

Farmer Practices for Sustainable Land Management and Climate Change Adaptation in the Municipality of Glazoué in Central Benin

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Abstract

Problem Statement: Land use changes, primarily driven by agricultural expansion and intensification, pose a major threat to global biodiversity and land resources. In the Municipality of Glazoué, Central Benin, agricultural production is increasingly challenged by climate hazards and unsustainable practices, threatening food security in this key “breadbasket” region. This study aims to characterize land management practices and evaluate their environmental impacts. **Methodology:** Surveys were conducted with 329 randomly selected farming households. The Normalized Difference Vegetation Index (NDVI) was used to assess land degradation, complemented by descriptive statistics, discourse analysis, and GIS mapping. Allan’s coefficient (L) was calculated to evaluate soil disturbance levels. **Results:** The results showed that 44% of municipal land is highly degraded, yet only 11% of producers adopt sustainable land management practices. Allan’s coefficient ($L < 5$) confirms widespread overexploitation. A positive area-production relationship ($R^2 = 0.73$) masks declining productivity per hectare. Significant socio-economic impacts include land conflicts (3 deaths, 5 injuries, 115 cattle killed) and reduced food security. The observed impacts significantly affect farmers in a municipality recognized as one of the “granaries” of the Collines Department. **Conclusion:** Given this situation, the State and decentralized territorial authorities must develop urgent programs

for behavioral change education and the dissemination of new sustainable land management technologies.

Keywords

Sustainable Land Management, Land Degradation, Climate Change, Adaptation, Benin

1. Introduction

Sustainable land management (SLM) refers to a set of practices and strategies aimed at using and preserving land resources in a way that meets current needs without compromising the ability of future generations to meet their own needs. It includes protecting biodiversity, conserving soil, using water responsibly, and promoting ecological and resilient agricultural systems. Land use changes, primarily due to agricultural expansion and intensification, are a major concern for global biodiversity. Currently, 25% of animal and plant species are threatened with extinction, while 74% of the land surface is undergoing degradation accompanied by significant greenhouse gas emissions [1]. In sub-Saharan Africa, agricultural production conditions are becoming increasingly difficult due to climate hazards. These profound climate changes negatively affect plant growth and compromise crop yields as well as the sustainability of farming systems [2]. African states face multiple and interdependent challenges: improving population living conditions, managing climate change, mitigating biodiversity loss, and combating food insecurity. However, land overexploitation seriously threatens land and water resources in some regions [3].

In Benin, the agricultural sector employs about 50% of the active population, contributes more than 28% to GDP, provides about 77% of export earnings, and 15% of state revenue, with a contribution to economic growth of 1.47% [4]. Nevertheless, soils are undergoing continuous degradation due to unsuitable agricultural practices, deforestation (21% of forest area declined in 10 years in favor of agricultural land and settlements according to [5]), and wind and water erosion. A study by the Laboratory of Soil, Water and Environmental Sciences in the Departments of Zou, Borgou, and Alibori indicates that 90% of the land has a low to very low fertility level [6]. Despite this alarming situation, sustainable land management initiatives remain limited on the ground.

Growing soil degradation leads to a decline in agricultural productivity, compromises food security, and exacerbates rural poverty. Farmers have little information on appropriate soil conservation measures and lack access to improved seeds and related technologies. Much research in Benin has addressed adaptation strategies developed by populations [7] [8] and the issue of food security [9]. Land degradation and the steady decline in soil fertility constitute a major constraint to Beninese agricultural production. Cultivated land is highly degraded due to poor

farming practices, leading to a decrease in agricultural production [10]. The production of important crops such as soybeans, maize, cowpea, rice, and yams fails to ensure year-round food availability, compromising food security.

In this context, issues related to the resilience of cropping systems and soil fertility management deserve particular attention in agricultural policies, in line with the objectives of the United Nations Decade on Ecosystem Restoration (2021-2030). This objective aligns with Sustainable Development Goal (SDG) target 15.3, which calls on countries to achieve land degradation neutrality by 2030. This study aims to analyze farmers' practices for sustainable land management and adaptation to climate change in the Municipality of Glazoué in Central Benin.

