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Ecosystem-Based Adaptation Practices of Smallholder Farmers in the Oti Basin, Togo: Probing Their Effectiveness and Co-Benefits

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Abstract: The ecosystem-based adaptation (EbA) strategy is considered an effective approach to address the impact of climate change while ensuring the continued provision of ecosystem services on which farming depends. However, understanding the EbA's effectiveness for smallholder farmers in the Savannah region remains limited. The focus of this study is to explore the EbA practices that have been implemented by farming communities in the Savannah region of Togo. The study aims to evaluate the effectiveness of these practices and the perceived co-benefits reported by 425 smallholder farmers who participated in the survey. Our findings show that five practices, namely agroforestry, crop rotation, grass hedge/stone bunds, in-field water drainage channel, and intercropping, were practiced mainly by smallholder farmers and perceived as effective in reducing their vulnerability to climate risks. In addition, the benefits observed were linked to all five EbA practices. As a result, we can determine the suitable combination of EbA practices that fulfil the requirements of smallholder farmers, including co-benefits such as food security, adaptation advantages, and ecosystem service provisions. Such findings provide insights for developing integrated agriculture and climate change policies suitable for weather-induced disaster-prone areas such as the Savannah region.

Keywords: agroecosystems; agroforestry; climate change adaptation; ecosystem services; effectiveness; perception; Savannah

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1. Introduction

Most farming communities in developing economies rely on rain-fed agriculture [1]. They account for a sizable proportion of the global farming population, with an estimated 450–500 million worldwide, accounting for 85% of all farms [2]. In addition, they are vulnerable to climate change because changes in temperature, rainfall, and higher frequency of extreme weather events affect crop and animal productivity, food security, income, and overall well-being [3,4]. Crop and livestock productivity in developing countries is expected to decline significantly over the next few decades because of increased climate variability and climate change, among others [5,6], posing major risks to smallholder farmers in poor communities who lack the financial, institutional, and technical capacity to adapt [7]. Smallholder agriculture's productivity and contribution to the economy, food security, and poverty reduction depend on ecosystem services such as soil fertility, freshwater delivery, pollination, and pest control [8]. The worsening weather conditions and extreme climate events seriously threaten the ecosystem, impacting the many services and benefits communities derive from. This puts small-scale farmers at risk of food and water shortages, especially in Africa, where the effects are most severe [4,9,10]. Enhancing agricultural productivity is critical for ensuring food and nutritional security for all, particularly for smallholder farmers. Without sustainable adaptation strategies, the long-term negative consequences of climate change on the livelihood of smallholder farmers could be severe [1].

The rural communities in the Oti basin, in the Savannah region of northern Togo, rely heavily on agroecosystems for livelihood-supporting services and resources, which mobilizes nearly 90% of rural households [11,12]. However, the region is one of the areas in Togo with high susceptibility to land degradation (e.g., soil erosion, loss of soil organic matter, and loss of biodiversity) due to the physical characteristics of its soils (low water retention capacity, fragile structure, a tendency to acidification), unsuitable human practices (e.g., deforestation, unsustainable agriculture practices), and the change in climatic conditions [13]. The region has recently been heavily impacted by climate change's effects, with a significant increase in the frequency and intensity of extreme events such as droughts, floods, erratic rain, and extreme temperatures, negatively affecting agriculture land and livelihood [14–17]. The higher frequency of extreme climate events observed in the study area, combined with population growth, and associated increased demands for food and energy production, is leading to significant changes in the landscape—land, water resources, and vegetation cover, resulting in the degradation of agroecosystem and the reduction in ecosystem services supply [18]. Although local communities may experience short-term benefits from fulfilling food and energy demands, it is essential to acknowledge that they will inevitably incur substantial costs in food insecurity and population welfare insecurity in the long-term. In this regard, farm management practices that balance improving community livelihoods with preserving agroecosystem health, such as sustainable land management practices, conservation agriculture practices, and integrated soil fertility management practices, have been introduced in the Savannah region through several projects from non-governmental organizations and local governments to develop an environmentally, economically, and socially sustainable farming system [17]. Previous research studies conducted in various countries show that one effective method of supporting smallholder farmers in maintaining their farm-based livelihoods amidst the growing challenges of climate change and variability is by promoting farm management practices that utilize agrobiodiversity and ecosystem services, which offer valuable adaptation benefits [19–23]. These benefits may result in greater resilience of agroecosystems to climate change, increased crop productivity and yield, and helping to improve food security and rural livelihoods [19–23]. Several international agreements highlighted that increasing trends in ecosystem degradation are increasing the vulnerability of communities to climate change and that Ecosystem-based Adaptation (EbA) strategies should be prioritized [24,25]. Ecosystem-based Adaptation (EbA) is one theoretical discourse that is drawing increasing attention, which acknowledges the importance of ecosystems in the adaptation process to improve societal resilience [7,26]. EbA is defined as using biodiversity and ecosystem services to help people adapt to the adverse effects of climate change [27]. Some examples of EbA approaches include management, conservation, and restoration of ecosystems that deliver services that can help to reduce climate change exposure [12]. EbA approaches are considered appropriate for African countries because of the potential for flexibility, cost-effectiveness, and co-benefits (e.g., biodiversity conservation, enhanced habitat conditions, conservation of traditional knowledge, livelihood, and food security) [28]. Existing studies in the Savannah region of Togo on climate change adaptation emphasized the importance of sustainable agriculture management practices to improve agricultural land resilience and boost crop productivity in the climate change context [15–17]. It is recognized that many smallholder farmers are already implementing practices that preserve agrobiodiversity and increase the capacity of their agroecosystems to resist, cope with, and/or recover from extreme weather events [20,28,29]. However, knowledge about the existing EbA practices and their effectiveness in addressing climate–related impacts remains scarce. Understanding how smallholder farmers view and use EbA practices can show the benefits for their farmlands and livelihoods, leading to more sustainable agriculture and resilience in the face of climate change. There appears to be a gap in research regarding the use and effectiveness of agricultural ecosystem-based adaptation practices for climate change. Additionally, there seems to be little information available on the perceived co-benefits of these practices. Furthermore, there is not much evidence from the literature that this scope of analysis underlines the current research that has been carried out to fit the current socioeconomic context in the study area. Therefore, this study aims to identify the EbA practices, the effectiveness, and co-benefits of each EbA appropriate for smallholder farmers in the Savannah region to address climate risks. Then, this study addresses the following questions:

(i) What are the main EbA practices in the agriculture sector to deal with climate-related risks in the Savannah region?
(ii) How do smallholder farmers perceive the effectiveness and the co-benefits of EbA practices in dealing with climate-related risks in the Savannah region?
(iii) How are the perceived effective EbA practices related to their perceived co-benefits of EbA practices and suitability for smallholder farmers in the Savannah region?

