 3

Kendall's coefficient of concordance (W_t) for gendered agreements on the causes and the indicators of land degradation.

	Pitoa			Balatchi		
	All	Male	Female	All	Male	Female
Causes of land degradation (n = 6)						
w_t	0.64	0.30	0.30	0.02	0.74	0.69
p-value	0.07	0.62	0.62	0.71	0.19	0.23
Land degradation indicators (n = 5)						
w_t	1.00	0.81	1.00	0.11	0.80	0.8
p-value	0.01	0.17	0.09	0.41	0.17	0.17
Plot productivity status (n = 3)						
w_t	1.00	0.25	0.25	0.06	0.25	0.25
p-value	0.05	0.61	0.61	0.62	0.61	0.61
Plot degradation rate (n = 4)						
w_t	0.36	1.00	0.90	0.04	0.30	0.40
p-value	0.18	0.11	0.15	0.66	0.62	0.49

numbers in parentheses () represent the number of options (or responses).

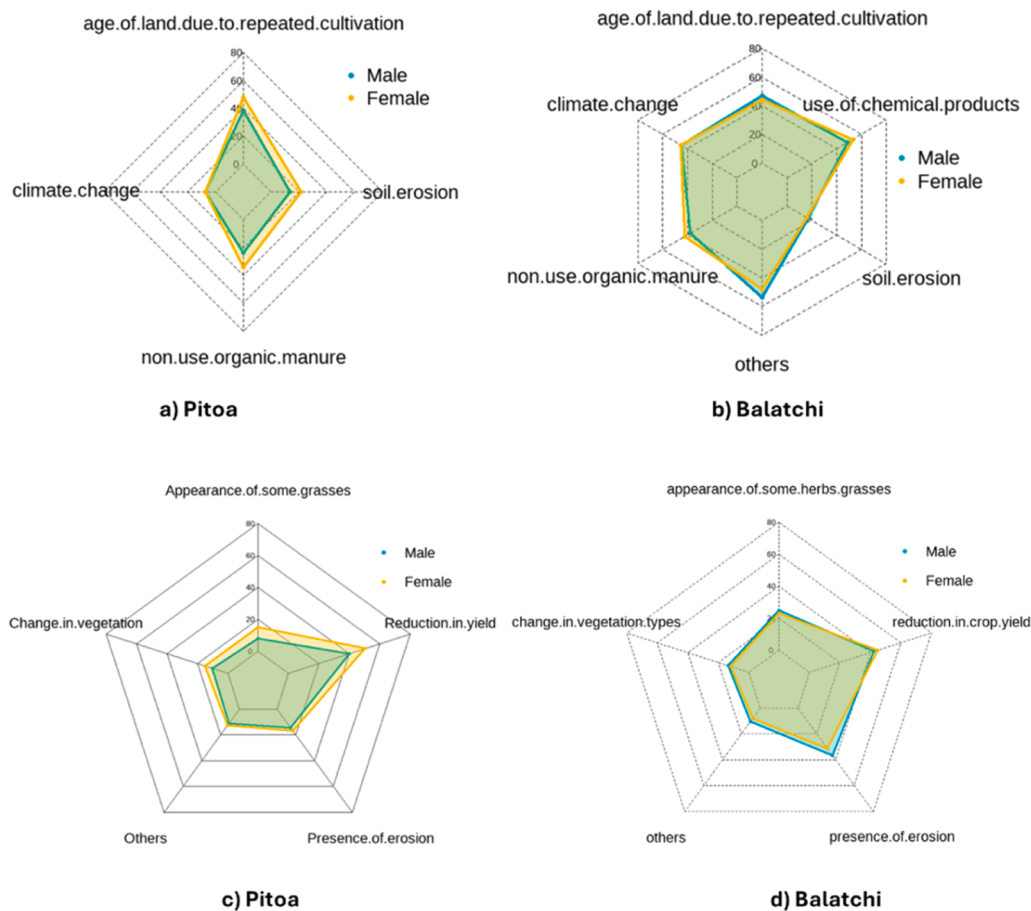


Fig. 4. Gendered perceptions of land degradation causes (a, b) and indicators of land degradation (c, d).

alignment. Despite this, both genders commonly identify repeated cultivation of the same plots as the principal cause of degradation, cited by 45.3% of women and 41.1% of men (Fig. 4).

Climate change is mentioned by a small share of respondents (8.5% of females and 6.2% of males), suggesting that although recognized, it is not seen as a primary driver. Greater divergence appears in secondary causes: men more frequently cite the non-use of organic manure (29.5%) and soil erosion (18.5%), compared to women (28.3% and 16.0%, respectively). These differences may reflect varying access to land, inputs, or information. Men may be more involved in managing larger or more erosion-prone plots, while women, who often manage smaller household plots, may face greater constraints in accessing organic inputs.

In Balatchi, the overall concordance among all respondents is extremely low ($W = 0.02$), indicating highly divergent perceptions when genders are combined. However, within gender groups, high concordance is observed: $w_t = 0.74$ for men and $w_t = 0.69$ for women, suggesting strong internal agreement.

As in Pitoa, repeated cultivation of the same plot is a leading cause, though reported less frequently (21.5% of females and 20.9% of males). Soil erosion is cited by 24.4% of females and 22.7% of males, and the use of chemical products is highlighted by 22.2% of women and 25.0% of men. The non-use of organic manure is noted by 17.1% of females and 20.1% of males. Interestingly, climate change features more prominently in Balatchi than in Pitoa, cited by around one-fifth of respondents (20.4% of females and 21.6% of males).

These findings suggest a more complex and dynamic degradation context in Balatchi, where internal gendered agreement coexists with broader divergence across the community. The prominence of both natural (erosion, climate change) and anthropogenic (chemical use, lack

of organic matter) drivers reflects the multifaceted nature of land degradation in this setting. The greater recognition of chemical input misuse and lack of organic fertilization also points to growing awareness of the long-term impacts of farming practices on soil health.