2. Materials and Methods

2.1. Study Area

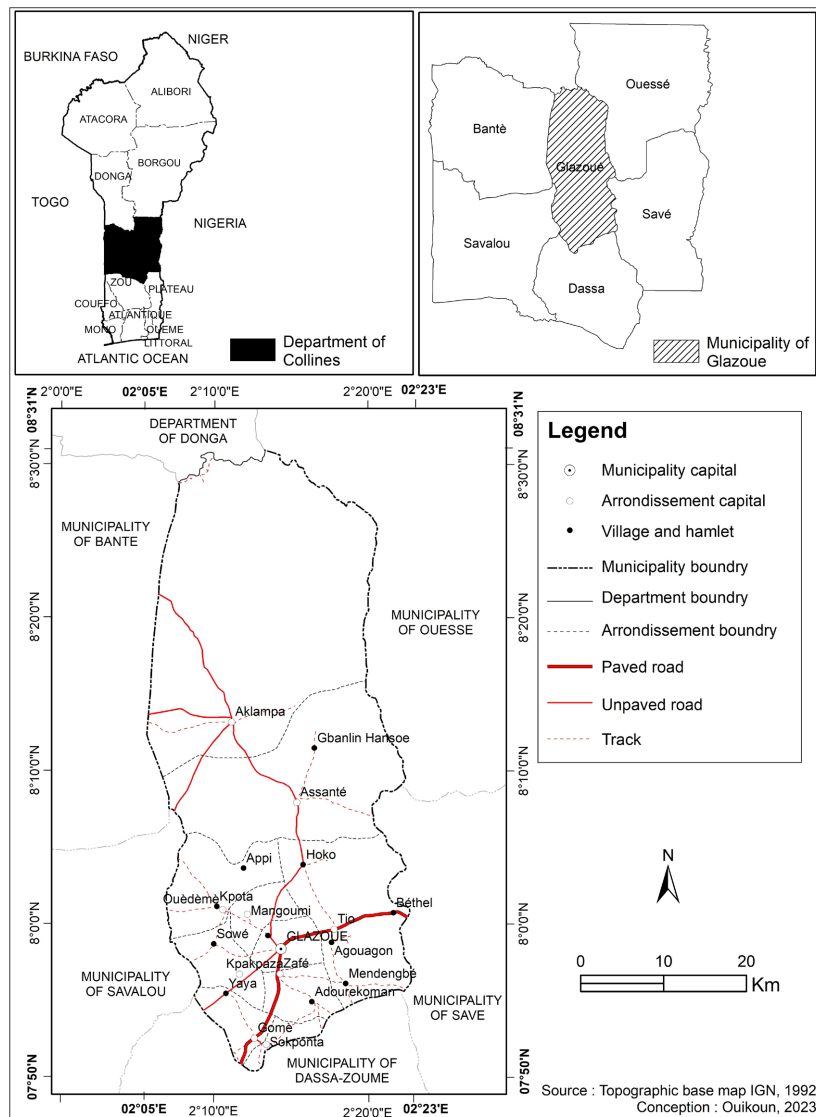


Figure 1. Distribution of surveyed localities in the Municipality of Glazoué.

The study was conducted in the Municipality of Glazoué, located in Central Benin (**Figure 1**). This area was chosen due to the context of low soil quality exacerbated by climate disturbances [11] [12]. The commune is located in the center of the country in agro-ecological zone 5, between 7°45' and 8°30' North latitude. The territory is characterized by plateaus (200 to 300 m altitude) dominated by a few hills (350 to 450 m altitude).

Several soil types constitute the main supports for agricultural production: tropical ferruginous soils, mineral hydromorphic soils, and raw mineral soils [13] [14]. Seven endangered species have been identified among the sacred woods: *Azelia africana*, *Borassus aethiopum*, *Khaya senegalensis*, *Milicia excelsa*, *Pterocarpus erinaceus*, *Vitellaria paradoxa*, and *Zanthoxylum zanthoxyloides*. Inappropriate farming practices negatively affect the commune's forest resources, leading to the loss of ecosystems and the destruction of wildlife habitats [14].

2.2. Sampling and Data Collection

A random sampling technique was used to select household heads. The sample size was determined from the results of the 2013 General Population and Housing Census (RGPH4), according to Schwartz's formula (Equation (1)) [15]:

$$n = Z^2 \times p(1 - p) / m^2 \quad (1)$$

where Z = confidence level according to the standard normal distribution (1.96 for 95% confidence), p = proportion of farming households to the total number of households, and m = tolerated margin of error (5%).

Thus, the total sample comprises 329 household heads. Additional data were collected from 30 key informants: farmers' organizations (15), deconcentrated state services (5), municipal services (3), and traditional leaders (7).