Our research provides new information on the use of EbA practices by smallholder farmers in the Savannah region of Togo, as well as important insights into their socio-ecological effectiveness and co-benefits in the context of climate.

The remainder of the paper is structured as follows: the sub-section of the introduction provides a review of the literature on existing conceptual frameworks for measuring EbAs effectiveness. Section 2 presents the study area and data collection and analyses. Results are then outlined in Section 3, discussing the empirical findings and limitations in Section 4. The paper concludes with Section 5.

Conceptual Frameworks for Measuring EbAs Effectiveness

To determine the most effective EbA measures in the face of climate change, it is crucial to use comprehensive assessment frameworks. Such frameworks help evaluate the measures' efficacy in promoting adaptive capacity and resilience while providing multiple benefits. For example, Munroe et al. [30] and Doswald et al. [31] assessed the state of the evidence-based effectiveness of EbA initiatives through a framework developed with stakeholders. However, such an assessment was limited to a systematic map of EbA-relevant peer-reviewed literature and a sample of grey literature to provide a methodical overview of EbA effectiveness. The authors concluded that effective EbA would reduce people's environmental, social, and economic vulnerability and provide benefits.

Reid and Alam [32] conducted an EbA assessment in two action research sites for community adaptation in Bangladesh. They evaluated how effectively EbA supports adaptive capacity and resilience in such communities. However, the EbA's effectiveness was viewed only through an ecosystem health lens. The authors argued that effective EbA should have two key components: the maintenance of ecosystem services and ecosystem resilience.

More recent EbA works further the analysis to include measurable parameters. Bertram et al. [33] developed a framework that sets out qualifications and quality standards for evaluating the effectiveness and robustness of an EbA intervention. This framework also provides a baseline for identifying areas where the intervention can be enhanced. Three key elements were featured to measure the effectiveness of EbA projects at national to local levels: (1) EbA helps people adapt to climate change; (2) EbA actively uses biodiversity and ecosystem services; and (3) EbA is part of an overall adaptation strategy. Each element contains one or two criteria and various indicators that must be met. The assessment framework is provided to help decision-makers design high-quality EbA measures during the planning phase of a project and improve the quality of measures during the implementation phase. Reid et al. [34] provided a framework for assessing the effectiveness of EbA approaches for overcoming barriers to EbA implementation and influencing policy. In this latter framework, EbA effectiveness is broadly classified along four axes: (1) effectiveness for human communities; (2) effectiveness for the ecosystem; (3) financial and economic effectiveness; and (4) policy and institutional aspects. The framework is being applied to strengthen the evidence and inform policy by consolidating and comparing evidence from 13 existing EbA project sites in Asia, Africa, and Central and South America. This framework was developed primarily to assist policymakers in determining when and how the EbA initiative is effective. However, it can also be used to develop indicators to help measure initiative effectiveness and support adaptive project management when planning and implementing new EbA projects.

Similarly, Vignola et al. [20] developed a framework for identifying effective EbA practices for smallholder farmers. The authors perceive that effective ecosystem-based agricultural practices can improve ecosystem resilience and service provision, increase adaptation benefits to climate change, and improve smallholder farmers' livelihood and food security. The proposed framework is seen to be a valuable tool to stimulate careful consideration of agricultural practices that are suitable or effective for smallholder farmers to reduce vulnerability to climate change while also conserving the capacity of agroecosystems to provide both on- and off-site ecosystem services and could be applied to the wide variety of agricultural systems that exist globally [20].

Although there are many frameworks to assess the effectiveness of EbA practices, they share some similarities, such as EbA measures that improve ecosystems' capacity to produce services, improve humans' well-being, adaptive capacity, or resilience, and reduce their vulnerability. In this study, we applied the framework presented by Vignola et al. [20], as it is specifically designed for smallholder farmers. Based on this framework, EbA is defined in agricultural systems as agricultural management practices that use or take advantage of biodiversity or ecosystem services or processes (either at the plot, farm, or landscape level) to help increase the ability of crops or livestock to adapt to climate change and variability. According to Vignola et al. [20], practices need to satisfy the three main dimensions and their underlying criteria to be considered as EbA practices that are suitable for smallholder farmers, namely: (1) ecosystem services provision; (2) adaptation benefits; and (3) livelihood and food security. The list of the underlying criteria for each dimension is presented in Table 1.

Table 1. Framework for identifying EbA for agricultural practices (based on Vignola et al. [20]).

Dimension 1: Ecosystem Services Provision	Dimension 2: Adaptation Benefits	Dimension 3: Livelihood and Food Security
Criterion 1: Is based on the conservation, restoration, and sustainable management of biodiversity (e.g., genetic, species, and ecosystem diversity) **Criterion 2:** Is based on the conservation, restoration, and sustainable management of ecological functions and processes (e.g., nutrient cycling, soil formation, water infiltration, carbon sequestration)	**Criterion 1:** Maintains or improves crop, animal, or farm productivity in the face of climate variability and climate change **Criterion 2:** Enhances buffering capacities against extreme events (heavy rainfall, floods, drought, extremely high temperatures, strong winds, etc.) **Criterion 3:** Reduces crop pest and disease hazards due to climate change	**Criterion 1:** Increases livelihood and food security of smallholder households **Criterion 2:** Increases or diversifies income generation of smallholder households **Criterion 3:** Takes advantage of local or traditional knowledge of smallholder farmers **Criterion 4:** Uses locally available and renewable inputs (e.g., using local materials from within the farm or landscape **Criterion 5:** Requires implementation costs and labor affordable to smallholder farmers

If the practices meet at least one of the criteria in dimensions 1 and 2, they are considered EbA practices. If the practices meet at least one criterion in dimension 3, they are EbA practices suitable for smallholder farmers. This framework has been successfully applied to smallholder coffee farmers in Mesoamerica [20]. In contrast, Nanfuka et al. [35] used the same framework for characterizing EbA practices for drought for the smallholder cattle farmers in the central corridor of Uganda.