3.3.2. Indicators of land degradation

Perceptions of land degradation indicators among rural producers in the two study sites, Pitoa and Balatchi, reveal both strong commonalities and context-specific differences. A high level of agreement among respondents is evident, particularly in Pitoa, where Kendall's coefficient of concordance (w_t) indicates perfect agreement across all participants ($w_t = 1.00$, $p = 0.01$) (Table 3). Gender-disaggregated analysis further underscores this alignment, with full concordance among women in both Pitoa ($w_t = 1.00$) and Balatchi ($w_t = 0.80$), and among men in Balatchi ($w_t = 0.80$). In contrast, overall concordance in Balatchi is weaker ($w_t = 0.11$), suggesting greater variability in perceptions across the population at this site.

Across both sites, the reduction in crop yield consistently emerges as the most frequently cited and widely recognized indicator of land degradation (Fig. 4). In Pitoa, 47.6% of women and 45.7% of men identified this as a key signal of declining soil health. Similar trends were observed in Balatchi, where 33.1% of women and 37.6% of men mentioned declining yields as the principal sign of land degradation. This widespread consensus highlights the salience of yield loss as a tangible and immediate consequence of land degradation, perceived uniformly across gender and location.

In addition to yield decline, respondents reported several biophysical indicators, reflecting the integration of local ecological knowledge in environmental assessment. In Balatchi, visible signs of erosion were reported by 28.8% of women and 26.2% of men, compared to 17.1% and

15.2% respectively in Pitoa. This suggests a higher perceived incidence or awareness of erosion processes in Balatchi. The appearance of specific herbaceous species, often associated with soil disturbance, was noted by 19.4% of women and 19.5% of men in Balatchi, while in Pitoa, this indicator was slightly less cited (9.5% of women and 13.8% of men).

Changes in vegetation types, indicative of shifts in species composition or structure, were reported with relatively similar frequency across all groups: 12.4% (women) and 13.8% (men) in Pitoa; 10.6% (women) and 10.1% (men) in Balatchi. Meanwhile, “other” indicators, such as soil colour changes, surface crusting, or compaction, were less commonly cited, though still present in the responses, particularly among women in Pitoa (13.3%).

These results underscore the importance of integrating gendered and site-specific knowledge into land degradation assessments. While quantitative metrics such as yield loss are dominant, qualitative biophysical observations remain critical, offering a nuanced, ground-level perspective. The combination of statistical concordance and consistent indicator prioritization illustrates the depth of farmer knowledge and its relevance for designing locally adapted soil management and restoration strategies.

3.3.3. Plot productivity status

The analysis of perceived plot productivity trends reveals distinct patterns of consensus and divergence across the two sites, as well as between gender groups (Table 3). In Pitoa, an exceptionally high level of agreement is observed across all respondents, as indicated by a perfect Kendall's coefficient of concordance ($w_t = 1.00$). This strong consensus reflects a widespread perception of declining productivity, with 73.5%

of women and 67.0% of men reporting a reduction in yields over time (Fig. 5). Notably, none of the female respondents indicated any improvement in productivity, while a small proportion of men (6.4%) did. Meanwhile, roughly one-quarter of both women (26.5%) and men (26.6%) perceive no change in productivity levels. Despite this overall consensus, the within-gender concordance in Pitoa is relatively low ($w_t = 0.25$ for both men and women), suggesting some divergence in individual perceptions within each group, potentially reflecting differences in land quality, farming practices, or access to inputs at the household level. These discrepancies may be masked when responses are aggregated across all respondents.

In contrast, Balatchi presents a more heterogeneous picture. While a majority of both women (65.4%) and men (68.3%) also report declining productivity, a higher proportion of respondents, particularly women (14.8%), perceive improvements, compared to 9.8% of men. Additionally, approximately one-fifth of both groups (21.0% of women and 20.7% of men) report no change. The within-gender concordance coefficients are notably higher than in Pitoa ($w_t = 0.70$ for women and $w_t = 0.74$ for men), suggesting a greater internal consistency in perceptions despite the diversity of outcomes reported. Although the dataset does not allow for definitive attribution, it is plausible that the reported productivity improvements in Balatchi may be linked to localized adoption of soil fertility management practices or improved land-use strategies, as discussed elsewhere in the study. Further qualitative or quantitative investigation would be needed to validate these potential associations.

Overall, these findings point to context-specific dynamics in plot productivity perceptions, with Pitoa respondents demonstrating more