This survey was conducted to gather people's perceptions of sustainable development issues in the municipality's agricultural sector, on the one hand, and to collect information on farming practices and their impact on the environment, on the other. The collected data relate to: farmers' perceptions of the level of fertility and land degradation; farmers' perceptions of the factors responsible for soil degradation; farming techniques and strategies developed in response to climate constraints; methods of managing soil fertility under cultivation; production strategies and degradation indices; and current crop yields.

2.3. Statistical Analysis

Data were analyzed using SPSS software version 20.0 [16]. To assess land degradation, a synthetic degradation index (SDI) was constructed by integrating two qualitative indicators and one quantitative indicator, as follows:

Degradation Type (Qualitative): This describes the dominant form of degradation observed on a plot. It was classified into four categories:

- 1) T1: Water Erosion (e.g., rills, gullies).
- 2) T2: Wind Erosion.
- 3) T3: Chemical Degradation (e.g., salinization, acidification, nutrient depletion).

4) T4: Physical Degradation (e.g., soil compaction, crusting).

Degradation Degree (Qualitative): This describes the intensity or severity of the degradation process, based on visible field evidence and farmer descriptions.

It was rated on a three-level ordinal scale:

- 1) D1: Slight (Superficial signs, easily reversible).
- 2) D2: Moderate (Clear signs, requires intervention for reversal).
- 3) D3: Severe (Profound signs, difficult or irreversible).

Degradation Extension (Quantitative): This measures the spatial extent of degradation within a given plot. It was assessed as the percentage of the plot area showing clear signs of degradation:

- 1) E1: < 25% of the plot area.
- 2) E2: 25% - 50% of the plot area.
- 3) E3: > 50% of the plot area.

Aggregation Method and Classification: To construct the Synthetic Degradation Index (SDI), the qualitative indicators (Type and Degree) were first converted into numerical scores to allow for aggregation with the quantitative indicator (Extension). The scoring system was as follows:

1) Degradation Type (T): Assigned a severity weight based on its perceived impact on productivity and reversibility (T1 = 1, T2 = 1, T3 = 2, T4 = 2).

2) Degradation Degree (D): Directly converted to a numerical score (D1 = 1, D2 = 2, D3 = 3).

3) Degradation Extension (E): The midpoint of each percentage class was used for calculation (<25% = 12.5%, 25% - 50% = 37.5%, >50% = 75%).

The SDI was then calculated for each plot using the following multiplicative formula, which integrates both the severity and the spatial extent of degradation (Equation (2)):

$$SDI = (\text{Weight of Type} \times \text{Score of Degree}) \times \text{Value of Extension} \quad (2)$$

The resulting SDI scores were distributed into three degradation intensity classes, which were defined as follows:

- 1) Slightly degraded: $SDI \leq 2.5$.
- 2) Moderately degraded: $2.5 < SDI \leq 7.5$.
- 3) Highly degraded: $SDI > 7.5$.

These classes were represented graphically with color codes (e.g., Green for Slightly, Yellow for Moderately, Red for Highly degraded) for the production of degradation maps via the Geographic Information System (GIS).

The maps of the Normalized Difference Vegetation Index and the soil degradation were created using satellite data from ARTEM GDEM, 2010; Landsat 9, 2022, and Topographic base IGN, 1992. The Allan coefficient is a relevant indicator of soil disturbance because it allows for the assessment of changes in soil structure and composition in response to farming practices and environmental disturbances. In the context of sustainable land management, it helps identify the impacts of human activities and guide restoration strategies [17]. Allan's coefficient "L" [17] was calculated to characterize the level of soil disturbance (Equation (2)):

$$L = (C + J) / C \quad (2)$$

where C = Number of years under cultivation and J = Number of years under fallow.

Interpretation follows the rule: $L \geq 5$ indicates well-exploited land without excessive pressure; $L < 5$ indicates overexploited and degrading land.

3. Results

3.1. Socio-Demographic Characteristics of Respondents

Table 1 presents the general characteristics of the actors. The study population is predominantly male (91%) and adult (64%), indicating that agriculture is not an activity practiced by minors. Married respondents represent 41%, divorced 25.8% and single 18.2%. Furthermore, 73% of respondents are uneducated, highlighting the need for knowledge transfer on new sustainable land management technologies. Agriculture occupies 95.7% of respondents, confirming the high dependence of the central Benin population on this activity. These producers have several years of farming experience (98% of respondents) and benefit from the services of the Territorial Agricultural Development Agency (ATDA), pole 4.

