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Article

Remote Sensing-Based and Participatory Analysis of Forests, Agricultural Land Dynamics, and Potential Land Conservation Measures in Kloto District (Togo, West Africa)

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Abstract: This study investigates proximate drivers of cropland and forest degradation in the Kloto district (Togo, West Africa) as a way of exploring integrated sustainable landscape approaches with respect to socioeconomic and environmental needs and requirements. Net change analysis of major cash and food crops based on Landsat data from three time steps (1985–2002, 2002–2017, and 1985–2017) and quantitative analysis from participatory survey data with farmers and landowners are used. The study underlines poor agricultural systems and cassava farming as major factors contributing to the alarming forest losses between 1985 and 2017. A significant net loss in forest cover of 23.6% and areas under maize and cocoa agroforestry farming of 12.99% and 10.1% between 1985 and 2017, respectively, was noted. These significant losses are due to intensive cassava cropping (38.78%) and settlement expansion (7.87%). Meanwhile, the loss of forest cover between 2002 and 2017 was marginal (8.36%) compared to the period 1985–2002, which had a considerable loss of 15.24%. Based on participatory surveys, the majority of agricultural lands are threatened by erosion or physical deterioration (67.5%), land degradation or salt deposits and loss of micro/macro fauna and flora (56.7%), declines in soil fertility (32.5%) and soil water holding capacity (11.7%), and changes in soil texture (3.3%). Most farmers adhere to the proposed climate smart practices, with an emphasis on cost-effective drip irrigation systems (45.83%), soil mulching (35%), and the adoption of drought-resilient varieties (29.17%) to anticipate adverse spells. We conclude that low adoption of improved soil conservation, integrated water management, and harvesting systems and the use of less productive and adaptive cultivars entail extreme degradation of cropland and a decline in crop productivity. Consequently, farmers are forced to clear more forest in search of stable and healthy soil to meet their food demands and improve their livelihood. Capacity building on integrated pathways of soil and land management practices is therefore needed to ensure sustainable and viable socio-ecological systems at a local scale.

Keywords: forests; agricultural systems; land degradation; food security; climate change; remote sensing; survey datasets; Kloto district

1. Introduction

One of the critical challenges facing humanity worldwide is land degradation and its negative effects, which translate directly into a decline in production, increase in poverty, diminished potential productivity, and climate change. Such effects of land degradation are more acute in regions with a high poverty rate where land use systems are threatening the sustainable maintenance and provision of land ecosystem functions and services and food security. In such conditions, integrated ecosystem management (IEM) and sustainable land management (SLM) are the most promising approaches to withstand soil degradation [1]. In the sectors of Agriculture, Forestry and Other Land Use (AFOLU), agriculture remains the main impediment to forest sustainability due to population growth and increasing human needs for food, energy, water, shelter, etc. With a global total area of nearly 4 billion hectares (30% of the Earth's surface cover), forests play a tremendous role when it comes to carbon cycling and ecosystem sustainability in a changing climate [2–5]. However, population growth associated with increasing food demand, socioeconomic orientations of countries, and political situations underpin the alarming loss of forests and exacerbate land degradation in developing countries. Several studies have focused on the various factors of land degradation (deforestation, forest degradation, and soil degradation). Ref [6] underscored the relationships between mining and land degradation, with potential socioeconomic impacts in Upper West Ghana. A case study in Cameroon and Congo also posited that institutional and policy factors are needed to combat deforestation, forest and land degradation [7,8] noted a significant net shrinkage in forest area, from 4128 to 3999 Mha, between 1990 and 2015, mainly in the tropics, with the highest rate of loss in low-income countries as a result of improper land management practices and exponential urbanization. Consequently, it is estimated, according to [9] and [10], that 1 to 2 billion Mg of carbon are released per year as a direct consequence of forest conversion to agricultural land. Moreover, 15–25% of annual greenhouse gas emissions emanated from tropical deforestation, forest and land degradation. Globally, efforts towards climate mitigation and adaptation emphasize Integrated Ecosystem Management approaches through the implementation of land degradation neutrality projects and policies [11]. In this regard, United Nations institutions (e.g., UNCCD, UNEP, UNFCCC, FAO) and affiliated research centers (e.g., CIFOR, WWF, ICRAF) have put forward an ambitious plan to halt deforestation and forest degradation, protect and promote forest reserves, restore degraded land and forest ecosystems, and improve capacity building on integrated forest and agriculture landscape management towards the achievement of land degradation neutrality [11]. In West Africa, and especially in Togo, deforestation and land degradation are acute environmental challenges occurring at an unprecedented rate due to exponential urbanization and unsustainable agricultural practices to meet the food demands of the growing population. Annual deforestation is alarming, occurring at a rate of up to 4.5% against a total forest cover of nearly 24.24% of national land (www.reddtogo.tg). Deliberate expansion of cropland entails significant degradation of native forestland in association with total conversion of forest area to cropland, mainly for cash crops (cocoa, coffee, teak, and oil palm) and food crops (rice, maize, and cassava) in forest zones [12]. These conversions drive on-site (e.g., soil degradation, loss of life and biodiversity, and property destruction) and off-site (e.g., greenhouse gas emissions, climate change, and global warming) drawbacks. Relevant studies on forest dynamics in a changing climate, its roles, drivers, policies, and reliable methods for their monitoring are duly undertaken using different approaches. While some of them are based on simple remote sensing e.g., [13–19], others have investigated the intensity analysis e.g., [20–23]. Though previous studies integrated remote sensing and household surveys to investigate landscape dynamics e.g., [24,25], little is known about the approach in Togo. In addition, a methodological gap exists with regard to integrating satellite data and household survey for the evaluation of existing farming and cropping systems and exploring willingness to adopt sustainable land management practices. This avenue of research is essential for achieving sustainable socio-ecological landscapes through integrated and participatory assessment, opportunities and policies identification, and formulations to circumvent land degradation and forest cover shrinkage under climatic and anthropogenic threats in Togo, especially in Kloto district.