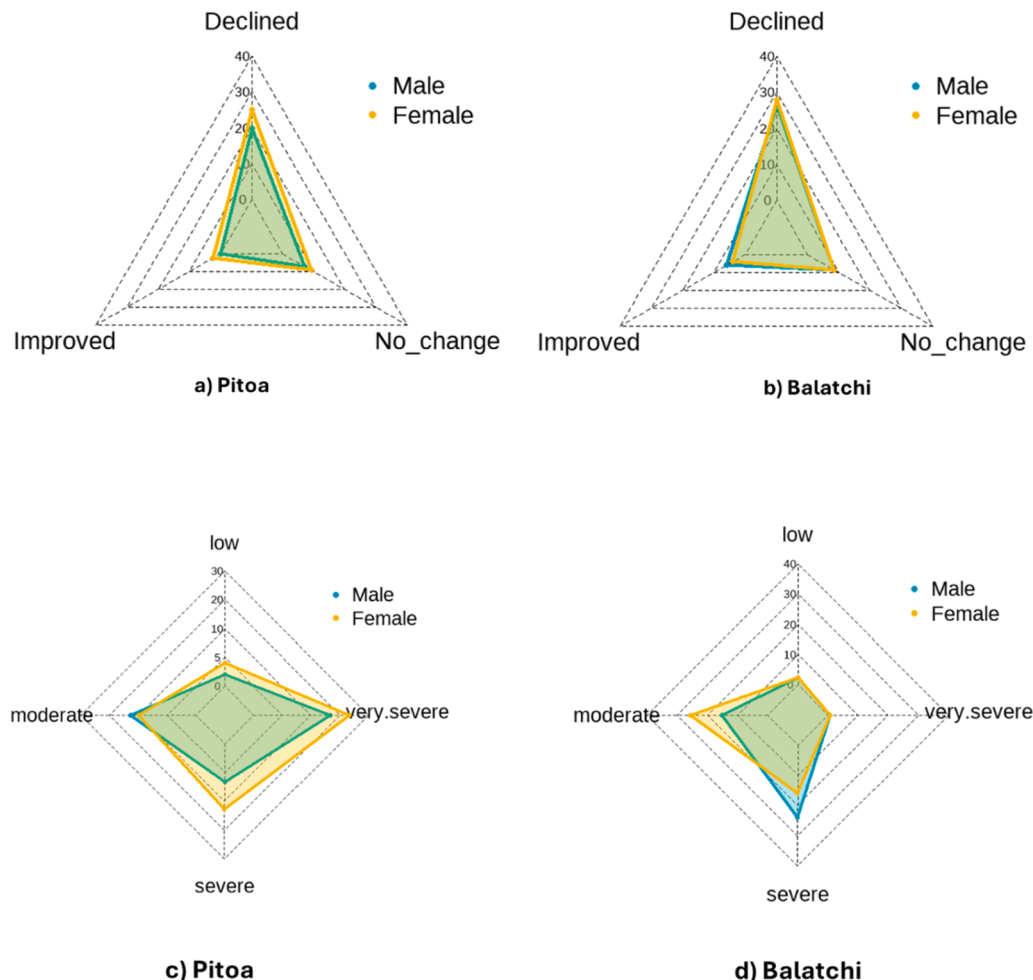


Fig. 5. Gendered perceptions of plot productivity status (a, b) and plot degradation rate (c, d).

uniform concern over declining yields, and Balatchi respondents showing greater variability in outcomes and perceptions. The gender-specific differences observed underscore the need to consider intra-community and gendered perspectives when designing agricultural development or land restoration interventions.

3.3.4. Plot degradation rate

The analysis of plot degradation rates reveals marked differences in perception both between the two study sites and across gender groups within each site (Table 3). In Pitoa, the overall Kendall's coefficient of concordance ($w_t = 0.36$) suggests a moderate level of agreement among respondents regarding the severity of plot degradation. When disaggregated by gender, male respondents show perfect consensus ($w_t = 1.00$), indicating strong alignment in their assessments. Female respondents also exhibit high concordance ($w_t = 0.90$), suggesting a relatively unified perception among women. The distribution of responses further underscores the perceived severity of land degradation in Pitoa. A majority of both women (45.5%) and men (43.1%) rated degradation as *very severe* (Fig. 5). An additional 22.7% of women and 29.3% of men perceived it as *severe*. Moderate degradation was noted by 38.6% of women and 25.9% of men, while a small fraction rated degradation as *low*—6.8% of women and 10.3% of men (Fig. 5). These findings indicate a widespread recognition of advanced degradation processes in Pitoa, particularly among male respondents who display complete consensus.

In contrast, responses from Balatchi indicate substantial divergence in perceptions. The overall concordance coefficient is extremely low ($w_t = 0.04$), suggesting that respondents hold heterogeneous views regarding plot degradation severity. Gender-disaggregated coefficients remain low ($w_t = 0.30$ for males and $w_t = 0.40$ for females), indicating weak agreement even within gender groups. Response distributions in Balatchi reflect this lack of consensus. Among female respondents, half (50.0%) rated degradation as *severe*, while only 1.7% considered it *very severe*. In contrast, male respondents most frequently selected *moderate degradation* (46.4%), followed by *severe* (29.0%). Very few males (1.4%) identified degradation as *very severe*, and low degradation was reported by 5.0% of women and 4.4% of men.

These results suggest that while degradation is recognized as a significant concern in both sites, Pitoa respondents perceive it as more severe and progressing faster. In contrast, Balatchi respondents tend to perceive degradation as occurring at a slower pace or with less intensity, with greater variation in opinions. The gender differences within each site further imply that men and women may experience or interpret plot degradation differently, possibly influenced by their distinct roles in land management or differential exposure to degradation processes.

3.4. Gendered assessment of land restoration practices and determinant factors for their implementation

3.4.1. Land restoration practices implemented by the respondents

The household survey examined men's and women's perspectives on land restoration practices across the two study sites, Pitoa and Balatchi, exploring the types of restoration methods adopted, factors influencing these choices, and training received by respondents. Analysis using Kendall's coefficient of concordance (w_t) (Table 4) reveals important gender- and site-specific patterns.

In Pitoa, there is a strong overall agreement between male and female respondents regarding the land restoration techniques employed, reflected by a high concordance coefficient of 0.76. This strong consensus suggests that men and women largely adopt similar restoration strategies, including crop rotation, intercropping, and the combined use of organic manure and mineral fertilizers. Looking closer at adoption rates (Fig. 6), women in Pitoa exhibit higher engagement in several soil fertility and restoration practices: 36.2% of women practice crop rotation compared to 26.5% of men; 25.7% of women apply organic manure versus 20.4% of men; and 33.3% of women use mineral fertilizers

Table 4

Kendall's coefficient of concordance (w_t) for gendered agreements on the land restoration practices and determinant factors for their adoption.

	Pitoa			Balatchi		
	All	Male	Female	All	Male	Female
Restoration practices implemented (n = 8)						
w_t	0.77	0.27	0.36	0.02	0.63	0.54
p-value	0.01	0.78	0.63	0.72	0.28	0.37
Factors that influence the choice of restoration practices (n = 6)						
w_t	0.44	0.70	0.65	0.02	0.31	0.37
p-value	0.10	0.23	0.27	0.71	0.68	0.59
Training received (n = 6)						
w_t	1.00	0.55	0.59	1.00	0.72	0.60
p-value	0.01	0.36	0.32	0.01	0.21	0.31

numbers in parentheses () represent the number of options (or responses).

against 26.5% of men. Interestingly, a considerable proportion, especially women, report no restoration practices (17.1% of women; 8.5% of men), potentially reflecting constraints such as limited access to knowledge, resources, or insecure land tenure.

Regarding soil protection and erosion control, men show a slight preference for practices such as contour ploughing and physical barriers, categorized under "Soil & Water Conservation" (2.4% for men vs. 1.9% for women), though adoption remains generally low. Conversely, women report slightly greater involvement in agroforestry activities such as tree planting and on-farm tree management (2.9% vs. 2.4%), highlighting their interest in long-term ecological benefits.