Table 1. Socio-demographic characteristics of respondents.

Variables	Modalities	Frequency (%)
Sex	Male	91
	Female	9
Age (years)	] 25 - 35 years]	21.3
	] 36 - 45 years]	22.8
	] 46 - 55 years]	19.8
	] 56 - 65 years]	17.9
	] 65 years and above]	18.0
Marital status	Single	18.2
	Married	41.0
	Widowed	14.9
	Divorced	25.8
Education levels	Primary	14.3
	Secondary	7.9
	Higher	4.9
	Uneducated	72.9
Types of activity	Agriculture	95.7
	Livestock	1.8
	Trade	1.5
	Teaching	0.9

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Experience	Agriculture	97.3
	Livestock	0.9
	Trade	0.9
	Teaching	0.3

3.2. Endogenous Perception of Climate Change Indicators

Producers recall abundant and regular rainfall in the past, with longer rainy seasons. Populations state that previously, the flowering of *Parkia biglobosa* (nééré) signaled the start of agricultural preparations as rains began predictably in mid-March. This result reflects the regularity of rainfall and the mastery of the agricultural calendar by producers based on natural indicators.

Over the last ten years (2013-2023), producers have observed a disruption of the rainy season. All respondents (100%) observed a delay in the onset of rains and an early cessation (Figure 2). The high mention (99.7%) of aborted rains reflects this irregularity. The early cessation of rains sometimes occurs during the flowering-maturation period of crops. According to producers, two to three well-distributed rains are often missing to allow crops to complete their cycle. Current rains are more intense and accompanied by strong winds.

Rainfall variability is characterized by sequences of wet periods (2002-2012), dry periods (1992-1997), and unstable periods (2013-2022). This alternation is manifested by its impacts on agricultural yields. Producers observe a decrease in soil fertility, agricultural yield, and a change in the rainy calendar as impacts of climate change.

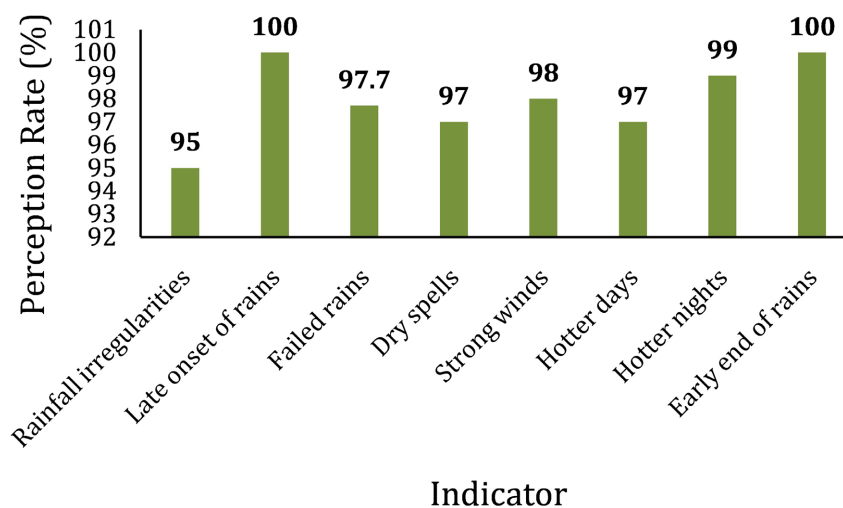


Figure 2. Endogenous perception of climate change indicators.

3.3. State of Degradation of Agricultural Land

Observation of agricultural practices and analysis of scientific data reveal major impacts on the study area. The Normalized Difference Vegetation Index (Figure

3) illustrates the extension of cultivation areas and their consequences on soils.

Reflectance in the red indicates bare soils resulting from erosion, mainly due to agricultural activities. **Figure 4** specifies the current level of degradation in the study area, showing a strong appearance of red in the south, southwest, center, and north of the municipality, indicating very high land degradation.

