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Ecosystem-Based Adaptation Practices for Climate Resilience: Evidence from Smallholder Farmers' Perceptions of Co-Benefits and Adoption Decisions in Mabalane District, Mozambique

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Abstract

This study was designed to evaluate and explore the ecosystem-based adaptation practices for climate resilience with evidence from smallholder farmers' perceptions of co-benefits and adoption decisions in Mabalane district, Mozambique. Ecosystem-based adaptation practice emerged as a sustainable approach to enhance rainfed smallholder farmers' climate resilience while delivering multiple social, economic and environmental co-benefits. This study evaluated and explored the perceived co-benefits from adopting ecosystem-based adaptation practices and examined how they shape adoption decisions among the rainfed smallholder farmers. A mixed-method approach was employed, combining a household survey of 360 farm household heads, key informant interviews and focus group discussions. The main findings of the study revealed mixed cropping (83.9%), integrated crop-livestock (57.2%), and mulch tillage (51.1%) as the most adopted practices, as well as smallholder farmers perceiving multiple ecological and socio-economical co-benefits from adopting ecosystem-based adaptation practices. Although the study confirmed statistically significant relationships between ecosystem-based adaptation practices and the perceived co-benefits, none of the perceived co-benefits were significantly associated with an increase in the number of the adopted practices. Therefore, it is concluded that adoption decisions among smallholder farmers are not shaped by perceived ancillary benefits from ecosystem-based adaptation practices alone, but a combination of enabling conditions and resources endowments.

Keywords: co-benefits; ecosystem-based adaptation; climate change; livelihood; sustainable; resilience; smallholder farmers

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1. Introduction

Climate change is a growing global threat that significantly impacts agriculture and food security [1]. Smallholder farmers in developing countries are vulnerable to weather extremes driven by climate change because their agricultural production and livelihoods depend on stable weather conditions. This is evident in Mozambique, where agriculture is the basis of its economy contributing about 27.5% of the total gross domestic product (GDP) and supporting approximately 4.3 million small-scale farmers within the population of about 32 million people [2]. Over the past decade, the effects of climate change in Mozambique have been increasingly manifested through weather extremes, especially agricultural dry spells caused by late onset (delayed November rains) and early cessation (lack of February–March rains) of precipitation. Such weather extremes driven by climate change have intensified drought conditions, leading to significant reduction in crop yields among rainfed farming communities [3]. During the 2015–2016 El-Nino event across southern Africa, the southern and central regions of Mozambique experienced severe drought conditions which caused a significant reduction in maize yields, by 20–30%, affecting the staple food crop for the majority of the population. The substantial decline in maize yield was due to the erratic rainfall patterns that resulted from delayed onset and early cessation of rain [4].

One effective method to support smallholder farmers in maintaining their farm-based livelihoods amidst the growing challenges of climate change and variability is by promoting farm management practices such as ecosystem-based adaptation practices that utilize agrobiodiversity and ecosystem services to offer valuable adaptation benefits [5].

A review by [2] pointed out conservation agriculture as one of the best and most promising solutions for smallholder farmers in the southern region of Mozambique under three principles: (1) minimal soil disturbance, (2) crop residue retention, and (3) crop diversification via crop rotation or intercropping. These principles can ultimately contribute to the reduction in soil erosion, enhanced water use efficiency, and regulation of upper soil temperatures among other beneficial effects. For instance, maize is the most widely cultivated crop in the southern region of Mozambique; therefore, the use of maize stover as mulch represents a practical advantage due to its widespread availability.

Ecosystem-based adaptation practice in the context of agriculture is defined as agricultural management practice that uses or takes 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 variabilities [6]. For ecosystem-based adaptation practice to be appropriate for smallholder farmers, it should improve food security, enhance or diversify income sources, build upon local or traditional knowledge, rely primarily on locally available inputs, and involve relatively low implementation and labour costs [6]. Ecosystem-based approaches can mitigate the impacts of climate change while simultaneously generating multiple co-benefits that contribute to poverty alleviation, biodiversity conservation and resilient livelihoods [7]. Although there is no standard definition of the term co-benefit in the context of ecosystem-based adaptation practices, for the purpose of this study, co-benefit is defined from the view point of [8] as the additional positive outcomes derived from ecosystem-based adaptation beyond the primary adaptation objective. These outcomes may include ecosystem goods and services such as improved water availability, enhanced soil fertility, biodiversity conservation, strengthened livelihoods, reduced disaster risk, and improved human well-being.

The co-benefits derived from ecosystem-based adaptation practices enhance their appeal and viability by linking climate resilience with improvements in food security, yield stability, income diversification, and reduced reliance on external inputs [9]. In this sense, the adoption of ecosystem-based adaptation practices by smallholder farmers should not be viewed solely as an additional cost, but also as an incentive that can enhance their livelihoods. The perception of smallholder farmers on co-benefits is generally across interconnected dimensions, including direct improvements in ecosystem services and natural resource quality, tangible adaptation benefits through the reduction in vulnerability to climate-related risks, and broader livelihood and food security benefits [6]. Ecosystem-based adaptation practices that provide observable and tangible benefits foster positive perceptions among smallholder farmers, which in turn can increase their willingness to adopt and sustain these practices over time [10]. Despite these potential advantages, limited empirical research has examined smallholder farmers' perspectives on the relationship between ecosystem-based adaptation practices and farm-level co-benefits, as well as the extent to which the perceived co-benefits may influence the adoption intensity of these practices.

Therefore, the objectives of this study were: (1) to identify the common ecosystem-based adaptation practices implemented by smallholder farmers at farm-level; (2) to examine the relationship between ecosystem-based adaptation practices and the co-benefits perceived at farm-level; and (3) to assess how perceived co-benefits influence adoption intensity of ecosystem-based adaptation practices among smallholder farmers.

This study explores smallholder farmers' perceptions of the relationship between the perceived co-benefits derived at farm-level and ecosystem-based adaptation practices, and examine how these perceived co-benefits influence adoption intensity. Understanding smallholder farmers' perceptions is a key determinant for explaining sustained adoption, as psychological constructs such as perceived co-benefits may significantly influence smallholder farmers' decision to adopt and maintain agricultural practices, sometimes even more strongly than economic or physical resource consideration alone [11]. Although financial and technical constraints remain important, examining underlying cognitive and social factors may provide potential insights into why smallholder farmers with comparable economic endowments differ in their adoption of ecosystem-based adaptation practices. Understanding these latent constructs is therefore essential for identifying and addressing barriers to adoption.

The findings of this study contribute to bridging the gap between scientific understanding and the lived experiences of smallholder farmers. Although a substantial body of literature highlights co-benefits as key incentives for the adoption of ecosystem-based adaptation practices, limited attention has been given to how smallholder farmers perceive and experience these practices. This gap has contributed to a disconnect between scientific explanations and lived realities of smallholder farmers. However, the results of this study indicate that perceived co-benefits do not significantly explain adoption intensity among smallholder farmers in the Mabalane district. By foregrounding smallholder farmers' perceptions and latent cognitive constructs, the analysis demonstrates that adoption of ecosystem-based adaptation practices is not determined solely by the presence or recognition of co-benefits. Rather, adoption decisions are shaped by a broader set of contextual and behavioural factors. In this way, the study contributes to aligning scientific perspectives on ecosystem-based adaptation with the lived realities, priorities, and decision-making processes of smallholder farmers.

Therefore, this study provides a framework for policymakers and development partners in designing context-specific and farmer-centred strategies to enhance resilience to the delayed onset and early cessation of rainfall experienced by smallholder farmers in the southern region of Mozambique. Such strategies can enhance the effectiveness of adaptation initiatives by promoting sustainable, low-cost, and locally tailored solutions that build upon farmers' local knowledge, practices, and lived realities.

1.1. Definition and Scope of the Study

Ecosystem-based adaptation originates from the concept of ecosystem, a fundamental idea in ecology that has a broader application in ecological research and environmental management [12]. The ecosystem-based adaptation is based on the premise that the sustainable management and restoration of ecosystems can enhance the capacity of people and communities to adapt to the adverse impacts of climate change [13]. Well-managed ecosystems are widely recognized for their ability to provide multiple adaptation benefits, including increased resilience to extreme weather events, improved recovery from disturbances, and the continued provision of ecosystem services that support human livelihood [14].

There are several definitions of ecosystem-based adaptation, in 2009, the concept of ecosystem-based adaptation was defined by the Secretariate of the Convention on Biological Diversity (SCBD) as "the use of biodiversity and ecosystem services to help people adapt to the adverse impacts of climate change" [13]. In 2010, this definition was revised by the Convention on Biological Diversity (CBD) to adopt a more holistic perspective, describing ecosystem-based adaptation as a sustainable management, conservation and restoration of ecosystems within an overarching adaptation strategy that takes into account multiple social, economic and cultural co-benefits for local communities [15].

The revised definition of ecosystem-based adaptation was based on three complementary adaptation approaches focusing on "human well-being"; "ecosystem management, conservation, and restoration"; and "climate change adaptation". Examples include the restoration of mangroves to shield against storms and sea-level rises; the management of water sheds to mitigate droughts and flooding; the sustainable management of range lands to prevent desertification and land degradation; and improved fisheries and forestry practices to enhance food security [16]. These three adaptation approaches distinguish ecosystem-based adaptation from certain forms of community-based adaptation that target specific and short-term goals. For instance, the introduction of improved crop varieties to smallholder farmers focuses on addressing immediate community needs, such as increasing yields, but often plays limited attention to the potential long-term impacts on ecosystem integrity.

For this study, we adopt the definition of ecosystem-based adaptation for agricultural systems proposed by [6] which describes ecosystem-based adaptations as agricultural management practices that utilize or take advantage of biodiversity or ecosystem services or processes either at the plot, farm or landscape level to increase the adaptive capacity of crops and livestock to climate change and variabilities. This definition extends the concept provided by the Convention on Biological Diversity (CBD, 2010) by explicitly incorporating both human and natural systems. It emphasizes the role of managed ecosystems at multiple scales (plot, farm, landscape) while integrating social, economic, and institutional dimensions to provide a more holistic approach to reduce vulnerability. Furthermore, this definition reinforces the view that ecosystem-based management practices benefit farmers at both landscape and on-farm levels.

It is important to recognize that, in the context of droughts, many mitigation strategies traditionally developed by smallholder farmers are inherently ecosystem-based [7]. Locally adapted sustainable agricultural practices and management strategies that enhance ecosystem function have been implemented to address challenges such as land degradation, food insecurity, and limited access to agricultural inputs [17]. Such local adaptation approaches can reduce the vulnerability of agro-ecosystems including croplands, rangelands, and agroforests to droughts risks, while increasing resilience and preparedness through the diversification of agricultural production. By leveraging ecosystem services, these sustainable practices utilize the inherent capacity of natural systems to buffer farmers and communities against the impacts of climate change and natural hazards [18].

Ecosystem-based adaptation (EbA) practices and ecosystem-based disaster risk reduction (Eco-DRR) are essential nature-based approaches that enhance the climate resilience of smallholder farmers by leveraging biodiversity and ecosystem services while providing tangible livelihood benefits [9]. The two concepts share more similarities than differences, particularly in addressing climate-related hazards [19], and their benefits extends beyond the traditional functions of disaster risk reduction and climate change adaptation. Both concepts emphasize the sustainable use of biodiversity and ecosystem services and include the restoration of degraded or transformed agro-ecosystems. Importantly, these approaches generate economic, social and environmental co-benefits, distinguishing them from more conventional measures such as dams and dikes [12]. When implementing ecosystem-based approaches for disaster risk reduction and climate change adaptation, adopting a landscape perspective is critical. Land-use decisions should consider the flow of ecosystem services across the landscape, as ecosystem functionality depends on interactions at multiple scales [20]. The multi-functional approach underscores the need to manage ecosystem services at field, farm and landscape-levels while integrating ecological principles [21]. Ecosystem-based approaches do not focus solely on individual interventions but prioritize the synergistic integration of actions across scales to maximize disaster risk reduction, climate change adaptation and broader development objectives. While some interventions target the landscape level, others operate at farm or field level, yet their cumulative impact often contributes to landscape level outcomes [12].