In contrast, in Balatchi, the overall concordance (w_t) between genders on restoration practices falls dramatically to 0.01, indicating substantial divergence in the approaches taken by men and women. This disparity reflects differentiated land restoration dynamics in Balatchi, potentially revealing gaps in knowledge sharing or unequal resource access impacting specific groups. Despite this divergence, individual practice adoption rates in Balatchi reveal some similarities and differences: crop rotation is practiced by 23.5% of women and 22.6% of men; organic manure use is nearly equal among women (30.6%) and men (30.7%); mineral fertilizer use is also similar (31.9% women; 29.4% men). Women tend to engage slightly less in soil and water conservation practices (18.9% women vs. 21.8% men), while a higher proportion of men report practicing following (17.0% men vs. 13.0% women). The share of respondents reporting no restoration practices is low for both genders in Balatchi (1.3% women; 3.0% men), possibly reflecting greater overall engagement in restoration activities compared to Pitoa.

Across both sites, women consistently demonstrate higher adoption rates of land restoration practices, especially those aimed at enhancing soil health, such as crop rotation, organic manure application, and agroforestry. This pattern may be linked to women's intensive daily involvement in agricultural and household land management, which equips them with practical knowledge and motivation to adopt sustainable practices. Nevertheless, women typically have less formal access to extension services and training than men, underscoring the need for gender-responsive support mechanisms to empower all producers. These findings highlight the importance of designing targeted interventions that address disparities in restoration practice adoption, particularly in Balatchi where gender differences are most pronounced. Bridging gaps in knowledge and resource access will be critical to scaling up effective land restoration strategies, thereby improving land health and productivity in both Pitoa and Balatchi.

3.4.2. Factors that influence the adoption of restoration practices

The analysis of factors influencing the adoption of land restoration practices revealed notable gender- and site-specific differences (Table 4). In Pitoa, there was moderate overall agreement between men and women regarding the importance of different influencing factors, as

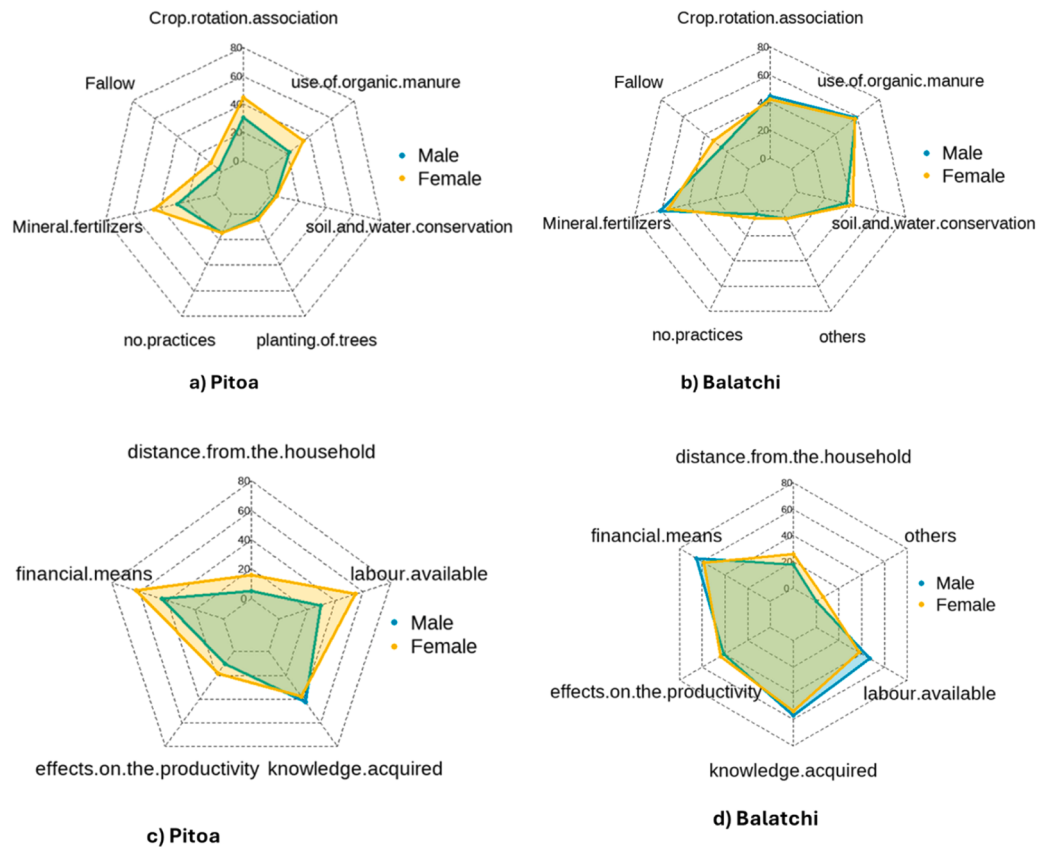


Fig. 6. Restoration practices implemented (a, b) and factors that influence the adoption of restoration practices (c, d).

indicated by a Kendall's coefficient of concordance ($w_t = 0.44$). In contrast, overall concordance was low in Balatchi ($w_t = 0.02$), although gender-disaggregated results showed slightly higher, but still limited, agreement ($w_t = 0.31$ for men; $w_t = 0.37$ for women).

Across both sites, key determinants of practice adoption included financial means, labour availability, knowledge from training, immediate productivity effects, and distance from household (Fig. 6). While these factors were relevant for both men and women, their relative importance varied by gender and location. Women consistently prioritized financial constraints (34.4% in Pitoa; 33.3% in Balatchi) and expected productivity gains (8.1% in Pitoa; 21.0% in Balatchi). These preferences reflect women's concerns with limited economic resources and the need to secure reliable yields. Men, by contrast, placed greater emphasis on labour availability (29.3% in Pitoa; 19.4% in Balatchi) and knowledge gained through training (20.3% in Pitoa; 27.6% in Balatchi). These differences may stem from men's comparatively greater access to labour pools and training opportunities. The distance of agricultural plots from the homestead was also cited more frequently by men (8.6% in Pitoa; 13.2% in Balatchi), than women (3.8% in Pitoa; 9.0% in Balatchi), suggesting that women may face specific constraints related to time allocation and domestic responsibilities.