Sustainable ecosystem management entails a coherent and integrated approach across all agricultural sectors and food systems through including farmers and rural people, who will adhere to the plans if they match up with their needs and interests [26–28]. This paper aims to assess forest and agricultural land dynamics in terms of (i) forest conversion to agricultural and residential areas; (ii) farmers' perceptions of current farming and cropping systems and the potential causes of land degradation in a changing climate; and (iii) willingness to adopt integrated soil and water conservation measures to mitigate the degradation of cropland and forest in a changing climate.

2. Materials and Methods

2.1. Study Area

The study was conducted in Kloto district, which encompasses 13 sub-districts located in the northwest of the capital, Lomé (Figure 1). Kloto is located between 0.50° and 0.77° East and 6.75° and 7.0° North. The district covers a total area of 528.23 km^2. The major economic activity is farming of food crops (e.g., maize and cassava) and cash crops (cocoa and coffee).

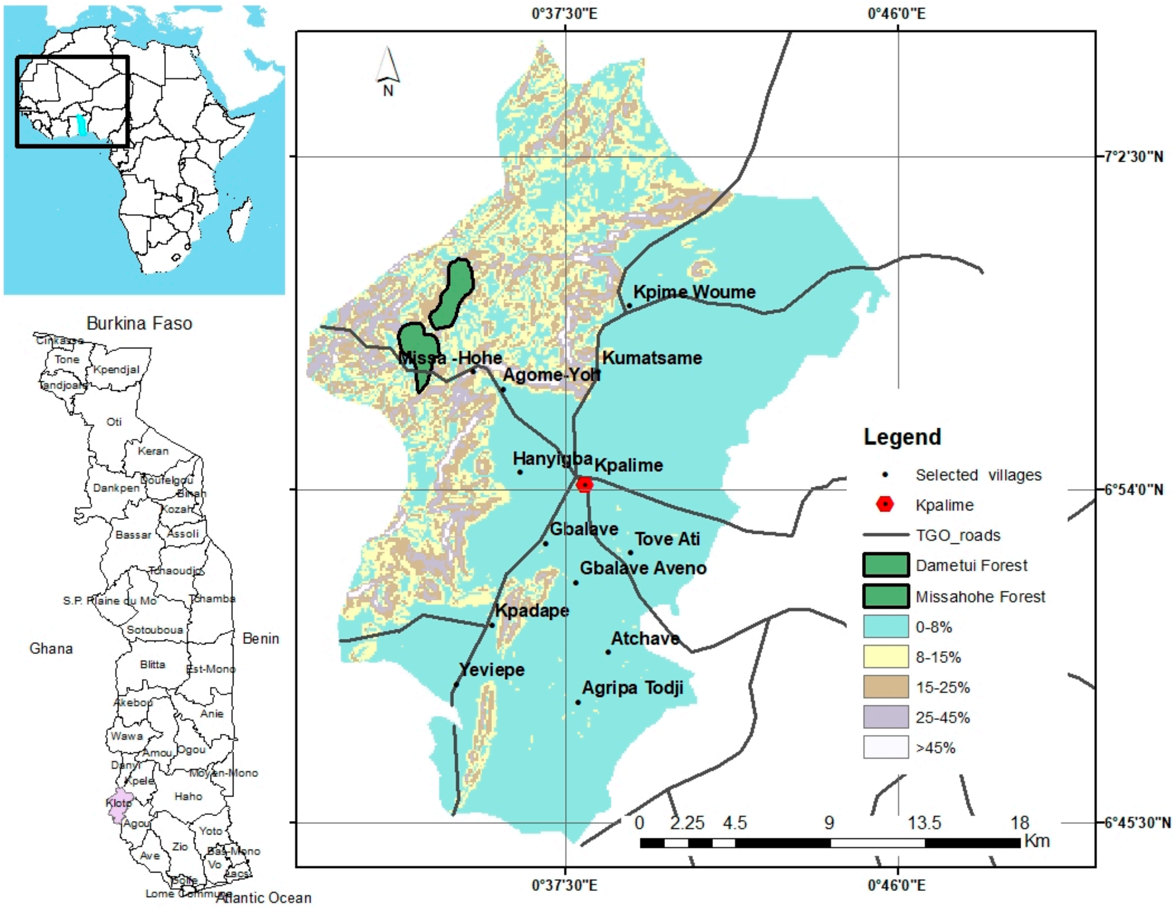


Figure 1. Kloto district, with select villages marked.

The average production of maize and cassava from 1990 to 2016 revealed an annual production of 10,928 and 19,498 tons for maize and cassava over an area of 8291 and 3080 hectares, respectively. From 2014 to 2016, cocoa agroforestry of 2762 hectares produced 1041 tons annually (DSID, 2017: analyzed statistic data). The average annual rainfall over a 16-year (2000–2016) total rainfall period is 1517.1 mm ($CI_{0.95}$ = 1517.1 ± 108.1 mm). The highest and lowest annual rainfall of 1830 mm and 1063 mm were recorded in 2016 and 2005, respectively. The study area has 20.5 ± 0.11 °C and