Despite their similarities, Ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction (Eco-DRR) differ in terms of their scope and approach, largely due to the nature of the hazards they address. Ecosystem-based adaptation primarily focuses on climate-related hazards and aims to enhance the adaptive capacity of ecosystems and communities to the impacts of climate change. In contrast, eco-disaster risk reduction addresses a broader range of natural hazards, including those not directly linked to climate change, such as earthquakes and landslides. Another subtle difference relates to temporal scale of analysis, which influences the types of strategies and measures implemented. Additionally, effective EbA planning typically requires consideration of long-term climatic changes, including shifts in the frequency and intensity of extreme events, as well as the potential impacts of slow-onset processes associated with climate change. In contrast, eco-disaster risk reduction strategies generally focus on managing existing risks and current disaster threats, with a strong emphasis on immediate risk reduction and preparedness.

Furthermore, comparative studies between the two concepts are constrained by significant conceptual and methodological limitations. The primary challenge lies in the conceptual ambiguity and inconsistency in the definitions of Eco-DRR and EbA [22], which makes it difficult to distinguish between specific outcomes and long-term climate adaptation processes. Consequently, this conceptual overlap hinders systematic comparison and weakens efforts to synthesize empirical findings across studies [23].

Moreover, the main limitation in relation to smallholder farmers' capacity to enhance climate resilience at the farm level is the inadequate integration of socio-economic and institutional realities tied to smallholder farmers' perceptions into the assessment of these approaches. Specifically, studies often understate or overlook critical constraints faced by smallholder farmers such as limited financial capital, limited access to market and extension services, labour shortage, insecure land tenure, and pressing short-term livelihood priorities. As a result, many proposed ecosystem-based interventions often remain theoretically robust but practically misaligned with the decision making of smallholder farmers in resource-constrained environments. This disconnect reduces the likelihood of sustained adoption and limits the translation of ecosystem-based concept into tangible improvement of farm resilience.

In this context, the implementation of EbA practices can be strengthened by adopting the framework developed by [6], which provides a structured approach to assess multiple co-benefits and trade-offs associated with EbA interventions. The framework explicitly evaluates ecological and socioeconomic co-benefits. By systematically identifying and measuring the co-benefits, the framework clarifies how EbA practices contribute simultaneously to risk reduction, productivity, and livelihood security. Importantly, this multidimensional assessment enhances relevance for smallholder farmers because adoption decisions are rarely driven by climate risk consideration alone.

Therefore, adopting the framework developed by [6] makes visible the synergies between adaptation and development objectives through bridging ecosystem-based adaptation with broader development, sustainable livelihood, and ecosystem-based disaster risk reduction (Eco-DRR) objectives.

1.2. Theoretical Framework

Different theoretical frameworks exist with key elements and criteria to select practices that are ecosystem-based which helps to evaluate the measures' efficacy in promoting adaptive capacity and resilience while providing multiple co-benefits. Ecosystem-based adaptation benefits represent the primary goals of reducing climate-related risks and enhancing adoptive capacity, whereas co-benefits are additional positive outcomes, often incidental, that contribute to broader climate resilience and socio-ecological well-being [24].

For the purpose of this study, the existing ecosystem-based adaptation framework developed by [6] was adapted to identify the ecosystem-based adaptation practices and co-benefits smallholder farmers perceived from their adaptation at farm-level. The framework is relevant for use in the context of smallholder farmers and is valuable in simulating careful consideration of agricultural practices that are suitable 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 [25]. The framework is based on applied interdisciplinary theories, drawn from various disciplines such as ecology, sociology, and economics to develop practical strategies for climate change adaptation in the agricultural communities. As such, the framework has been applied in a wide variety of agricultural systems that exist globally, from smallholder coffee farmers in Mesoamerica to smallholder farmers in the Otti basin, Togo [6].

The framework (Figure 1) was used in this study to identify agricultural practices that are considered ecosystem-based adaptation practices appropriate for smallholder farmers and also to provide indicators for identifying the co-benefits smallholder farmers perceived from the adoption of ecosystem-based adaptation practice at farm level.

Therefore, a given agricultural practice that provides at least one co-benefit in all the three dimensions ("ecosystem service provision, "adaptation benefits", "livelihood and food security improvement") is considered an ecosystem-based adaptation practice appropriate for smallholder farmers [6]. The underlying criteria for each dimension are presented in the Figure 1 below.

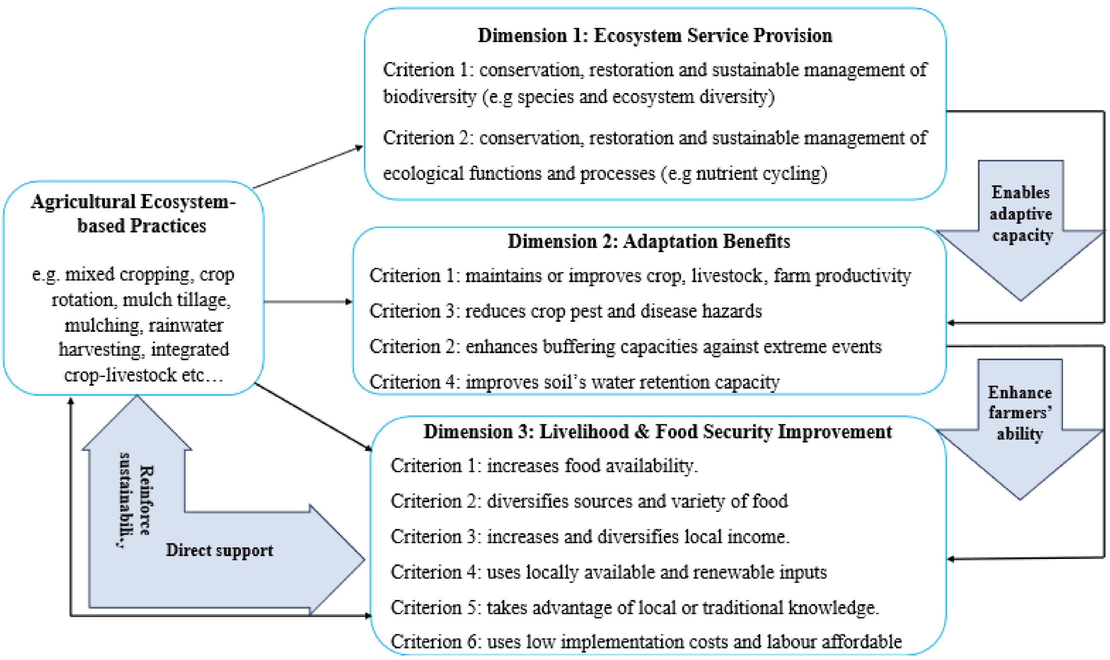

Figure 1. Theoretical framework, source: adopted and modified from [6].

2. Materials and Methods

2.1. Study Area

The Mabalane district (Figure 2) is located in Gaza Province (Lat 23.859° S, Lon 32.62° E) approximately 314 km North of the capital Maputo. The area is approximately 9580 km^2, of which 75% is ASALs (arid and semi-arid lands) that falls within the semi-arid southern agro-ecological zones (generally characterized as R1/R3/R6/R8 in national classification) [26]. The population is 32,040 inhabitants with the population density of 3 people per km^2, far below the national average of 25 people per km^2 [27]. The population has limited access to infrastructure, credit, and markets, reflecting national rural challenges. The district shares a part of the Great Limpopo Transfrontier Park about 1600 km^2 and it belongs to the drainage basin of the Limpopo which includes River Limpopo as the main perennial—River Chigombe, River Sangutane and River Chichakuarre, all are seasonal [28].

The climate is tropical arid with average temperature of 24 °C, rainfall is low and variable, averaging 623 mm/year falling mostly from November to March. The evapotranspiration is very high at 1413 mm/year more than the rainfall [27]. The forest ecosystems consist of woodland that cover more than 80% of the land mainly consisting of dry Mopane (*Colophospermun mopane*) woodlands [29].

The area is gradually flat to undulating and the soils consist of marine deposits overlain in some places by more recent colluvial and alluvial deposits. Soils close to the river are sandy and fertile, while the rest are loamy sand in texture (82% sand, 13% silt, 5% clay) with low carbon and nutrient content (0.4% C, 0.05% N) [26].

The major economic activities include charcoal production and commercialization; households' livelihoods depend traditionally on rainfed agriculture and livestock keeping [26]. The farms' size average to 4.1 hectares, and the main agricultural products include maize, beans, pumpkin, sweet potato, watermelon, cassava, and groundnuts, all of which are vulnerable to the negative effects of climate change [30].

The Mabalane district serves as a microcosm of Mozambique's high vulnerability to climate change, being a hotspot for drought and environmental degradation [31]. The district faces frequent, cyclical droughts (every 3–4 years nationally), in 2024 it was identified as one of the worse-hit districts in Gaza province by El Nino-induced dry conditions, with high risks of acute food insecurity. Mabalane is highly representative of the semi-arid south with its agricultural productivity significantly lower and relies on coping mechanisms higher than in wetter regions. Furthermore, while southern Mozambique is exposed to cyclones, Mabalane district is more typical of inland drought risk rather than the severe flood risk that hits coastal districts [32].

The district is a prime, highly representative case study for semi-arid agriculture in Mozambique. It encapsulates the worst-case scenario of climate change impacts on rural livelihoods, making it a crucial representative site for developing and evaluating adaptation strategies. The geographical location of the study area Figure 2 below was generated using QGIS Desktop 3.38 1.

2.2. Sampling and Data Collection

2.2.1. Definition of Target Population

The target population for this study was formally defined as rainfed smallholder farmers operating within the administrative boundaries of the Mabalane district.

The sampling frame was derived from the official source of statistics of the smallholder farmers population documented by Serviço Distrital de Actividades Económicas (SDAE), a government institution that provides technical support to local communities and stakeholders particularly in the sectors of agriculture, fisheries and climate resilience at the district level. The district registered a total of 5479 smallholder farmers, comprising

1643 male and 3836 female. Additionally, a total number of 44 farmer's associations are registered by the district, of which 33 are active with 754 members comprising 226 male and 528 female.

The sample size (n ≈ 359.05, rounded to 360) was derived from Cochran's formula for sample size of finite population given by:

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

where S = sample size; Z^2= deviation set at 1.96 corresponding to 95% confident level; P = population proportion; Q = 1 − P; and E = 5% margin of error.