2. Materials and Methods

2.1. Study Area

The research was conducted in 15 localities from the seven prefectures of the Savannah region in the Oti Basin (Figure 1). The Oti Basin is the largest of the three basins that share the Togolese territory. It stretches for nearly 600 km between 6°10′ and 11°10′ north latitude and 0° to 1°25′ east longitude. It encompasses the entire Savannah region. The study area has a tropical climate with a dry season from November to March and a rainy season from April to October. The annual rainfall ranges from 900 mm to 1400 mm, with August being the wettest month. The average temperature ranges from 26 °C to 28 °C. The high-water period lasts from August to September, while the low-water period lasts from December to June. The basin comprises numerous creeks and streams with an abundant water flow toward the main river—the Oti River, which is relatively erratic by nature. It has extended periods of low water flows and, at times, complete dryness. The average monthly flow observed in March (minimum low water level) is only 3.6 m^3/s, 500 times less than the average flow observed in September, the main flood month, demonstrating the river's great seasonal irregularity. Most of the population relies on subsistence crop farming and livestock farming for a living, both of which are threatened by the effects of climate change.

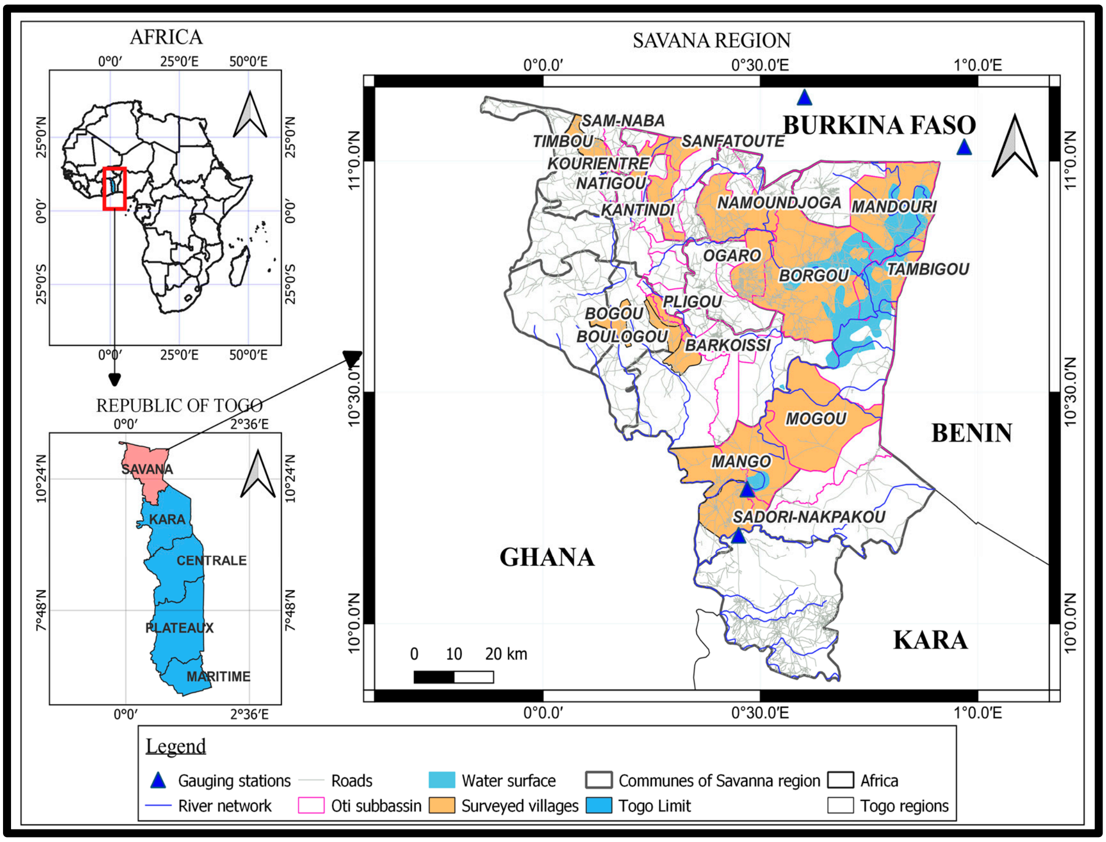

Figure 1. The geographical location of the Savannah region.

2.2. Data Collection

2.2.1. Focus Group Discussion

A list of EbA practices for climate-related risks in agriculture systems was initially established from the literature deemed appropriate for the study area (cf. Table 2). This list was used to discuss with key informants working in sustainable and resilient agriculture (i.e., local NGOs, local public institutions, and farmers' organizations).

Table 2. List of agricultural EbA practices based on literature.

Agricultural EbA Practices	Brief Description and Sources
Agroforestry	Agroforestry systems are land management practices in which trees and shrubs are grown alongside crops or livestock on the same plot [20,28,29,36].
Conservation tillage	A tillage system entails planting, growing, and harvesting crops with as little disturbance to the soil surface [19,36].
Contour farming	Contour farming entails plowing the land along the field's contours rather than straight lines [36,37].
Contour stone bunds	Contour stone bunds are constructed with quarry rock or stones along the land's natural contour to a height of 20–30 cm from the ground and spaced 20 to 50 m apart, depending on the terrain's inclination [35–37].
Crop rotation	The practice of growing various crops in the same area over several growing seasons [20,36].
Grass hedges	Planting lines of trees or shrubs along farm boundaries or the borders of home compounds, pastures, fields, or animal enclosures [35–37].
In-field water drainage channel	A structure that acts as a runoff collector and evacuator. The drainage channels are oriented towards streams, rivers, or retention basins. They are implemented at the start of each season so that they can perform the function of evacuating excess water [38,39].
Integrated crop-livestock	Agricultural management systems in which land is rotated between crop, pasture, and livestock use over time and space [20,36,40].
Intercropping	Intercropping is a practice that involves growing two or more crops on the same field at the same time [35–37].
Mulching	The process of covering the open surface of the ground with a layer of external material [19–21,36,37].
Terrace farming	Terrace farming is a sloped plane cut into successively receding flat surfaces or platforms that look like steps [36,37].