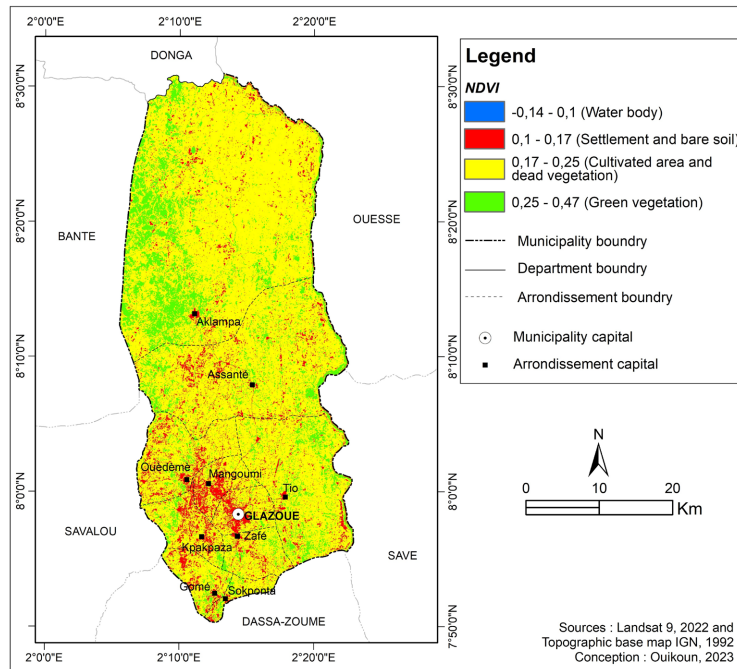


Figure 3. Map of the Normalized Difference Vegetation Index of the municipality.

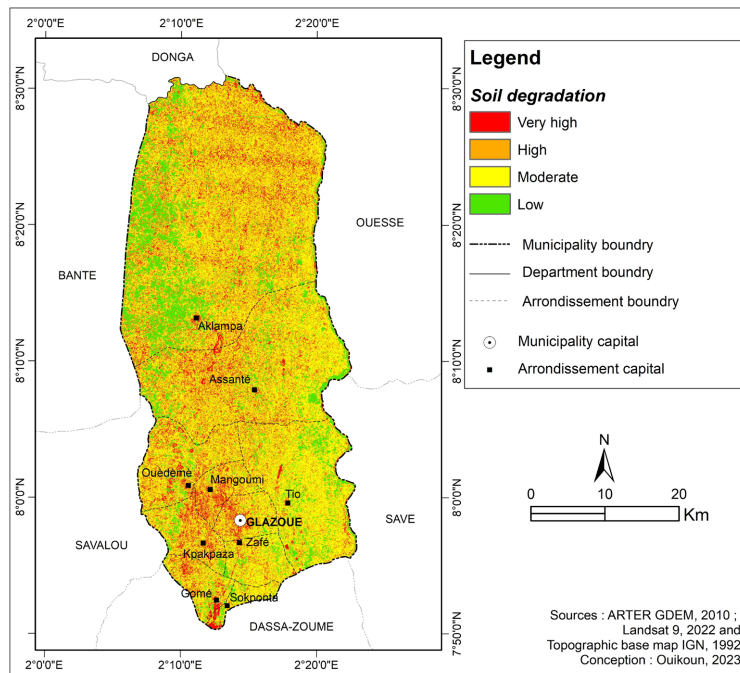


Figure 4. Soil degradation map.

Figure 5 illustrates the evolution of this degradation from 2017 to 2023, revealing that the municipality of Glazoué is affected by the problem of poor land management. Nearly 44% of the land in the study area is degraded, with only about 14% slightly degraded.

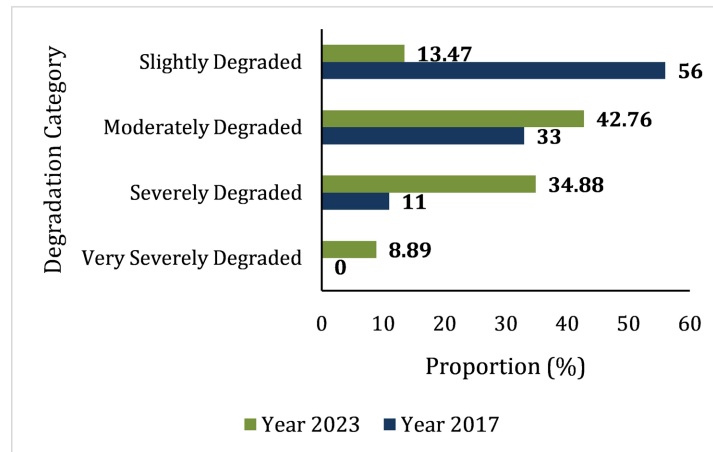


Figure 5. Evolution of arable land degradation in the study area from 2017 to 2023.