Substituting the values, S = 384.16

Since smallholder farmers' population (N) = 5479 is finite, the initial sample size (S) was adjusted using the finite population correction formula:

$$n = \frac{S}{1 + \frac{S-1}{N}} \quad (2)$$

Therefore, substituting the values, n ≈ 359.05

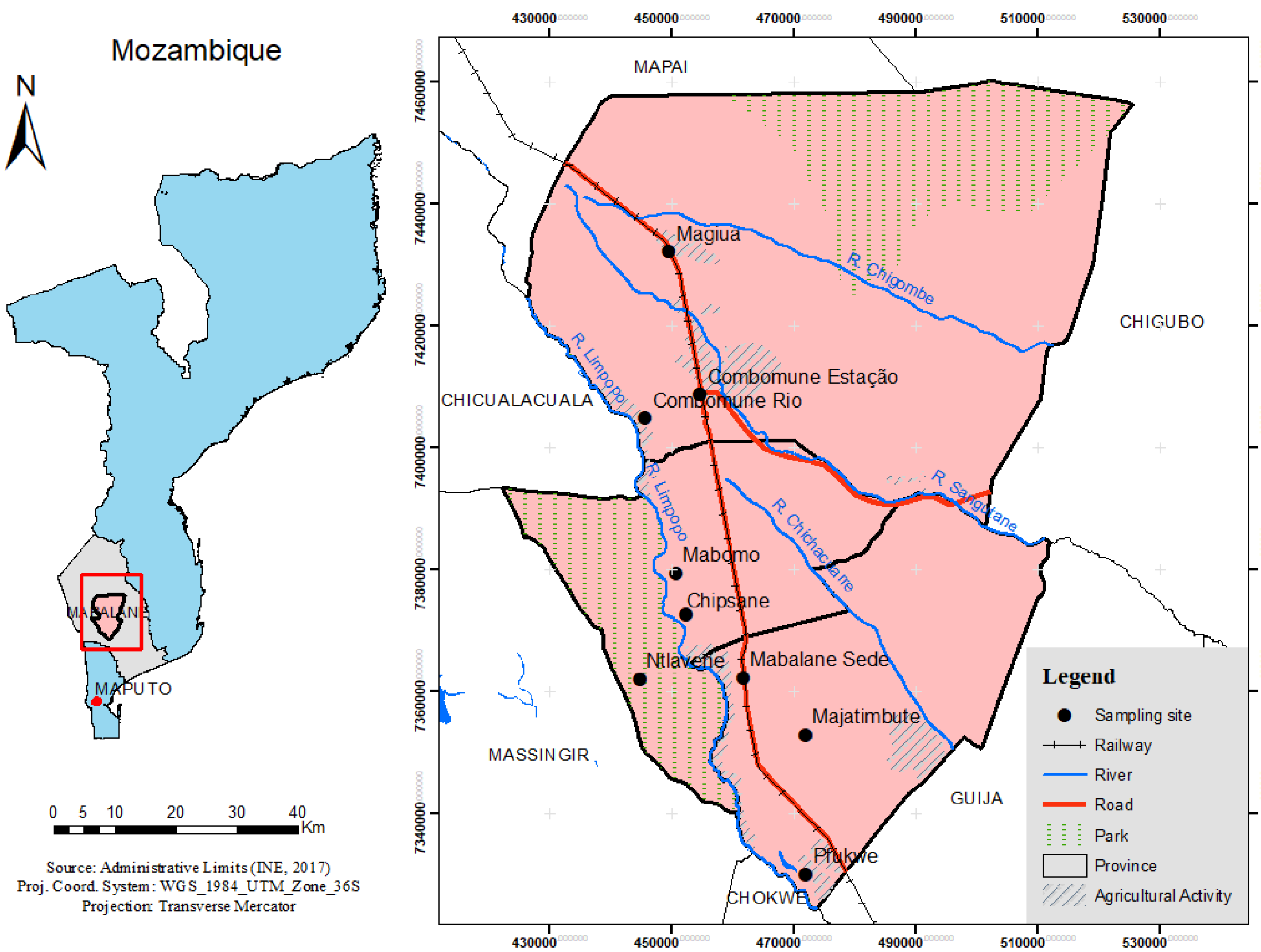

Figure 2. The geographical location of the study area.

2.2.2. Sampling Framework and Stratification

Due to lack of detailed statistics on the smallholder farmers in the three administrative posts of the district and their localities, a stratified sampling was carried out where the sample size was equally divided across the three administrative posts (approximately 120 farmers each) and further sub-divided for the nine localities (approximately 40 farmers per locality). The localities were selected randomly to include areas near River Limpopo where most farming activities take place due to the fertile soils and water availability for irrigation and the dry areas far away to cover diverse agroecological niche. Within each locality, household heads were selected using a random walk sampling method. Random walk sampling is considered appropriate within stratified sampling when a complete household sampling frame for the localities are unavailable, but the geographical boundaries of the strata or localities are clearly defined [33]. When sample quota was not met in one of the selected localities, the random walk was extended to nearby farms within the locality where some farmers live to address the shortfall.

2.2.3. Operational Definition and Participant Selection

The operational definition of the target population was defined through specific inclusion and exclusion criteria. With the assistance of district agriculture extension officers, a representative group of both male and female were selected. Participants were chosen based on two primary criteria: (1) direct experience with farming practices and yields in semi-arid conditions, and (2) duration of residence in the study area requiring a minimum of five years to ensure familiarity with local farming conditions and practices.

To maintain the focus on rainfed smallholder agriculture, farmers who practiced irrigation and monoculture primarily for commercial purposes were explicitly excluded from the survey. This exclusion criterion ensured that the study's finding specifically reflect the conditions, challenges and practices of rainfed smallholder farmers, rather than being confounded by the distinct operational characteristics of commercial-oriented agricultural enterprises.

2.2.4. Data Collection Methods

Data collection was carried out using a mixed-method approach that includes semi-structured questionnaires, key informant interviews, and gender-specific focus group discussions to allow free sharing of information. The questionnaires' items were developed based on the comprehensive review of the relevant literature. The insights from key informant interviews were used to contextualize and refine the items. Established theoretical constructs from prior studies were also used to define the key dimensions of the concepts measured in this study.

A pre-test of the questionnaires was conducted during a reconnaissance survey to validate the instrument and acquire preliminary information that could inform the data collection process. The only adjustment made following the pre-test was replacing the term intercropping with mixed cropping to better reflect the actual farming practice in the study area. The pre-test involved 108 participants selected following the thumb rule for pilot studies (30% of the targeted sample size) to assess clarity, relevance, and stability. The instrument consisted of scale items to measure respondents' perceptions or attitudes towards the study variables, typically rated using a five-point Likert scale. The internal consistency of the survey instrument was assessed using Cronbach's alpha to evaluate the reliability of the three-item factors measuring the perceived co-benefits that may influence the adoption intensity of ecosystem-based adaptation practices among smallholder farmers. Because the scale was multidimensional, reliability analysis was conducted separately for each factor extracted from the scale. The results showed that Factor 1 had a Cronbach's alpha of 0.828, Factor 2 had an alpha of 0.699, and Factor 3 had an alpha of 0.785. These values demonstrate acceptable internal consistency, indicating that the items within each scale are sufficiently correlated to reliably measure the intended constructs [34]. The

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content and face validity were established through expert review of the questionnaire items to ensure clarity, appropriateness for the target population, and consistency with the study objectives, thereby minimizing ambiguity and potential bias. Additionally, construct validity was ensured by deriving the questionnaire items from established theoretical constructs and relevant literature to ensure that the instrument adequately captured the intended concepts and all the dimensions of the study variables.

The survey questionnaires were used to collect data at farm-household level targeting farm-household heads (male or female). The questionnaire's topics included: socio-demographic characteristics of the respondents, farming practices, types of food crops planted, livestock raised, co-benefits farmers perceived from implementing EbA practices at farm level and co-benefits that influence adoption of EbA practices.

The language barrier must be considered as the study was conducted in the English language and the official language is Portuguese; the majority of the farmers speak their local language, Changana. As such guided interviews using the questionnaire were conducted to allow the establishment of trustworthiness with the respondents hence providing validation to the responses [35]. The questionnaire provided an opportunity for the respondent to add any other information if necessary. The respondents were interviewed by the research assistants in local language Changana at their homesteads or farms to avoid interruption of their work.

To supplement the information and ensure quality control, two gender-specific focus group discussions were conducted in both Portuguese and Changana language in each of the administrative post: Mabalane Sede, Ntlavene and Combomune Estação respectively. Each focus group consisted of a maximum 12 participants optimal for facilitating interaction and ensuring diverse perspectives [36]. In addition, 5 key informant interviews were held in each administrative post. Key informants were selected based on their technical skills, social position, experience and knowledge to capture diverse perspective without redundancy [37].

2.2.5. Scope of Conclusions

Based on the sampling strategy and the defined population boundaries, the conclusions drawn from this study are specific to the rainfed smallholder farming population within Mabalane district. The stratification across the three administrative posts and the deliberate inclusion of both riparian and dry land localities ensure that the findings capture the heterogeneity of farming experiences across the district's major agroecological zones. The exclusion of commercial-oriented irrigation farmers serves to maintain analytical focus on the rainfed dependent majority, to enhance the relevance of the study's recommendations for climate resilience interventions targeting vulnerable smallholder population. The study's conclusion is drawn within this defined scope, recognizing that they are statistically representative of and generalizable to the rainfed smallholder farmers in Mabalane district.

2.3. Data Analysis

Descriptive statistics of the identified ecosystem-based adaptation practices were generated using IBM SPSS statistical package version 25 to determine the most commonly adopted ecosystem-based adaptation practices with the frequency of each practice expressed as a percentage of the overall total of all the frequencies. The identification process of EbA practices followed the underlying criteria for each of the three dimensions in the theoretical framework.

The relationships between the perceived co-benefits and ecosystem-based adaptation practices were defined by conducting correspondence factor analysis (CFA) separately for each of the framework's dimensions (ecosystem service provision; adaptation benefits;

livelihood and food security improvement), with a chi-square independence test setting α (type I error) at 5%.

Correspondence factor analysis is a multivariate statistical method use to analyze and visualize relationships within categorical datasets typically displayed as contingency table [38]. By projecting row and column profiles onto a reduced space defined by the first two axes of a biplot, the method identifies significant relationships based on shared inertia derived from Pearson's chi-squared statistics [39]. Such a statistical technique is applicable in research studies that seek to map and visualize relationships among qualitative variables, particularly within the fields of ecology, perception-based studies and practice-oriented inquires.

To assess how perceived co-benefits influence adoption intensity of ecosystem-based adaptation practices among smallholder farmers, two analytical steps were employed. The first step was principal axis factoring to identify latent co-benefits constructs and the second step was negative binomial regression to assess how variation in these constructs is associated with differences in the number of ecosystem-based adaptation practices adopted per smallholder farmer.

The analyses emphasized latent factors such as smallholder farmers' perceptions of co-benefits as key determinants in shaping the sustained adoption [40]. Smallholder farmers' perceptions constitute a key psychological construct that plays a central role in shaping long-term responses to ecosystem-based adaptation practices as they influence how smallholder farmers interpret climate risks, evaluate adoption benefits, and make adoption decisions [41]. Understanding the latent factor is essential for identifying and addressing behavioural barriers to adoption.

To identify the latent co-benefits constructs, principal axis factoring was applied to group highly correlated indicators of the perceived co-benefits into a reduced set of interpretable latent dimensions. This approach enhances analytical parsimony and mitigates potential multicollinearity among explanatory variables. Factors extracted were based on an eigenvalue greater than 1, communality loading above 0.3, rotation based on Promax, and the threshold for factor loading cut-offs was 0.60 for interpreting strong relationship [42]. In the assessment of latent behavioural constructs, a communality threshold value > 0.3 is widely accepted as a valid criterion for variable retention, particularly within perception-based and attitudinal research. While a more stringent threshold of 0.5 is often preferred in physical sciences, scholars in social and environmental sciences argue that, value > 0.3 ensures that nuanced indicators are not prematurely excluded, provided the sample size is sufficient to maintain the stability of the factor structure [43]. Retaining nuanced indicators helps identify complex relationships and prevents misinterpreting the underlying structure [44].