During the focus group discussions (FGDs), the key informants were asked to select the most common practices they observed utilized by smallholder farmers (at the farm level) as strategies to reduce climate-related risks. Seven FGDs were conducted, one in each of the seven districts or localities in the study area (Figure 1). Each group was composed of five to ten people of mixed gender. The discussions were conducted in French and local dialects, namely, Moba and Tchokossi.

2.2.2. Household Survey

The information generated from the seven FGDs was used to develop the survey questionnaire. Eight farm management practices were considered agricultural EbA strategies used by farmers to respond to climate-related risks. The question topics include (1) household and livelihood characteristics; (2) perception of climate-related risk affecting agroecosystem and livelihood; (3) the selected EbA practices implemented on the farm level; and (4) perceived effectiveness of EbA practices using the framework. A 5-point Likert scale ranging from "No improvement" (1) to "Significant improvement" (5) was used to assess farmers' perceptions of the effectiveness of each EbA practice, whereas a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5) was also used to assess farmers' perceptions of the benefits of EbA practices.

A pretest was conducted in December 2020 with 30 farm households chosen at random in Sanfatoute and Borgou localities to ensure that the questions were clear and relevant. The final structured face-to-face survey was conducted between January and February 2021. The farm household was the unit of analysis in this study, and the interviewees were the household heads or their wives. A total of 425 farm households were surveyed following Cochran's formula as shown below (with 60 households in each district):

$$S = \frac{Z^2PQ}{E^2} \quad (1)$$

where, S = sample size per locality, Z = deviation set at 1.96 corresponding to a confidence level of 95 percent; P = number of households in the locality; Q = 1—P; E = margin of error, which is equal to 5 percent.

As the field survey was carried out during the COVID-19 crisis, COVID-19 safety protocols established by the government were implemented during the field survey to avoid contamination. These measures include face masks and hand sanitizers for enumerators and respondents and maintaining a social distance of 1–2 m. The data collection was completed without any reports of illness from any field team member.

2.3. Data Analysis

Data analysis was conducted using the Statistical Package for Social Science (SPSS) version 26 [41] and Microsoft Excel software. Descriptive statistics were drawn to describe household and farm characteristics and summarized in table forms. The frequency of each EbA practice was expressed as a percentage of the overall total of all frequencies.

The Weighted Average Index (WAI) was used to assess the effectiveness of the agricultural EbA practices. The effectiveness level of each of the EbAs was categorized based on the three dimensions, i.e., ecosystem services provision, adaptation benefits to climate-related risks, and livelihood and food security improvement (Table 1). A weighted average (WA) is a type of average where each observation in the data set is multiplied by an assigned weight reflecting its importance before summing all data into a single average value [42]. WAI is estimated using the following formula as shown below:

$$\mathrm{WAI} = \frac{\sum \mathrm{w_i X_i}}{\sum \mathrm{w_i}} \tag{2}$$

where $\mathrm{w_i}$ indicates the respective weights for the items, and $\mathrm{X_i}$ indicates the value of each item.

The EbA effectiveness analysis proceeded using first a rating scale to compute five effectiveness levels (EL) from the WAI values: Highly effective (HE) (3.49–4.28); Effective (E) (2.69–3.48); Moderately effective (ME) (1.89–2.68); Least effective (LE) (1.08–1.88); and not effective (NE) (1–1.08).

Furthermore, the Relative Importance Index (RII) analysis was used to rank the perceived EbAs' benefits. According to Rooshdi et al. [43], the following formula is used to determine the relative importance index, as shown below:

$$\mathrm{RII} = \frac{\sum \mathrm{W}}{\mathrm{A} * \mathrm{N}} \tag{3}$$

where, W is the weighting assigned by each respondent on a scale of one to five, with one implying the least and five the highest. A is the highest weight, and N is the total number of the sample.

According to Akadiri et al. [44], five important levels can be drawn from RII values: high (H) ($0.8 \le \mathrm{RII} \le 1$); moderately high (H–M) ($0.6 \le \mathrm{RII} \le 0.8$); moderate (M) ($0.4 \le \mathrm{RII} \le 0.6$); moderately low (M–L) ($0.2 \le \mathrm{RII} \le 0.4$); and low (L) ($0 \le \mathrm{RII} \le 0.2$).

Further analysis made used a correspondence factor analysis (CFA) to assess the relative relationship between the perceived EbA's benefits and the most suitable EbA practices for smallholder farmers under each dimension of EbA; to this extent, a chi-square independence test between the two categorical variables (EbA practices and perceived EbA's benefits) was employed, setting α (Type I error) at 5 percent. For each dimension, the different perceptions of EbA's co-benefits and EbA practices were projected into a system of factorial axes resulting from the CFA.

3. Results

3.1. EbA Practices

Eight practices were reported as commonly practiced by the respondents to deal with climate-related risks (Figure 2). These EbA practices can be categorized into the following three groups: (1) conservation agriculture practices (i.e., conservation tillage mulching, crop rotation, and intercropping); (2) soil and water conservation practices (i.e., grass hedge/stone bunds and in-field water drainage channel); and (3) integrated soil fertility management practices (i.e., agroforestry and integrated crop-livestock). Many farmers were engaged in agroforestry, crop rotation, in-field water drainage channel, grass hedge/stone bunds practices, and intercropping. Agroforestry is the most dominant among the reported practices, and mulching is the least known practice.