Overall, the findings indicate that while the same general set of factors influences adoption across both genders, the weight assigned to each factor is shaped by gendered access to resources, labour, and information. These differences underscore the importance of gender-responsive extension services and targeted support mechanisms to improve the uptake of sustainable land restoration practices. Addressing structural inequalities in access to training, credit, and labour will be essential for enhancing adoption rates and achieving inclusive restoration outcomes.

3.4.3. Training received by the respondents

The analysis of training participation among respondents in Pitoa and Balatchi reveals a generally strong alignment in the types of agricultural training received across genders, as indicated by Kendall's coefficient of concordance ($w_t = 1.00$) for both sites (Table 4). This high level of concordance suggests that men and women within each site were exposed to similar training opportunities in land restoration and sustainable agriculture.

Across both study areas, respondents reported having received training in crop production, soil fertility management, agroforestry, and soil and water conservation, key domains in sustainable land management (Fig. 7). In Pitoa, women and men participated in crop production training at similar rates (approximately 33% each). Men reported slightly higher attendance in agroforestry training (25% vs. 19% for women), while women showed marginally greater involvement in soil fertility management (33% vs. 30%) and animal production (12% vs. 11%). Although attendance in soil and water conservation training was low overall, women again showed slightly higher participation (3.5% vs. 1.8%). In Balatchi, gender disparities were more pronounced in certain training domains. Women reported higher participation in animal production training (20% vs. 11% for men), but lower participation in crop production (20% vs. 31%). Both men and women showed similar engagement in soil fertility management (around 40%) and soil and water conservation (approximately 10–11%). Participation in agroforestry training was low and similar across genders, while forestry-related training was minimal and reported only by men (2.8%).

These findings reflect gendered roles and responsibilities in agricultural systems. Women's relatively higher participation in animal husbandry and soil fertility-related training aligns with their day-to-day involvement in managing household plots and ensuring soil productivity. Men's greater representation in agroforestry and crop production training in Balatchi may indicate localized differences in training access,

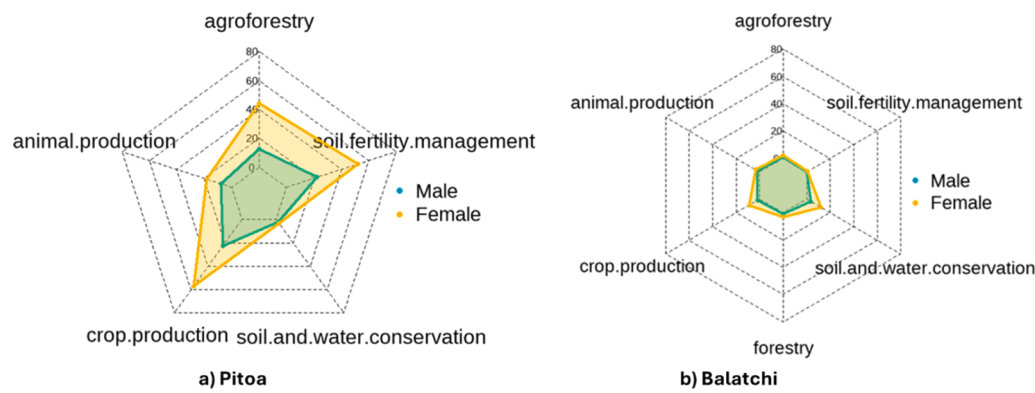


Fig. 7. Training received by respondents: a) Pitoa and b) Balatchi.

labour division, or institutional targeting. Overall, the data highlight women's active and, in many cases, equal or greater engagement in training activities critical to land restoration. This underscores their pivotal role in implementing sustainable practices and the importance of designing training programs that are inclusive and responsive to gender-specific constraints and capacities. Ensuring equitable access to training is essential for maximizing adoption and impact of restoration efforts across both communities.

4. Discussion

This study examined the complex dynamics of land degradation and restoration in the contrasting agro-ecological contexts of Pitoa and Balatchi, with a specific focus on gendered dimensions of land management. Drawing on field surveys, remote sensing, geospatial analysis, and household interviews, the findings offer critical insights into the ecological and socio-economic factors shaping restoration efforts. The results reveal both commonalities and divergences in how male and female land users perceive and respond to degradation, underscoring the interplay between gender roles, environmental change, and land management strategies.

Gendered perspectives on land degradation: This study reveals clear gendered divergences in how land degradation is perceived, shaped by distinct roles, responsibilities, and access to resources. While both men and women identified similar visible signs, such as declining yields and soil fertility, their explanations diverged. Men emphasized external, market-driven causes like monocropping and agrochemical overuse, whereas women more often cited locally embedded factors such as nutrient depletion, fuelwood collection, and reduced fallow periods. These contrasting interpretations reflect gendered land-use roles, with women focused on subsistence and household provisioning, and men more engaged in market-oriented production (Baada et al., 2023; Clay and Yurco, 2024).

These gendered interpretations of degradation are also closely connected to differentiated rights, responsibilities, and authority over land resources. Women's stronger emphasis on soil fertility declines and household provisioning reflects their direct dependence on maintaining productive subsistence plots under often insecure tenure conditions. In many customary systems, women cultivate land through secondary or negotiated access rights that may be temporary or socially contingent, limiting their ability to make long-term investments in restoration. Men, by contrast, frequently exercise greater control over commercially valuable land and productive resources, which may explain their stronger focus on market-oriented degradation drivers and input-intensive agricultural systems. This reinforces broader arguments within feminist political ecology that environmental perceptions are shaped not only by labour divisions, but also by unequal power relations and differentiated control over natural resources (Agarwal, 1997; Vigil, 2024).

Site-specific differences further nuance these perceptions. In Pitoa, the semi-arid environment and greater environmental stress led both men and women to emphasize biophysical constraints—poor soils, drought, and rainfall variability. In contrast, respondents in Balatchi, located in the more densely populated and humid highlands, more frequently pointed to human-induced drivers such as land pressure and unsustainable farming practices. Cultural norms also differed: traditional tenure systems in Balatchi appeared to restrict women's land access more than in Pitoa, potentially influencing their perspectives on both degradation and viable restoration options.