To assess how variation in latent co-benefits constructs is associated with differences in the number of adopted ecosystem-based adaptation practices (adoption intensity), factor scores from principal axis factoring were computed and used as continuous independent variables representing the latent co-benefit constructs. The dependent variable was the number of ecosystem-based adaptation practices adopted per smallholder farmer, expressed as a count variable.

A negative binomial regression model was employed to assess the association, as the count of the adopted ecosystem-based adaptation practices exhibited overdispersion, violating the equidispersion assumption of the Poisson model. The use of the factor scores in the regression analysis enhanced analytical clarity and reduced potential multicollinearity among explanatory variables. By condensing correlated indicators into a smaller set of latent dimensions, the approach improves model stability and interpretability. Given the use of Promax rotation, the resulting factors were allowed to be correlated, providing a more realistic representation of the underlying cognitive constructs.

3. Results

3.1. Identified Ecosystem-Based Adaptation Practices

Based on the theoretical framework guideline, the study identified mixed cropping, integrated crop-livestock, mulch tillage, crop rotation, agroforestry, mulching and rainwater harvesting as the common ecosystem-based adaptation practices used by the respondents in their day-to-day farming systems. Mixed cropping, integrated crop-livestock and mulch tillage were found to be the most highly adopted ecosystem-based adaptation practices compared to the other identified practices as shown in Figure 3.

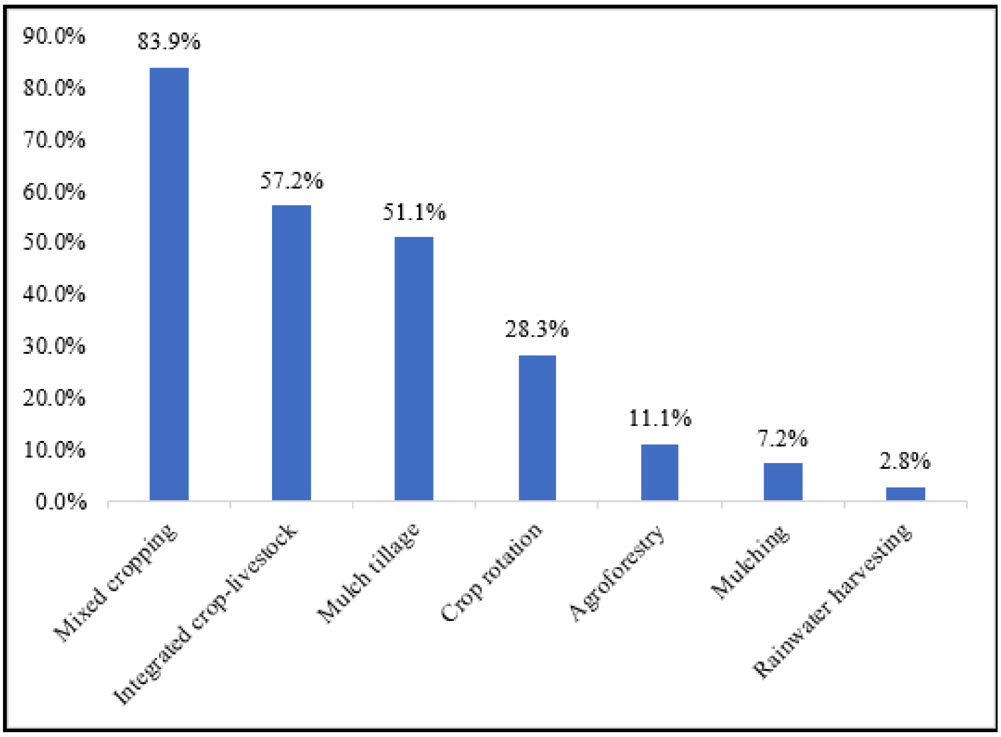

Figure 3. Identified ecosystem-based adaptation (EbA) practices.

3.2. Relationships Between EbA Practices and the Perceived Co-Benefits

The results of the correspondence factor analysis (CFA) conducted separately based on the framework's dimensions (ecosystem service provision; adaptation benefits; livelihood and food security improvement) revealed a statistically significant relationship at 5% significance level (p-value < 0.001) between the ecosystem-based adaptation practices smallholder farmers adopted at farm-level and the co-benefits they perceived from implementing those practices. The chi-squares for the three different analyses revealed that the association between ecosystem-based adaptation practices and co-benefits was statistically significant. A close association was also observed among the ecosystem-based adaptation practices.

3.2.1. Ecosystem Service Provision

Under this section, Table 1 generated from correspondence factorial analysis shows the frequency cross-tabulation of ecosystem-based adaptation practices and their associated co-benefits as reported by smallholder farmers. The table has counts for each practice–co-benefit combination and active margins used as primary inputs for analysis.

Table 1. Frequency cross-tabulation for ecosystem service provision.

Correspondence Table							
Ecosystem-Based Adaptation Practices	Co-Benefits						
	Improve Soil Fertility and Quality	Improve Soil Nutrients Regulation	Improve Water Infiltration and Control Erosion	Surface Runoff Regulation	Agrobiodiversity Improvement-Pollinators	Agrobiodiversity Improvement-Plant Diversity	Active Margin
Mixed cropping	285	289	295	212	5	35	1121
Crop rotation	89	90	15	14	3	2	213
Mulch tillage	183	116	171	81	1	2	554
Mulching	29	10	25	12	0	0	76
Agroforestry	23	9	14	1	38	39	124
Integrated crop-livestock	206	195	1	0	0	0	402
Rainwater harvesting	4	0	8	10	0	0	22
Active Margin	819	709	529	330	47	78	2512

The degree of variation in the dataset is explained in the summary table (Table 2) by each extracted axis generated through correspondence factor analysis. The value of the total chi-square (1402.726) and p-value < 0.001 indicate a statistically significant association between the variables analyzed. Axis 1 explained the majority of variation in the data and captured the dominant pattern of the association (69.3%), whereas Axis 2 explained additional 28% of the variation. Axes 3, 4 and 5 explained less than 3% of the total variation (inertia) contributing very little to the overall variation, hence neglected for the interpretation.

Table 2. Summary table for ecosystem service provision.

Summary								
Axis	Singular Value	Inertia	Chi-Square	Sig.	Proportion of Inertia		Confidence Singular Value	
					Accounted for	Cumulative	Standard Deviation	Correlation 2
1	0.622	0.387			0.693	0.693	0.035	0.027
2	0.395	0.156			0.280	0.973	0.012	
3	0.111	0.012			0.022	0.995		
4	0.050	0.002			0.004	0.999		
5	0.020	0.000			0.001	1.000		
Total		0.558	1402.726	0.000 [a]	1.000	1.000		

[a] 30 degrees of freedom.

The results of the correspondence factorial analysis on the biplot below (Figure 4) revealed that the two Axes (Axis-1 and Axis-2) accounted for 97.3% of the total inertia (Axis-1 = 69.3% and Axis-2 = 28%). This suggests that the analysis of the two axes explained 97.3% of the information.

3.2.2. Adaptation Benefits

The frequency cross-tabulation of ecosystem-based adaptation practices and the associated co-benefits is shown in Table 3, with counts for each practice–co-benefit combination and active margins.

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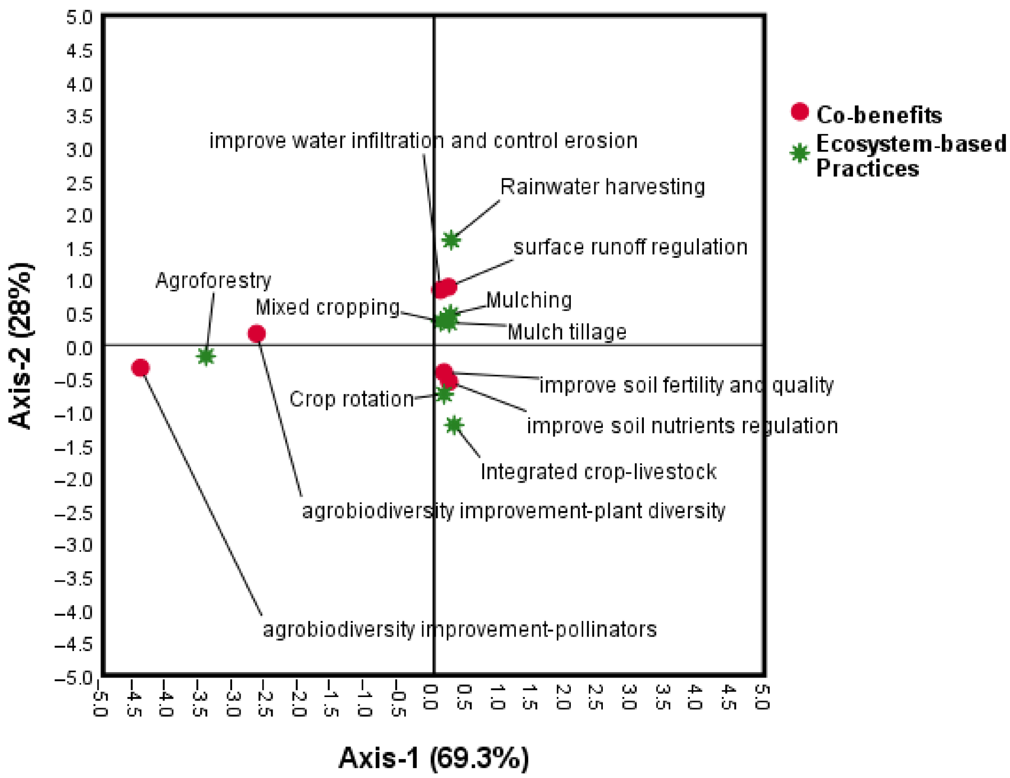

Figure 4. Projection of co-benefits and EbA practices into system of axes for ecosystem service provision.

Table 3. Frequency cross-tabulation for adaptation benefits.

Correspondence Table					
Ecosystem-Based Adaptation Practices	**Co-Benefits**				
	Improve Crop Productivity	**Reduce Pests and Diseases Incidents**	**Improve Buffering Capacity**	**Improve Soil Water Retention**	**Active Margin**
Mixed cropping	299	282	288	262	1131
Crop rotation	94	95	5	7	201
Mulch tillage	176	5	108	173	462
Mulching	25	1	22	26	74
Agroforestry	16	3	37	14	70
Integrated crop-livestock	204	1	0	0	205
Rainwater harvesting	10	0	7	9	26
Active Margin	824	387	467	491	2169

The summary table (Table 4) shows that correspondence factor analysis extracted three axes (Axis 1, Axis 2 and Axis 3). Axis 1 explained the highest proportion of inertia (54%), followed by Axis 2 (41.6%), the two Axes together accounting for 95.6% of the total variation. Axis 3 contributes 4.4% offering limited additional insight that is negligible for the interpretation. The analysis revealed that, the association between the variables was statistically significant with chi-square = 764.749 and p-value < 0.001.

Table 4. Summary table for adaptation benefits.

Summary								
Axis	Singular Value	Inertia	Chi-Square	Sig.	Proportion of Inertia		Confidence Singular Value	
					Accounted for	Cumulative	Standard Deviation	Correlation 2
1	0.436	0.190			0.540	0.540	0.014	−0.122
2	0.383	0.147			0.416	0.956	0.017	
3	0.125	0.016			0.044	1.000		
Total		0.353	764.749	0.000 [a]	1.000	1.000		

[a] 18 degrees of freedom.