28.9 ± 0.22 °C as the minimum and maximum 16-year mean temperature, respectively. The lowest minimum temperature (20.3 °C) was recorded in 2001, 2008, 2014, and 2015, with the highest (21.1 °C) in 2016. The hottest year was 2016 with a maximum mean temperature of 29.5 °C.

2.2. Data Collection and Analysis

Three Landsat datasets (5, 7 and 8) from March 1985, 2002, and April 2017 were downloaded from the USGS website with cloud cover less than 10% using path 193 and row 055. For the selected years, we assumed the same phenological conditions prevailed at the acquisition date because of the bimodal climate season in the study area. Thereafter, thematic analysis was performed in ENVI software based on six (06) land use land cover types, namely forest, cocoa agroforestry, maize, cassava farms, settlements, and unclassified (Table 1).

Table 1. Definition of the land use/land cover types used in this study.

Land Use Land Cover Type	Definition	Source
Forest	Areas covered with original vegetation of different tree species of a minimum height of 5 m at maturity and 30% maximum crown cover with 0.5 ha minimum area spanning.	[29]
Cocoa agroforestry	Perennial arable and tillable land of mixing cocoa, trees and other crops (plantains) under conventional and family cropping systems.	Authors' definitions
Cassava	Annual/perennial arable and tillable land of local or improved cassava under conventional and family cropping systems.	
Maize	Annually tilled lands for cropping improved maize varieties (Ikenne or Obatanpa) under conventional family cropping systems.	
Settlement	Areas covered with human habitations where tree cover is negligible.	
Other	Places occupied by, e.g., road, water.	