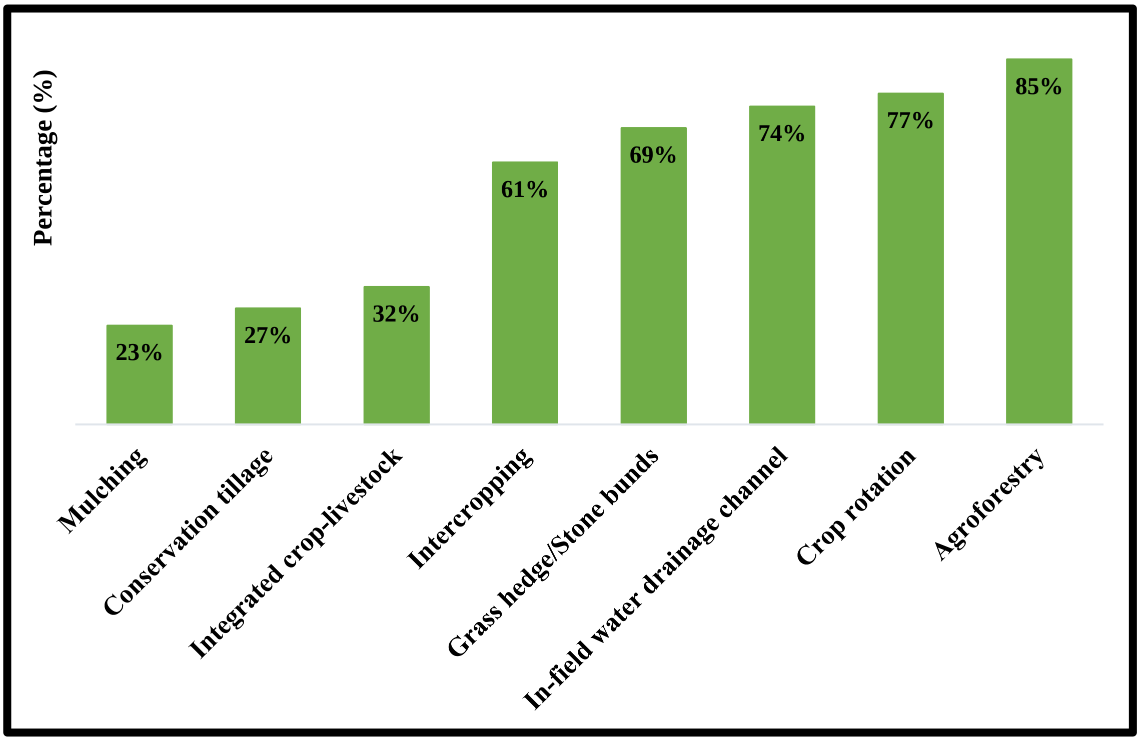

Figure 2. EbA practices by smallholder agricultural farmers (n = 425).

Regarding locality level, the respondents across the localities used an average of four EbA practices per farm, ranging from 0 to 8 (Table 3). The average number of EbA practices per farm was the highest in the Mogou locality, with almost six EbA practices than the rest.

Table 3. Variation in the adoption of EbA practices across the districts.

Locality	A Minimum of EbA Implemented	Maximum of EbA Implemented	Average EbA Implemented
Barkoissi	1	6	4.18
Bologou	2	7	4.65
Borgou	2	6	4.59
Kantindi	0	5	2.97
Kourientre	2	7	5.54
Mandouri	2	6	4.40
Mango	1	5	3.72
Mogou	3	8	5.70
Namoudjoga	1	6	3.63
Ogaro	3	7	4.87
Pligou	2	7	4.60
Sadori-Nakpakou	3	6	4.60
Sanfatoute	1	6	3.77
Tambigou	3	7	4.64
Timbou	1	8	3.81
Overall	**0**	**8**	**4.40**

3.2. Perceived Effectiveness of EbA Practices

Table 4 summarizes the perceived effectiveness of identified EbA practices about the framework's three dimensions: (1) ecosystem service provision; (2) adaptation benefits; and (3) livelihood and food security improvement. The respondents perceive agroforestry as the most effective (HE) EbA practice for enhancing all the dimensions. Grass hedge/stone bund is perceived as most effective (HE) in dimensions 1 and 2 and effective (E) in dimensions 3. Both crop rotation and in-field water drainage channels were perceived as effective (E) in all dimensions. In contrast, mulching practice is perceived as the least effective at improving the three dimensions.

Table 4. Perceived effectiveness of EbA practices according to the framework's dimensions.

EbA Practices	(1) Ecosystem Services Provision		(2) Adaptation Benefits		(3) Livelihood and Food Security Improvement	
	WAI (1)	Effectiveness Level	WAI (2)	Effectiveness Level	WAI (3)	Effectiveness Level
Agroforestry	3.69	HE	3.84	HE	3.80	HE
Conservation tillage	2.48	ME	1.88	LE	2.46	ME
Crop rotation	3.36	E	3.34	E	3.16	E
In-field water drainage channel	3.05	E	2.98	E	3.11	E
Integrated crop-livestock	1.88	LE	2.42	ME	1.85	LE
Intercropping	2.59	ME	2.16	ME	3.10	E
Grass hedge/stone bund	3.50	HE	3.51	HE	3.22	E
Mulching	1.87	LE	1.80	LE	1.84	LE

Legend: Highly effective (HE) (3.49–4.28); Effective (E) (2.69–3.48); Moderately effective (ME) (1.89–2.68); Least effective (LE) (1.08–1.88); and not effective (NE) (1–1.08).

These results suggest that agroforestry, grass hedge/stone bunds, crop rotation, and in-field water drainage channels are the most suitable EbA practices for smallholder farmers in the study area. At the same time, those practices were the most applied by the smallholder farmers in the study area (Figure 2).

3.3. Perceived Benefits of Agricultural EbA Practices

The relative importance values of each benefit as perceived by the respondents are presented in Table 5. For dimension 1: ecosystem services provisions, the top-ranked is soil fertility improvement (0.91), followed by water infiltration and erosion regulation (0.89) and runoff regulation (0.88). These results suggest that respondents perceived these ecosystem services as important benefits of implementing EbA practices critical for agroecosystem resilience.

For dimension 2: adaptation benefits, the highest rank is crop productivity improvement (0.88), followed by reduction in climate-related risks on crop and farming systems (0.85). This showed that respondents perceived crop productivity improvement and the reduction in climate risks on crops and farming systems as important benefits gained from implementing EbA practices to resist climate change impacts.

For dimension 3: livelihood and food security, the highest rank is the improvement of local income (0.87), followed by the improvement of food security (0.86). These results reveal that respondents perceived local income and food security improvement as important benefits of implementing EbA practices to improve their livelihoods and well-being.