The results of the correspondence factorial analysis shown on the biplot (Figure 5) revealed that Axis 1 explains 54% of the information about perceptions of ecosystem-based adaptation practices, whereas Axis 2 accounts 41.6% meaning that the correspondence factor analysis of the two axes explained 95.6% of the information.

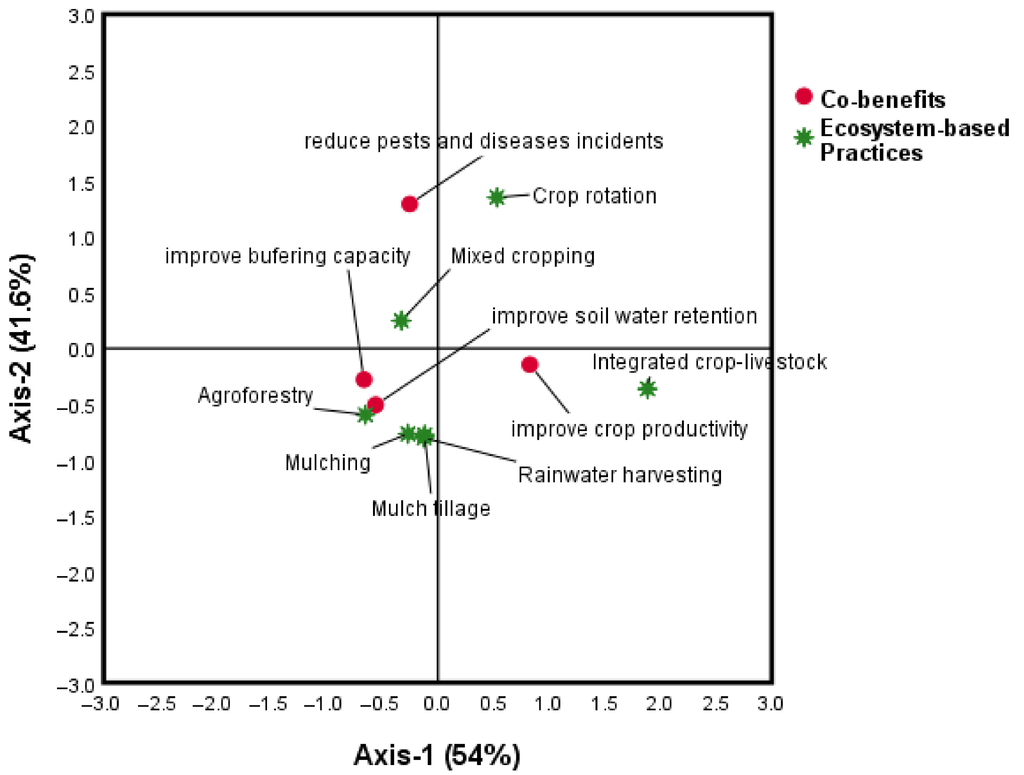

Figure 5. Projection of co-benefits and EbA practices into system of axes for adaptation benefits.

3.2.3. Livelihood and Food Security Improvement

Table 5 presents count of each practice–co-benefit combination, derived from the frequency cross-tabulations of ecosystem-based adaptation practices with the associated co-benefits, and active margins used as primary inputs for correspondence factor analysis to determine axes, inertia and the overall structure of the data.

The summary table (Table 6) generated from the correspondence factor analysis revealed a statistically significant association between the variables with the value of the total chi-square = 952.182 and p-value < 0.001. The analysis extracted five axes. Axis 1 explained the majority of variation in the data and captured the dominant pattern of the association

(88.4%), whereas Axis 2 explained substantially 10.7% of the variation. Axes 1 and 2 together account for 99.1% of the total variation. Axes 3, 4 and 5 contributions are negligible.

Table 5. Frequency cross-tabulation for livelihood and food security improvement.

Correspondence Table							
Ecosystem-Based Adaptation Practices	**Co-Benefits**						
	Improve Food Security	**Diversify Sources and Variety of Food**	**Increase and Diversify Local Income**	**Use Local Inputs**	**Use Local Knowledge**	**Low Cost and Labour Affordable**	**Active Margin**
Mixed cropping	295	293	280	246	276	273	1663
Crop rotation	90	6	2	56	88	95	337
Mulch tillage	163	4	2	170	169	172	680
Mulching	20	0	0	27	26	27	100
Agroforestry	35	37	36	6	6	6	126
Integrated crop-livestock	46	3	1	204	204	204	662
Rainwater harvesting	9	0	0	4	4	6	23
Active Margin	658	343	321	713	773	783	3591

Table 6. Summary table for livelihood and food security improvement.

Summary								
Axis	**Singular Value**	**Inertia**	**Chi-Square**	**Sig.**	**Proportion of Inertia**		**Confidence Singular Value**	
					Accounted for	**Cumulative**	**Standard Deviation**	**Correlation**
								2
1	0.484	0.235			0.884	0.884	0.011	−0.106
2	0.168	0.028			0.107	0.991	0.015	
3	0.047	0.002			0.008	1.000		
4	0.009	0.000			0.000	1.000		
5	0.001	0.000			0.000	1.000		
Total		0.265	952.182	0.000 [a]	1.000	1.000		

[a] 30 degrees of freedom.

The result on the biplot (Figure 6) revealed that Axis 1 explains 88.4% of the association, whereas Axis 2 explains 10.7% which implies that 99.1% of the information is being explained by the correspondence factorial analysis of the two axes.

3.3. Underlying Co-Benefits That Influence Adoption Intensity of EbA Practices

The statistical result from the principal axis factoring shown in Table 7, confirmed the appropriateness of the data for factor analysis. Bartlett's test of sphericity was significant (X^2 = 594.774, df = 15, $p < 0.001$), indicating that the correlation matrix significantly differs from an identity matrix, meaning sufficient correlation exists among the variables to justify factor analysis. The Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy yielded a value of 0.585, confirming that the sampling was adequate to proceed with factor analysis. According to [45], and 1 [46], a bare minimum KMO value of 0.5 is recommended for factor analysis to be considered acceptable [47].

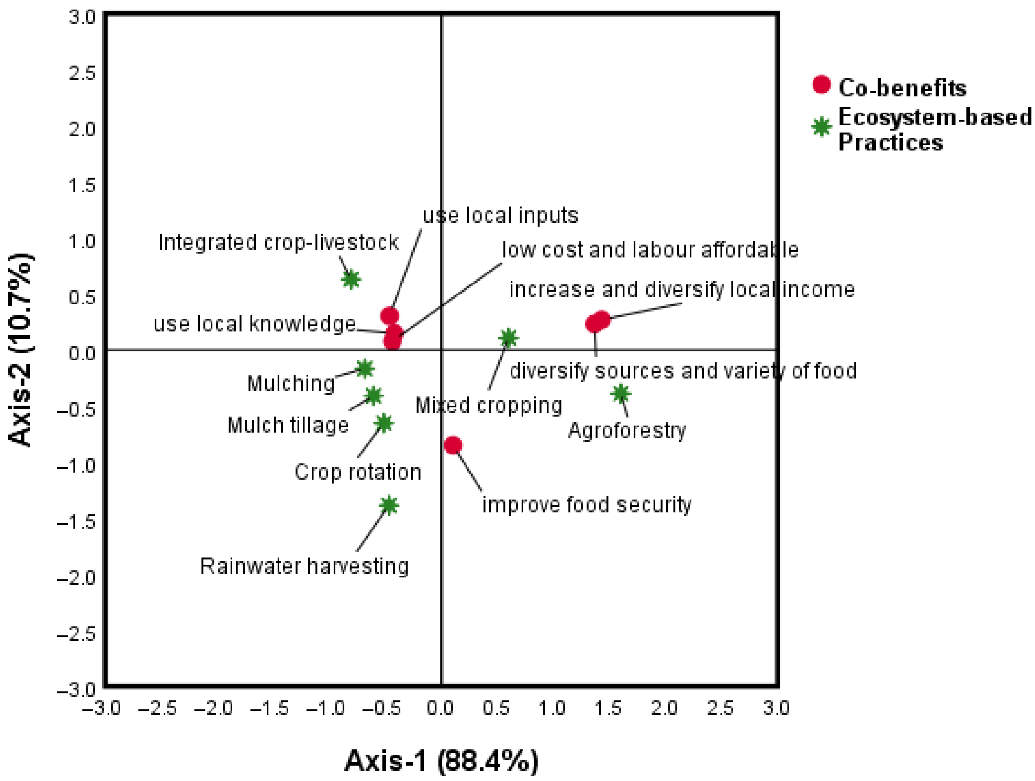

Figure 6. Projection of co-benefits and EbA practices into system of axes for livelihood and food security improvement.

Table 7. Bartlett's test of sampling adequacy.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.585
Bartlett's Test of Sphericity	Approx. Chi-Square	594.774
	df	15
	Sig.	0.000

The total variance explained in Table 8 below identified the underlying structure of the data by reporting the eigenvalue, percentage of total variance attributed to each factor, and the cumulative percentage of variance explained by the extracted model. The result of the factor analysis revealed three distinct factors, with cumulative variance explaining 61% of the variance retained by the extracted factors. The remaining 39% of the unexplained variance signify variance not shared among the observed variables since the model shared structure in the data. The level of the explained variance is considered acceptable where a cumulative variance between 50 and 60% of the total variance are regarded as satisfactory [48].

The scree plot (Figure 7) below displays an elbow, or point of inflexion, where the slope of the eigenvalue curve changes sharply from steep to shallow. Factors that appear before the elbow are retained, while those after the elbow are considered less meaningful or often represent noise [49] The scree plot supports a three-factor solution, as the eigenvalues drop sharply below one beginning at Factor 4. The scree plot is particularly useful for clarifying the factor structure because the different criteria provide somewhat mixed indications regarding the number of factors to retain from Table 8 [49]. Specifically, the initial eigenvalues suggest a three-factor solution, extraction eigenvalues indicate a one-factor solution, rotation eigenvalues support a three-factor solution, although rotation is methodologically secondary to the extraction stage because it only redistributes variance among the extracted factors rather than determining how many factors should be retained. Therefore, the scree plot serves as visual aid to balance this methodological ambiguity by highlighting the most point of inflexion in the eigenvalue's distribution. Based on the scree plot, the initial eigenvalues and rotation solution, a three-factor solution appears both reasonable and methodological justifiable [50].

Table 8. The explained variance in the dataset.

Total Variance Explained							
Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings [a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	2.315	38.575	38.575	1.989	33.155	33.155	1.714
2	1.404	23.397	61.972	0.910	15.164	48.319	1.508
3	1.114	18.571	80.543	0.765	12.751	61.070	1.018
4	0.525	8.754	89.297				
5	0.385	6.417	95.715				
6	0.257	4.285	100.000				

[a] when factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

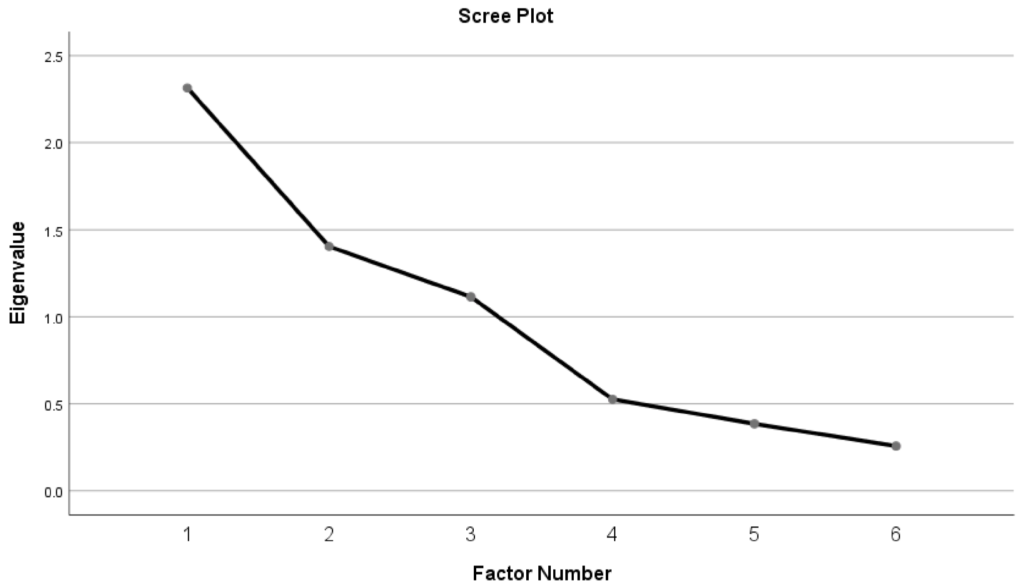

Figure 7. Scree plot showing three-factor solution.