Kendall's weighted concordance coefficients reflect this complexity. While there was moderate overall agreement on degradation drivers ($w_t = 0.64$), low within-gender scores ($w_t = 0.30$ for both men and women) highlight substantial intra-group variation. This suggests that gender alone cannot explain the full diversity of perceptions; other intersecting factors, such as age, tenure, education, and livelihood, likely shape individual viewpoints. Among these intersecting factors, land tenure security play an important role. Secure and recognized land rights can influence how land users perceive degradation risks and whether they consider restoration investments worthwhile over the long term. Conversely, insecure tenure arrangements may discourage restoration practices whose ecological and economic benefits require several years to materialize. This dynamic may be especially relevant for women, whose land access in many rural contexts remains mediated through customary institutions or male household members. Consequently, gendered perceptions of degradation cannot be fully understood without considering the governance structures that shape access to, and control over, land resources (Doss and Mika, 2026). Still, women's stronger emphasis on soil fertility may be linked to their daily management of food production under constrained conditions, while men's focus on commercial drivers likely reflects their better access to land, inputs, and extension services. These findings echo prior studies linking environmental perceptions to gendered labour divisions and resource control (Carnegie et al., 2020; Mponela et al., 2023).

Incorporating these differentiated and context-specific perceptions into land degradation assessments is essential. Top-down interventions that ignore local knowledge risk being ineffective or inequitable. Gender-responsive and site-sensitive approaches are needed to design interventions that reflect the lived realities of diverse land users. By showing how gender and context interact to shape perceptions of degradation, this study strengthens the case for more inclusive and legitimate land management strategies. The next section explores how these perceptions translate into gendered differences in the adoption of restoration practices.

Gendered access and control over land and tree species: This study highlights the importance of incorporating gender-specific perspectives into land restoration strategies, particularly in agroforestry systems. The spatial analysis of plot distribution in both Pitoa and Balatchi revealed no significant gender-based segregation in access to land. Contrary to

earlier findings suggesting that women are often relegated to marginal or less fertile areas, our data show that both men and women manage plots across the landscape (Doss and Meinzen-Dick, 2020). This equitable spatial distribution suggests a level of inclusivity in physical access to land, which is a critical prerequisite for enabling broader participation in land restoration initiatives.

However, equitable spatial distribution should not be interpreted as evidence of equitable tenure security or decision-making authority. A critical distinction exists between access to land and control over land. While women may cultivate plots across the landscape, they may still face important restrictions regarding tree planting, inheritance rights, long-term land investments, or decisions over commercially valuable resources. This distinction is central within land governance scholarship, which argues that restoration outcomes depend not only on physical access to land, but also on the security, duration, and legitimacy of land rights held by different user groups (Chigbu et al., 2019; Doss and Meinzen-Dick, 2020). Restoration practices such as agroforestry, assisted natural regeneration, and soil conservation often require long-term investments whose benefits accrue gradually over time. Under insecure tenure conditions, land users, particularly women, may therefore have weaker incentives to invest in such practices.

Nonetheless, spatial access alone does not equate to full control over land or decision-making authority. Existing literature underscores that even when women have access to plots, they may lack the autonomy to manage economically valuable trees or to make decisions over land use (Gautier and van Santen, 2014; Fortnam et al., 2019). These dynamics highlight the need to go beyond assessing access and examine gendered control over land resources, which has significant implications for the success and equity of restoration efforts.

Our findings on tree species preferences further emphasize the importance of integrating gendered priorities into agroforestry and land restoration strategies. In both Pitoa and Balatchi, men showed a preference for commercially valuable tree species such as *Azadirachta indica* and *Persea americana*, while women favoured species that support subsistence needs, including *Acacia nilotica* and *Adansonia digitata*. These preferences reflect broader gender roles and responsibilities—men often engage more in market-oriented activities, whereas women focus on household needs like food, fuelwood, and fodder (Soh Wenda et al., 2024). These differentiated species preferences also reflect broader gendered livelihood strategies and tenure arrangements. Men's preference for commercially valuable species may be associated with their comparatively greater authority over tree tenure, market access, and cash-generating activities. Women's preference for multipurpose subsistence-oriented species reflects their central role in household food security, energy provision, and daily resource management. Similar patterns have been documented across African agroforestry systems, where gendered control over tree resources strongly influences restoration priorities and adoption behaviour (Kiptot and Franzel, 2011; Elias et al., 2025).

These patterns align with existing studies showing that men and women often have distinct motivations for tree planting. They are shaped not only by economic roles but also by cultural norms, roles, gender-specific knowledge systems, and constraints in resource control (Fortnam et al., 2019; Gachuiri et al., 2022; Ota et al., 2024). Notably, women's access to land and tree resources does not always translate into control, especially over economically valuable species, as men often retain decision-making authority in both cultivated and uncultivated areas (Gautier and van Santen, 2014). Taken together, these insights underscore the necessity for restoration programs to account for both the economic and subsistence priorities of different land users. Designing interventions that include a diverse range of species, reflecting ecological, economic, and social value, can enhance adoption, equity, and long-term sustainability (Kiptot et al., 2014). Promoting equitable participation also requires addressing the underlying power dynamics and decision-making structures that influence access to, and benefits from, restored landscapes.

Adoption of land restoration practices: This study reveals clear gender-based differences in the adoption of land restoration practices, shaped by both ecological context and socio-cultural dynamics. Women across both sites showed higher uptake of practices focused on soil fertility restoration, particularly the use of organic manure and crop rotation, consistent with their roles in sustaining household food systems and their tendency to prioritize long-term land health (Doss et al., 2014). Men, by contrast, more frequently adopted input-intensive techniques such as mineral fertilizers, reflecting greater access to capital and external support services.