Table 5. Ranking of the EbA practices based on the associated benefits.

EbA Dimension	Perceived EbA Benefits	Relative Index	Ranking	Importance Level
(1) Ecosystem services provision	• Soil fertility improvement	0.91	1	H
	• Improvement of water infiltration and erosion regulation	0.89	2	H
	• Runoff regulation	0.88	3	H
	• Agrobiodiversity conservation	0.85	4	H
	• Nutrient regulation	0.83	5	H
	• Improvement of pollination	0.36	6	M–L
(2) Adaptation benefits	• Improving crop productivity	0.88	1	H
	• Reduction in climate risks on crop and farming systems	0.85	2	H
	• Reduction in crop pests and disease incidence	0.64	3	H–M
(3) Livelihood and food security improvement	• Improvement of local income	0.87	1	H
	• Improvement of food security	0.86	2	H
	• Use of locally available and renewable inputs	0.83	3	H
	• Requires implementation costs and labor affordable to smallholder farmers	0.83	4	H
	• Take advantage of traditional knowledge	0.82	5	H

Legend: High (H), high–medium (H–M), medium (M), medium–low (M–L), and low (L).

3.4. Relationships between Perceived Effectiveness and Benefits of EbA Practices

The CFA results show that the most effective EbA practices and their perceived benefits are statistically associated (p-value = 0.000) under all three dimensions. The chi-square test showed a significant relationship between the EbA practices and the perceived EbA benefits in all three dimensions.

Significant relationships were observed between agroforestry and crop rotation, intercropping and crop rotation, grass hedge/stone bunds, and in-field water drainage channels.

For dimension 1: ecosystem service provision (Figure 3), axis 1 explains 82 percent of the information related to perceptions of EbA provisions based on various EbA practices, whereas axis 2 explains 16 percent, suggesting that the correspondence analysis of the two axes explains 98 percent of the information. There are three key relationships observed under this dimension: (1) in the lower half of the plot, crop rotation and agroforestry are closely associated and perceived to relate to nutrient regulation, soil improvement, and agrobiodiversity conservation; (2) at the left side of the lower half of the plot, in-field water drainage channel is perceived distinctively to other EbAs and closely relate to runoff regulation; whereas, (3) on the upper half, grass hedge/stone bund is perceived distinctively to other EbAs and closely related to water infiltration and erosion.

For dimension 2: adaptation benefits (Figure 4), axis 1 accounted for 92 percent of the information about perceptions of EbA benefits based on various EbA practices, whereas axis 2 accounted for 8 percent, suggesting that the correspondence analysis of the two axes accounts for 100 percent of the information. In Figure 4, the EbA practices, such as grass hedge/stone bunds and in-field water drainage, are perceived distinctly from agroforestry and crop rotation. Regarding associated ecosystem services, grass hedge/stone bunds and in-field water drainage are closely related to reducing climate risks on crop and farming systems; agroforestry and crop rotation are perceived to improve crop productivity and reduce crop pest and disease incidence, respectively.

For dimension 3: livelihood and food security improvement (Figure 5), axis 1 explains 97 percent of the information about perceptions of EbA benefits based on various EbA practices, whereas axis 2 explains 2.6 percent, implying that the correspondence analysis of the two axes explains almost 100 percent of the information. On the lower half of the plot on the right side, crop rotation and intercropping are perceived related to food security improvement and affordable implementation cost and labor. On the left side of the plot, grass hedge/stone bunds and in-field water drainage channel are associated with each other and perceived to relate to using locally available and low costs materials; and taking advantage of traditional knowledge. Agroforestry is perceived to relate to local income improvement.

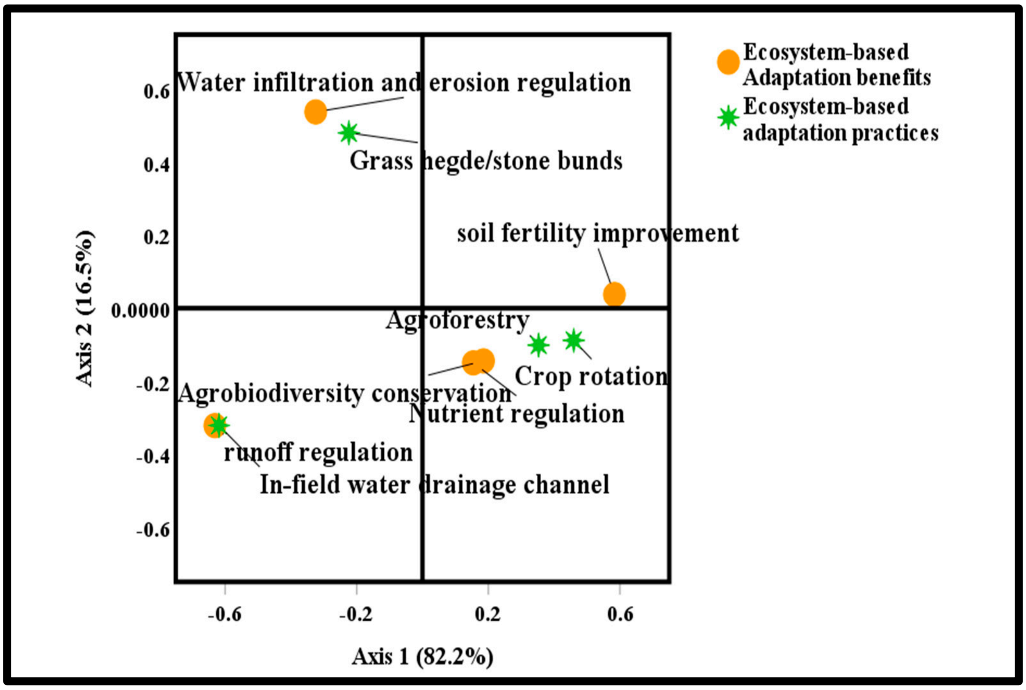

Figure 3. Projection in a system of axes of EbA benefits and effective EbA practices (Dimension 1: ecosystem services provision).