Three factors emerged from the pattern matrix (Table 9), illustrating how the identified co-benefits cluster into three distinct groups based on smallholder farmers' perception. The pattern matrix identified three distinct factors representing clusters of perceived co-benefits among smallholder farmers: (1) livelihood diversification, (2) local input reliance, and (3) soil quality management. All items loaded strongly on their respective factors, with loadings ranging from 0.661 to 0.886 and no substantial cross-loadings, indicating a clear factor structure and strong conceptual coherence. Although each construct is represented by only two items, the high factor loadings and strong inter-item associations suggest that they capture meaningful underlying dimensions [51]. Specifically, the first factor reflects the role of EbA in enhancing food diversity and local income opportunities, the second emphasizes reliance on locally available inputs and traditional knowledge, and the third captures perceived improvements in soil fertility and nutrient regulation.

Table 9. Underlying factors identified from principal axis factoring.

Pattern Matrix [a]			
Co-Benefits	**Factor**		
	Factor 1: Livelihood Diversification	**Factor 2: Local Inputs Reliance**	**Factor 3: Soil Quality Management**
Diversify sources and variety of food	0.886		
Increased and diversify local income	0.828		
Use local inputs		0.782	
Use local traditional knowledge		0.770	
Improvement of soil fertility and quality			0.718
Improvement of soil nutrient regulation			0.661

[a] when factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Given the two-items factor, for each construct, reliability was assessed using Spearman–Brown coefficient, which is more appropriate than Cronbach's alpha for two-item factors. The results indicate overall acceptable internal consistency, with strong reliability for livelihood diversification (0.845), acceptable reliability for local input reliance (0.750), and moderate reliability or soil quality management (0.644).

Collectively, these findings suggest that EbA practices are perceived by smallholder farmers as supporting economic stability, cultural compatibility, and long-term soil health within smallholder farming systems [6].

The results of negative binomial regression analysis in Table 10 indicates that livelihood diversification is positively associated with adoption intensity of ecosystem-based adaptation practices, but not statistically significant (IRR = 1.03, 95% CI: 0.92–1.71, $p = 0.594$). This suggests that a one-unit increase in the livelihood diversification factor score is associated with an estimated 3% increase in the expected number of ecosystem-based adaptation practices adopted by a smallholder farmer; however, this relationship is not statistically significant.

Table 10. Results of negative binomial regression.

Parameter Estimates							
Parameter	**B**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	0.881	0.0627	0.758	1.004	197.497	1	0.000
Livelihood diversification	0.033	0.0617	−0.088	0.154	0.284	1	0.594
Local inputs reliance	0.002	0.0581	−0.112	0.116	0.002	1	0.967
Soil quality management	0.028	0.0521	−0.075	0.130	0.280	1	0.597
(Scale)	1 [a]						
(Negative binomial)	1 [a]						
Dependent Variable: EbA Practices Count Model: (Intercept), Livelihood diversification, Local inputs reliance, Soil quality management							

[a] Fixed at the displayed value.

Similarly, local inputs reliance shows no statistically significant association with the adoption of ecosystem-based adaptation practices (IRR = 1.00, 95% CI: 0.89–1.12, $p = 0.967$), indicating that variations in reliance on local inputs do not meaningfully influence the number of ecosystem-based adaptation practices adopted.

Soil quality management also exhibits a positive but non-significant relationship with ecosystem-based adaptation practices adoption (IRR = 1.03, 95% CI: 0.93–1.14, $p = 0.597$). Therefore, the results show no evidence of statistically significant association between perceived co-benefits and the adoption intensity since none of the perceived co-benefit constructs show statistically significant effects, and the estimated coefficients are small with confidence interval spanning zero.

4. Discussion

The adoption of ecosystem-based adaptation practices by smallholder farmers was linked to the community's traditional farming systems, livelihood needs, and the immediate biophysical constraints of the local environment farmers face, such as the recurrent dry spells [6]. The descriptive analysis revealed that mixed cropping, integrated crop-livestock, and mulch tillage are the most widely adopted EbA practices in Mabalane District. The predominance of these three EbA practices over the other EbA options was attributed to their direct and synergistic contributions to climate resilience operating within the framework of locally important staple food crops and livestock systems.

Farmers in Mabalane district believed that mixed cropping emerged as a primary risk management strategy in rainfed and semi-arid agricultural context. For instant, farmers commonly practice mixed cropping by cultivating maize alongside crops such as beans, watermelon or pumpkin on the same plot of land. This system is not a modern innovation, but a refined traditional practice that has evolved to help farmers cope with erratic rainfall patterns and frequent dry spells. Farmers reported that when maize is grown with crops such as beans, pumpkin, and watermelon, the maize canopy provides partial shading that moderates microclimatic conditions for the understory crops. In turn, beans, pumpkin, and watermelon function as a living mulch, reducing direct solar radiation on the soil surface, lowering soil temperature, and contributing to moisture conservation. This traditional system is regarded by the rainfed smallholder farmers as bet-hedging strategy. In seasons when maize yields decline due to droughts, beans, which are relatively more drought-tolerant, and moisture-rich crops like pumpkins or watermelons continue to provide a harvest, ensuring that households still have access to food. Additionally, during dry periods, watermelon serves a dual purpose by providing food source for the family and a source of hydration for livestock.

The benefits of this mixed farming system can be explained from an agroecological perspective. While maize is particularly susceptible to water stress, the integration of legume such as beans, introduces functional diversity that enhances the resilience of the farming system [52]. Specifically, beans contribute to soil fertility through biological nitrogen fixation via symbiotic relationships with rhizobia, thereby increasing soil nitrogen content and improving nutrient availability within the cropping system. This enhanced nutrient status supports companion crops such as maize, particularly under suboptimal conditions in drought-prone environments [53]. The mixed farming system, which includes maize, beans, pumpkin, and watermelon embodies the ecological principle of diversity and complementarity [54]. This functional complementarity strengthens the farms' capacity to withstand climatic variability serving as a bet-hedging strategy [55].

Furthermore, an integrated crop–livestock system aligns with the community's existing resources and seasonal cycles. This practice establishes a closed-loop system wherein farmers in Mabalane district feed their livestock mainly cattle, in open grazing on maize stover left in the fields after the corn harvest during the dry season. As the cattle graze, they deposit manure directly onto the fields, enhancing soil organic matter and structure. Farmers have acknowledged that this process improves soil fertility, water infiltration, and soil's water holding capacity, thereby creating a more favourable seedbed for the subsequent planting season and establishing a feedback loop that contributes to long-term resilience.

Moreover, grazing livestock on maize stover in the fields serves both a mechanical and biological role in residue breakdown, transforming the stover into smaller, more decomposable particles [56]. Farmers have reported that this natural process renders the residue an ideal input for mulch tillage, which involves incorporating it into the soil using traditional ox-plough techniques. This practice provides a sustainable, low-cost input strategy for climate resilient agriculture [57].

The adoption of crop rotation was found to be very low, despite the perceived co-benefits such as soil nutrient regulation, enhanced soil fertility and quality, reduced pests and diseases, and increased crop productivity and food security. During focus group discussions, participants highlighted that household food security in their communities relies on the continuous cultivation of a single staple food crop (maize). Additionally, limited land availability makes crop rotation a less viable option for smallholder farmers who prioritize year-round food crop production. Agroforestry on the other hand, was perceived to offer co-benefits including the enhancement of agrobiodiversity for both pollinators and vegetation diversity. However, farmers reported that livestock ownership has reduced the likelihood of agroforestry adoption due to browsing damage caused by open grazing. In livestock systems, tree seedlings are often damaged or eaten by free-grazing animals, thus discouraging tree planting unless adequate fencing or protection is provided.

Although mulching is one of the most widely promoted ecosystem-based adaptation practices in drought-prone areas, its adoption remains very low in Mabalane district. This is largely because a significant proportion of maize stover produced by farmers is used as livestock feed during the dry season either through in situ stubble grazing or ex situ forage collection. This trade-off in which crop residues constitute a critical feed resource for livestock, fundamentally constrains smallholder farmers from retaining stover as surface mulch, thereby highlighting the inherent resource competition within the farming system. These findings are consistent with those reported by [58] in Mexico, who examined maize stover use and sustainable crop production in mixed crop-livestock systems in semi-arid areas. The study found that farmers were hesitant to adopt conservation agriculture practices that require the retention of stover for mulching as this practice directly competes with the need to use the stover as livestock feed.

The findings from correspondence analysis provide deeper insight into the relationships between adopted ecosystem-based adaptation practices and the co-benefits perceived by smallholder farmers. The results demonstrate statistically significant associations between ecosystem-based adaptation practices and perceived co-benefits across three key dimensions (ecosystem service provision, adaptation benefits, and livelihood and food security improvement). This strong associations suggest that farmers are aware of the multiple co-benefits associated with the ecosystem-based adaptation practices they adopted. Furthermore, a close clustering was observed among several practices, including mixed cropping with mulching and mulch tillage; rainwater harvesting with mulching and mulch tillage; and crop rotation with mulching and mulch tillage. This clustering indicates that farmers tend to implement these practices as complementary components of an integrated resilience strategy rather than as isolated interventions. This finding is consistent with the review by [59] on complementary practices supporting conservation agriculture in southern Africa, which revealed that climate-smart approaches consistently bundle practices such as mulching, crop rotation, mixed cropping, soil and water conservation, and improved water management as part of integrated strategies aimed at strengthening resilience and enhancing food security among smallholder farmers.

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Under the ecosystem service provision, the analysis confirmed that mixed cropping, integrated crop–livestock systems, and mulch-based practices are strongly associated with improvements in soil fertility, nutrient regulation, water infiltration and erosion control. In semi-arid environments such as Mabalane district, soil organic matter plays a critical role in enhancing resilience to dry spells. Manure deposition within integrated crop-livestock systems enhances nutrient cycling and improves soil structure, thereby increasing moisture retention capacity. Similarly, mixed cropping and mulch-based practices, contribute to canopy cover, root diversity, and surface protection which reduce evaporation and promote water infiltration [60].

In contrast, rainwater harvesting appears to be more closely associated with short-term water availability than with improvements in soil fertility, suggesting that hydrological interventions alone may be insufficient without complementary inputs of organic matter. However, the adoption of rainwater harvesting remains constrained by limited resources and technical capacity, particularly among resource-poor smallholder farmers in drought-prone areas.

In terms of adaptation benefits, integrated crop-livestock systems were closely associated with perceived improvement in crop productivity and yield stability. Increased soil organic carbon enhances nutrient availability and improves access to residual soil thereby supporting crop production during intra-seasonal dry spells [61]. Mixed cropping was also associated with greater buffering capacity against total crop failure, improved productivity and reduced pests and disease incidence as species diversity disrupts pest cycles while spreading climatic risk across different crops.