Forty random points were collected for each land use type to train and validate the classification. Image calibration of the three years was done using ground truth (survey data), archived land occupational georeferenced points (40 in total) of each land use type of the subsequent years from available statistics (DSID, 2017: Agriculture Census statistic data) and Google Earth historical data records. Supervised classification was done using Maximum Likelihood Classifier and a post-classification technique was initiated to derive the extended cross-tabulation matrix for land use change and intensity analysis. A field campaign was organized from May to October 2017 for historical land occupational information via interviews with land owners and farmers in 12 villages (Figure 1) at a rate of 16 respondents per village, selected randomly based on the following criteria: proximity to the original sampled forest (1 km to forest site), land occupational time frame (minimum five year) after deforestation, and spatial distributions in the same geomorphological soil unit and climate condition. This aims to calibrate and validate land use land cover maps, to characterize actual farming and cropping systems and their related effects on cropland, and finally to appraise the will of farmers to adopt integrated soil fertility, conservation, and water management techniques in a changing climate. Images were classified with 95% accuracy with a Kappa coefficient equal to 0.9 with 95% producer and user accuracy. Classified maps were used to derive the net changes graphs of 1985–2002, 2002–2017, and 1985–2017 using the ArcGIS 10.3 raster calculator module. Descriptive statistics of net land use changes were performed at a 95% confidence level using Microsoft Excel 2013. Questionnaire-based information was processed using SPHINX 4.5 software.

3. Results

3.1. Net Change Analysis

Land use land cover maps (Figure 2) and the statistical results (Table 2) depicted a significant decrease in forest area from 42.78% in 1985 to 27.62% and 19.26% in 2002 and 2017, respectively. In the meantime, areas under cassava production and settlements increased up to 52.98% and 9.44% in 2017, respectively.