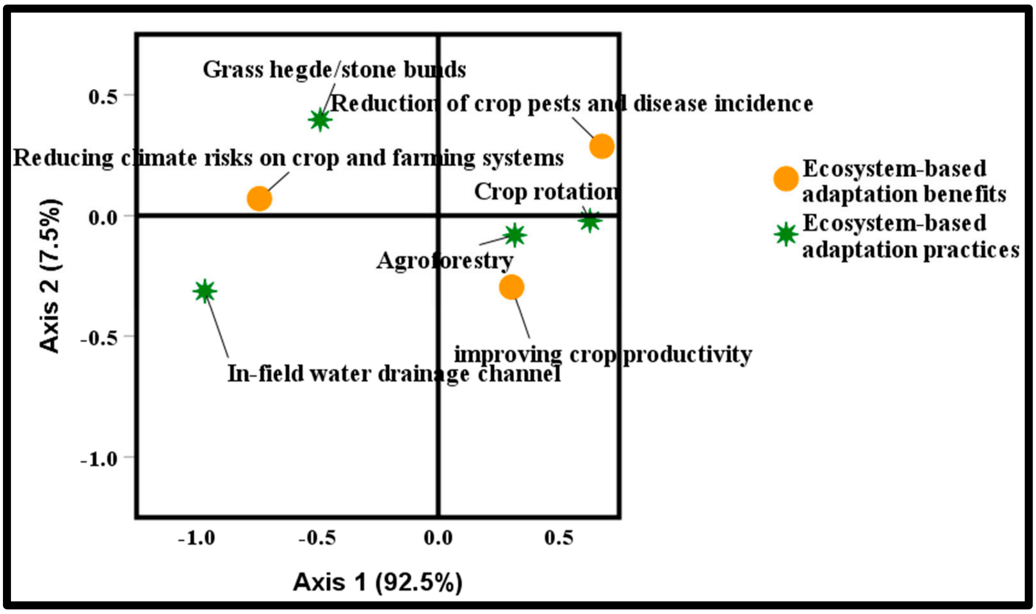

Figure 4. Projection in a system of axes of EbA benefits and effective EbA practices (Dimension 2: Adaptation benefits).

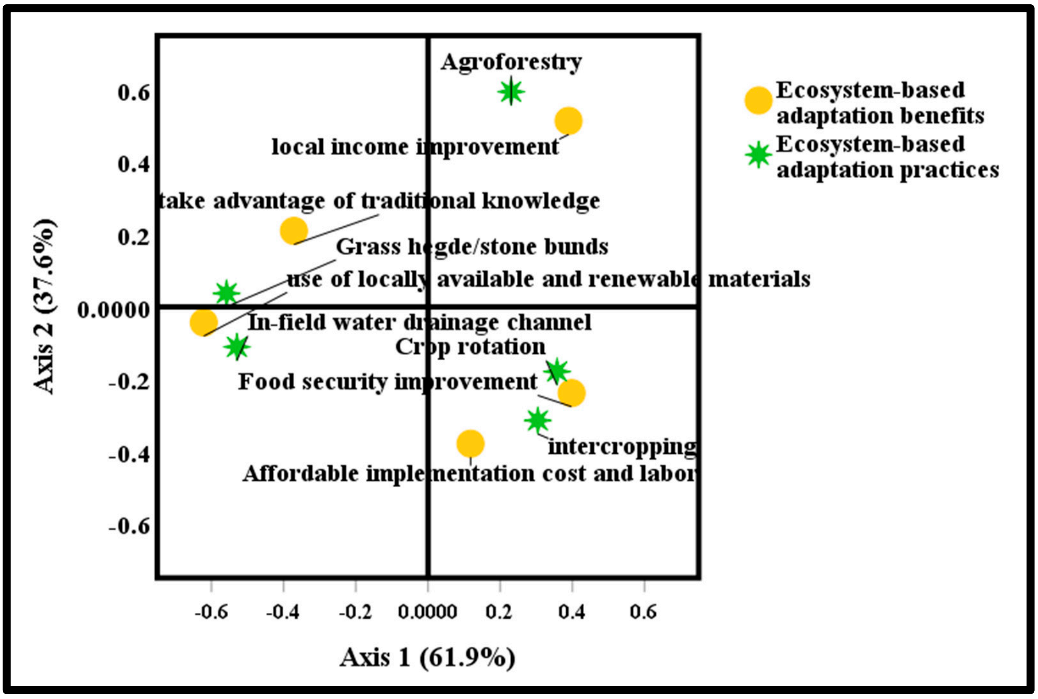

Figure 5. Projection in a system of axes of EbA benefits and effective EbA practices (Dimension 3: Livelihood and food security improvement).

4. Discussion

In agricultural systems, EbA is seen as the adoption of agricultural management practices that help increase the ability of crops or livestock to adapt to climate variability through the delivery of multiple co-benefits that are appreciated as ecosystems services, adaptation benefits, and livelihood and food security improvement [12,20,45]. In the study area, smallholder farmers are increasingly implementing EbA practices on their farms to deal with the impacts of climate change, particularly on their livelihoods. For question 1: what are the main EbA practices in the agriculture sector to deal with climate-related risks in the Savannah region? The most common EbA practices implemented by smallholder farmers are agroforestry, grass hedge/stone bunds, crop rotation, in-field water drainage channel, and intercropping.

For question 2: how do smallholder farmers perceive the effectiveness and the co-benefits of EbA practices in dealing with climate-related risks in the Savannah region? Assessing the effectiveness of EbA measures is critical to better understanding and deploying EbA and maximizing its benefits while minimizing its limitations [27]. Based on our study, smallholder farmers practicing more EbA strategies (such as in the locality of Mogou) have higher chances to adapt to climate change because of the wide range of co-benefits these strategies provide than those farmers employing one strategy or almost none. Using the EbA framework, we can identify the best combination of EbA practices that meet all criteria needed by smallholder farmers, such as food security, adaptation benefits, and ecosystem services provision. Capturing the perceptions helps assess EbA effectiveness without available scientific or quantitative data on social-ecological effectiveness criteria [31,46–48]. In comparison with the other frameworks [30–34], which help assess the effectiveness of EbA projects or interventions at the national to the community level, the framework provided by Vignola et al. [20], used in this study, makes it simple to connect the EbA agricultural practices about providing ecosystem services (provisioning services, regulating and supporting services) and the desired adaptation benefits and co-benefits related to their livelihood improvement at the smallholder farmer level. However, the respondents may need more consistency in understanding the dimensions and criteria used for the assessment, and their perception is likely to be limited.