Mulching and rainwater harvesting were perceived by farmers to be jointly associated with improved soil water retention and microclimate regulation, which are critical determinants of crop survival in semi-arid regions characterized by recurrent dry spells.

Livelihood and food security improvement dimension further illustrates the interconnectedness between ecological and socio-economic resilient. Mixed cropping and agroforestry contribute to the diversification of food sources and income streams, thereby supporting household subsistence even when staple crop yield declines [55]. Integrated crop-livestock systems were perceived as cost-effective and grounded in indigenous knowledge, reducing dependences on external inputs. While mulch-based practices were recognized for their benefits to soil health, their limited adoption reflects the competing demand to allocate crop residues such as maize stover for livestock feeds. Crop rotation contributes indirectly to food security by stabilizing yields through pest suppression and improved soil fertility [62].

Despite the statistically significant relationships observed across all the three co-benefits dimensions (ecosystem service provision, adaptation benefits and livelihood and food security improvement), the negative binomial regression analysis revealed an important divergence. While rainfed smallholder farmers clearly perceived multiple co-benefits associated with EbA practices, these perceptions were not found significantly associated with adoption intensity, measured as number of practices adopted. The absence of statistically significant relationships between the perceived co-benefit factor scores and the number of EbA practices adopted suggests a possible disconnect between perception and behavioural uptake. While perceived co-benefits shape how smallholder farmers conceptualize the value of EbA practices across economic, socio-cultural, and ecological dimensions, such perceptions may not necessarily translate into measurable increases in adoption intensity [63].

This potential gap reflects the mediating influence of structural constraints faced by smallholder farmers, including limited capital, labour shortages, insecure land tenure, and inadequate access to extension services. These constraints may restrict smallholder farmers' ability to convert favourable perception into concrete action. In this context, perceived co-benefits appear to function as a necessity but insufficient condition for the adoption of ecosystem-based adaptation practices.

Limitation: The study is based on cross-sectional data and is geographically limited to the study area which restricts the generalizability of the findings to other contexts. The analysis focused only on smallholder farmers who are adopters of EbA practices. Adoption intensity was measured solely by the number of practices, without capturing differences in quality, complementarity, or effectiveness. The study also emphasized psychological constructs and does not account for socioeconomic, household, farm size, biophysical, or structural factors that may influence adoption.

Future research should use broader samples, more nuanced measures of adoption, and incorporate key contextual factors to better understand the drivers and constraints of EbA adoption among rainfed smallholder farmers in Mabalane district.

5. Conclusions

It is concluded that, mixed cropping, integrated crop livestock, and mulch tillage were the most widely adopted EbA practices due to their strong alignment with community's traditional farming systems, local livelihood needs, and the semi-arid conditions of the region.

The study also revealed a critical trade-off in which crop residues which are essential for mulching are simultaneously required as livestock feed. This computing demand fundamentally constrains the adoption of mulch-based practices despite their widely recognized benefits. Importantly, although smallholder farmers clearly perceived multiple co-benefits associated with EbA practices, these perceptions alone do not drive adoption intensity. Instead, they appear to function as a necessity, but insufficient condition for adoption. The disconnect between perception and behavioural uptake can be explained by the nature of the perceived co-benefits. It is plausible that farmers recognize these co-benefits primarily because they provide immediate and tangible contributions to daily subsistence rather than being consciously adopted as part of a deliberate long-term strategy for sustainability or climate adaptation.

Consequently, even when co-benefits are acknowledged they may not translate into increased adoption if they are not framed within a long-term adaptation or action-oriented perspective. This reflects what is commonly described as the value–action gap or intention–behaviour gap [64].

Therefore, adoption decisions among smallholder farmers may be shaped more strongly by enabling conditions and resources endowments than by perceived ancillary benefits alone [65]. In this context, policy interventions aimed at scaling up EbA practices should extend beyond awareness creation and instead prioritize strengthening institutional support mechanisms, improving access to finance, markets, secure land tenure and agricultural inputs, and enhancing agricultural extension services. Addressing these structural barriers, will be essential to facilitate sustained adoption and scaling of ecosystem-based adaptation practices among smallholder farmers.

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Institutional Review Board Statement: This study is waived for ethical review by the Institutional Research Ethics Committee of Eduardo Mondlane University, as it involves no collection of personal or identifiable data, entails no human interventions, and poses no physical, psychological, or social risks to participants.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the main author on request.

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Conflicts of Interest: There is no conflict of interest declared by the authors.

Abbreviations

The following abbreviations are used in this manuscript:

CBD	Convention on Biological Diversity
CE-AFSN	Centre of Excellency in Agri-Food Systems and Nutrition
CFA	Correspondence Factorial Analysis
EbA	Ecosystem-based Adaptation
Eco-DRR	Eco-Disaster Risk Reduction
Fig	Figure
GDP	Gross Domestic Product
MSc	Masters of Science
RII	Relative Important Index
SCBD	Secretariate of the Convention on Biological Diversity
SDAE	Serviço Distrital de Actividades Económicas
WAI	Weighted Average Index

References

1. Wiebe, K.; Robinson, S.; Cattaneo, A. Climate Change, Agriculture and Food Security: Impacts and the Potential for Adaptation and Mitigation. In *Sustainable Food and Agriculture*; Academic Press: New York, NY, USA, 2019; pp. 55–74. [CrossRef]
2. Mondlhane, C.; Munjonji, L.; Victorino, Í.; Huenchuleo, C.; Pimentel, P.; Cornejo, P. Sustainable Agricultural Alternatives to Cope with Drought Effects in Semi-Arid Areas of Southern Mozambique: Review and Strategies Proposal. *World* **2025**, *1*, 23. [CrossRef]
3. Baez, J.E.; Caruso, G.; Niu, C. Extreme Weather and Poverty Risk: Evidence from Multiple Shocks in Mozambique. *Econ. Disasters Clim. Change* **2020**, *4*, 103–127. [CrossRef]
4. Rembold, F.; Kerdiles, H.; Lemoine, G. *Impact of El Ni ñ o on Agriculture in Southern Africa for the 2015/2016 Main Season Contact Information*; European Union: Brussels, Belgium, 2016; pp. 1–55. [CrossRef]
5. Mburu, S.W.; Koskey, G.; Kimiti, J.M.; Ombori, O.; Maingi, J.M.; Njeru, E.M. Agrobiodiversity Conservation Enhances Food Security in Subsistence-Based Farming Systems of Eastern Kenya. *Agric. Food Secur.* **2016**, *5*, 19. [CrossRef]
6. Vignola, R.; Alice, C.; Bautista-solis, P.; Avelino, J.; Rapidel, B.; Donatti, C.; Martinez, R. Agriculture, Ecosystems and Environment Ecosystem-Based Adaptation for Smallholder Farmers: De Fi Nitions, Opportunities and Constraints. *Agric. Ecosyst. Environ.* **2015**, *211*, 126–132. [CrossRef]

7. Dorren, L.; Schwarz, M. Quantifying the Stabilizing Effect of Forests on Shallow Landslide-Prone Slopes. In *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*, 1st ed.; Renaud, F., Sudmeier-Rieux, K., Estrella, M., Nehren, U., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2016; Volume 42.
8. IPCC. *Climate Change 2014–Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report*; Cambridge University Press: Cambridge, UK, 2014; p. 1132. [CrossRef]
9. Alpizar, F.; Donatti, C.; Avelino, J. Ecosystem-Based Practices for Smallholders' Adaptation to Climate Extremes: Evidence of Benefits and Knowledge Gaps in Latin America. *Agronomy* **2022**, *12*, 2535. [CrossRef]
10. Kissi, A.E.; Villamor, G.B.; Abbey, G.A. Ecosystem-Based Adaptation Practices of Smallholder Farmers in the Oti Basin, Togo: Probing Their Effectiveness and Co-Benefits. *Ecologies* **2023**, *4*, 535–551. [CrossRef]
11. Morara, N.; Pfei, L.; Spaulding, A.; Russell, M. Farmers' Attitudes and Perceptions of Adoption of Agricultural Innovations in Kenya: A Mixed Methods Analysis. *J. Agric. Rural Dev. Trop. Subtrop.* **2022**, *123*, 147–160. [CrossRef]
12. Dong-Uuro, P.P.; Peprah, K. Ecosystem-Based Adaptation Practices to Stem Climate Change Impacts: Smallholder Farmers' Perspectives. *Clim. Policy* **2024**, *24*, 573–585. [CrossRef]
13. Secretariat of the Convention on Biological Diversity. *Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change*; Technical Series No. 41; Secretariat of the Convention on Biological Diversity: Montreal, PQ, Canada, 2009.
14. Uy, N.; Shaw, R. The Role of Ecosystems in Climate Change Adaptation and Disaster Risk Reduction. In *Community, Environment and Disaster Risk Management*; Emerald Group Publishing Limited: Bingley, UK, 2012; Volume 12, pp. 41–59. [CrossRef]
15. Ladekjær, M.; Funder, M. *Nature-Based Solutions to Development and Climate Change Challenges: Understanding Ecosystem-Based Adaptation Approaches*; Danish Institute for International Studies: Copenhagen, Denmark, 2021.
16. Chong, J. Ecosystem-Based Approaches to Climate Change Adaptation: Progress and Challenges. *Int. Environ. Agreem. Politics Law Econ.* **2014**, *14*, 391–405. [CrossRef]
17. Mabhaudhi, T.; Hlahla, S.; Chimonyo, V.G.P.; Henriksson, R.; Chibarabada, T.P.; Murugani, V.G.; Groner, V.P.; Tadele, Z.; Sobratee, N.; Slotow, R.; et al. Diversity and Diversification: Ecosystem Services Derived From Underutilized Crops and Their Co-Benefits for Sustainable Agricultural Landscapes and Resilient Food Systems in Africa. *Front. Agron.* **2022**, *4*, 859223. [CrossRef]
18. Dinesh, D. *Agricultural Practices and Technologies to Enhance Food Security, Resilience and Productivity in a Sustainable Manner: Messages for SBSTA 44 Agriculture Workshops*; CCAFS Working Paper No. 146; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS): Copenhagen, Denmark, 2016.
19. Whelchel, A.W.; Beck, M.W. Decision Tools and Approaches to Advance Ecosystem-Based Disaster Risk Reduction and Climate Change Adaptation in the Twenty-First Century. In *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*; Advances in Natural and Technological Hazards Research; Springer: Cham, Switzerland, 2016; Volume 42, pp. 133–160. [CrossRef]
20. Vignola, R.; Gonzalez-Rodrigo, B.; Lane, O.; Marchamalo, M.; McDaniels, T. A Scenario Approach to Assess Stakeholder Preferences for Ecosystem Services in Agricultural Landscapes of Costa Rica. *Reg. Environ. Change* **2017**, *17*, 605–618. [CrossRef]
21. McGranahan, D.A. Ecologies of Scale: Multifunctionality Connects Conservation and Agriculture across Fields, Farms, and Landscapes. *Land* **2014**, *3*, 739–769. [CrossRef]
22. Dimitrova, M.; Snair, M. Classifying Disaster Risk Reduction Strategies: Conceptualizing and Testing a Novel Integrated Approach. *Global. Health* **2024**, *20*, 7. [CrossRef] [PubMed]
23. Giffin, A.L.; Brown, C.J.; Nalau, J.; MacKey, B.G.; Connolly, R.M. Marine and Coastal Ecosystem-Based Adaptation in Asia and Oceania: Review of Approaches and Integration with Marine Spatial Planning. *Pac. Conserv. Biol.* **2021**, *27*, 104–117. [CrossRef]
24. Rubio, F. Ecosystem-Based Adaptation to Climate Change: Concept, Scalability and a Role for Conservation Science. *Perspect. Ecol. Conserv.* **2017**, *15*, 65–73. [CrossRef]
25. Munang, R.; Thiaw, I.; Alverson, K.; Mumba, M.; Liu, J.; Rivington, M. Climate Change and Ecosystem-Based Adaptation: A New Pragmatic Approach to Buffering Climate Change Impacts. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 67–71. [CrossRef]
26. Woollen, E.; Ryan, C.M.; Baumert, S.; Vollmer, F.; Grundy, I.; Fisher, J.; Fernando, J.; Luz, A.; Ribeiro, N.; Lisboa, S.N. Charcoal Production in the Mopane Woodlands of Mozambique: What Are the Trade-Offs with Other Ecosystem Services? *Philos. Trans. R. Soc. B Biol. Sci.* **2016**, *371*, 20150315. [CrossRef]
27. Ng'ang'a, S.K.; Jeannette, V.; Notenbaert, A.; Moyo, S.; Herrero, M. Household Livelihood Strategies and Livestock Benefits Dependence in Gaza Province of Mozambique. *Afr. J. Agric. Res.* **2011**, *6*, 560–572.
28. Ministério de Administração Estatal. *Perfil Do Distrito de Mabalane Província de Gaza*; Ministério da Administração Estatal: Maputo, Mozambique, 2005; 55p. Available online: https://en.wikipedia.org/wiki/Mabalane_District (accessed on 30 March 2026).
29. Falcão, M.P. Charcoal Production and Use in Mozambique, Malawi, Tanzania, and Zambia: Historical Overview, Present Situation and Outlook. In Proceedings of the Conference on Charcoal and Communities in Africa, Maputo, Mozambique, 16–18 June 2008; pp. 20–34.
30. Baumert, S.; Luz, A.C.; Fisher, J.; Vollmer, F.; Ryan, C.M.; Patenaude, G.; Zorrilla-Miras, P.; Artur, L.; Nhantumbo, I.; Macqueen, D. Charcoal Supply Chains from Mabalane to Maputo: Who Benefits? *Energy Sustain. Dev.* **2016**, *33*, 129–138. [CrossRef]