The Principal Component Analysis (PCA) performed to describe the variations in degradation types by district shows that the first component explains 81.63% of the information, and the first two components explain 94.40% of the sought information (**Figure 6**). The correlation circle of degradation levels shows that “Very highly degraded” (TD) and “Highly degraded” (FD) degradations are positively correlated with the first axis, while “Slightly Degraded” (FbD) and “Moderately Degraded” (MD) are negatively correlated with this same axis (**Figure 6(a)**). The projection of the districts reveals that average degradation (MD) is more frequent in Thio, Sokponta, Zaffé, and slightly in Assanté, while highly and very highly degraded soils are found in Magoumi, Gomé, Kpakpaza, Ouèdèmè, and Glazoué. Slight degradation is observed mainly in Aklampa (**Figure 6(b)**).

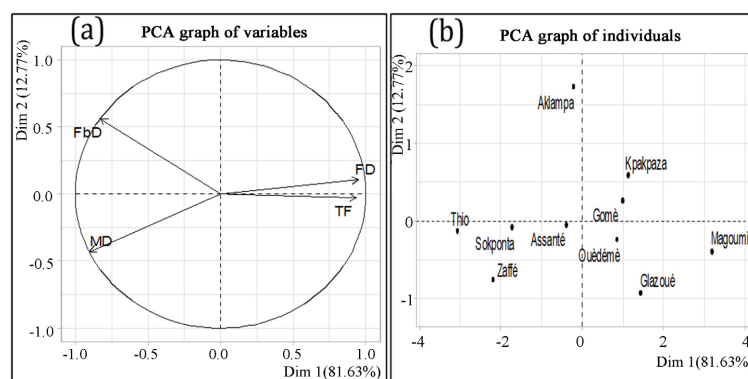


Figure 6. Results of the principal component analysis for describing the relationships between the different types of degradation and the survey areas. (a) Correlation circle of degradation types; (b) Projection of districts in the first factorial plane formed by axes 1 and 2 defined by the degradation types.

3.4. Allan's Coefficient and Land Exploitation Level

Table 2 presents fallow duration and cultivation duration data by district. The results show that Allan's coefficient is less than 5 ($L < 5$) in all ten districts, indicating that the land is overexploited and degrading throughout the commune.

Table 2. Fallow duration and number of years of land cultivation.

Districts	Population 2013	Minimum Average Exploitable Area (ha)	Maximum Average Exploitable Area (ha)	Number of Years under Cultivation	Fallow Duration	Allan's Coefficient L
Aklampa	25,756	4	150	15	8	1.533
Assanté	9,704	4	50	15	7	1.467
Ouèdèmè	9,687	2	45	20	7	1.350
Thio	11,947	2	40	21	5	1.238
Magoumi	10,538	0.5	5	21	0	1
Kpakpaza	8,017	0.5	5	23	0	1
Zaffé	13,053	1	30	30	3	1.1
Glazoué	20,036	1	3	30	3	1.1
Sokponta	7,758	0.5	5	33	2	1.061
Gomé	7,935	0.5	5	35	2	1.057

3.5. State of Use of Sustainable Land Management and Climate Change Adaptation (SLM-CCA) Measures

Despite the perception of land degradation and the very low level of soil fertility, producers apply some SLM-CCA measures based on their endogenous knowledge. These measures are organized around six categories: Integrated Soil Fertility Management (ISFM), Conservation Agriculture (CA), Soil and Water Conservation (SWC), Crop-Livestock Integration, Agroforestry, and Climate Change Adaptation.

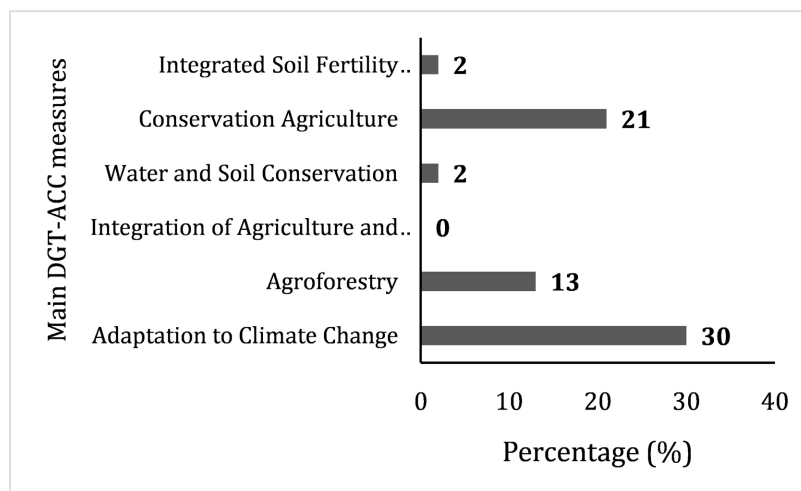


Figure 7. State of use of SLM-CCA measures.