Crucially, site-specific differences emerged. In Pitoa, the semi-arid context appeared to intensify concerns over environmental constraints. Both men and women emphasized biophysical challenges like soil degradation and rainfall variability, and gender differences in restoration practices were more pronounced. Conversely, in Balatchi's more humid highlands, where population density and land pressure are greater, respondents more often highlighted human-induced drivers of degradation, such as land overuse and unsustainable farming practices. Here, gendered differences in restoration choices were less stark, possibly reflecting more cohesive knowledge systems or greater overlap in livelihood roles.

Cultural factors also shaped restoration practices. Traditional tenure systems in Balatchi impose stronger restrictions on women's land access compared to Pitoa, likely constraining women's ability to implement restoration at scale and influencing their perceptions of viable land management options (Abera et al., 2023). Despite these constraints, women in both sites demonstrated strong engagement with ecologically sustainable practices, underscoring the need for targeted support. Importantly, the adoption of restoration practices should not be viewed solely as an individual technical choice, but rather as a socially embedded decision shaped by access to land, labour, financial resources, and institutional support. Restoration investments frequently involve delayed returns, making tenure security a particularly important determinant of adoption. Land users who lack secure or recognized rights may be reluctant to invest in labour-intensive or long-term restoration measures such as agroforestry, soil conservation structures, or assisted natural regeneration. This challenge disproportionately affects women in many customary tenure systems, where land rights are often secondary, seasonal, or dependent on male relatives. Consequently, restoration policies that fail to address tenure inequalities risk reinforcing existing gender disparities in restoration participation and benefits.

Interestingly, training access showed consistently high concordance across gender and site, suggesting that knowledge dissemination may bridge some of these contextual divides. However, the differential outcomes observed underscore that training alone is insufficient; effective restoration support must be tailored to local agro-ecological and cultural realities. These findings support emerging calls for rights-based restoration approaches that integrate ecological restoration with inclusive land governance reforms. Increasingly, restoration scholars and international policy frameworks argue that securing equitable access to land and strengthening local participation are essential conditions for achieving durable restoration outcomes and avoiding the exclusion of vulnerable groups from restoration benefits (Mansourian, 2018; UNCCD, 2022). These findings support the original hypothesis that both agro-ecological and socio-cultural contexts significantly shape gendered perceptions and responses to land degradation and restoration.

Training and knowledge dissemination: A key finding of this study is the high level of women's participation in agricultural training across both Pitoa and Balatchi, particularly in areas such as crop production, soil fertility management, and agroforestry. This reflects women's proactive engagement in land restoration despite structural barriers such as limited land rights, capital, and extension support. Nevertheless, participation in training does not automatically translate into equal capacity to implement restoration practices. Structural inequalities related to land tenure security, access to credit, labour availability, and

decision-making authority may continue to constrain women's ability to operationalize acquired knowledge. This finding highlights an important limitation of many restoration and extension programs, which often emphasize technical training while insufficiently addressing the institutional and governance barriers that shape restoration adoption in practice. Notably, this strong uptake may also reflect the influence of development projects that have explicitly prioritized women's inclusion in training programs.

Training often translated into a preference for ecologically sustainable practices, such as organic manure application and crop rotation, underscoring women's long-term commitment to soil health and food security. These trends align with broader evidence of women's roles as custodians of agroecological knowledge (Doss et al., 2014; FAO, 2017). However, site-specific differences remain. In Balatchi, gendered disparities in the implementation of restoration practices were more pronounced than in Pitoa, suggesting that training alone is insufficient. Cultural norms, time burdens, and unequal access to productive assets continue to limit women's capacity to act on acquired knowledge.

These findings highlight the need for gender-responsive and context-specific training approaches. Beyond technical content, programs must address the systemic constraints that shape implementation. Inclusive, participatory models that reflect local gender dynamics, and build on existing project momentum, are essential to ensure both equitable engagement and lasting impact in land restoration.

Overall, the findings of this study reinforce growing evidence that land degradation and restoration are not purely ecological processes, but are deeply embedded within social relations, tenure systems, and governance structures. Gendered differences in degradation perceptions, restoration priorities, and land management practices emerge not simply from cultural roles, but from differentiated access to land, resources, knowledge, and decision-making power. While women demonstrated strong engagement in restoration activities across both study sites, persistent structural inequalities, including insecure land rights, limited control over productive assets, and unequal access to institutional support, continue to shape restoration opportunities and outcomes. These results therefore support calls for more socially inclusive and rights-based restoration approaches that place equity, tenure security, and participatory governance at the centre of restoration planning and implementation.

5. Implications for land restoration policies

The findings of this study carry important implications for land restoration policy, particularly in the context of growing international commitments to landscape restoration under initiatives such as AFR100, the Bonn Challenge, and the United Nations Decade on Ecosystem Restoration. Beyond the technical dimensions of restoration, the results demonstrate that land degradation and restoration are fundamentally shaped by gender relations, land governance systems, and unequal access to productive resources. Effective restoration policies must therefore move beyond gender-neutral approaches and adopt governance frameworks that explicitly recognize the differentiated rights, priorities, constraints, and knowledge systems of women and men. Restoration success depends not only on ecological rehabilitation, but also on ensuring equitable participation, secure land rights, and inclusive decision-making processes.

The results highlight the necessity of gender-responsive approaches that account for the distinct priorities, knowledge systems, and constraints faced by men and women. While consensus on specific restoration practices may be useful, it is not essential for success. What matters more is the design of flexible interventions that reflect local gender dynamics and diverse land-use strategies. The case of Balatchi, where gender disparities in the implementation of restoration practices are particularly pronounced, underscores the need for targeted support mechanisms.

Particular attention should be given to strengthening women's

tenure security and decision-making authority within restoration landscapes. While women may actively participate in agricultural production and restoration activities, their rights to land are often informal, secondary, or mediated through customary systems dominated by male authority. Such tenure insecurity can reduce incentives for long-term restoration investments and limit women's access to restoration benefits. Policies aimed at improving land restoration outcomes should therefore integrate measures that enhance women's legal recognition, participation in local land governance institutions, and access to land registration, credit, extension services, and restoration financing mechanisms (Takoutsing et al., 2023).