31. CIAT; World Bank. *Climate-Smart Agriculture in Mozambique*; International Center for Tropical Agriculture: Washington, DC, USA, 2017.
32. Muleia, R.; Maúre, G.; José, A.; Maholela, P.; Adjei, I.A.; Karim, M.R.; Trigo, S.; Kutane, W.; Inlamea, O.; Kazembe, L.N.; et al. Assessing the Vulnerability and Adaptation Needs of Mozambique's Health Sector to Climate: A Comprehensive Study. *Int. J. Environ. Res. Public Health* **2024**, *21*, 532. [CrossRef]
33. Maduekwe, E.; de Vries, W.T. Random Spatial and Systematic Random Sampling Approach to Development Survey Data: Evidence from Field Application in Malawi. *Sustainability* **2019**, *11*, 6899. [CrossRef]
34. Tavakol, M.; Dennick, R. Making Sense of Cronbach's Alpha. *Int. J. Med. Educ.* **2011**, *2*, 53–55. [CrossRef]
35. Nanfuka, S.; Mfitumukiza, D.; Egeru, A. Characterisation of Ecosystem-Based Adaptations to Drought in the Central Cattle Corridor of Uganda. *Afr. J. Range Forage Sci.* **2020**, *37*, 257–267. [CrossRef]
36. O.Nyumba, T.; Wilson, K.; Derrick, C.J.; Mukherjee, N. The Use of Focus Group Discussion Methodology: Insights from Two Decades of Application in Conservation. *Methods Ecol. Evol.* **2018**, *9*, 20–32. [CrossRef]
37. Muellmann, S.; Brand, T.; Jürgens, D.; Gansefort, D.; Zeeb, H. How Many Key Informants Are Enough? Analysing the Validity of the Community Readiness Assessment. *BMC Res. Notes* **2021**, *14*, 85. [CrossRef] [PubMed]
38. Sourial, N.; Wolfson, C.; Zhu, B.; Quail, J.; Fletcher, J. Correspondence Analysis Is a Useful Tool to Uncover the Relationships among Categorical Variables. *J. Clin. Epidemiol.* **2010**, *63*, 638–646. Erratum in *J. Clin. Epidemiol.* **2010**, *63*, 809. [CrossRef]
39. Greenacre, M. *Biplots in Practice*, 1st ed.; Greenacre, M., Ed.; Fundación BBVA (Banco Bilbao Vizcaya Argentaria Foundation): Bilbao, Spain, 2010.
40. Grothmann, T.; Patt, A. Adaptive Capacity and Human Cognition: The Process of Individual Adaptation to Climate Change. *Glob. Environ. Change* **2005**, *15*, 199–213. [CrossRef]
41. Adger, W.N.; Dessai, S.; Goulden, M.; Hulme, M.; Lorenzoni, I.; Nelson, D.R.; Otto, L.; Johanna, N.; Anita, W. Are There Social Limits to Adaptation to Climate Change? *Clim. Change* **2009**, *93*, 335–354. [CrossRef]
42. MacCallum, R.C.; Widaman, K.F.; Zhang, S.; Hong, S. Sample Size in Factor Analysis. *Psychol. Methods* **1999**, *4*, 84–99. [CrossRef]
43. Costello, A.B.; Osborne, J.W. Best Practices in Exploratory Factor Analysis: Four Recommendations for Getting the Most from Your Analysis. *Pract. Assess. Res. Eval.* **2005**, *10*, 7. [CrossRef]
44. Sukserm, P. 7Rs Steps to Guide Exploratory Factor Analysis in EFL Research. *High. Educ. Stud.* **2025**, *15*, 193–202. [CrossRef]
45. Hutcheson, G.D.; Sofroniou, N. *The Multivariate Social Scientist: Introductory Statistics Using Generalized Linear Models*; SAGA Publication: Thousand Oaks, CA, USA, 1999. [CrossRef]
46. Kaiser, H.F.; Rice, J. Little Jiffy, Mark Iv. *Educ. Psychol. Meas.* **1974**, *34*, 111–117. [CrossRef]
47. Ul Hadia, N.; Abdullah, N.; Sentosa, I. An Easy Approach to Exploratory Factor Analysis: Marketing Perspective. *J. Educ. Soc. Res.* **2016**, *6*, 215–223. [CrossRef]
48. Phong, N.B.; Nhuan, M.T.; Chien, D.D. Identifying the Role of Determinantsand Indicators Affecting Climate Change Adaptive Capacity in Da Nang City, Vietnam. *VNU J. Sci. Earth Environ. Sci.* **2020**, *36*, 70–80. [CrossRef]
49. Cattell, R.B. The Scree Test for the Number of Factors. *Multivar. Behav. Res.* **1966**, *1*, 245–276. [CrossRef]
50. Finch, W.H. Methods for Determining the Number of Factors to Retain in Exploratory Factor Analysis. In *Exploratory Factor Analysis*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2020; pp. 71–92. [CrossRef]
51. Yong, A.G.; Pearce, S. A Beginner's Guide to Factor Analysis: Focusing on Exploratory Factor Analysis. *Quant. Methods Psychol.* **2013**, *9*, 79–94. [CrossRef]
52. Muhammad, A.; Giller, K.E.; Rusinamhodzi, L.; Rasche, F.; Koomson, E.; Marohn, C.; Cadisch, G. Field Crops Research Enhancing the Resilience of Intercropping Systems to Changing Moisture Conditions in Africa through the Integration of Grain Legumes: A meta-analysis. *Field Crops Res.* **2025**, *321*, 109663. [CrossRef]
53. Nassary, E.K.; Baijukya, F.; Ndakidemi, P.A. Assessing the Productivity of Common Bean in Intercrop with Maize across Agro-Ecological Zones of Smallholder Farms in the Northern Highlands of Tanzania. *Agriculture* **2020**, *10*, 117. [CrossRef]
54. Wenda-piesik, A.; Synowiec, A. Productive and Ecological Aspects of Mixed Cropping System. *Agriculture* **2021**, *11*, 395. [CrossRef]
55. Mihrete, T.B.; Mihretu, F.B. Crop Diversification for Ensuring Sustainable Agriculture, Risk Management and Food Security. *Glob. Chall.* **2025**, *9*, 2400267. [CrossRef]
56. Sun, Y.; He, X.Z.; Hou, F.; Wang, Z.; Chang, S. Grazing Increases Litter Decomposition Rate but Decreases Nitrogen Release Rate in an Alpine Meadow. *Biogeosciences* **2018**, *15*, 4233–4243. [CrossRef]
57. Jaleta, M.; Kassie, M.; Shiferaw, B. Tradeoffs in Crop Residue Utilization in Mixed Crop—Livestock Systems and Implications for Conservation Agriculture. *Agric. Syst.* **2013**, *121*, 96–105. [CrossRef]
58. Hellin, J.; Erenstein, O.; Beuchelt, T.; Camacho, C.; Flores, D. Maize Stover Use and Sustainable Crop Production in Mixed Crop-Livestock Systems in Mexico. *Field Crops Res.* **2013**, *153*, 12–21. [CrossRef]
59. Thierfelder, C.; Baudron, F.; Setimela, P.; Nyagumbo, I.; Mupangwa, W.; Mhlanga, B.; Lee, N.; Gérard, B. Complementary Practices Supporting Conservation Agriculture in Southern Africa. A Review. *Agron. Sustain. Dev.* **2018**, *38*, 16. [CrossRef]

60. El-beltagi, H.S.; Basit, A.; Mohamed, H.I.; Ali, I.; Ullah, S.; Kamel, E.A.R.; Shalaby, T.A.; Ramadan, K.M.A.; Alkhateeb, A.A.; Ghazzawy, H.S. Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. *Agronomy* **2022**, *12*, 1881. [CrossRef]
61. Githongo, M.; Kiboi, M.; Muriuki, A.; Fliessbach, A.; Musafiri, C.; Ngetich, F.K. Organic Carbon Content in Fractions of Soils Managed for Soil Fertility Improvement in Sub-Humid Agroecosystems of Kenya. *Sustainability* **2023**, *15*, 683. [CrossRef]
62. Al-musawi, Z.K.; Vona, V.; Kulmány, I.M. Utilizing Different Crop Rotation Systems for Agricultural and Environmental Sustainability: A Review. *Agronomy* **2025**, *15*, 1966. [CrossRef]
63. Shah, S.I.A.; Zhou, J.; Shah, A.A. Ecosystem-Based Adaptation (EbA) Practices in Smallholder Agriculture; Emerging Evidence from Rural Pakistan. *J. Clean. Prod.* **2019**, *218*, 673–684. [CrossRef]
64. Mdoda, L.; Mudhara, M. Assessing the Adoption and Impact of Climate-Smart Agricultural Practices on Smallholder Maize Farmers' Livelihoods in Sub-Saharan Africa: A Systematic Review. *Front. Sustain. Food Syst.* **2025**, *9*, 1543805. [CrossRef]
65. Antwi-agyei, P.; Mawuli, E.; John, A.; Baffour-ata, F. Motivations, Enablers and Barriers to the Adoption of Climate-Smart Agricultural Practices by Smallholder Farmers: Evidence from the Transitional and Savannah Agroecological Zones of Ghana. *Reg. Sustain.* **2022**, *2*, 375–386. [CrossRef]

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