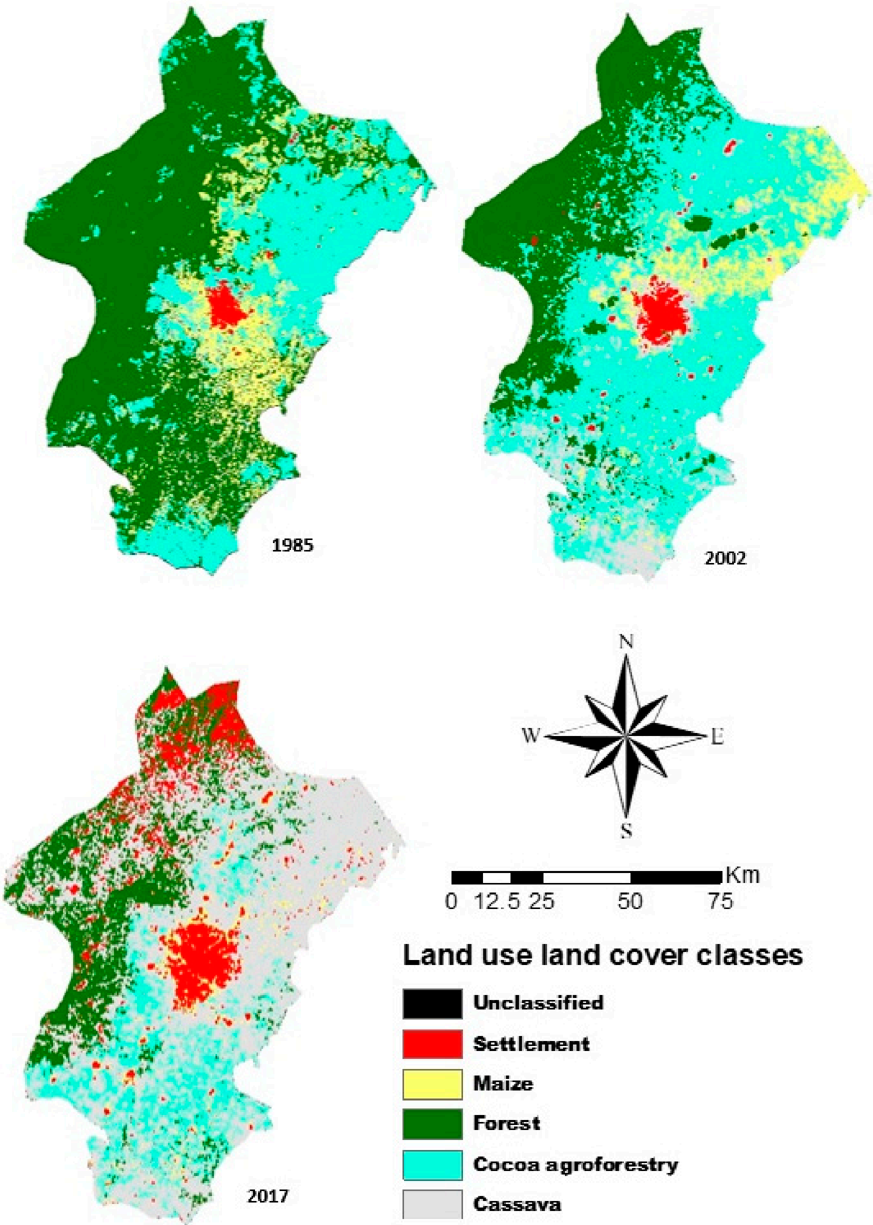


Figure 2. Maps of historical land use/land cover types in 1985, 2002, and 2017.

Maize and cocoa agroforestry farming was less intense. The proportion of areas under maize cultivation decreased from 15.96% in 1985 to 9.36% and 3% in 2002 and 2017, respectively. Meanwhile, cocoa agroforestry expanded during the first period (1985–2002) from 25.23 to 50.38% and decreased considerably during the second period (2002 to 2017) from 50.38 to 15.18%. The net change analysis (Figure 3) results revealed a significant loss in forest cover by 23.6% and surface areas under cultivation of cocoa agroforestry and maize by 12.99 and 10.1% from 1985 to 2017 due to intensive cassava cropping (38.78%) and settlement expansion (7.87%). Meanwhile, the loss of forest cover between 2002 and 2017 was marginal (8.36%) compared to the earlier period (1985–2002), when the loss was considerable (15.24%).

Table 2. Areal distribution of land use/land cover types in 1985, 2002, and 2017.

	1985		2002		2017	
	Km^2	%	km^2	%	km^2	%
Unclassified	0.54	0.10	0.75	0.14	0.72	0.14
Settlement	8.29	1.57	11.24	2.13	49.89	9.44
Cassava	75.03	14.37	54.76	10.37	279.85	52.98
Maize	84.46	15.96	49.42	9.36	15.86	3.00
Cocoa agroforestry	133.52	25.23	266.14	50.38	80.16	15.18
Forest	226.37	42.78	145.92	27.62	101.74	19.26
Total	528.21	100.00	528.23	100.00	528.22	100.00