Although several studies have claimed a lack of understanding of the multiple co-benefits of EbA practices in responding to the impacts of climate change as major barriers to EbA implementation [30,49–51], our findings show that smallholder farmers in the study area are incredibly aware of the multiple co-benefits of EbA practices. Several of the EbA practices have been previously described in other studies for maintaining local genetic diversity, organic soil management, water conservation and harvesting, general enhancement of agrobiodiversity, and enhancement of the regulation of weeds, diseases, and insect pests, while increasing pollination services and maintaining soil fertility and crop production [52–56].

For question 3: how are the perceived effective EbA practices related to their perceived co-benefits of EbA practices and suitability for smallholder farmers in the Savannah region? Adopting agroforestry by smallholder farmers is expected in the study area. Consequently, the widespread use of this practice is due to increasing land degradation caused by climate-related risks that threaten smallholder farmers' agricultural production and livelihood. Thus, they purposefully incorporate trees into their various cropping systems to provide a variety of co-benefits and services. Trees on their farm are believed to improve agroecosystem functions, agrobiodiversity, crop productivity, and increase income [57–59]. This finding is in line with the results of a study in the Arasbaran biosphere reserve of Iran, where a vast majority of farmers were involved in agroforestry for an additional source of income and its effectiveness in adapting to climate change [22]. Other studies showed that agroforestry could prevent agroecosystem degradation, improve agricultural productivity, and support healthy soil and healthy ecosystems while providing stable incomes and other co-benefits to human well-being [60,61].

In the study area, crop rotation is one of the most used practices to replenish the soil nutrients and alleviate fertilizer constraints, as well as weed and pest control. The respondents believe crop rotation improves agroecosystem function by managing soil fertility, ensuring integrated management of weeds, diseases, and pests, and improving agrobiodiversity, crop productivity, and food security. Similar findings have been recorded by Thierfelder et al. [62], Kollas et al. [63], and Shah et al. [23]. Besides the results above, these studies also showed that crop rotation could increase organic matter in the soil, maintain long-term soil fertility, aid in weed control, and improve crop productivity, soil moisture, water infiltration, and soil carbon.

Regarding intercropping practice, smallholder farmers prefer it because of limited land and access to commercial fertilizers. They primarily combine pulse crops and cereals (e.g., maize, sorghum, millet, beans, groundnut). Such crop associations maintain crop productivity and soil moisture and reduce the risk of soil erosion. Combined with pulse crops, cereal also helps conserve agrobiodiversity, manage soil fertility, and weed control. These observations are consistent with the findings of Sharma et al. [64] and Senyolo et al. [65] that intercropping is a valuable strategy for increasing farmer production and income while improving water use efficiency, land fertility, and reducing runoff and soil loss.

Concerning soil and water conservation techniques, grass hedge/stone bunds and in-field water drainage channels are used by smallholder farmers to stop or trap water runoff and reduce soil erosion in the study area, where grassed lines are planted at the edges of plots. In addition, a stone bund of blocks of rubble or stones (pebbles) is arranged in one or more rows along a contour line. Further, in-field water drainage channels act as runoff collectors and evacuators. Smallholder farmers use grassed lines, stone bunds, as well as in-field drainage channels as devices that help to reduce crop vulnerability to flooding by improving agroecosystem function through water infiltration, soil erosion, runoff control, and maintaining soil moisture. Those practices were also seen to enhance buffering capacities of agroecosystems against extreme events, increase crop productivity, and livelihood and food security. These observations are consistent with the findings of Amado and Assefa [66] that grass hedges, stone bunds, and in-field drainage channels help reduce runoff, halt erosion, increase infiltration and soil moisture, and are also considered insurance to sustain and boost soil fertility and land productivity.

Mulching and integrated crop-livestock are the farm management practices least utilized by smallholder farmers and are perceived as the least effective. This observation could be why crop residues are used mainly for cooking (instead of mulching), whereas livestock farming is primarily based on poultry farming. Studies by Harvey et al. [37] and Nanfuka et al. [35] reported that mulching is among the rarely used EbA practice despite its promotion among farmers.

In terms of limitation, this study does not include the factors affecting the perceived effectiveness (e.g., psychological factors influencing smallholder farmers' behavior), including factors influencing the adoption and non-adoption of EbA practices. Such studies are critical for policy formulation and should be addressed in future research. Furthermore, this research study is geographically limited and based on cross-sectional data.

5. Conclusions and Recommendations

Our study identified the ecosystem-based adaptation (EbA) practices in the study area. Based on smallholder farmers' perceptions, it assessed their effectiveness in reducing their vulnerability to climate-related risks, including the co-benefits and suitability in the Oti River basin, Togo. Eight agricultural practices were identified in the study area. Among the eight practices, five practices were mainly used and perceived as the most effective at reducing vulnerability to climate-related risks while at the same time improving agroecosystem services provision, adaptation co-benefits, and livelihood and food security. Those practices are agroforestry, crop rotation, intercropping, grass hedge/stone bunds, and in-filed rain-water drainage channels. Smallholder farmers perceived wide socio-ecological co-benefits gained from implementing those EbA practices. The most critical co-benefits gained from the combination of the effective practices include soil fertility improvement, nutrient regulation, water infiltration and erosion control, runoff control, agrobiodiversity conservation, reduction in extreme events impacts on crop and farming systems, reduction in pest and crop disease incidence, an increase in crop productivity, and an increase in food security and local income. Implementing those practices also used locally available and low-cost materials and traditional knowledge. This shows the awareness and the good understanding of smallholder farmers in the study area on the co-benefits and the effectiveness of some agricultural EbA practices to reduce vulnerability to climate-related risks.

Based on the study's findings, EbA practices in agriculture deserve the major attention of public programs, donor agencies, and government policies of climate change adaptation and poverty alleviation in the study area. This study recommends further research to examine the sustainability of the identified EbA practices, which will provide the necessary information on the potentiality of EbA practices to effectively address land degradation issues related to climate change in the study area. Doing so can encourage the broader adoption of EbA practices as a climate adaptation strategy in the study area.

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