The findings also support the growing recognition of rights-based restoration approaches, which argue that restoration initiatives should not only restore ecosystems, but also strengthen local rights, social equity, and procedural justice. Restoration programs that fail to consider local tenure systems and power relations may unintentionally reinforce existing inequalities or exclude vulnerable groups from restoration benefits. In contrast, participatory and rights-sensitive restoration approaches can enhance local legitimacy, increase community ownership, and improve the long-term sustainability of restoration interventions. Integrating customary institutions, women's organizations, and local land users into restoration planning and governance processes is therefore essential for building socially inclusive restoration systems.

Ensuring equitable and secure land tenure should constitute a central pillar of restoration policy. Strengthening women's tenure security is not only a question of social justice, but also a practical requirement for achieving sustainable restoration outcomes. Policies should support inclusive land governance reforms that enhance women's participation in land-related decision-making, strengthen legal recognition of women's land rights, and improve equitable access to restoration resources and benefits.

While this study advances understanding of gendered dynamics in land degradation and restoration, several research gaps remain. Longitudinal studies are needed to evaluate the long-term ecological and socio-economic impacts of gender-inclusive restoration approaches, particularly under shifting climatic and land-use conditions. These would provide valuable evidence on the sustainability and scalability of such practices. Further research should also examine the role of community-based organizations in mobilizing collective action and enabling gender-responsive restoration. Understanding how grassroots initiatives promote women's leadership, build social capital, and mediate resource access could inform more effective policy and program design (Abera et al., 2023). Land tenure remains a critical issue: future studies should explore how changes in land ownership and control influence men's and women's participation in restoration, and how policy reforms might support more equitable and secure access to land (Dugasseh et al., 2021).

More broadly, restoration initiatives should adopt governance approaches that recognize restoration landscapes as socially negotiated spaces shaped by competing interests, unequal power relations, and differentiated resource claims. Gender-responsive restoration cannot be achieved solely through technical interventions or training programs. It also requires institutional mechanisms that promote transparency, participation, accountability, and equitable representation within restoration governance structures. Local governance systems, including customary institutions, producer organizations, and community-based restoration groups, play a critical role in shaping restoration outcomes and should therefore be actively engaged in restoration planning and implementation. This study call for more intersectional research that considers how gender interacts with other axes of inequality, such as age, ethnicity, disability, and economic status, to shape individuals' capacities to engage in restoration. This would help identify and support the most marginalized groups, ensuring that land restoration contributes not only to environmental recovery, but also to social justice and resilience (Opoku Mensah et al., 2025).

Overall, this study demonstrates that gender matters not only in how

land degradation is experienced, but also in how restoration opportunities, responsibilities, and benefits are distributed across landscapes. Restoration interventions that ignore gendered inequalities in land access, tenure security, labour burdens, and decision-making risk reproducing existing social inequities and undermining restoration effectiveness. By contrast, socially inclusive and rights-based restoration approaches can simultaneously contribute to ecological recovery, livelihood resilience, and social justice. Integrating gender equity, tenure security, and participatory governance into restoration policy should therefore be viewed not as an optional addition, but as a fundamental condition for achieving sustainable and equitable restoration outcomes.

6. Conclusion

This study examined the gendered dimensions of land degradation and restoration across two contrasting agroecological zones in Cameroon, with particular attention to how men and women perceive degradation, adopt restoration practices, and engage in land management under different socio-ecological conditions. The findings challenge simplified narratives that portray women solely as victims of land degradation. Instead, the study demonstrates that women, like men, are active environmental actors whose land-use decisions can both contribute to and mitigate degradation processes. While there was moderate overall agreement on degradation drivers, low within-gender differences for both men and women highlight substantial intra-group variation. This suggests that gender alone cannot explain the full diversity of perceptions; other intersecting factors, such as age, tenure, education, and livelihood, likely shape individual viewpoints. At the same time, women play a particularly important role in promoting ecologically sustainable restoration practices, especially those linked to soil fertility improvement, agroforestry, and long-term land stewardship. More importantly, the study shows that gendered restoration dynamics cannot be fully understood without considering the broader governance systems within which land management decisions occur. Differences in restoration priorities, perceptions, and practices are shaped not only by gender roles, but also by unequal access to land, tenure security, productive resources, training opportunities, and decision-making authority. The findings therefore reinforce growing evidence that land restoration is not solely a technical or ecological process, but also a deeply social and political one, embedded within power relations, customary institutions, and land governance structures.

However, the study also highlights that women's active engagement in restoration frequently occurs despite persistent structural barriers, including insecure land tenure, unequal control over productive assets, labour constraints, and limited influence within land-related decision-making processes. These findings underscore the importance of strengthening women's land rights and institutional participation as part of broader restoration strategies. Restoration efforts that fail to address such governance inequalities may limit both restoration effectiveness and social inclusiveness over the long term.

By integrating biophysical analysis, geospatial assessment, and gender-disaggregated socio-economic data, this study contributes to emerging scholarship on gender-responsive and rights-based restoration. The results demonstrate that restoration outcomes are closely linked to issues of land governance, tenure security, and social equity. In doing so, the study responds to increasing international calls, including those advanced by the UNCCD Global Land Outlook 2, for restoration approaches that move beyond purely technical interventions and incorporate inclusive governance, local participation, and equitable resource access into restoration planning and implementation.

Ultimately, achieving sustainable land restoration requires more than the rehabilitation of degraded ecosystems; it also requires transforming the social and institutional conditions that shape access to land, participation in restoration, and distribution of restoration benefits. Gender-responsive restoration should therefore be understood not as an optional component of restoration policy, but as a fundamental

condition for ecological sustainability, social justice, and long-term resilience. Policies and restoration programs that strengthen tenure security, support inclusive governance, and recognize both women and men as legitimate restoration actors are more likely to generate durable, equitable, and widely adopted restoration outcomes across diverse landscapes.

CRediT authorship contribution statement

Tor-Gunnar Vagen: Writing – review & editing, Methodology, Conceptualization. **Mary Crossland:** Writing – review & editing, Methodology, Conceptualization. **Simon Djakba Basga:** Writing – review & editing, Methodology. **Leigh Winowiecki Leigh:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Ann Degrande:** Writing – review & editing, Supervision, Conceptualization. **Bertin Takoutsing:** Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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