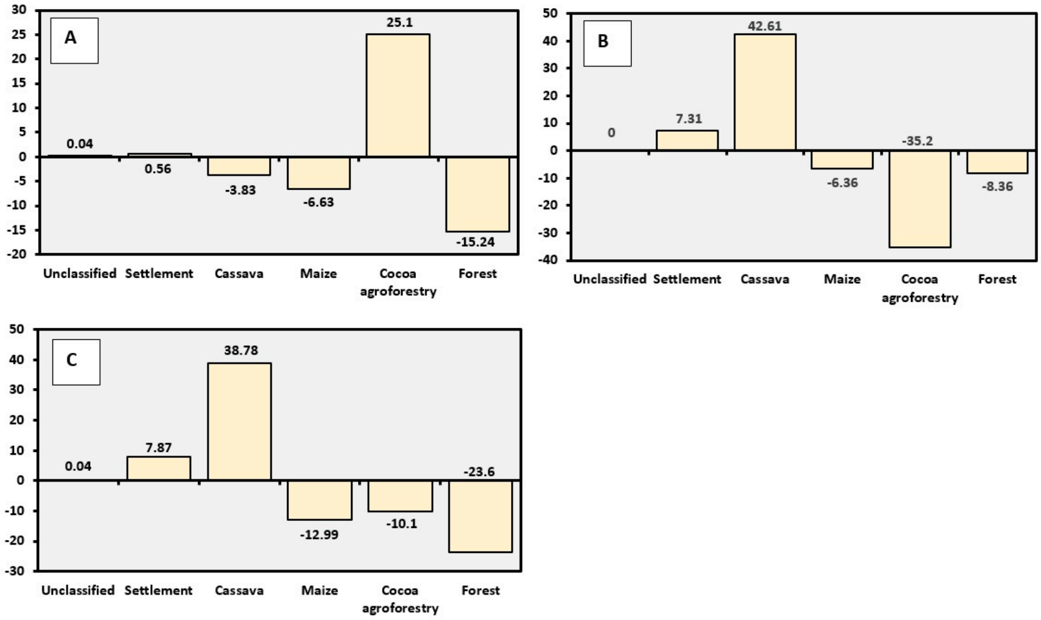


Figure 3. Net land use/land cover changes during the periods 1985–2002 (**A**); 2002–2017 (**B**); and 1985–2017 (**C**).

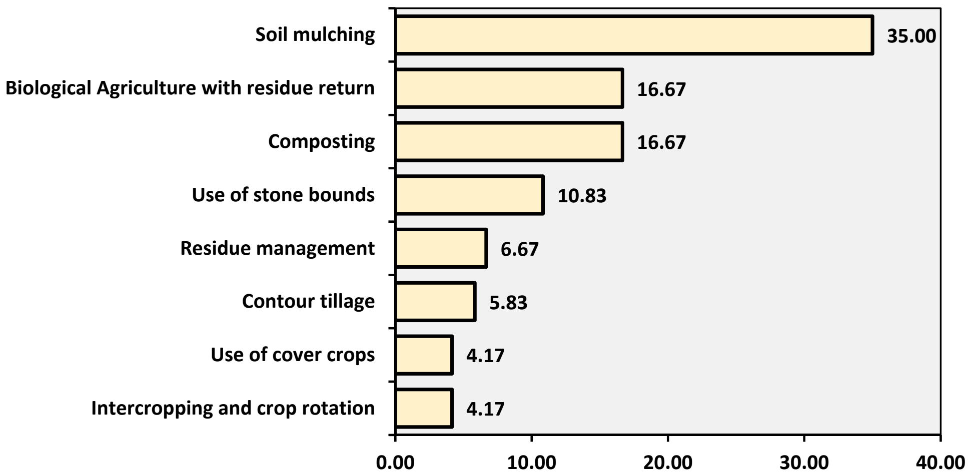
Similarly, between 1985 and 2002, cassava and maize lost 3.83% and 6.63% of their area of cultivation to settlement expansion and cocoa agroforestry cultivation, which gained 0.56% and 25.1%, respectively (Figure 3). During the following period (2002–2017), settlement and cassava areas expanded up to 7.31% and 42.61%, respectively. In the meantime maize, cocoa agroforestry, and forests underwent negative changes of 6.36%, 35.2%, and 8.36%. Cocoa production was low in some villages (e.g., Gbalave Volove and Kpime Woume). In the meantime, deforestation and forest degradation rates were also alarming in some areas, e.g., Kpime Woume and Atchave.

3.2. Current Local Farming and Cropping Systems in a Changing Climate

Results from questionnaire data revealed an agricultural system largely dominated by men (104/120; 86.7%). The age of the interviewed active farmers ranged between 19 and 56 years. Most farmers have reached secondary (47.6%) and senior high (40%) school, while 11.7% have primary degrees. Among the respondents, only 0.6% have an official degree and none have earned a university degree. The test of knowledge on climate change and related effects on the agroecosystems showed that most respondents (63.3%) have not heard of or been educated about climate change issues; a minority (36.7%) confirmed they have some knowledge of the subject matter. The majority of agricultural lands are threatened by erosion (67.5%), followed by land degradation (56.7%), soil fertility decline (32.5%), a decline in soil water holding capacity (11.7%), and changes in soil texture (3.3%). In terms of farming activities, cassava, cocoa agroforestry (cocoa associated with plantain; trees and/or cassava at early stage), and maize are mainly produced at 34.2%, 33.3%, and 32.6%, respectively, under various crop management systems. Land preparation and farm management are based on manual (75%) and chemical tillage (70.8%), followed by slash and burning (49.2%). Meanwhile, 59.2% are used to mixed cropping, especially in cocoa production farming, while 29.2% and 11.7% are practicing monoculture and rotational cropping, respectively. However, none of the respondents used fallow and/or agroforestry farming systems. Monoculture is predominant under maize (55%) compared to cassava (32.5%), while all farmers (100%) practiced mixed cropping under cocoa agroforestry compared to cassava (45%) and maize (32.5%) farming.