Figure 7 indicates that two SLM measures are practiced by the majority of producers: adaptation to climate change (30%) and Conservation Agriculture (21%). The other measures are very poorly known and little used. To increase agricultural yields, all respondents (100%) use mineral fertilizers (NPK, Urea, Single Super-phosphate) subsidized by the State. Despite the perception of climate change and the high level of land degradation, the average adoption rate of SLM-CCA measures reaches only 11%.

3.6. Socio-Economic Impacts of Land Degradation

3.6.1. Impact on Crop Yields

The linear regression model performed on the evolution of sown areas and agricultural yields of 10 crops (maize, rice, sorghum, yam, cassava, cowpea, peanut, voandzou, goussi, and soybean) reveals significant results (**Table 3**). Fluctuations in sown area explain 73% of the fluctuations in production for all crops. The R^2 close to 1, along with a Fisher probability ($\text{Prob} > F = 0.0031$), demonstrates a good quality fit. For a 1% increase in sown area, production increases by 3.55%, indicating a positive relationship between these indicators.

The abandonment of traditional crops with long vegetative cycles and high yields without the use of chemical fertilizers is a notable consequence. **Figure 8** illustrates the effect of soil poverty unamended by chemical fertilizers, showing an abandoned maize field in Assanté. The effects of climate change on crops, combined with soil poverty, contribute to the degradation of household food security and decreased income, according to 97% of respondents.



Figure 8. Effect of soil poverty unamended by chemical fertilizers, showing an abandoned maize field in Assanté.

Table 3. Results of the linear regression model.

Source	SS	df	MS	Number of Obs	=	9
				F (1, 7)	=	19.56
Model	0.000 014 782	1	0.000 014 782	Prob > F	=	0.0031
Residual	5.2892e ⁻⁰⁶	7	7.5560e ⁻⁰⁷	R-squared	=	0.7365
				Adj R-squared	=	0.6988
Total	0.000 020 071	8	2.5089e ⁻⁰⁶	Root MSE	=	0.000 87

Continued

	Coef.	Std. Err	t	P > |t|	[95% Conf.	Intervall]
1Prod_Totalel						
1Emblave_Totall	3.556 931	0.804 182 8	4.42	0.003	1.655 341	5.458 521
_cons	-0.197 703 7	0.091 674 8	-2.16	0.068	-0.414 480 1	0.019 072 7

3.6.2. Land Conflicts and Consequences

Land conflicts are one of the main causes of land degradation. These conflicts affect all villages in the commune and even pit the commune against neighboring municipalities (Dassa-Zoumé, Savalou, Ouèssè, Bantè), particularly between farmers and herders (**Table 4**).

Table 4. Summary of human and animal losses (2015-2022).

Serious Injuries	Loss of Human Life	Cattle Killed	Economic Loss in FCFA (Number of Cattle Killed)
5	03	115	23,000,000

4. Discussion

The farming population was predominantly male, adult, experienced, and uneducated (73%). These results corroborate the observations of [18], who highlighted the challenges of disseminating agricultural technologies in rural Benin. The level of education is a determining factor in the adoption of agricultural innovations, as demonstrated by [9] in Burkina Faso. The predominance of agriculture (95.7%) confirms the data from [19] on the high dependence of the central Benin population on this activity.

Farmers' perceptions of climate change in the Municipality of Glazoué are consistent with regional scientific observations. The use of phenological indicators such as the flowering of *Parkia biglobosa* to predict the start of rains illustrates the richness of local knowledge, as highlighted by [20] in their work on local knowledge and adaptation strategies in Benin. The unanimous observation (100%) of delayed onset and early cessation of rains aligns with the analyses of [21] on past climate trends in Benin. The observed rainfall variability (wet sequences 2002-2012, dry 1992-1997, unstable 2013-2022) corresponds to the climate variability cycles documented by [2] in the region.