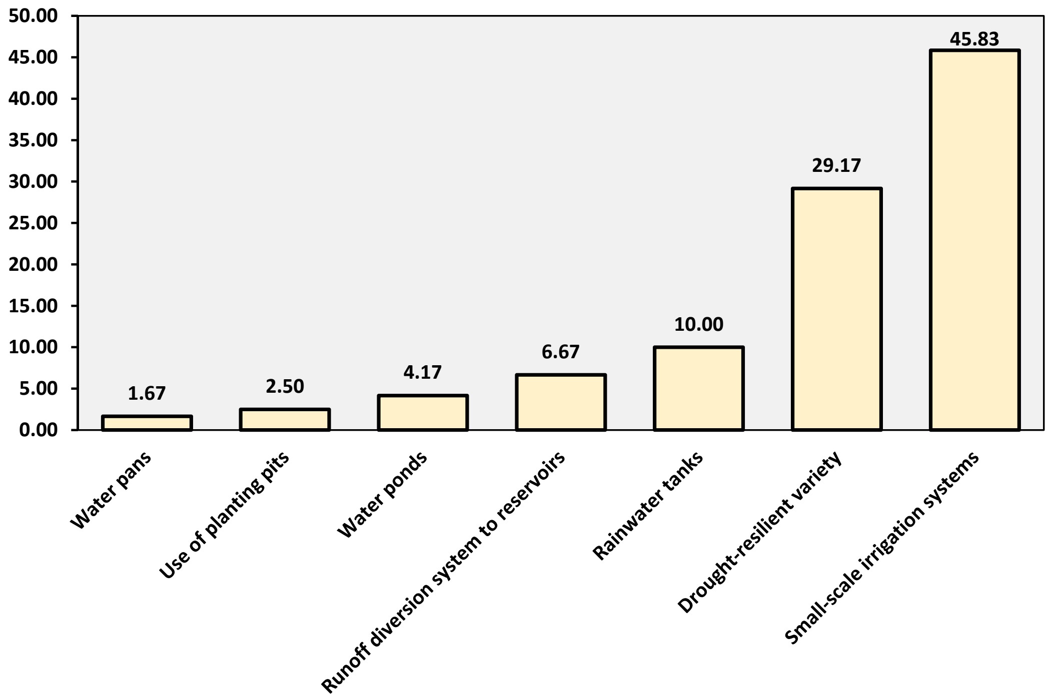
3.3. Local Willingness to Adopt Integrated Soil and Water Conservation (SWC) Practices

Analysis of questionnaire data on the adoption of improved agricultural SWC practices and rainwater harvesting systems showed favorable responses from respondents (Figure 4a,b). Regarding SWC measures, soil mulching (35%) was given more attention compared to composting (16.67%), biological agriculture with residue return (16.67%), and contour tillage (5.83%) (Figure 4a). In addition, some farmers expressed their willingness to use stone bounds (10.83%) and other SWC measures such as intercropping, crop rotation, and the planting of cover crops.



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. (**a**) Expressed willingness to adopt soil and water conservation practices. (**b**) Expressed willingness to adopt improved water management and harvesting techniques.

Regarding integrated water management and harvesting (WMH) techniques, farmers pay more attention to small-scale irrigation systems (cost effective drip irrigation), at 45.83% (Figure 4b). In the meantime, a relatively large proportion of farmers intend to adopt drought-resilient varieties (29.17%) to anticipate the adverse effects of drought spells. Additionally, respondents showed a strong willingness to adopt other useful rainfall harvesting systems such as rainwater tanks (10%), construction of runoff diversion systems to reservoirs (6.67%), use of planting pits (2.50%), water pans (1.67%), and ponds (4.17%).

4. Discussion

The net deforestation rate (Figures 2 and 3) is a product of both agricultural activity and settlement expansion. Survey analysis revealed the weaknesses of the agricultural systems in terms of farming and cropping systems that deteriorate farmland. Indeed, in response to fertility decline and erosion problems, forests are cleared for fresh and stable lands for cropping to sustain food production. In this study, the majority of agricultural lands are threatened by erosion (67.5%), followed by land degradation (56.7%), soil fertility decline (32.5%), a decline in soil water holding capacity (11.7%), and changes in soil texture (3.3%) due to deliberate use of conventional practices (e.g., monoculture, tillage), non-adoption of climate-smart practices, and exponential population growth. This study contributes to our understanding of the role of agricultural practices in the deforestation, forest, and land degradation processes in changing climate conditions e.g., [7,30,31]. On the other hand, exponential shifting of maize production to cassava production and the overall expansion of cassava farming could be the result of cropland health status. Maize production requires a certain minimum soil fertility conditions, and when soil fertility declines, productivity is compromised. At this point, farmers find an alternative: growing crops with low input demand to restore soil fertility and derive benefits from crop leaves for food. Moreover, Kloto farmers associate cassava with cocoa agroforestry production, mixed with plantain and wild trees at early stages of cocoa planting. Some farmers also practice crop association and/or rotational cropping on soil with low fertility. It is evident that the land use systems, the adoption of cropping systems, and fertility management are responsive to various factors specific to the location. Ref [32] showed that the major traits of farming and cropping systems in West Africa in a changing climate are mostly a result of their weaknesses vis-à-vis technical, environmental, and sociopolitical constraints.

Similarly, these findings confirm the results of existing studies on the potential drivers of forest and land degradation due to land misuse and agricultural activities in developing countries. In Upper West Ghana, [31] revealed that illegal mining is the major cause of land degradation. Additionally, land misuse not only affects agricultural productivity but also impacts negatively on household stability and security [6]. Therefore, the formulation of strategies must be based on the assessment and understanding of the farming systems at a local level through a participatory approach with stakeholders. As African soils are poor in organic matter, improved soil fertility management, erosion control, and water management techniques are fundamental to guarantee the coexistence of agriculture and forest in the study area and developing countries in general. This study underlines the current poor agricultural systems and presents the need for the adoption of sustainable practices to achieve food security, forest sustainability, and climate change mitigation. It is therefore important to undertake awareness-raising and integrated land management for halting land degradation. Accordingly, [1] estimated that environmental regulations to halt soil degradation could be effective when associated with integrated ecosystem management approaches.

5. Conclusions

A better understanding of West African farming, cropping, and population dynamics is a prerequisite to developing measures and technologies promoting the coexistence of agriculture and forest sustainability schemes. In this light, this study, which combines remote sensing and survey data to analyze the historical net changes in forest and agricultural land, helped us to assess and understand the reasons for deforestation, forest and land degradation in Kloto district (Togo, West Africa). This approach enables us to better comprehend the proximate drivers of deforestation forest and land degradation by perceiving the weaknesses in existing farming and cropping systems, major reasons for shifting from one farming system to another, and, most importantly, the reasons for the deliberate conversion of native forests and the willingness of farmers to adopt improved soil conservation and water management practices. Simply put, the participatory approach shows that pressure on cropland from actual farming and cropping systems entails severe land degradation. To circumvent these situations, farmers are obliged to shift from cereal mono-cropping (e.g., maize) to root crops (e.g., cassava) as an alternative to restore degraded soils, or clear existing adjacent forests in the search for more stable and healthy soil to sustain food production. This study is useful for policy formulation towards appropriate cropland land management, land use planning strategies, and capacity building of smallholders. These are of the utmost relevance for slowing forest shrinkage and land degradation while sustaining food production and improving the livelihood of people residing in the poorest and most remote communities of Kloto district (Togo, West Africa), who depend on agriculture and forest products. Accordingly, joint efforts between governments, civil societies and farming collectives to evaluate actual and emerging problems in the agricultural sector and identify and implement sustainable solutions to promote agro- and forest ecosystems are imperative. We also believe that one of the optimal ways of achieving these goals is through the greater involvement of women in the decision-making process and in land management. Furthermore, adhering to governance principles of transparency, fair accountability, and inclusive sustainable agricultural land management (SALMP), along with advance crop breeding projects, will be critical.

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Conflicts of Interest: The authors declare that they have no competing interests.

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