The concerning state of land degradation (44% of highly degraded land) corroborates the results of [10], who highlighted the degradation of agricultural land in other regions of Benin. Allan's coefficient is less than 5 in all districts, confirming the widespread overexploitation of land, consistent with the conclusions of [22] and [23] on the intensification of land pressure in Benin. The NDVI analysis reveals heterogeneous spatial degradation, more pronounced in areas of high population density (Glazoué, Magoumi, Kpakpaza), in accordance with the observations of [24] on the relationship between population pressure and degradation of natural resources.

The adoption rate of SLM-CCA measures (11%) remains very low despite the

perception of environmental problems. This result can be explained by several factors. First, land tenure security is often precarious in many regions, which discourages farmers from investing in long-term practices that require a long-term commitment. Uncertainty about land ownership may encourage farmers to favor traditional short-term methods. Second, access to credit is a major obstacle. Farmers often struggle to obtain financing to adopt sustainable technologies or management practices, which can require significant upfront investments. Without financial support, it becomes difficult to experiment with new methods. Finally, labor constraints play a crucial role. In many regions, the lack of available skilled or sufficient labor can limit farmers' ability to implement sustainable practices that require additional work or specific training. These combined obstacles, despite awareness of environmental degradation, contribute to the slow adoption of sustainable land management measures. This situation is explained by the non-integration of these measures into agricultural development programs, as observed by [5] and [22]. The predominance of chemical fertilizer use (100% of respondents) illustrates the dependence on external inputs, highlighting the limitations of current agricultural policies, as analyzed by [25] and the OECD [26]. The low knowledge of agroforestry and soil and water conservation techniques contrasts with their potential to improve fertility, as demonstrated by [27] and [28] in their work on integrated soil fertility management in Benin.

The positive relationship between sown area and production ($R^2 = 0.73$) masks the degradation of productivity per hectare, as observed by [29] and [25]. This concerning situation predicts a future collapse of yields if producers can no longer access chemical fertilizers, in line with the predictions of the OECD [25]. The documented land conflicts (3 deaths, 5 seriously injured, 115 cattle killed) illustrate the social tensions generated by land degradation. These results corroborate the analyses of [30] and [31] on the intensification of agro-pastoral conflicts related to the scarcity of fertile land in West Africa.

The results underline the urgency of reorienting agricultural policies towards the promotion of sustainable land management technologies. As recommended by the FAO [32] and TERRAFRICA [33], agricultural development programs must integrate participatory approaches and take into account local pedoclimatic specificities. The need to achieve land degradation neutrality by 2030 (SDG 15.3) requires urgent mobilization of resources and strengthening of producers' technical capacities, in line with the objectives of the UNCCD [34] [35].

For severely degraded areas, several specific technological options can be adopted to restore degraded land and promote sustainable agriculture. Integrating trees into agricultural systems could improve biodiversity, reduce soil erosion, and increase fertility. For example, planting legumes such as *Gliricidia* or *Leucaena* can enrich the soil with nitrogen while providing shade and fodder. The use of agricultural waste, such as corn stalks or cassava leaves, for composting or mulching will help maintain soil moisture, improve soil structure, and nourish crops. Implementing fallow periods with cover crops such as sorghum or millet could re-

store soil fertility while preventing erosion. These crops can be tilled back into the soil to enrich organic matter. Adopting practices such as minimum tillage or terracing could reduce erosion and conserve soil moisture. Grass strips can also be established to slow water runoff and trap sediment. Crop rotation could prevent nutrient depletion by alternating cash crops and legumes.

5. Conclusions

This study reveals a concerning situation of land degradation in the Municipality of Glazoué, with 44% of agricultural lands severely degraded. The generalized over-exploitation of soils, confirmed by Allan's coefficient less than 5 in all districts, requires urgent interventions. The low adoption rate of SLM-CCA measures (11%) contrasts with the generalized perception of environmental problems by farmers. This situation is mainly explained by the lack of education, technical supervision, and the non-integration of these measures into agricultural development programs. The observed socio-economic impacts (declining yields, land conflicts, food insecurity) compromise the sustainability of production systems in this municipality, recognized as a granary of the Collines Department.

Faced with these challenges, it is imperative to implement an integrated program for education and dissemination of sustainable land management technologies, adapted to local pedoclimatic specificities and actively involving farmers. This participatory approach should be part of a coherent national strategy aimed at land degradation neutrality by 2030, in accordance with the Sustainable Development Goals. Strengthening agricultural extension services, providing financial incentives, and establishing practical agricultural schools are essential complementary measures for improving farmers' skills and promoting sustainable agricultural practices.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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